Disaster Resilience and Green Growth
Series Editors: Anil Kumar Gupta
Sivapuram Venkata Rama Krishna Prabhakar · Akhilesh Surjan

Shalini Dhyani
Anil Kumar Gupta
Madhav Karki *Editors*

Nature-based Solutions for Resilient Ecosystems and Societies

Springer

Disaster Resilience and Green Growth

Series Editors

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Disaster Management is an emerging discipline of higher education, research and practice. Over the years, interrelation between environment, climate change and disasters have attained significant recognition. Environmental and anthropogenic factors are known key attributes of both hazard-risk and vulnerability and, therefore, are critically important in delineating risk-management solutions. Integrating Ecosystem based and Nature Based Solutions with development programmes offer sustainable, economically viable and acceptable options to support resilience of infrastructure, urban, rural and peri-urban systems, livelihoods, water, health and food security, and promotes people centric approaches, as prevailing current concerns.

Integrated implementation of the Sendai Framework of Disaster Risk Reduction, Paris Climate Agreement and Sustainable Development Goals (2015-2030) is a global concern, necessitating institutions in UN, academia, governments and society to take lead, and synchronize the UNDRR Agenda to aligned national, sub-national and local actions. Disaster management under the on-going paradigm shift lays special focus on risk mitigation and sustainability concerns along with safeguarding and restoring resources, livelihoods and businesses, and at the same time integrating ecological safeguards and carbon neutrality into disaster relief and recovery including reconstruction. EcoDRR is now being advocated by the UN agencies, academia and field practitioners. Researchers and professionals across these domains look eagerly for publications to fulfil their knowledge support demands.

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Nature-based Solutions for Resilient Ecosystems and Societies

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Foreword by the IUCN President

South Asia is one of the most vulnerable regions to climate change impacts due to high population density and fragile environment. The most impacted ecosystems are agricultural, fresh water, mountain, and coastal ecosystems. All the countries in the region are signatories to the SDG and the Paris Agreement. However, the region is facing intractable challenges in meeting these global goals and targets due to ecosystem degradation, loss of biodiversity, persistent poverty, hunger, pollution, and weak governance. These challenges are doubly difficult to address for coastal, mountainous, and dryland communities in the region. Close to 2.5 billion people mostly living in the downstream plains directly depend on the ecosystem goods and services, especially water originating from the Himalayas for their survival. Climate change has caused severe impacts on these natural resources due to rapid melting of ice and snow and affecting region's fresh water supply. Natural habitats of flora, fauna, and the ecosystems as a whole are affected that has increased the threats to the livelihoods of millions of people living both upstream and downstream. Agriculture and natural resource sectors face gravest risks in the region due to changes observed in seasonality of rainfall and presence of too much or too little water. However, there are also emerging opportunities in terms of new areas opening up for agriculture in the upper slopes and likely increase in the volume of water supply in the short run due to glacier melting. Therefore, finding appropriate nature-based solution such as ecosystem-based adaptation (EbA) and eco-system-based disaster risk reduction (EcoDRR) has become a necessity to tackle these complex challenges. It is rather an urgent priority due to large-scale poverty and underdevelopment in the South Asian countries as the climate change and globalization processes have dramatically affected the capacity and skills of the countries and communities to adapt to these changes.

The ecosystem services sectors can definitely improve the capacity of countries and communities to adapt and mitigate the future risks and reduce and manage the current vulnerabilities. These are collectively described as nature-based solutions (NBS) by the authors of this book. The chapters contain reports of both research-based findings and synthesis of knowledge gathered over several years by the authors. Since, the sustainability at every level, from an individual household to the global community, depends on secure supplies of the equitable access to water, food, and energy in a healthy environment, most emphasis has been placed on protecting productive ecosystems that include both human modified and natural ecosystems. Since South Asia is experiencing the fastest rate of urbanization, some of the articles also cover urban ecosystems and the role of NBS in protecting and managing them.

In summary, this book includes important use and potential of NbS in addressing challenges posed by climate change, natural disasters, food and energy crisis, water scarcity and desertification, loss of biodiversity, degradation of ecosystems, migration, and rapid urbanization.

I congratulate the authors for their insightful analysis of their work and good writing suitable for reading by general public, especially policy makers. I also warmly congratulate the editors—Shalini Dhyani, Madhav Karki, and Anil Kumar Gupta, all CEM members—for their timely and laudable efforts to produce this book in record time. I am sure this book will be an important contribution to the IUCN CEM's knowledge pool. I thank Springer for publishing this volume. I am sure readers will not be disappointed by reading this useful book. I wish the authors all success in their endeavor.

IUCN, Gland, Switzerland Zhang Xinsheng
24 February, 2020

From the Desk of the Chair IUCN-CEM

In the last few years, disasters across the world have taken center stage in global news. Frequency of disasters has increased tremendously primarily due to increasing human interference with nature especially their role in changing climate. Recurring floods, cyclones, coastal storms, landslides, and tsunamis not only cost many human lives but also suppress the development and economic growth.

Asia is one of the most vulnerable regions to climate change impacts due to high population density and fragile environment. The most impacted ecosystems are forests, fresh water, marine, dry land, mountain, and coastal ecosystems. Countries in the region are signatories to the Sustainable Development Goals (SDG), 2015, and the Paris Agreement. However, the region is facing intractable challenges in meeting global goals and targets due to persistent environmental degradation, loss of biodiversity, poverty, hunger, pollution, and weak governance. These challenges are becoming more difficult to manage, especially in coastal, mountainous, and arid ecosystems of the region. Close to 2.5 billion people mostly living in the downstream area directly depend on the ecosystem goods and services, especially water originating in the cryosphere of the Himalayas to meet their food, energy, water, and environmental security. Climate change has resulted in severe impacts on cryosphere creating new hazards in the form of glacial lake outburst flood (GLOF) formed due to rapid melting of ice and snow. Melting of permafrost is creating landslides and other extreme events. Natural habitats of flora and fauna and the ecosystems as a whole are affected, increasing the threats to the livelihoods of millions of people in the region. Agriculture and natural resources sectors, on which the livelihoods of half a billion poor in the region depend, face gravest risk to these changes in the seasonality, duration and amount of rainfall, river discharge of water, and amount of groundwater resources. Coastal, dry land, and riverine ecosystems are highly vulnerable facing different levels of threats due to increasing developmental and climate stresses. Building consensus and raising awareness on the protection of nature for our common future have been considered the most important safeguard against growing disaster risks in the warming earth.

Therefore, finding appropriate nature-based solution (NbS) such as ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction (EcoDRR) is a necessity to tackle these intractable challenges. Since, climate change and globalization processes have accelerated the pace of change so dramatically that the capacity and skills of countries and communities to adapt have been constantly challenged, more innovative and robust tools have become necessary. It is rather an urgent priority due to large-scale poverty and underdevelopment in South Asian countries. The vital importance of using nature and ecosystems for reducing disaster and climate risks is still not well tapped in the region. The agriculture and bio-resource sector can definitely help to adapt to the change, mitigate the future risks, and reduce and manage the current vulnerabilities.

The book chapters report both research-based findings and synthesis of knowledge gathered over several years by the authors. Since sustainability at every level, from an individual household to the global community, depends on secure supplies of and equitable access to water, food, and energy in a healthy environment, most emphasis has been placed on protecting productive ecosystems that include both human modified and natural ecosystems. Since South Asia is experiencing the fastest rate of urbanization, some of the chapters also cover urban ecosystems and the role of ecosystems and restoration of urban green and blue spaces in protecting and managing them.

In summary, this book contains important use and potential of NbS in addressing challenges posed by climate change, natural disasters, food and energy crisis, water scarcity and desertification, loss of biodiversity, degradation of ecosystems, migration, and rapid urbanization. I congratulate the authors for their insightful analysis of their work and good writing suitable for reading by the general public, especially policy makers. I also warmly congratulate the editors Shalini Dhyani, Madhav Karki, and Anil Kumar Gupta and all CEM members for their timely and laudable efforts to produce this book in record time. I am sure this book with tested and established examples and case studies will be an important contribution to the IUCN CEM's knowledge pool. I thank Springer Nature for publishing this volume. I am sure readers will not be disappointed by reading this useful book.

CEM/IUCN, Gland, Switzerland Angela Andrade

Acknowledgments

Putting together a book on a relatively futuristic topic of nature-based solutions would not have been possible without having support and contributions from many dedicated and hardworking authors. We are enormously grateful to many international and national experts, scientists, and researchers who volunteered their precious and busy time out of their heavy academic engagements and helped to critically review the book chapters. We truly appreciate their cooperation and good understanding in meeting our rather strict paper submissions and review deadlines. Many of our supporters deserve special appreciations.

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Each individual chapter included in this book was finalized with the primary responsibility of the author and coauthors. The editors have gone through all the chapters included and reviewed them with careful scrutiny following international standards including ethics of publication. We shall be highly obligated to receive constructive comments and suggestions from readers for further improvement of our publications in future editions. Any errors found in this book are the collective responsibility of the chapter authors and of the editors. Last but not least, we thank our family members, especially our parents, spouse, and children, for their understanding, patience, and encouragement to continue and complete this mammoth task well in time.

In closing, we express our gratitude to the IUCN President Hon. Zhang Xinsheng and the IUCN CEM Chair Dr. Angela Andrade.

Shalini Dhyani
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About the Editors

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Abbreviations

AbC	Area-based Conservation
AFR100	African Forest Landscape Restoration Initiative
AMF	Arbuscular Mycorrhizal Fungi
AMRUT	Atal Mission on Rejuvenation and Urban Transformation
ASTER GDEM V2	Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model Version 2
ATREE	Ashoka Trust for Research in Ecology and the Environment
AUD	Ambedkar University Delhi
BAP	Bagmati Action Plan
BBTC	Bombay Burmah Trading Corporation Ltd.
BEI	Building Environment Index
BHU	Banaras Hindu University
Bn	Battalion
BNC	Black-necked crane
BOD	Biochemical oxygen demand
BRBIP	Bagmati River Basin Improvement Project
BRP	Badrivan Restoration Programme
BTAD	Bodoland Territorial Areas Council
BTF	Bhutan Trust Fund for Conservation
BZUCs	Buffer Zone User Committees
BZUGs	Buffer Zone User Groups
CA	Conservation agriculture
CAS	Climate Adaptation Services
CBA	Community-based adaptation
CBD	Convention on Biological Diversity
CBD	United Nations Convention on Biological Diversity
CBST	Community-based sustainable tourism
CCa	Community Conserved Areas
CERC	Central Electricity Regulator Commission
CGED, Nepal	Centre for Green Economy Development, Nepal

CHEA	Central Himalayan Environment Association
CHFST	Contour Hedgerow Farming System Technology
CIFOR	Centre for International Forestry Research
CITES	Convention on International Trade on Endangered Species
COP	Conference of Parties
CPSU	Central Public Sector Undertaking
CRZ	Coastal Regulation Zone
CSE	Centre for Science and Environment
CSIR-NEERI	CSIR-National Environmental Engineering Research Institute
CWSRF	Clean Water State Revolving Fund
DDMA	District Disaster Management Authority
DEM	Digital Elevation Model
DJB	Delhi Jal Board
DoFPS	Department of Forest and Park Services
DRR	Disaster Risk Reduction
EAWM	Ecosystem approach to watershed management
EbA	Ecosystem-based Adaptation
EbA	Ecosystem-based approaches
EbM	Ecosystem-based Management
EC	Electrical Conductivity
EcoDRR	Ecosystem-based Disaster Risk Reduction
EDC	Electricity distribution companies
EDCs	Eco-development committees
EE	Ecological Engineering
EEO	Energy Efficiency Obligations
EIA	Environmental Impact Assessment
EKW	East Kolkata Wetlands
EMS	Environmental Management System
ER	Ecological Restoration
ESS	Ecosystem Services
ETF	Eco Task Force
EU	European Union
FGD	Focus group discussion
FLR	Forest Landscape Restoration
FSI	Forest Survey of India
FYM	Farmyard manure
GAs	Green areas
GBI	Green Building Index
GESI	Gender Equality and Social Inclusion
GGP	Global Gross Product
GI	Galvanized iron
GI	Green Infrastructure
GI	Green Infrastructure
GLADA	Global Assessment of Land Degradation and Improvement

GLASOD	Global Assessment of Human-Induced Soil Degradation
GLOF	Glacial Lakes Outburst Floods
GMWL	Global Meteoric Water Line
GP	Green Power
GPDP	Gram Panchayat Development Plan
GPFLR	Global Partnership for Forest Landscape Restoration
gpm	Gallons per minute
GUIDE	Gujarat Institute for Desert Ecology
HAWs	High Altitude Wetlands
HHC	Higher Himalayan Crystallines
HHD	Higher Himalayan Domain
HKH	Hindu Kush Himalayan
HMHs	Hydrometeorological hazards
IBMTCL	Indo-Bhutan Manas Tiger Conservation Landscape
ICAR	Indian Council of Agriculture Research
ICDP	Integrated Conservation and Development Projects
ICF	International Crane Foundation
ICFRE	Indian Council of Forestry Research and Education
IDS-N	Integrated Development Society, Nepal
IGP	Indo-Gangetic Plain
IHR	Indian Himalayan Region
ILK	Indigenous and Local Knowledge
INDCs	Intended Nationally Determined Targets
INTACH	Indian National Trust for Art and Cultural Heritage
IPPC	Intergovernmental Panel on Climate Change
IPZ	Island Protection Zone
IRBM	Integrated River Basin Management
IRMS	Isotopic Ratio Mass Spectrometry
IVI	Importance Value Index
IWM	Integrated Watershed Management
IWRM	Integrated Water Resources Management
JFM	Joint Forest Management
KBA	Key Biodiversity Areas
KII	Key Informant Interviews
KRC	Knowledge Resource Centre
KU	Kachchh University
LCA	Life Cycle Assessment
LDN	Land Degradation Neutrality
LEED	Leadership in Energy and Environmental Design
LHD	Lesser Himalayan Domain
LMWL	Local Meteoric Water Line
LPG	Liquid Petroleum Gas
LST	Land Surface Temperature
LULC	Land Use Land Cover

MCT	Main Central Thrust
MDGs	Millennium Development Goals
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme of Govt. of India
MoAF	Ministry of Agriculture
MoU	Memorandum of Understanding
MPAs	Marine Protected Areas
NAP	National Afforestation Programme
NAPCC	National Action Plan on Climate Change
NbS	Nature-based Solution
NCBS	National Centre for Biological Science
NCF	Nature Conservation Foundation
NDC	Nationally Determined Contribution
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NFPP	Natural Forest Protection Programme
NIFoS	National Institute of Forest Science
NMC	Nagpur Municipal Corporation
NMEEE	National Mission for Enhanced Energy Efficiency
NP	Jigme Singye National Park
NPCA	National Plan for Conservation of Aquatic Ecosystems
NPV	Net present value
NRAA	National Rainfed Area Authority
NRCP	National River Conservation Plan
NTFP	Non-timber forest product
NUC	Neglected and underutilized crops
NUHHP	National Urban Housing and Habitat Policy
NUS	Neglected and underutilized species
ODF	Open Defecation Free
OSV	Off-season vegetable cultivation
PCA	Phobjikha Conservation Area
PES	Payment for Ecosystem Service
PICP	Permeable Interlocking Concrete Pavers
PIWM	Participatory integrated watershed management
PPS	Permeable Pavement Systems
PRA	Participatory Rural Appraisal
PSM	Phosphate solubilizing micro-organisms
PVTG	Primitive Vulnerable Tribal Group
R&D	Research and Developmental
RAMBLE	Research and Monitoring in the Banni Landscape
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RF	Ripu-Chirang Reserved Forests
RG	Resource Group

RMDD	Rural Management and Development Department, Government of Sikkim
RNR	Renewable Natural Resources
ROAM	Restoration Opportunities Assessment Methodology
RRPs	Rural Resource Persons
RS	Remote Sensing
RSPN	Royal Society for Protection of Nature
SAC	Space Applications Centre
SAR	Synthetic Aperture Radar
SCP	Smart City Project
SDGs	Sustainable Development Goals
SDM	Species Distribution Modeling
SEA	Strategic Environmental Assessment
SEOs	Strategic Environmental Opportunities
SEPE	Socio-ecological Production Ecosystem
SERI	Shristi Eco-Research Institute
SFDRR	Sendai Framework on Disaster Risk Reduction
SFP	Social Forestry Programme
SHG	Self-Help Group
SLCP	Sloping Land Conversion Program
SLWM	Sustainable land and water management
SMOW	Standard Mean Ocean Water
SNNP	Shivapuri Nagarjun National Park
SNU	Shiv Nadar University
SOM	Soil organic matter
SUDS	Sustainable Urban Drainage Systems
SWEET	Sloping Watershed Environment Engineering Technology
TCL	Tiger Conservation Landscape
TEEB	The Economics of Ecosystems and Biodiversity
TRMM	Tropical Rainfall Measuring Mission
UAW	Assess the amount of Unaccounted Water
UAW	Unaccounted Water
UGI	Urban Green Infrastructure
UGSs	Urban Green Spaces
UHI	Urban Heat Islands
UNCCD	United Nations Convention to Combat Desertification
UN-FAO	Food and Agriculture Organization of United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN-SDGs	United Nation Sustainable Development Goals
UNU-IAS	United Nations University Institute for the Advanced Study of Sustainability
VAM	Vesicular-arbuscular mycorrhiza
VGF	Viability Gap Funding
WDCD	World Day to Combat Desertification

WLS	Wildlife Sanctuary
WRI	World Resources Institute
WWAP	World Water Development Report
WWF	World Wildlife Fund

Chapter 1
Opportunities and Advances to Mainstream Nature-Based Solutions in Disaster Risk Management and Climate Strategy

Shalini Dhyani, Madhav Karki, and Anil Kumar Gupta

Abstract There has been tremendous advancement around the world in terms of conceptualisation, research, implementation and policy uptake for Nature-based Solutions (NbS) to address and reduce the severity of disaster risk and climate vulnerability. There has been growing momentum in ongoing international policy dialogues to understand, include and facilitate implementation of NbS. This book includes scientific articles and study reports drawing from research-based knowledge and experience by professionals from the diverse fields of science, policy and practice to enrich the existing knowledge base on effectively implementing NbS especially highlighting its potential in using ecosystems and ecosystem services for climate change adaptation and reduction of disaster risk. Some of the highlighted evidences in this book are from mountains, wetlands as well as urban built environments. The thematic and cross-cutting chapters that the book comprises share scientific evidence that further support and emphasise the prospective ability of NbS to create co-benefits that include environmental, economic and social benefits. NbS has the potential to help achieve and localise goals and targets proposed in international agreements related to biodiversity conservation, disaster risk reduction,

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climate change adaptation, and mitigation to name a few. Apart from an introduction of NbS and its application in disaster risk management and development of climate change strategy, the present chapter also offers a synopsis of the chapters in the book.

1.1 Introduction

Human civilisation is facing wide-ranging challenges, from pressures on ecosystems to human well-being and rapid depletion of natural capital, resulting in increased risk of disasters and compromised food, water and energy security (Faivre et al. 2017). Countries across the world are increasingly exposed to growing disaster risks due to loss of ecosystem services and emerging climate vulnerability (Peduzzi 2019). Increasing disasters such as droughts, floods, landslides and land degradation not only degrade ecosystem services but also affect human lives and economic growth of nations (Renaud et al. 2016; Botzen et al. 2019). Climate change is a pressing challenge that the global community is facing today, with its noteworthy influence on ecosystem functioning and human well-being (van der Geest et al. 2019). Well-managed, healthy and diverse ecosystems are crucial for human existence and well-being, resulting in resilient and prosperous social structures (Diaz et al. 2015). Ecosystems have a proven ability to mitigate climate vulnerability and protect communities by reducing the intensity and impact of disasters (Lo 2016). NbS, as a novel concept, was introduced by the International Union for Conservation of Nature (IUCN) to endorse the benefits that nature brings in as important solutions to meet challenges of climate vulnerabilities (Cohen-Shacham et al. 2016).

Growing awareness of NbS and its wise application can help safeguard people against the severity of climate change impacts by reducing additional surface warming, improving biodiversity and reinstating ecosystem services (Seddon et al. 2020a). NbS facilitates judicious utilisation of natural resources for human well-being with minimum impact on the surrounding environment. Since 2015, when the European Commission presented the European Union (EU) research and innovation policy agenda for NbS and developing green infrastructure of cities in Horizon 2020 (European Commission 2015) that was later followed by IUCN (Cohen-Shacham et al. 2016), incredible progress has been made in NbS research, related policies and field-based implementations. Some of these original concepts and ideas were discussed at a workshop on ‘Ecosystem Management, Nature-based Solutions and Sustainable Development Goals (SDGs)’ co-organised by the IUCN India office, New Delhi, at CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India, and at the South Asia Regional chapter of the Commission on Ecosystem Management of IUCN in New Delhi, on December 2014. The workshop had dedicated discussion on ecosystems management and NbS to address emerging challenges of climate vulnerability and increasing frequencies of extreme climate events and disasters.

There were four important sessions with focus on:

1. Evidence and ground-based examples of NbS implementation.
2. Scientific, Indigenous and Local Knowledge (ILK) and tools for field implementation of NbS.
3. Innovative institutional arrangements for NbS.
4. New pathways for mainstreaming NbS in policies and decision making processes: transformative approaches in resilience building.

Chapters in this book are authored by key participants of this workshop as well as from experts specially invited based on their distinct work experience. As a concept, NbS received immense global attention and recognition after 2015 in terms of its importance for achieving and localising major global agreements related to climate change (UNFCCC), biodiversity (CBD), wetlands (Ramsar), sustainable development goals (SDGs, 2015) and land degradation (UNCCD) (European Commission 2015; Cohen-Shacham et al. 2016, 2019; Nesshöver et al. 2017; Albert et al. 2017; Fernandes and Guiomar 2018). The Sendai Framework for Disaster Risk Reduction 2015–2030 emphasises on NbS as an important strategy for climate change adaptation, mitigation, disaster risk reduction and strengthening of community and ecosystem resilience (Arce Mojica et al. 2019; Ruangpan et al. 2020). These solutions were also acknowledged as part of the Paris Agreement (UNDP 2019; Seddon et al. 2020b) and Ramsar convention targets (Nagabhatla 2018). NbS has been considered useful for helping to achieve the SDGs set by the UN General Assembly in 2015 (Keesstra et al. 2018a, b; Seifollahi-Aghmiuni et al. 2019; Sørup et al. 2019).

Ecosystems and ecosystem services emanating from the application of NbS play a pivotal role in reducing disaster vulnerability and developing resilience. It offers noteworthy approaches through ecosystem and biodiversity-based interventions that are cost-effective and discourage intensive use of engineering structures (Sahani et al. 2019). NbS helps achieve sustainable development by reducing climate risks through adaption and mitigation strategies that are well recognised by experts, featuring in various recent international dialogues and agreements (Fig. 1.1).

In the last few years, there have been considerable efforts to understand the potential multi-functionality of NbS and to enhance its benefits for improving human well-being across the world (Keesstra et al. 2018a). NbS includes diverse concepts such as green infrastructure, ecological engineering, ecological restoration, forest landscape restoration, area-based conservation, ecosystem-based management, natural infrastructure, ecosystem-based adaptation, ecosystem-based disaster risk reduction, ecosystem-based mitigation, climate adaptation services and many similar ideas, which have emerged or are being further developed in recent years to address emerging societal and development challenges especially climate change, water security, food security, human health, disaster risk and socio-economic development (Cohen-Shacham et al. 2016). Restoration of degraded landscapes using natural practices has proved to be more sustainable and effective than engineering solutions, as it involves the natural course of matter and energy flow with solutions based on local and traditional knowledge that includes the understanding of periodic changes in ecosystems (Meli et al. 2014). NbS has emerged as a sustainable and

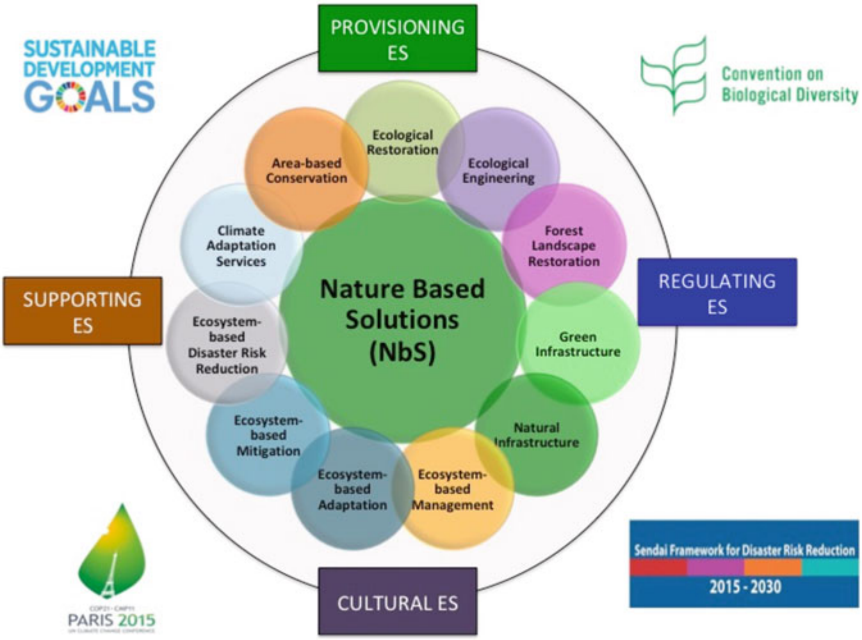

Fig. 1.1 NbS uses ecosystem services for achieving community resilience and helps realise the goals and promises of international agreements and national goals and targets [Adapted from: Keesstra et al. 2018a]

efficient approach for rehabilitating degraded ecosystems and reducing climate and disaster risks (Temmerman et al. 2013; Nel et al. 2014), as proved by established field-based experiences.

Recent years, however, have seen diverse definitions of NbS. The multiplicity of concepts and different definitions create problems of conceptual clarity making the term more subjective and unrealistic (European Commission 2015; Cohen-Shacham et al. 2016; Albert et al. 2017). There have been discussions on developing criteria that can help implement and reinforce NbS, while mainstreaming it in policy discourse to address societal challenges (Albert et al. 2017). These include benefits to local communities, the environment as well as to the economy. There is also a need to understand the concept from a trans-disciplinary approach that includes natural infrastructure in engineering structures, nature's contribution to socio-economic landscapes, as well as physical landscape functions from environmental planning perspectives (Diaz et al. 2015; Albert et al. 2017). Further, there is a need to introduce NbS and provide enough time to cautiously assess its applications on ground level and how they can be further refined.

With fast advancement of various NbS concepts, its integration and mainstreaming in policies and field-based implementation projects, it is imperative to understand and take stock of the lessons from NbS implementation from practical point of views. The main purpose of this book is to report successful NbS experiences from Asia in general and South Asia in particular, to be presented at the IUCN World Conservation Congress on ‘One Nature, One Future’ in France and the landmark UN biodiversity conference, ‘Ecological Civilisation: Building a Shared Future for All Life on Earth’ in Kunming, China. The book captures the essence of established examples of NbS from South Asia, where years of experience of local communities in tackling and addressing climate and disaster risks have either been ignored or have not received due consideration. In the forthcoming subheadings of the chapter, we will deliberate on concept of NbS by showcasing how the concept has been endorsed in scientific research and field-based implementation over the last few years. The chapter will provide an understanding of the importance of scientific advances of NbS in natural (forest, mountains) and human modified (urban green spaces) ecosystems. Opportunities, new pathways for transformative development of NbS and entry points in sectoral policies, instruments and business continuity perceptions and practices are argued in the last chapters (Gupta et al. Chap. 23 and 24).

1.2 Nature-Based Solutions (NbS)

The concept of NbS has been discussed in all chapters of this book. The scope and definition for NbS is broad, and the core highlight is on augmenting the resilience of ecosystems and communities by building back the natural stock against traditional engineered approaches (Cohen-Shacham et al. 2016). It has been well defined as engagements stimulated by or sustained by impersonating nature to support people in ecological, societal and financial tasks through sustainable ways. Evolution in the archetypes of decreasing disaster vulnerability and adapting to climate change in a framework that is continuously shifting from ‘response and relief’ to ‘mitigation and preparedness’ has appealed a lot of attention to NbS, which is a fairly new concept. It is defined as an umbrella term covering an assortment of approaches to adapt and mitigate climate impacts and reduce disaster risks (Jones et al. 2012). All the NbS definitions proposed in this book highlight the vital importance of managed, diverse ecosystems that help build human resilience and well-being by protecting and creating healthy ecosystems. NbS as a term involves a group of solutions grounded on natural practices and ecosystem services to resolve diverse societal challenges. Climate mitigation and adaptation approaches of NbS are of particular importance in addressing disaster risks and climate-related challenges (Kalsnes and Capobianco 2019) that are surging past technical abilities. It is well aligned with ideas of adaptive or natural systems agriculture (Dubey et al. 2019), natural solutions (Dudley and Stolton 2003; Lopoukhine et al. 2012; Dudley et al. 2018), ecosystem-based approaches (Renaud et al. 2016), green infrastructures (Andersson et al. 2014; Kopperoinen et al. 2014) and ecological engineering (Dhyani and Dhyani 2016; Dhyani and Thummarukuddy 2016).

In the late 2000s, the World Bank first introduced the NbS approach (MacKinnon et al. 2008) for promoting ecosystem-based methodologies in their projects to address climate vulnerability and increasing disaster risks. The concept was first used by the European Commission (EC) in their Horizon 2020 research programme for its uptake and promotion in growing urban sprawls to institute Europe as the world leader in NbS, but the notion was not well defined by the EC. The EC has expressed NbS as, '*…living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits* (European Commission 2015; Maes and Jacobs 2017)'. Ecosystem-based adaptation (EbA), urban natural infrastructure (UNI), urban green infrastructure (UGI) and ecosystem services (ESS) were regularly discussed in theoretical arguments and have been progressively included and mainstreamed in policy making (Pauleit et al. 2017).

NbS is a way to adapt to climate change and mitigate impacts of climate change, secure clean water, food, fodder and energy demands, and reduce socio-economics by driving economic growth (Balian et al. 2014; Cohen-Shacham et al. 2016). IUCN has been spearheading NbS in UN climate dialogues and negotiations, to halt and reverse the trend of biodiversity and ecosystem loss, while developing core principles and principles for successful application and upscaling of NbS (Cohen-Shacham et al. 2016, 2019). The term is not only restricted to dialogues and discussions on ecosystem services and natural capital build-up, it has been regularly used to provide information related to soft engineering practices that increase resilience from disasters and climate change (Marton-Lefevre 2012; van Wesenbeeck 2014). IUCN defines NbS as, '*…actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits* (WCC-2016-Res-069-EN) (Cohen-Shacham et al. 2016)'.

According to the IUCN, the predominant aim of NbS is to sustain the success of societal goals of development to protect well-being of society in means that redirect cultural and societal standards and enhance the resilience capacities of ecosystems, as well as their capability for regeneration along with improving provision of services. Maes and Jacobs have defined NbS as, '*Transition to use ecosystem services with reduced inputs of non-renewable natural capital and enhanced investment in renewable natural processes* (Maes and Jacobs 2017)'. Eggermont et al. have deliberated three significant characteristics of NbS: a) no or nominal external interferences in ecosystems, b) interferences in managed ecosystems that involve multi-functionality and sustainability for establishment, and c) expansion of natural ecosystems to foster green and blue setups to recover the flow of variety of ecosystem services (Eggermont et al. 2015). These methods have been materialised from a range of domains (some from scientific investigation fields, others from customary or policy frameworks) but allocate a mutual emphasis on ecosystems and ecosystem services to tackle socital challenges. NbS statement by the EC's professional group (European Commission 2015) listed 310 actions that include: safeguard and growth of forests to absorb gaseous contaminants, plantation of wind breaks for soil protection, creation and protection of urban green spaces and planning green roofs for various co-benefits viz. biodiversity conservation, improving carbon sinks and flash flood management as examples (Kabisch et al. 2017).

In our introductory chapter, to be precise, we have used the acronym, NbS, to emphasise the role of NbS to enhance the capability of communities and ecosystems to adapt to climate change and disaster risk reduction and management. Therefore, we define NbS as *the conservation, sustainable management and restoration of ecosystems as per site-specific natural and cultural contexts by engaging communities to build community and ecosystem resilience against climate adversaries and disaster risks and achieving equitable sharing of sustainable and resilient development dividends*.

It is to be noted that authors of succeeding chapters of this book have been free to detail and use the term and concept of NbS that best describes their study or work.

1.3 Global Recognition and Acceptance of NbS

Climate adaptation and resilience building play a synergistic role in developing strategies for addressing impacts of growing climate vulnerability to ecosystems and societies. Resilience building is considered to be an inherently nature-based approach for enhancing the capacity of communities and ecosystems to adjust to current risks and future uncertainties.[1]

Nature-based solutions are projected and endorsed as alternatives to grey engineering/concrete structures, viz. protection walls from rivers and seas as well as irrigation or drainage structures. While in reality there is an array of approaches that include both 'grey-green' interventions (hybrid solutions), the evidence base for NbS is still growing. However, it has been observed that NbS can offer low-risk and cost-effective solutions to hazards created due to climate change and are beneficial over engineered solutions. Though engineering structures provide instant and quantifiable impacts to reduce immediate threats, they are many times costlier and do not have the ability to deliver co-benefits; whereas NbS are inexpensive and, if appropriately implemented, can bring many co-benefits such as livelihood opportunities (Andersson et al. 2017) including making the engineering structures more resilient and long lasting. The Paris Climate Agreement clearly identifies the role of nature to address the adverse impacts of climate change. Calling on all parties, the Paris Agreement acknowledges the significance of safeguarding ecosystems and conservation of biodiversity. This view has been explained and endorsed at high-level policy dialogues and national commitments mainly in the form of Nationally Determined Contributions (NDCs) submitted by parties to the Paris Agreement to UNFCCC (Seddon et al. 2019, 2020b).

[1] https://www.undp.org/content/dam/nepal/docs/projects/EbA/UNDP_NP_EbA%20Project%20Document.pdf

Considerable research work are available to show the potential of NbS in making the climate change strategies and actions plans to provide over 1/3 of the total cost-effective climate adaptation and mitigation needed by 2030. Such work can reduce climate warming well below 2 °C to achieve nature's mitigation potential of 10–12 gigatonnes of CO_2 per year (Environment UN 2017; Griscom et al. 2017). In total, more than 65% of the parties of the Paris Agreement have included NbS to achieve their NDCs. A total of about 103 countries have highlighted at least one or more type of NbS actions for achieving adaptation constituent of NDC, while 27 nations have highlighted NbS in achieving their climate mitigation targets (Seddon et al. 2019, 2020a, b).[2] Such an impressive global acceptance of NbS as a noteworthy adaptation tool is a welcome move. National intent to use and deliver NbS, however, will differ by diverse levels of financial conditions, state boundaries and their natural resources affecting the translation and achievement of robust targets-based on-the-ground actions (Seddon et al. 2020a). Cohen-Shacham et al. (2019) presented the core principles for successfully implementing and upscaling NbS. IUCN has developed global standard for NbS by involving all stakeholders including governments, non-governmental organisations, practitioner communities, private sector and financial institutions. For developing global standard for NbS, a public consultation was carried out in 2018–2019 to create common understanding and consensus. Draft NbS standards are composed of seven criteria broken into several indicators. The standards planned to be launched at the upcoming World Conservation Congress will accompany a verification tool that will help define to what extent a project can be considered as NbS, as per the IUCN framework (Cohen-Shacham et al. 2016, 2019). Watkin et al. proposed an agenda for evaluating benefits of NbS that will help to mainstream infrastructure choices (Watkin et al. 2019) (Fig. 1.2). This framework can be adapted to suit different national situation in South Asia region using multiple conceptualisation of values—taking into consideration of both direct and indirect benefits. This is extremely important since unlike other regions, in South Asia economic and short-term benefits are given much higher priority which disadvantages NbS.

Başoğlu et al. proposed an urban-scale life cycle assessment (LCA) as a broad valuation tool to assess the potential and success of NbS (Başoğlu et al. 2018). This approach uses urban metabolism as a predominant methodology to model the urban ecosystem. Undertaking a dynamic valuation using time series data helps to identify the hotspots of key indicators considered within a definite time frame.

In the subsequent sections, a few contemporary scientific progresses of NbS are additionally presented to describe how the process has helped restore degraded landscapes, growing urban sprawls and mountain ecosystems for adaptation to climate change and disaster risk management.

[2] https://www.NbSpolicyplatform.org/

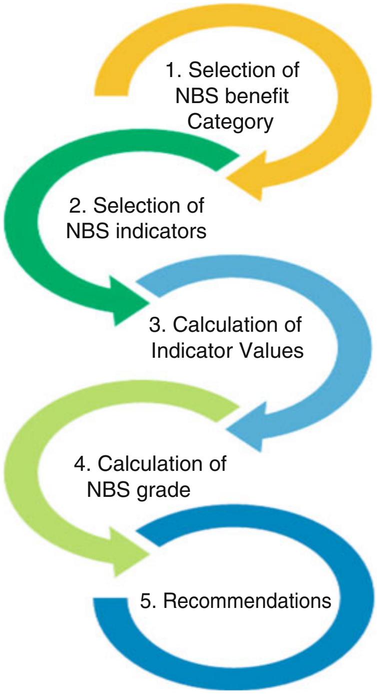

Fig. 1.2 (Watkin et al. 2019) Outline for Evaluating Benefits of Realised NbS

1.4 Progress and Developments in NbS on the Science Front

1.4.1 Restoration of Degraded Landscapes and Natural Forests for Increasing Ecosystems Resilience

The vigour and efficiency of global land capitals have been rapidly declining, with increasing demand of land resources. Land degradation neutrality (LDN) targets to preserve or improve land-based natural assets and allied ecosystem services (Chasek et al. 2017). Land degradation across the world has negatively affected more than 3.2 billion people and costed more than 10% of the annual global gross product (GGP) due to massive loss of biodiversity (Pandit et al. 2018; IRP 2019) (Fig. 1.3). Most policy documents highlight only physical degradation of land focusing on erosion due to water and landslides, and chemical degradation of land, due to point contamination such as organic and inorganic contamination, etc. Other common sources of degradation such as compaction, soil subsidence, loss of organic matter and biodiversity are usually not considered, though they affect the natural, social and economic spheres.

The Intergovernmental Panel on Climate Change (IPPC)'s special reports on 'Climate Change and Land, 2019' and Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) report 'Land Degradation Assessment, 2018' have highlighted the seriousness of land degradation in global discussions. The

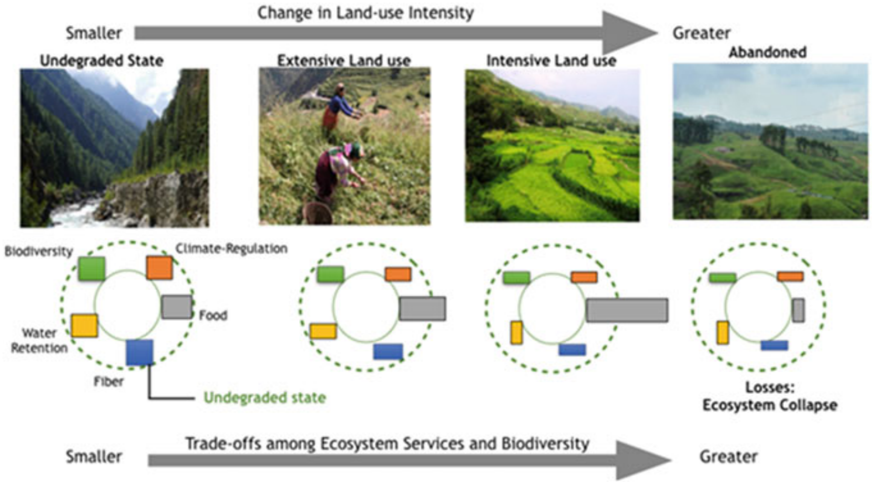

Fig. 1.3 Change of land-use intensity leading to degradation and trade-offs in ecosystem services and biodiversity (adapted from IPBES Land Degradation Assessment 2018)

rehabilitation of land is a crucial approach to improve resources, services and ecosystems (Keesstra et al. 2018b). Decision makers at all levels are facing the pressing need to protect the remaining forests and restore deforested and degraded landscapes. NbS has been observed to work at the interface of both socio-economic systems and ecosystem, and it helps and reduces the vulnerability of the socio-ecological system by developing community and building ecosystem resilience by protection, restoration and judicious management of ecosystems (Seddon et al. 2020a). A comprehensive meta-analysis on the global conservation drivers of forest restoration success, including 221 landscape study areas, disclosed that forest rehabilitation improves biodiversity by 15–84% and vegetation structure by 36–77% in comparison to degraded ecosystems (Crouzeilles et al. 2016). Decision makers and policy planners have demonstrated inspiring political will and determination to achieve ambitious global targets (Bonn Challenge and Paris COP 2015) through the restoration process, declaring 2021–2030 as the UN decade on Ecosystem Restoration (Chazdon et al. 2017; Chazdon and Guariguata 2018; Lewis et al. 2019). Considering the scale of restoration of degraded landscapes, the opportunity to re-vegetate a large part of degraded landscapes and natural forests is enormous for adapting to and mitigating climate change (Lewis et al. 2019). Few on-ground instances of successful implementation of NbS across the world are:

- Thailand, Indonesia and Philippines are employing large-scale mangrove restoration exercises to reverse the effects of such degradation, especially from increasing storm surges, cyclones and typhoons and other coastal disasters (Furuta et al. 2016), while improving blue carbon, livelihood and other benefits for the coastal communities.

- Considering the restoration of 2 billion ha of degraded ecosystems for the global economy, a systemic approach of four returns (financial capital, employment or social capital, biodiversity and ecosystem services or natural capital) resulting in human well-being or inspirational capital, in three landscaping zones (natural, mixed, along with an economic zone), for a period of 20 years to scale up landscape restoration for creating a restoration industry by corporates could also (Ferwerda 2016) be followed for involving corporates in mass-scale restorations.
- Six strategic ecological restoration projects were launched in China in the late 1970s. Total annual Carbon (C) sink from 2001 and 2010 was assessed to be 132 Tg C/year, and more than half of it (74 Tg C/year, 56%) was a result of six projects, which depicted that ecological rehabilitation missions in China has helped to meaningfully increase carbon sink across the country (Lu et al. 2018).
- In Canada the effect of ecosystem-scale rehabilitation and restoration in a peatland developing season CO_2 exchange was carried out that determined that the place was a clear sink of $\sim 20 \pm 5$ g C m^{-2} during the developing season only 2 years post restoration, and the degraded peatland ecosystem was to revert to a net carbon sink in 6–10 years of post-restoration itself (Waddington et al. 2010).
- Ecological restoration can help in moderating flood hazards, but this has hardly been the major goal of restoration. Nilsson et al. have provided evidences for ecological restoration which have been helpful in managing inland flood hazards (Nilsson et al. 2018).
- Ecological restoration has been proven to help in slope stabilisation and landslide prevention while also giving other co-benefits to communities (Xu et al. 2019). Restoration degraded slopes in Nepal to landslide stabilisation (Devkota et al. 2019) and restoration of wastelands in Central Himalayas, India (Dhyani and Dhyani 2016), helped in reducing deforestation and addressed women's drudgery.
- The Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) of the Government of India, considered one of the biggest payment of ecosystem services (or PES), uses NbS (116) and works through more than 200 direct and indirect activities including restoration that supports biodiversity conservation, restoration at landscape level and the livelihood of the rural poor.
- Proposed 103 NbS inclusive NDCs by the signatories of the Paris Agreement are managing, protecting and restoring terrestrial ecosystems, especially forests (41%), followed by management, protection and restoration of coastal ecosystems (28%), and catchment area treatment of rivers and wetlands (28%). In addition, agro-forestry was included in 23% of the relevant NDCs (47% of

NDCs by African countries) along with a few sporadic instances from mountain ecosystems (4%) and grasslands (10%).[3,4]

- A study based on people's perception suggests that models related to restoration or ecological engineering of river highlight the significance of re-wilding and re-naturising to develop capacity of riverine ecosystems for their rejuvenation (Han and Kuhlicke 2019).

All these examples highlight the cause-effect connection amid ecosystems and disaster risk management that can be confined to the area. There are various factors, which can reduce the risks of an impending disaster by incorporating NbS. However, grounded on these comprehensions and many empirical evidences not being reviewed and included, numerous technical guidelines, standards, criteria and indicators on NbS are currently being developed. Five of the total chapters in this book deliberate on the role of restoration in DRR, climate adaptation and mitigation in varying details.

1.4.2 NbS to Manage Heat Islands and Flood Risks in Urban Areas

Global urbanisation has resulted in high population densities in hazard and risk-prone areas (Andersson et al. 2017). Urban resilience and NbS approaches based on ecological ideologies are being pushed to be included in urban planning and climate change-related actions (Suárez et al. 2018). There is growing acceptance of NbS due to increasing disaster risks in urban areas (Dhyani et al. 2018) that the interaction of probable impacts of climate variability and growing uncontrolled urban expansions will bring severe stress on urban planning and water management. NbS and resilience have been endorsed as balancing approaches in urban planning to counter the problem of global warming (Suárez et al. 2018). Decreasing urban green cover and increased built up and concretisation of surface are resulting in increased city temperatures and heat islands, coupled with decreasing ground water recharge (Lahoti et al. 2019). Cities across the world are already facing issues with drainage systems, increasing flash flooding, life-threatening heat stress and droughts (Liu et al. 2014; Majidi et al. 2019). To solve challenges of growing urban sprawls especially climate vulnerability, human health and well-being, existing policy dialogues are shifting the attention from ecosystem-based solutions to NbS (Raymond et al. 2017).

The prospective of introducing NbS (green infrastructure, natural infrastructure, urban green spaces, urban forests, ecological engineering, urban agriculture,

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[3] https://wedocs.unep.org/bitstream/handle/20.500.11822/29988/Compendium_NBS.pdf?sequence=1&isAllowed=y

[4] https://www.conservation.org/docs/default-source/publication-pdfs/guide-to-including-nature-in-ndcs.pdf?sfvrsn=99aecda2_2

Eco-DRR, EbA, etc., to name a few) into urban planning is being acknowledged by academicians, scientists, urban planners as well as policy makers as approaches that can deliver cost-effective and sustainable results for climate adaptation, mitigation and DRR (Armson et al. 2013; Dhyani and Thummarukuddy 2016; Raymond et al. 2017; Dhyani et al. 2018, 2019). Some research findings have showed benefits of NbS implementation in urban areas that include improving air quality (Calfapietra et al. 2015), urban biodiversity (Connop et al. 2016; Tan and Jim 2017; de Oliveira and Mell 2019), heat islands (Makido et al. 2019), urban floods reduction (Majidi et al. 2019), and addressing other cross-cutting challenges like urban sustainability (Perez and Perini 2018), public health and well-being (Bennett et al. 2015).

Some of the significant examples of NbS approach to manage urban heat islands and storm water management are:

- Research findings by Liu et al. on the use of community-scale simulation models endorsing the importance of green infrastructure (GI) in reducing the impact of urban flooding by reducing the volume and peak flow of urban flooding. The study shows that the capacity of single GI to reduce urban flooding is not sufficient to address larger rainstorms, and integrated GIs have better impact for augmenting the benefits. The study notes that grey infrastructure (trenches and catch basins, channels and concrete drains) commonly used for managing urban floods does not offer the co-benefits that come with NbS (Watkin et al. 2019).
- Reynolds et al. assessed CO_2 sink potential, sequestration and emission offsets by trees in urban public green spaces in the Medellin Metropolitan Area, Colombia, and projected it as a potential of viable NbS for the Neotropics (Reynolds et al. 2017). They mentioned that if available space for plantations is considered, carbon offsets may be much more inexpensive, bringing many co-benefits including socio-economic upliftment. Nowak et al. and Zheng et al. have supported the role of trees in carbon sequestration of urban and community areas in the United States (Nowak et al. 2013; Zheng et al. 2013).
- Yao et al. demonstrate how urban and peri-urban green areas, tree and shrub cover have noteworthy and encouraging impact on tree and shrub carbon, while tree and shrub density have even greater impact (Yao et al. 2017). This approach can be used to quantitatively recognise the less discovered fundamental necessities between drivers and ecosystem services.
- Surveys show that lined parks along city waterways improved thermal well-being and helped in developing community resilience in Cyprus (Giannakis et al. 2016).
- The Chinese Government is working on the Sponge City model in Beijing for managing flood risks in urban areas. The programme was launched in 2015 and it is based on NbS principles, to address urban flash flood issues by natural infiltration, retention and detention, and natural cleaning (Li et al. 2017; Zhang et al. 2018; Qiao et al. 2019).
- A study carried out by Govindarajulu (2014) on urban green space design for climate adaptation in Indian urban sprawls supports the NbS approach to address climate variability and vulnerability challenges for developing Asian countries (Govindarajulu 2014). Padigala, Imam and Banerjee have also provided

inferences on how depleting green spaces in urban sprawls in India will jeopardise ecosystem benefits for India's urban citizens (Padigala 2012; Imam and Banerjee 2016).

- The exploration of the flood in Benevento, Italy, in 2015 offered an overview on NbS approaches that helped to accomplish three specific aims, i.e. reducing impermeable plains, preventing further sealing of soil and recuperating the ecosystem (Galderisi and Treccozzi 2017).

A framework mechanism based on more than 1700 research papers within and across ten prominent societal challenges globally for evaluating the costs and co-benefits of NbS was developed (Raymond et al. 2017). Recent research on benchmarking NbS and smart city assessment schemes with reference to liveability against the SDG indicator framework is important to mention as well. A study revealed that strategic approach in selection of an NbS assessment scheme that carefully supports one or more sub-goals of urban SDG 11 can actually exploit functional proficiency by developing synergies amid assessment schemes (Wendling et al. 2018).

Though promoting NbS in urban areas will be an important concern, there is growing consideration on this issue in international administrative dialogues and agreements due to lack of availability of sufficient financial support for its implementation. Public expenses on NbS will be important to understand and address owing to limited municipal self-sufficiency (Droste et al. 2017). Mainstreaming NbS will need larger partnerships amongst diverse policy areas, sectors and stakeholders. It will require multi-stakeholder partnerships, leadership from private sector and required citizen involvement, to support and enhance benefits from NbS applications in urban areas (van Ham and Klimmek 2017).

1.4.3 Slope Stabilisation and Reducing Landslide Risks

Mountain regions across the world suffer from governmental and economic negligence and less prioritised attention because of their remoteness and marginalities. However, they are immensely vulnerable to climatic and demographic alterations[5] (Gioli et al. 2019; Krishnan et al. 2019). Hindu Kush Himalayan Mountains are no exceptions. Progressive warming at higher altitudes has been reported to be up to three times higher than the global average. Climate and other global changes are creating tremendous uncertainties in the mountain ecosystems. In the Hindu Kush Himalayan (HKH) region, rapid warming is evident in scientific observations of increased snow, glacial melt and the frequency of extreme events not limited to devastating floods and droughts. These have further exacerbated the more local problems of poverty and hunger.

[5] https://NbS2017.eu/wp-content/uploads/2017/12/NBS2017_AbstractBook_211217.pdf

Landslides result in human casualties and loss of property across the world. With expansion of human activities in mountainous areas and changing global environment, the frequency of landslides has increased (Lin et al. 2017). Global warming has destabilised mountain slopes and has enhanced landslide risks. Global increase of landslides has been mainly been referred to uncontrolled degradation of ecosystems and deforestation, leading to extensive land-use changes including urbanisation (Dhyani and Dhyani 2016). Moreover, permafrost melts and water percolation deeper into mountains crags, extreme rain and snowstorms trigger hazardous landslides, mudslides and rock falls.[6] Studies on estimation of loss due to landslides in mountain areas have received immense attention. Papathoma-Köhle et al. (2015) developed an integrated approach for the assessment and documentation of exposure and damage. It was observed that most of the existing research evidences on NbS carried out in China, USA or Europe primarily focus on slope stability and use of vegetation, along with several similar terms used for NbS (Arce Mojica et al. 2019). Protection of forests that target minimising shallow landslide hazard and related slope stabilisation is one of the several instances of using the potential role of vegetation to reduce disaster risk by building community resilience (de Jesús et al. 2019).

Some significant examples of NbS that help slope stabilisation and reduction of landslide risks in a warming planet are:

- Eco-engineering as a hybrid NbS approach has been applied in combination with civil engineering and plantation of deep-rooted plants for slope stability and drainage support in Panchase region in Nepal (Devkota et al. 2019). This approach can help in long-term sustainability of rural roads using community-based and inter-disciplinary research. Eco-safe rural road assessment framework developed is a well-organised procedure for design, construction and maintenance of eco-safe rural roads (Devkota et al. 2019).
- Klima 2050 [Centre for Research-based Innovation (SFI) supported by the Research Council of Norway for risk reduction through climate adaptation] provided novel NbS for landslide protection, including essential and significant approaches to ensure protection from flood and storm water (Kalsnes and Capobianco 2019).
- The Fodder Bank Model used fast growing high biomass yielding fodder trees, shrubs and grasses in upper Kedarnath valley in Uttarakhand, India, to reduce rural women's drudgery and the region's deforestation by aiding slope stabilisation, reducing land and mudslides during the 2013 Himalayan Tsunami (Dhyani et al. 2011; Dhyani and Dhyani 2016; Dhyani and Thummarukuddy 2016).
- Landslide risk is becoming progressively regular in Sri Lanka, where there is a growing awareness of opting for NbS or hybrid approaches for landslide risk management against pure engineering solutions (Bank 2019).

[6]https://insideclimatenews.org/news/26092018/climate-change-mountains-landslide-hazard-thawing-permafrost-rockfall-extreme-weather-glaciers-global-warming

- In Nepal a compilation of 28 ecosystem and community-based adaptation work at scale established that by altering vital characteristics of a system in response to climate change and its effects, NbS benefited larger population in a better way by means of multiple skills and good local governance. Scaled-up ecosystem-based adaptation influences policy, capital structure, awareness, practice and capacity using evidence and knowledge. These NbS typologies indicate the following co-benefits: (a) social and professional networking, (b) knowledge, information and best practice sharing, (c) local innovation in community mobilization and tapping local government finances and (d) improved governance of climate change adaptation resources. NbS therefore can address multi-dimensional vulnerability towards a resilient state. Peer learning, learning through practice and inclusive knowledge management can transform capacity development and technology transfer (Spotlight, Nepal; June 12, 2019).[7]
- Debele et al. presented a comprehensive classification of outline, key features and essentials required for designing NbS for alleviating the adverse effects of hydrometeorological hazards (HMHs) including landslides in Europe (Debele et al. 2019).
- The First International Conference on 'Landslides Risk Reduction and Resilience, 2019' in New Delhi, India, highlighted the importance of NbS in stabilising slopes and reducing landslides.[8]
- The Natural Forest Protection Programme (NFPP) to naturalise and stabilise slopes by promoting the alteration of agriculture fields to forest as well as orchards under the Sloping Land Conversion Program (SLCP) remain important soil bioengineering NbS to restore degraded slopes in China and have been very efficient examples from Asia (Stokes et al. 2010).
- Sloping Watershed Environmental Engineering Technology (SWEET) is an excellent example of NbS, where natural resources are managed by using simple and appropriate technological interventions to reduce landslide hazards in Indian Himalayan Region (IHR) (Maikhuri et al. 2011).
- Arce Mojica et al. evaluated more than 13,000 research papers (over 2000–2018) and finally evaluated 275 for NbS. The assessment reflected that though NbS is being promoted in many policies, there is still not enough research-based evidences of the subject. However, the efforts have increased over the past decade and will require more trans-disciplinary studies to reduce shallow landslide reduction using NbS (Arce Mojica et al. 2019).
- The proceedings of the first International Eco-Engineering Conference of September 13–17, 2004, brought research advances on ecological and ground bioengineering experiences by using plants to help landslide risks and slope stabilisation (Stokes et al. 2010). Studies reflected different characteristics of the multidisciplinary aspects of NbS. It included mechanisms and modelling of root structure and characters (Wu 2007) to develop the decision support in slope

[7] https://www.spotlightnepal.com/author/new-spotlight-online/

[8] https://nidm.gov.in/PDF/pubs/Final_Abstract_book.pdf

stabilisations. Experiences from Italy (Bischetti et al. 2007), biotechnical characters of Mediterranean region (Mattia et al. 2007), Southern England (Norris 2007), role of protection forests and trees in slope stabilisation in Iran (Bibalani et al. 2007), slope stabilisation in Iwate prefecture in Japan (Nakamura et al. 2007) and indigenous riparian plant root system of New Zealand (Marden et al. 2007) are few important mentions of the role of plants and vegetation in significantly reducing disaster risk and slope stabilisation. Dupuy et al. (2007) carried out a numerical analysis to understand the role of soil and root architecture in the stability of trees. 'SLIP4EX' used by Greenwood (Greenwood 2007) and image stress analysis procedure by Hamza et al. (2007) are a few important scientific advances using cutting-edge technological tools, which are presented in the book (Stokes et al. 2010).

- Example of agro-forestry helping locals of Burundi in improving slope stabilisation, landslide reduction and local livelihood transformation using NbS under an important project funded by Birdlife International, MacArthur Foundation and The Nature Conservancy remains an important instance of NbS from the ground.[9]

With a detailed review of available work and research, NbS seems to be more descriptive (Cohen-Shacham et al. 2016; Faivre et al. 2017; Keesstra et al. 2018b; Arce Mojica et al. 2019) with different terms such as restoration, ecological and ground engineering, natural and green infrastructure and agro-forests. The varied instances from different parts of the world with community inputs only point to the increasing prominence of NbS.

The NbS examples and advances based on review of examples from different natural ecosystems, viz. mountains, forests and coasts, reflect the growing interest and momentum for NbS among scientists, practitioners, governments as well as international organisations and policy makers. However, there is a need for more relevant cutting-edge science and engineering tools, along with ILK-based knowledge systems for mitigating and reducing risks and resilience building. Further developments, field-based experiences and recommendations as a way forward for NbS are provided in different chapters of the book.

1.5 Structure of the Book

This book includes 23 chapters that are further distributed into four core sections, which include this introductory chapter and conclusion chapter by Gupta et al. (Chap. 23) that present the way forward, and further deliberates on the emerging challenges of the core themes cited in the beginning of the chapter.

[9]https://www.birdlife.org/africa/news/transforming-livelihoods-through-nature-based-solutions-burundi

Part I of this book entitled, ‘Decision-Making Tools for Mainstreaming NbS’, is a collection of seven chapters. Tambe et al. (Chap. 2) present an overview of the revival of natural springs in the Indian Himalayan Region (IHR) and discuss the NbS framework for springshed revival in the context of depleting water resources in the Himalayas. Experiences and lessons from the successful initiative of community participation for spring rejuvenation using NbS in Sikkim are the major focus of the chapter. Wagley and Karki (Chap. 3) make the case on Integrated and Participatory Watershed Management (IWM) to address protected landscape management challenges in Nepal, by providing an overview of best practices and field-based experiences. Baral and Rahman (Chap. 4) provide an overview of the food, energy and environment trilemma in Indonesia, offering an outline of NbS considerations that can help achieve a balance in this warming world. The chapter by Kumar and Saluja (Chap. 5) presents how wetlands can be used as buffers to address water-mediated risks. This chapter brings instances of water-mediated risks from India and explores opportunities for using wetlands as efficient buffers. Chapter 6 by Barlett outlines the importance of using community perspectives in understanding the ecosystem services for land-use planning before NbS applications. Participatory ecosystem system services assessment in data deficient areas and for remote and fragile ecosystems is a growing tool that can help the mainstreaming of NbS. Kumar and Ghosh (Chap. 7) bring insights from fast-growing megacities in Asia and their water management woes. The chapter outlines the importance of integrating NbS for improving water management for developing resilient cities of the future. Finally, in Chap. 8, Bhattarjee throws light on Forest Landscape Restoration (FLR) experiences as a prominent NbS approach for achieving the Bonn challenge pledge. The chapter focuses on efforts and examples of FLR from India and its wider benefits for ecosystems and communities.

Part II of the book, titled ‘Evidence and Examples of NbS Implementation’, comprises five chapters. The opening chapter by Ramesh and Ghosh (Chap. 9) presents a case from an important protected area along the Indo-Burma border. The chapter highlights the NbS approach, especially FLR, which has helped in restoration of armed conflict landscapes for DRR. Chapter 10 by Kinley and Norbu showcase the co-benefits of NbS (restoration and protection of wetland and riparian ecosystems) in Bhutan that have helped conserve the habitat of threatened black-necked cranes and white-bellied herons. Srivastava et al. (Chap. 11) provide additional incentives for reducing risk of high-altitude wetlands due to climate change by using Remote Sensing (RS) and Geo-Information System (GIS) tools in mapping and monitoring. In Chap. 12, Bhatt et al. provide a framework of restoration of waste and degraded community lands in IHR. This chapter involves an array of successful scientific and people-centric approaches that have helped restore large landscapes in the Himalayas. The last chapter of Part II (i.e. Chap. 13) by Tewari et al. outlines the co-benefits of NbS enabled land restoration by using appropriately transferred technologies in strengthening capacities of the indigenous community of Van Rajis in India.

Part III, titled ‘Advanced Institutional Provisions and Policies for NbS’, is composed of five chapters, with the opening chapter by Dalwani and Gopal (Chap. 14) highlighting and reviewing the need of freshwater ecosystems and how

NbS can help rejuvenate lakes and wetlands across India. Lahoti et al. (Chap. 15) talk about the situation of growing urban sprawls and increasing risks associated with hazards. The chapter outlines the role of green infrastructure, especially urban forests and urban green spaces, for addressing the risks and building urban resilience. Chapter 16 by Dubey et al. addresses the importance of NbS for ensuring food and nutritional security for a growing population. Kumar and Singh (Chap. 17) bring instances from agro-forestry practices and their importance in reducing deforestation, degradation and safeguarding rain-fed areas. Finally, Chap. 18 by Adhikari et al. provides an overview of the importance of various trees, shrubs and herbs in slope stabilisation and reducing landslide risks in the Eastern Himalayas, which have been sensitive to extreme climate events, especially floods and landslides. The chapter integrates the role of plants as an efficient soil binder to address the erosion problem.

Part IV, titled 'Insights to Research Innovations in NbS', is composed of five chapters. Dhyani et al. (Chap. 19) review the importance of including habitat suitability modelling tools, along with NbS as an effective combination to realise the targets of the Bonn challenge in South Asia. In Chap. 20, Das and Sarkar bring forth the importance of ecosystem services of wetlands with special focus on the carbon sink potential of the Barak river basin in North East India. Chapter 21 by Saikia et al. highlights the importance of forests and how depletion of forest ecosystem services will increase the risks that can be addressed by NbS. In the last two chapters (Chaps. 22 and 23), Gupta et al. provide a detailed overview of NbS as entry points in sectoral policies, economic instruments and business partnership, along with how new pathways are required for localising and achieving SDGs as a transformative approach in resilient building.

Through this book volume, the authors anticipate good response from wide ranging readership stimulating constructive critiques, insightful and forward looking professional discussions on the pros and cons of NbS as well as identification of new research issues, effective implementation and enhanced mainstreaming of NbS to improve the understanding and applicability of different types of NbS in addressing intractable sustainable development challenges. Finally, wider application of NbS for disaster risk reduction and climate change adaptation would help countries meet their NDC targets.

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Part I
Decision Making Tools for Mainstreaming NbS

Chapter 2
Scaling up Spring Revival in the Himalaya: Graduating from Spring-Centric to Aquifer-Centric Nature-Based Solutions

Sandeep Tambe, Subash Dhakal, Deepak Dhakal, Ghanashyam Sharma, Pem Norbu Sherpa, Himanshu Kulkarni, Nima Tashi Bhutia, Dinesh Dhakal, Sarika Pradhan, U. K. Sinha, Archana Tiwari, Ghanashyam Kharel, Indrani Phukan, and M. L. Arrawatia

Abstract The Himalayas are undergoing rapid climate change, and the prevailing narrative has revolved around glaciers and river hydrology. While ironically, in the

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densely populated Himalayan mid-hills, it is the network of rain-fed springs that are the principal source of drinking water. Recent studies highlight the worrying trend of these springs drying up affecting women and children the most. Reviving these springs by artificial recharge using geohydrology and isotope approaches has shown positive results. However, the ‘spring-centric’ approach is too intensive for scaling up, and we explore the possibility of using the ‘mountain aquifer’ as the unit of planning. In this study, we investigate the inner workings of the mountain aquifer system using environmental isotopes and landscape-level recharge experiments. Are the aquifers disjoint or connected? Do they have annual or multi-year storage capacity? Can these aquifers be recharged using landscape-level approaches? The purpose of this research is to examine these questions in an action research mode using biophysical and socio-economic approaches in the context of Sikkim Himalaya. The findings show that mountain aquifers are connected by fractures, having multiple recharge and discharge points along the elevation gradient. These rain-fed aquifers are sensitive to rainfall patterns as they do not have the capacity for multi-year storage. Landscape-level recharge projects on hilltop forests benefitted springs in the lower and middle part the most, and an intensive socio-economic assessment further reinforced the theory of connected aquifers. Based on this understanding, we propose scaling up spring revival, by graduating from ‘spring-centric’ to ‘aquifer-centric’ approaches.

2.1 Introduction

2.1.1 Himalayas and Climate Change

The Himalayas function as the water towers of Asia, giving rise to its ten largest rivers and provisioning water to over 20% of the global population (Immerzeel et al. 2010; Xu et al. 2009). They hold the largest mass of ice outside the polar region (Bolch et al. 2012). The Himalayas are undergoing rapid climate change with the average annual mean temperature rise of 0.06 °C $yr.^{-1}$ being higher than the global average (Shrestha et al. 2012). Temperatures across the Himalayan region will increase by about 1–2 °C by 2050, and precipitation will change with the monsoon expected to become more erratic (Shrestha et al. 2015). In the eastern Himalayas too, the precipitation patterns are intensifying with the annual rainfall concentrated in fewer number of rainy days. Torrential downpours are replacing the long spells of light drizzle during the monsoons which are impacting infiltration rates and thus resulting in inadequate aquifers recharge (Tambe et al. 2011; Chaudhary and Bawa 2011; Vashisht and Bam 2013). Winter droughts are becoming longer and more frequent (Seetharaman 2008). Climate forecast models predict higher rainfall with more intensity, which will result in higher surface runoff and reduced spring recharge, thereby further impacting the spring discharge (Negi et al. 2012). Climate change adaptation approaches involve developing water storage facilities (both natural and artificial), using water saving devices in agriculture and changing the structure of economic activities (Dhyani and Dhyani 2020; Vaidya 2015).

2.1.2 A Paradigm Shift in Perspective

Much of the climate change research in the Himalayas has focused on glaciers and their retreat as this impacts future downstream water supplies (Barnett et al. 2005; Intergovernmental Panel on Climate Change [IPCC] 2007). Declining water in these rivers mainly impacts the lowland communities that depend on it for water, food and energy. From a mountain perspective, the densely populated villages and towns in the mid-hills (500–2000 m) cannot readily access the water from the glaciers and rivers, as the rivers cut deep gorges and flow several hundred metres below, while the glaciers are far above these habitations. Studies over the last decade have helped shift the focus back on the mountain communities (Chaudhary and Bawa 2011; Tambe et al. 2012; Tambe et al. 2019). The mountain springs are locally known as *dhara, mool, kuan* in the central and eastern Himalayas and *chashma* and *naula* in the western Himalayas. Several studies from various parts of the Himalayas highlight that in the densely populated mid-hills, communities depend on rain-fed springs and streams to meet their water requirements. These studies also report the drying up of springs and water scarcity impacting women and children (Jeelani 2008; Agarwal et al. 2012; Chapagain et al. 2017; Poudel and Duex 2017; Kumar and Sen 2018; Sharma et al. 2019; Tarafdar et al. 2019). These studies highlight the drivers behind dying springs as climate change, intensifying precipitation patterns, land use change, poor watershed management, reduced infiltration and deforestation. On the demand side, pressure on springs has increased manifold due to growing human population and the steep rise in tourist arrivals in the Himalayan region. Taking note of the pivotal role springs play in ensuring water security and their declining status, NITI Aayog, the apex think tank of the country, convened a working group to brainstorm on this issue and prepared a roadmap for inventory and revival of Himalayan springs for water security (NITI Aayog 2018).

2.1.3 Present State of Knowledge

It is estimated that there are roughly three million springs in the Indian Himalayan region providing water security to more than 60% of the 50 million population (NITI Aayog 2018). Springs are observed and reported to be drying up all across the mid-hills of the Himalaya. Can we safeguard Himalayan springs from these natural and anthropogenic pressures? The present approach to address water security in the mid-hills focusses on constructing water supply schemes, which collect spring water in a source tank and then distribute it through galvanized iron (GI) pipes to the communities and households downhill by gravity flow. These schemes fail during the lean season as the spring discharge declines. Present studies on Himalayan springs cover the hydrology, discharge pattern, revival experiments, water quality and impacts of climate change. High population density, agriculture intensification, limited forest cover and growing levels of degradation characterize the mid-hills making these mountain communities all the more vulnerable (Schreier et al. 2006). The mid-hills receive bulk of the rainfall during the monsoons, followed by a long dry season (Tarafdar et al. 2019). Negi and Joshi (2002) used a combination of engineering, vegetative and social measures to revive a near-extinct spring in the western Himalaya and protected it as a spring sanctuary. They found that these measures helped in increasing the spring discharge significantly. Shivanna et al. (2008) used isotope techniques to identify recharge areas of springs in western Himalayas and took up a range of artificial recharge measures. As a result, not only did the spring discharge increase but the springs did not dry up during summer. Tambe et al. (2012) took up action research in the eastern Himalaya and found that it was possible to revive springs by identifying the recharge areas using geohydrology approaches and taking up artificial groundwater recharge works. This approach is based on the conceptual framework of aquifers, called 'springsheds', the first pilots of which evolved through the *Dhara Vikas* initiative implemented in Sikkim (RMDD 2014). Kumar et al. (2014) used natural isotopes to delineate the spring recharge area in the western Himalaya, and by creating recharge structures showed that spring discharge could be increased. Chinnasamy and Prathapar (2016) carried out a detailed review of the methods to review the hydrology of springs and recommend a holistic approach that combines reconnaissance surveys, field observation, isotope studies and simulation models. Matheswaran et al. (2019) took up an environmental isotope study in the mid-hills of far-western Nepal coupled with hydrometric and hydrogeological assessments to identify the spring recharge zones. The study found a strong rainfall contribution to spring discharge, and interestingly the mean recharge elevation of the springs was found to lie either fully or partially beyond the surface water catchment.

These spring revival experiments are dominantly 'spring-centric' and focus on identifying the recharge area for each spring and taking up recharge works in these springsheds. Upscaling this intensive approach across the mid-hills of the Himalayan landscape in a time-bound manner is constrained by the availability of trained para-hydrogeologists, lack of expertise to delineate recharge area, sheer number of springs and fund availability. While the spring-centric approach has demonstrated proof of concept that springs can be revived, this method is too intensive and does not lend itself for scaling up over larger units such as districts and states. Can we develop alternative planning approaches that are scalable and can be applied over larger areas, so as to create a visible impact at landscape level?

In the present study, we explore the possibility of using the 'mountain aquifer' as the unit of planning instead of the spring. Mahamuni and Kulkarni (2012), based on their studies on springs in the Sikkim Himalaya, highlight the importance of gaining an understanding of mountain aquifers as the key to the effective management of Himalayan springs. While the spring and stream discharges have been studied, there is limited understanding on the inside workings of the aquifer systems (Tarafdar et al. 2019). The connection between the rainwater and the spring discharge is through the aquifer system about which little is known. While methods to assess spring hydrology are now well known, what needs greater understanding is the mountain aquifer characteristics. This understanding will help to efficiently design the artificial groundwater recharge strategy. Implementation of this approach will still require the support of para-hydrogeologists, with plans prepared on a larger scale. This study has important implications on upscaling spring revival and in strengthening village water security in the mid-hills of the Himalaya.

2.2 Objectives and Research Questions

The purpose of the study is to devise scalable solutions to revive Himalayan springs at the landscape level. Instead of 'recharging springs' which are the discharge points of the aquifer, can we instead 'recharge mountain aquifers' feeding the springs. This study aims to provide a better understanding of the nature and characteristics of mountain aquifers and their recharge and discharge characteristics. The study has two parts: firstly using natural isotope analysis, we examine the structure and function of the aquifers. Secondly, in action research mode we take up landscape-level artificial recharge experiments and study their impacts on spring discharge along the elevation gradient to discern the aquifer characteristics. This action research focusses on three key questions. Firstly, are Himalayan springs in the mid-hills fed by small, localized aquifers, or are the aquifers large and interconnected? Secondly, is the storage capacity of these aquifers annual or multi-year and what is its relationship with rainfall? Thirdly, what is the impact of landscape-level groundwater recharge projects on spring discharge across the elevation gradient? We examine these questions in action research mode in the context of the Sikkim Himalaya.

This is among the first Himalayan study that attempts to describe the mountain aquifer and its recharge and discharge characteristics across the elevation gradient. The study explores functional visualization of the aquifers, their relationship with rainfall, the role they play in sustaining springs and how the natural recharge can be augmented to enhance the lean period discharge of the springs. The implications of this study are to better inform the scaling up of spring revival initiatives and enable the graduation from 'spring-centric' to 'aquifer-centric' approaches in the mid-hills of the Himalayas. Based on the findings of this study, we advocate shifting the conceptual spotlight from springs to aquifers while planning spring conservation works.

2.3 Methods

2.3.1 Study Area

Sikkim is a small state of India located in the eastern Himalaya and is known for its tectonic complexity. Most of the inhabited area in the lower and central parts of Sikkim state comprises of the Lesser Himalayan Domain (LHD). This area is

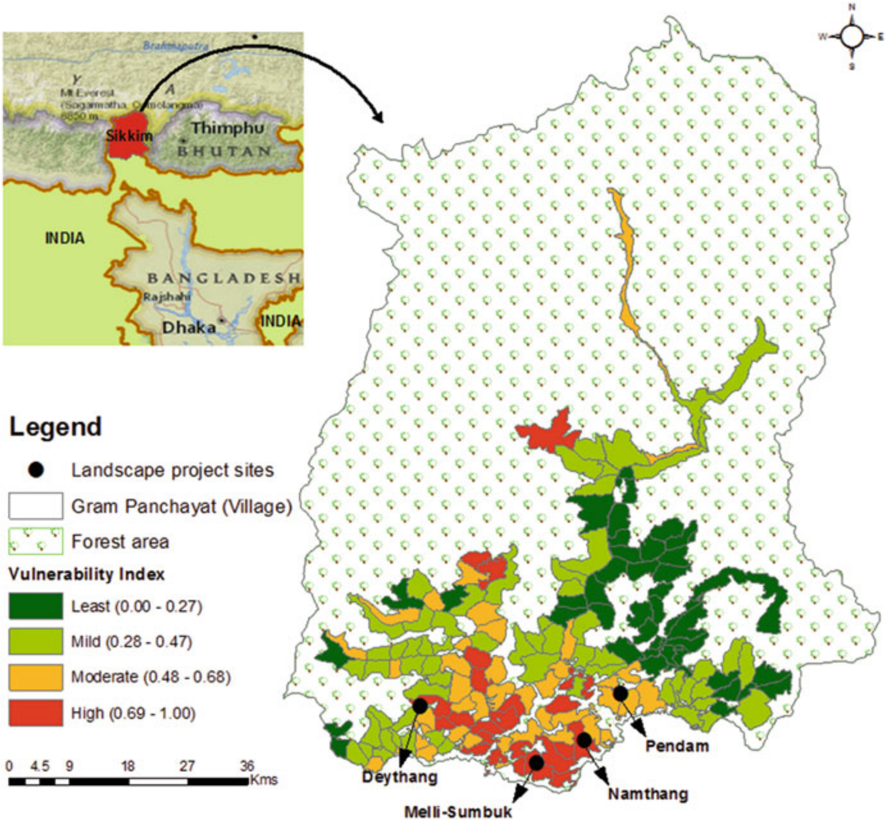

Fig. 2.1 Location of four mid-hill sites, namely Pendam, Namthang, Melli-Sumbuk and Deythang, in southern part of Sikkim state of India where isotope and artificial groundwater recharge landscape experiments were conducted (adapted from Tambe et al. 2011)

covered by the Daling group of rocks and particularly the Gorubathan formation. The Daling group of rocks comprises quartz–chlorite–sericite phyllite, muscovite–biotite phyllite, slates, quartzose phyllite, and quartzites of the Gorubathan formation (Tambe et al. 2012). Further north, the Higher Himalayan Crystallines (HHC) occur, known as the Higher Himalayan Domain (HHD) separated by the sinusoidal shaped Main Central Thrust (MCT) (Das et al. 2004). The mid-hills of the Sikkim Himalaya cover 500–2000 m elevation gradient and span across the southern and central parts of the state. The south-central part of the mid-hills are the most vulnerable to climate change (Fig. 2.1) due to high exposure, high sensitivity and low adaptive capacity (Tambe et al. 2011; Barua et al. 2014). This zone falls in the rain shadow of the Darjeeling Himalaya and receives half (150 cm) of the average state rainfall. It is covered by low grade metamorphic rocks of Daling group comprising mostly of Phyllite and Quartzite. The active tectonics of the region is clearly reflected in complex and omnipresent rock fractures in the region.

2.3.2 Landscape-Level Experiments

We used a combination of biophysical and socio-economic tools to gather evidence on the inner workings of the mountain aquifers. Environmental isotopes have a distinct advantage over artificial tracers as they facilitate the study of various hydrological processes on a much larger temporal and spatial scale through their natural variation in a system. We took up an environmental isotope study in Pendam and landscape-level groundwater recharge experiments at Namthang, Melli-Sumbuk and Deythang landscapes (Fig. 2.1). We selected these four sites so as to focus on the climate change vulnerability in the villages which face acute water shortage during the dry season (Tambe et al. 2011).

2.3.3 Environmental Isotope Study

Environmental isotopic techniques used in conjunction with conventional hydrogeology, geochemistry and geomorphology are very effective in identifying the dominant recharge zone of the springs. Applications of stable isotope ratios of hydrogen and oxygen in groundwater are based primarily upon isotopic variations in precipitation. These relative isotope concentrations can be determined by a differential isotope ratio measurement using double collecting mass spectrometers.

$$\delta = \frac{R - R_{std}}{R_{std}}$$

The relative difference is called δ value where R represents the isotope ratio of a sample ($^2H/^1H$ and $^{18}O/^{16}O$) and R_{std} represents the corresponding ratio in a standard. The δ value is generally expressed in parts per thousand (per mil, ‰) and written as

$$\delta = \left(\frac{R - R_{std}}{R_{std}}\right) \times 10^3$$

δ^2H and $\delta^{18}O$ values are reported relative to Standard Mean Ocean Water (SMOW). Stable isotopic composition of water (δ^2H and $\delta^{18}O$) is modified by processes like evaporation and condensation, and hence the recharge water in a particular environment will have a characteristic isotopic signature. Globally, δ^2H and $\delta^{18}O$ of precipitation show good correlation given by $\delta^2H = 8\delta^{18}O + 10$ (Clark and Fritz 1997). This equation is called Global Meteoric Water Line (GMWL). Variation in local climatic conditions and source of the moisture affect the isotopic composition of precipitation, and therefore the local meteoric water line (LMWL) needs to be constructed for each location under study. The application of stable isotopes to recharge problems is based on the spatial and temporal variation of the isotopes of elements of the water molecules.

Isotope hydrological investigations were carried out in Pendam block of Sikkim. Samples were collected from 13 springs located in 5 villages spread across the elevation gradient of 700–1600 m. The rainwater samples were collected at different elevations above the springs. These samples were measured for environmental isotopes ^{2}H,^{18}O and ^{3}H at the Isotope and Radiation Application Division, Bhabha Atomic Research Centre, Mumbai. Samples were collected in high quality polythene bottle of 20 to 25 ml capacity with a tight screw for both ^{2}H and ^{18}O analysis whereas samples were collected in one-litre bottle for tritium analysis. Samples were collected during pre-monsoon and post-monsoon period for consecutive 2 years. Rainwater samples were collected from different altitudes at the interval of 100 m from all the location of investigations. Monthly discharge rates of all springs were measured during the period of investigation. Isotope ratio mass spectrometry (IRMS) is the conventional method for measuring stable isotope ratios (Epstein and Mayeda 1953). Some amount of hydrogen gas is equilibrated with the water sample in a closed bottle whereby isotopic exchange takes place, and the $^{2}H/^{1}H$ ratio of the hydrogen gas is changed to a value determined by that of the water. The $^{18}O/^{16}O$ ratio in water samples is measured by equilibrating carbon dioxide gas with the water sample at 50 °C temperature and subsequently measure the isotopic composition of the carbon dioxide gas. The equilibrated CO_2 gas is isotopically representative of the water sample because by equilibration it attains a specific isotope ratio relative to the water. The deuterium and oxygen-18 signature of a water sample was measured by introducing equilibrated hydrogen and carbon dioxide gases into IRMS. The error of measurement (2σ) was found to be ±0.5‰ and ± 0.1‰ for deuterium and oxygen-18, respectively. Tritium measurement involves distillation of original sample followed by electrolytic enrichment and then neutralization and distillation of electrolyzed samples. Finally, Hisafe-3 scintillator (Perkin Elmer) is mixed with neutralized and distilled water sample (8 ml water sample + 14 ml scintillator) in 24 ml high density polythene vial and counted in ultra-low level Quantulus 1220 Liquid Scintillation Counter for 500 min. Minimum detection limit is 0.5 TU.

2.3.4 Landscape-Level Groundwater Recharge Experiment

The artificial groundwater recharge projects were designed by para-hydrogeologists and implemented by the Rural Management and Development Department, Government of Sikkim (RMDD), with funding support from the national flagship programme—Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). For the Deythang landscape, a total of 40 hectares of recharge area was identified on the hilltop and recharge structures dug on sloping land not affected by landslides in the spring of 2010 before the monsoons. The structures comprised of

581 trenches (2 m × 0.8 m × 0.6 m), 535 percolation pits (2 m × 0.4 m × 0.6 m), 610 hedge rows of 3 m each and 90 loose boulder check dams. Wherever farmer's fields were used, incentives in the form of horticulture and fodder plantations were provided. The lean period discharge (Jan to May) of three fracture springs, namely Nunthaley Dhara, Aitbarey Dhara and Kharkharey Kholsa, which were becoming seasonal, was monitored as the impact indicator. In the Namthang landscape, a total of 30 ha area was used for treatment in which 3000 trenches (2 m × 0.8 m × 0.6 m) and 150 percolation tanks (3 m × 3 m × 0.6 m) were dug in the identified recharge site in 2011 (Fig. 2.2).

In the Melli-Sumbuk landscape, the recharge area was identified mostly over the ridge around the drainage lines following the prominent fractures and the gently sloping exposed portion of the escarpment close to the ridge (Fig. 2.3). A total of 100 ha area was used for treatment in which 10,000 trenches (2 m × 0.8 m × 0.6 m) and 500 bowl shaped pits (6 m diameter and 1 m centre depth) were dug in the identified recharge site in 2010. For this landscape experiment, an independent social impact assessment was carried out to assess the effectiveness of landscape-level groundwater recharge experiment by The Mountain Institute India in 2014. The selection of *gram panchayats* (village council) was done through consultation with the Rural Management and Development Department, Government of Sikkim (RMDD) officials, elected representatives, local community members and field visits. Following this, three *gram panchayats,* namely Turuk-Ramabong, Mellidara-Payong and Lungchok-Kameray, were selected for the study. Within a *gram panchayat* the villages were selected based on the three criteria of presence of *dhara vikas* (spring revival) intervention, disparity in water availability with elevation and prevailing water security (Table 2.1). In these eight villages, 339 (50 percent) households were interviewed using a household schedule. These households were selected so as to cover the village in a representative manner. In the survey we covered aspects of water stress, water availability and access, community well-being and livelihoods (Sharma 2016).

2.4 Results

2.4.1 Environment Isotope Study

Local meteoric water line (LMWL) was constructed by plotting $\delta^{18}O$ Vs SMOW and δD Vs SMOW of rainwater samples and drawing best-fit regression line having equation $\delta D = 8.6\delta^{18}O + 9.6$ ($R^2 = 0.991$) (Fig. 2.4). The spring's samples are enriched in isotope content when compared to rainwater. The isotope values for spring water samples lie around the LMWL indicating rainwater to be the source. The clustering of isotope values of spring water sample for the spatial distribution of spring (spring density 2.5 spring/sq. km) indicates that the aquifer for all springs is recharged by precipitation with mixing of water taking place from various recharge elevations. Spring samples collected during October falls slightly below the LMWL

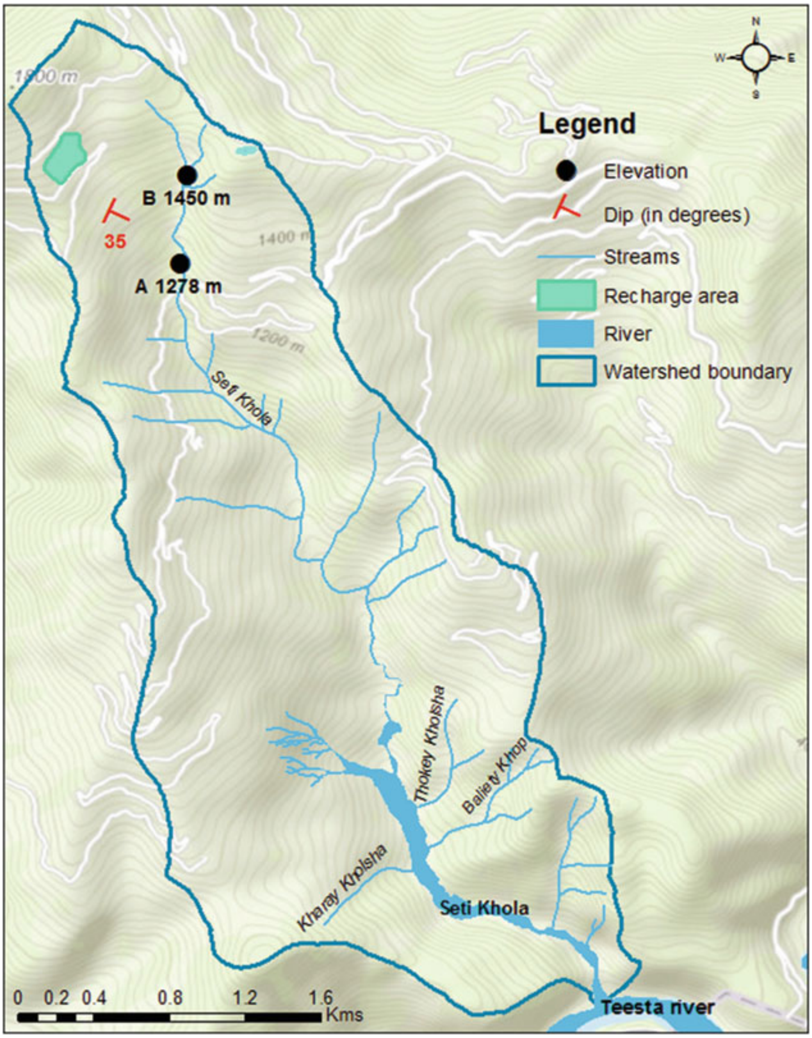

Fig. 2.2 At Namthang in Seti khola, in the lean season before the recharge works, about 100 households used to tap water from an elevation of 1278 m (Point A). After the recharge works, there is an increase in the lean season stream flow and currently more than 300 households are tapping water from this point. Also, during the lean season now the stream has water at 1450 m from which the number of households accessing water has increased from 22 to 60 (Point B)

suggesting evaporation. The best-fit line is comparable with LMWL indicating spring samples are being recharged by precipitation. Three clusters show that these 13 spring samples are being recharged from three recharge zone having different altitudes (Fig. 2.5). The Tritium analysis suggests that the water is juvenile and its mean residential time is less than 2 years and may vary from 9 months to 22 months.

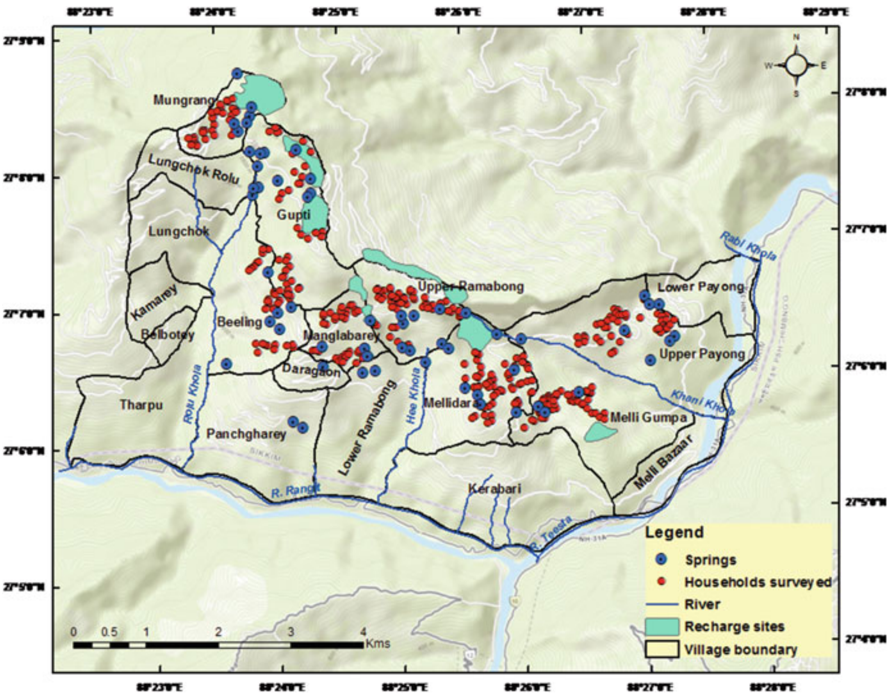

Fig. 2.3 The households in the upper reaches of the mid-hills (1500–2500 m) are served by ephemeral springs while the households in the foothills (< 1000 m) are well served round the year by perennial springs. The health of the springs declines as we move from the foothills to the ridge top. Groundwater recharge projects differentially benefit the households with elevation, with those in the lower and middle sections of the mid-hills benefitting the most

The electrical conductivity (EC) of the springs discharge ranges between 17 and 108 μS/cm and shows variation with seasons. The maximum variation of EC is within a fluctuation of 45 μS/cm. In most of the springs the EC increases with a decrease in discharge and reaches a maximum. This is probably due to older water flowing out of the aquifer during the lean period. The peak value of EC during the onset of monsoon may be due to flushing out of older water by the new recharging water.

2.4.2 Landscape-Level Groundwater Recharge

At Namthang landscape, we found that in the lean season before the recharge works about 100 households used to tap water from Seti khola from an elevation of 1278 m (Fig.2.2). After the recharge works, there is an increase in the streamflow during lean season and currently, more than 300 households are tapping water from this point

Table 2.1 Villages selected for social impact assessment of landscape-level groundwater recharge projects along the elevation gradient

Village name	Elevation range (m)	Mid-hills	Access to water	Household response to impact of intervention on 10 point scale[a]	
				Mean	SD
Lower zone	**500–1000**	**Low**	**Assured**	**5.99**	**1.78**
Mellidara	500–200	Low	Access to perennial water sources and government water supply pipelines	5.67	2.05
Upper Payong	235–1600	Low		6.23	1.78
Melli Gumpa	235–930	Low		6.16	1.33
Middle zone	**1000–1500**	**Mid**	**Mixed**	**4.02**	**2.02**
Upper Ramabong	930–1610	Mid	Medium water scarcity. While many households have access to perennial water sources, some fetch water during the lean season	4.24	1.27
Manglabarey	840–1510	Mid		3.00	1.92
Beeling	600–1210	Mid		5.47	1.67
Upper zone	**1500–2000**	**High**	**Scarcity**	**2.27**	**1.68**
Mungrang	1500–2000	High	Critical water scarcity. During lean season water fetched from 2 km with fetching time of 2 hours	1.56	1.02
Gupti	1210–2050	High		3.09	1.91

[a] n (lower zone) = 140, n (middle zone) = 113, n (lower zone) = 73

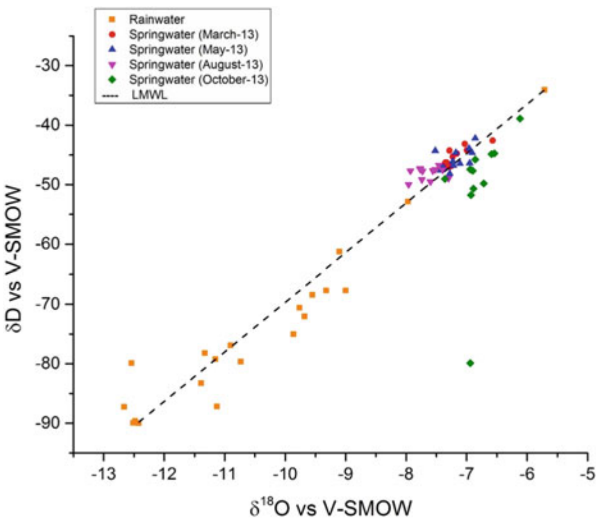

Fig. 2.4 The isotope values for spring water samples of 13 springs across the elevation gradient of 700–1600 m in 5 villages lie around the local meteoric water line (LMWL) indicating rainwater to be the source

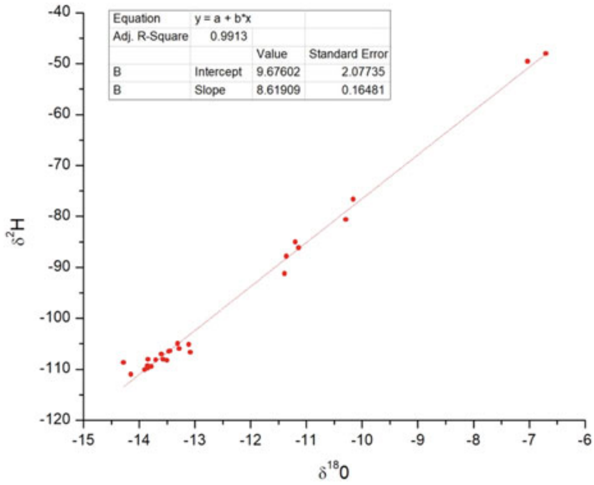

Fig. 2.5 The clustering of isotopes values of spring water sample of 13 springs across the elevation gradient of 700–1600 m in 5 villages indicates that these springs are being recharged from a common aquifer having three recharge zones at different altitudes

(Location A). Also, during the lean season now the stream has more water at 1450 m from which the number of households accessing water has increased from 22 to 60 households (Location B).

At Melli-Sumbuk landscape we found that springs are the only source of drinking water and households accessed spring water either through government water supply pipelines or using their own rubber pipes or by manually fetching water from the spring located downhill (Table 2.1, Fig. 2.3). We found that in the upper reaches of the mid-hills (1500–2000 m) adjacent to the ridge, government water supply schemes were absent due to the ephemeral nature of the springs. Hence in the lean season, households accessed water manually from springs located below the village. In the middle reaches (1000–1500 m), the local communities relied on neighbouring springs during the lean season and on government water supply schemes in other seasons. The lower altitude villages (200–1000 m) were well served round the year by government water supply schemes (Seidler et al. 2016). This also implies that the health of the springs declines as we move from the foothill to the ridge top. The most vulnerable springs are located near the hilltops and ridgeline, while the healthy ones are near the foothills. Consequently, households in the upper reaches travelled longer distances and spent more time in manually fetching water. These are the most vulnerable households as they do not have any perennial water source above their village. The household response on the impacts of the landscape groundwater recharge initiative along the elevation gradient in the Melli-Sumbuk landscape was collected on a 10-point scale (Table 2.1). The households in the lower zone of the mid-hills (500–1000 m) had a score of 5.99 $\pm$ 1.78 ($n = 140$), those in the mid zone (1000–1500 m) had 4.02 $\pm$ 2.02 ($n = 113$) score, while the ones in the upper zone (1500–2000 m) had a score of 2.27 $\pm$ 1.68 ($n = 73$). Hence, we found that the impacts of the landscape projects are not uniform and equitable, but benefit the households in the lower and middle zone of the mid-hills the most. This higher water availability in the lower belt as a result of the recharge projects had provided a boost to animal husbandry with 75% of the poultry farming and 65% of the dairy farming directly attributable to it.

At Deythang post the landscape groundwater recharge initiative, long-term monitoring of the spring discharge was carried out. We found that between 2010 and 2019 for the three springs the lean period discharge had increased by 25%, 41% and 111% (Fig. 2.6). Over the last few years, the discharge has started declining and it was found that leaf litter, humus and debris have partially filled up the trenches and ponds. There is a need to maintain these structures every 5–6 years in order to retain their recharge potential.

2.5 Discussions

2.5.1 Aquifers Characteristics and Inequity in Groundwater Storage

The environmental isotope and landscape-level artificial recharge experiments provide evidence that in the mid-hills of the Himalayas, the springs share aquifers which are often interconnected by fractures (Fig. 2.7). These mountains can thus be visualized as a connected aquifer system with multiple recharge and discharge points. The conical geometry of the mountains with a large base and tapering ridge results in a dominant aquifer volume feeding the lower and mid-hill springs making them relatively perennial and healthy. While the springs in the upper parts are ephemeral as the aquifer volume above feeding it is small and hence they get drained fast. This aquifer system gets charged annually by rainfall from various elevations and drains naturally and rapidly from several springs. It was also observed in the landscape experiments that the households in the lower and middle belt of Melli-Sumbuk landscape reported a higher impact from artificial recharge compared to the households in the upper reaches. Also, the lean period water level in Seti khola in Namthang landscape has risen with an increase in discharge volume as well. Hence the charging of this interconnected aquifer system on the onset of the monsoons can be visualized as a ‘bucket getting filled’ with the water tower rising from the base of the mountain. Post monsoons due to the natural discharge from several springs the water level declines from the top to the bottom. This cyclic rising and falling water tower resulting from interconnected aquifers mirrors the rainfall pattern as it is the only source of recharge (Fig. 2.8). Also, the artificial recharge benefits the springs in the lower and middle parts the most as the lean period water tower rises from its minima (Fig. 2.8).

Most of the artificial recharge works are feasible in the upper part of the mid-hills as government-owned, non-agriculture sloping lands are available, while the benefits of this are mostly reaped by the households in the lower and middle parts of the mid-hills. Hence, holistic and multi-sectoral policies will be required to build water security across a range of stakeholders with different set of vulnerabilities (Sen and

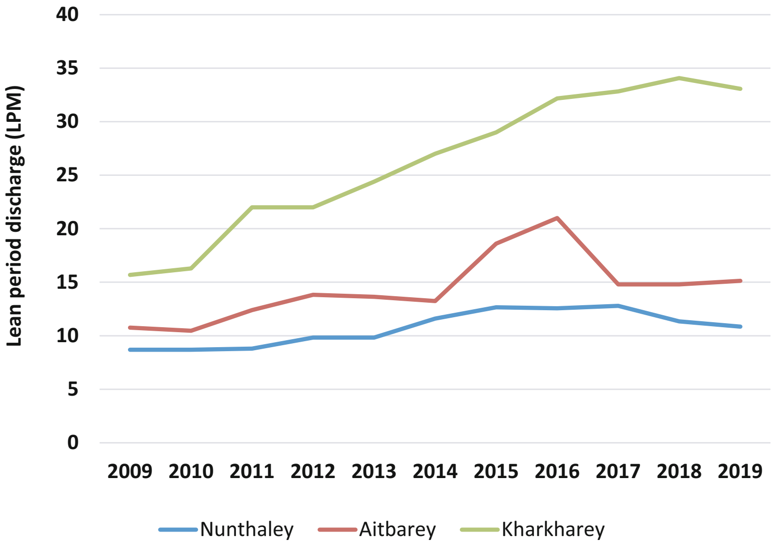

Fig. 2.6 Artificial groundwater recharge works were taken up on the hilltop forests of Deythang in May 2010. Long-term monitoring of three springs indicates an increase in the lean period (Jan-May) discharge

Kansal 2019). One way to compensate for this inequity in natural groundwater storage is to strengthen the above-ground artificial water storage infrastructure in the upper part of the mid-hills by public funding household and community water storage tanks (Fig. 2.9). Even when the discharge is low, these tanks can store the night flow of the springs which can be used during daytime. This initiative will require sizeable investments and the Government of Sikkim has been pooling funds from existing multi-sectoral programmes of rural development, agriculture, horticulture and climate change adaptation since 2011 to develop this critical infrastructure. In these four landscapes of Pendam, Namthang, Melli-Sumbuk and Deythang, there are a total of 10 villages in the upper reaches comprising of 823 households. Household water storage tanks of 10,000-litre capacity each have been provided to 45% of these households by creating a water storage infrastructure of 4.58 million litres with a total investment of 700,000 USD. This initiative needs to be further scaled up to saturate the vulnerable upper part of the mid-hills of the Himalayan regions.

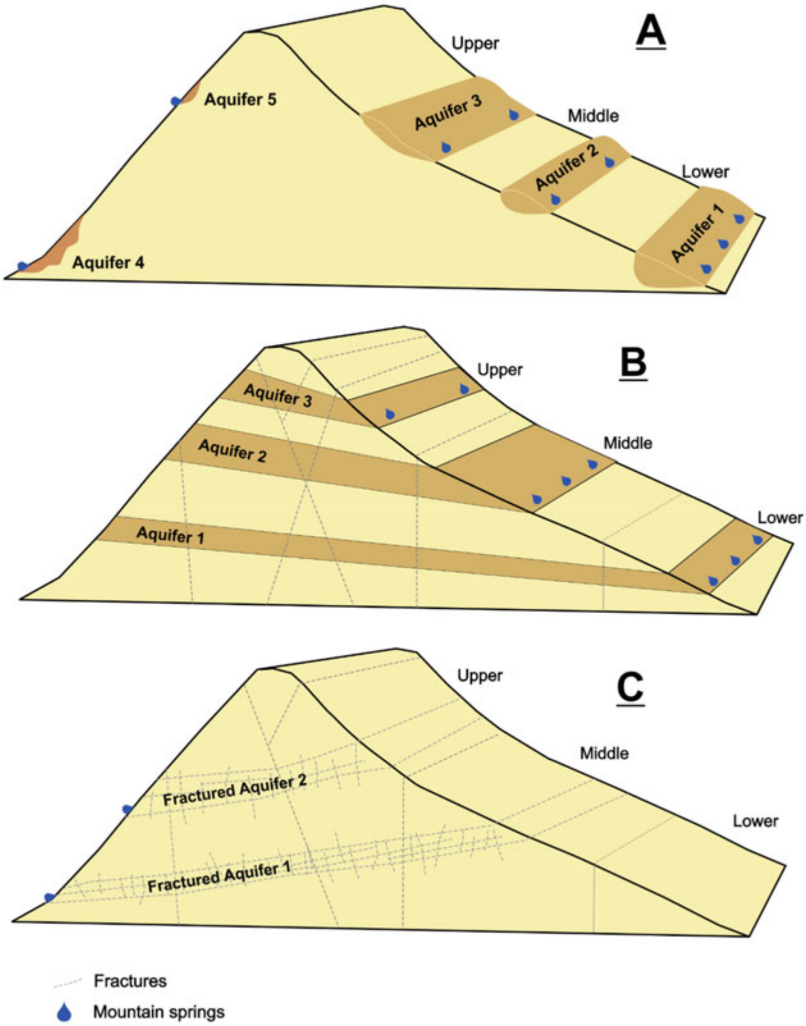

Fig. 2.7 Conceptual model representing different hydrogeological possibilities for mountain aquifers discharging spring water in the Himalaya. Generalized section of a water tower assuming that the entire ridge is either a single aquifer or multiple aquifers represented by the three scenarios: (**a**) Shallow, close to surface, local aquifers, (**b**) Regional, interconnected aquifers spread under multiple watersheds and (**c**) Regional fractured aquifer(s)

2.5.2 Mountain Aquifers Super-Sensitive to Precipitation Patterns

In the lowlands, the groundwater levels fall by several metres due to over-extraction during the poor rainfall years. However, this fall can be replenished by higher

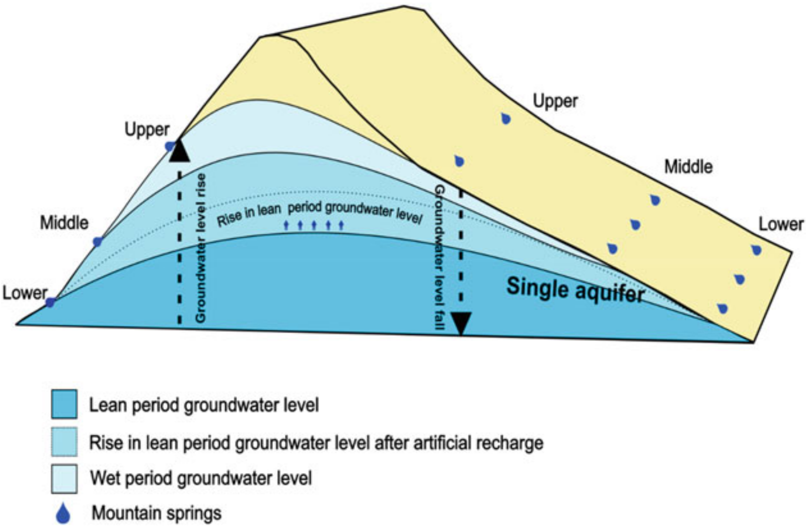

Fig. 2.8 Landscape-level artificial recharge works planned at the aquifer level help in raising the lean period groundwater level, selectively benefiting the villages in the middle part of the mid-hills (adapted from Upadhya 2009)

Fig. 2.9 Water storage tanks are a viable option for households located on the ridge top. Spring water and rooftop rainwater can be channelized into these reinforced concrete tanks having 10,000 litre capacity and built with an investment of USD 19,000 each

recharge during the good rainfall years. Thus the lowland aquifers are resilient and store a buffer that can be used during the drought years. Unlike the lowland aquifers, the mountain aquifers in the mid-hills of the Himalayas get annually recharged and discharged. They do not have the capacity for multi-year storage specially in the middle and upper part to feed the spring discharge. This is what makes the mountain springs more sensitive to droughts and adversely affects the water security profile of the Himalayan communities in the mid-hills. The mountain aquifers get discharged naturally and automatically through the discharging springs without having to extract the groundwater. Unlike lowland aquifers which can be over-extracted by digging tube wells and bore wells, the Himalayan springs in the mid-hills flow naturally from the mountain aquifers. So while in the lowlands, water scarcity can be temporarily warded off by over-extraction from the aquifer, in the mid-hills this short-term solution is not available and when the uphill spring dries up, the women and children are forced to carry water manually uphill from the spring located downhill.

2.5.3 Visualizing the Aquifers Systems

The mountain aquifers are complex, more so in the Himalayan region. Based on a variety of experiences from across the Himalayan region and particularly from the springshed management experience in Sikkim (Tambe et al. 2012; ACWADAM and RMDD 2011; ACWADAM 2013), one can conceptualize three different scenarios (A, B and C) of aquifer systems in the mid-hills of the Himalaya as indicated below and illustrated in Fig. 2.7:

1. A) *Shallow, close to the surface, local aquifers*: Multiple, local aquifers are formed out of weathering of the rock closer to the topography and/or deposition of material at various points along the slopes of the ridge. These aquifers are quite local in nature and form groundwater storages at various elevations—mostly close to the surface—along different slopes of the ridge. These porous and permeable rock formations will form aquifers that have limited extents and depths but have moderate to high transmissivity and storage. While these aquifers seem discrete, they form a fairly well-integrated 'aquifer system' that could be connected both by fractures and by the topography itself. Spring discharge from upstream aquifers may flow along the surface, a part of which may enter the lower aquifers as recharge (depending upon prevailing conditions). While the sizes of the local aquifers may be similar, the aquifers towards the crest of the ridge would tend to dewater first and spring discharges from these aquifers may be largely seasonal. On the other hand, aquifers at the base are likely to remain saturated longer as they receive water for recharge over longer periods from upslope sources and resources. Fractures (although not illustrated in the conceptual model) would further complicate the scenario as they can establish subsurface connectivity between an upslope aquifer and a downslope one, with the fractures providing a sustained flow of groundwater under gravity.
2. B) *Regional, interconnected aquifers spread under multiple watersheds*: Alternate layers of permeable and impermeable strata dip in one direction, forming inclined aquifers. Such a situation prevails over large regions of the Himalaya, especially in the mid-hills. The porous and permeable layers constitute multiple aquifers, usually connected through fractures. These aquifers are quite complex. Groundwater is under phreatic conditions in each layer, when the layer is exposed

at or close to the surface, while it may be under confined conditions (under hydrostatic pressure) when the layer is deep in the subsurface. While the layers constitute separate, but often leaky aquifers, each aquifer usually has a distinct recharge area on one side of the ridge with a spring (discharge zone) on the other. The upper aquifer would tend to dewater quickly because of the conical geometry of the ridge which would mean a limit to the size of the upper aquifers. The upper aquifer, therefore, would be much smaller, inhibiting large storages in the aquifer. The lower aquifers owing to their tabular geometries would be relatively larger. Being able to store larger volumes of groundwater, the lower aquifers would be able to sustain springs for longer periods, often perennially.

3. C) *Regional fractured aquifer(s)*: Instead of distinct layers of permeable rocks, some portions of the single rock formation or multiple layers of rock at different depths are fractured. These fractures may form distinct aquifers. The aquifer storage capacity and transmissivity depend upon the nature and geometry of fractures. Like in (B) above, the upper fractured aquifer will have potentially smaller aquifer storage due to the smaller volume of the overall fractured space, given the conical shape of the ridge, as compared to the lower aquifer. Both aquifers will have multiple recharge zones, depending upon the connectivity and hydraulic continuity of the fractures. Springs will emerge where fractures carrying groundwater from the fractured aquifer outcrop at the surface. The upper aquifer is likely to dewater first, with seasonal springs, while the lower one, due to a relatively larger storage of groundwater, will support springs, usually perennially.

2.5.4 Recharge Implications

A springshed management approach, in the form of the eight-step methodology first developed under Dhara Vikas initiative in Sikkim (RMDD 2014) or the more recent six-step protocol (Shrestha 2018), includes the local mapping of aquifers and springsheds at the scale of a water tower. Undertaking recharge activities at the scale of a water tower, rather than at the scale of the immediate (surface water) catchment of the spring, clearly has advantages. Whether it is a single aquifer with multiple recharge areas or multiple aquifers with local but numerous recharge areas, the multiplicity of recharge sites makes it relevant to undertake recharge activities at regional scales, such as at the scale of a water tower. Considering that even springs are interlinked in various complex ways, it becomes important to ensure that all recharge areas are covered so that the aquifer gets optimally charged during the wet season. Improvements at the level of individual springs cannot reach full potential unless groundwater recharge at the scale of the entire system is undertaken. Spring revival in the Himalayan region can be efficiently recast by applying the paradigm of using a 'valley-to-valley' approach to watershed management in the region rather than the more conventional ridge-to-(the next) valley paradigm. Reviving springs at landscape scale will also result in multiple benefits such as improved forest cover, reduced soil erosion and enhanced base flows of streams and rivers.

2.6 Conclusions

The spring-centric approach is intensive as it involves geohydrological planning and recharge measures at spring aquifer level and is too intensive for upscaling. Can more efficient recharge approaches be designed that have the economy of scale and do not need spring-level planning? The present study shows that this is possible if we shift the focus from the spring which is the discharge point to the regional aquifer system which feeds the springs. This approach will not only have economy of scale but will be easier and less complicated to plan and execute as the target of recharge is the regional mountain aquifer and not the localized spring aquifer. This approach will also help in optimizing funds and efforts as the focus shifts to landscape-level interventions instead of targeting individual springs. In order to balance the inequity in the water stored in the below ground aquifers, this study highlights the need to supplement the above-ground water storage infrastructure in the hilltop villages. This change in orientation from spring recharge to aquifer recharge will need capacity building and further strengthening of the cadre of para-hydrogeologists. The practice of reviving Himalayan springs is ahead of science and this study too builds on ‘learning by doing’. Further studies on mountain aquifers are needed to assess the generalizability of these findings across the Himalayan mid-hills.

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Chapter 3
Ecosystem-Based Integrated and Participatory Watershed Management

Mohan Prasad Wagley and Madhav Karki

Abstract The chapter describes an integrated and participatory watershed management approach that involves multiple stakeholders in decision-making processes that provides managers (a) opportunities to exchange knowledge, build awareness, and integrate different sectors; (b) build consensus on priorities and aspirations; (c) enable local community to set agenda and outcomes; and (d) build institutions to work for collective actions. Different options were tested under this integrated approach enabling inclusive participation of local community and government agencies enhancing relevance, effectiveness, and sustainability of activities with good outcomes. The approach was implemented in four settlements situated within the Shivapuri Nagarjun National Park, Nepal. The protected area (PA) focuses on habitat protection and management, and wild animals co-exist with indigenous peoples' settlements within the Park boundaries. The three-year pilot work indicates high feasibility for upscaling the approach. The major findings are the following: (a) well-organized and aware buffer zone communities are better environmental stewards to conserve the biodiversity and co-manage the socio-ecological production ecosystems; (b) the buffer zone community if equipped with knowledge and skills can improve their livelihoods and support habitat improvement; (c) new generation of integrated watershed management approach is accepted due to its flexible and adaptive approach; and (d) incentivized and enabling mechanisms and tools are necessary to address historical grievances of the communities and reduce park-people conflict. It was also found that capacitated and empowered people are better conservation partners. The prerequisite is the access and benefit sharing rights of local communities need to be recognized and respected.

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3.1 Introduction

Watershed or sub-watershed or micro-watershed is defined as a topographically delineated area whose natural drainage system sends water through a gradient flow to a river system or other water bodies. It can also be described as a land area from which water flows from upstream to downstream in a gravitational drainage system to a water body such as river, lake, or sea (Virginia Tech 2018). In other words, watershed is a naturally occurring unit of landscape, which contains a complex matrix of land use system such as forest, agricultural cropped areas, grass/range land, water bodies, and other categories of land use and land cover types (Wani et al. 2008; Wani and Garg 2009; Wang et al. 2016). Likewise, an ecosystem of a watershed can be expressed as a home to all the living creatures (plants, animals, and micro-organisms) that live in coexistence within a watershed through interacting with each other and with the physical environment of the watershed within and outside (Raju et al. 2008). Through the interaction between and among the living and the physical environment there exists a continuous cycling of nutrient, water, and energy flow within the watershed system (Brandes et al. 2005; Wani and Garg 2009).

3.2 Literature Review

Among the most cited water and watershed management frameworks are participatory integrated watershed management (PIWM) (FAO 1996); integrated water resources management (IWRM), and integrated river basin management (IRBM) (Karki et al. 2011).[1] PIWM is a participatory and multidisciplinary process and approach of conservation, development, and optimal utilization of the available natural resources in a watershed on a sustained basis. It is a people-centered approach as they are mobilized, trained, and empowered as the main decision makers and actors. IWRM is "a process that promotes the coordinated development and the management of water, land, and related resources to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (UNESCO-IHP and NARBO 2011:3). "The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner. Both are holistic approaches that seek to integrate the management of the physical environment within that of the broader socioeconomic and political framework." Different management interventions for the restoration of the BRB have been identified by past studies (GoN/NTNC 2009). As the issues are complex and stakeholders are multiple, improvement of the watershed is

[1]See Mountain Development; http://www.bioone.org/doi/pdf/10.1659/MRD-JOURNAL-D-11-00017.1).

challenging. The Bagmati Action Plan (BAP) has recommended a strategic and systematic approach. In this chapter, we present a multi-stakeholder, multi-sectoral, multi-scale, and multidisciplinary approach linking local action to national policies and regulations. Participatory integrated watershed management (PIWM) approach (FAO 1996; ICIMOD 2011) meets these criteria. The approach involves multiple stakeholders in decision-making processes to provide the team (a) opportunities to share views, needs, and knowledge; (b) build consensus on shared values and aspirations; (c) enable local community to influence project agenda and results; and (d) build commitment and a feeling of ownership to enhance and ensure project implementation. Different options presented in our approach based on sustainable land and water management (SLWM) principles will have a high degree of participation at local community and government levels that will help to ensure relevance of activities with good outcomes for strengthening sustainability of the work.

Integrated watershed management (IWM) is the inclusive management of all the components of natural resources within a watershed such as snow and ice, soil, land, minerals, agriculture, water, plants, animals, and micro-organisms that exist within a particular watershed (Wani et al. 2006). In other words, integrated management of a watershed is the complete management of physical, hydrological, and biophysical resources of a watershed. Besides these natural capitals, the human capital also exists in the watershed and their social, economic, and cultural norms, values, and practices are equally important to consider in an integrated approach to watershed management. Further, there exist constant interactions between and among the physical, hydrological, biophysical, and socioeconomic capitals within the watershed, which need to be considered carefully to get sustainable benefits from the ecosystem-based IWM. Therefore, the ecosystem-based IWM is based on the principle that requires the holistic management of both ecological and sociocultural systems for creating harmony between human and nature.

3.3 Ecosystem-Based Watershed Management Approach

Ecosystem is defined as a community of plants, animals, and smaller organisms that live, feed, reproduce, and interact in the same area or environment (Barrow et al. 2012). Ecosystems have no fixed boundaries. It can be a single lake, a watershed, or an entire region. An ecosystem consists of a dynamic and complex system of plant, animal, and micro-organism or biotic and abiotic components. Examples of ecosystems are agro-ecosystem, aquatic ecosystem, marine ecosystem including coral reef sub-system, desert ecosystem, forest ecosystem, human ecosystem, coastal ecosystem, ocean ecosystem, etc. Grass or range land ecosystem includes steppe, prairies, rainforest, savanna, pampas, taiga, and tundra and built or modified ecosystem includes urban and peri-urban ecosystems. According to Khan Academy, the major points to remember to better understand what ecosystems are (a) an ecosystem consists of a community of organisms together with their physical environment; (b) Ecosystems can be of different sizes and shapes (e.g., marine, aquatic, or terrestrial); and c) broad categories of terrestrial ecosystems are called biomes (Khan Academy 2020).

Ecosystems with higher biodiversity tend to be more stable with greater resistance and resilience in the face of disturbances and disruptive events, and this is called ecosystem stability. In an ecosystem, the biotic components interact with each other and with the abiotic environments in which they live for nutrient uptake, nutrient cycling, and energy flow for the growth, abundance, and survival of the organisms, which is termed as a functional unit of an ecosystem. Similarly, the structural units of an ecosystem consist of biotic (producers, consumers, decomposers) and abiotic components. In an ecosystem, any change in these structural units (change either in biotic or abiotic units) impacts the functions of the ecosystem, i.e., change in nutrient uptake, nutrient cycling, and energy flow for the growth, abundance, and survival of the organisms that takes place constantly. These principles apply in any terrestrial and aquatic ecosystems of a watershed. Therefore, watershed is an ecosystem with distinct features of water flow through gravitational drainage networks, groundwater recharging, potential for high alteration of geographical features, and upstream-downstream relationships between and among different ecosystem components. Watershed ecosystem has an added feature that it produces vital ecosystem services especially water, food, and energy (provisional services); hydrological, biodiversity, and water purification (regulating services); and different cultures, heritages, languages, and practices (cultural services).

Watersheds are managed for the above ecosystem services based on ecosystem-based management approaches. According to Wikipedia, “Ecosystem-based management is an environmental management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation” (Christensen et al. 1996).

Therefore, an ecosystem-based approach or ecosystem approach to watershed management (EAWM) can be defined as an applied science and art of implementing integrated ways of management of all biotic and abiotic components that exist within the watershed in order to maintain the ecological integrity and to reach a balance between conservation, utilization, and equitable sharing of benefits obtained from the integrated management of natural resources of all watersheds (Yaffee 1999; Grumbine 1994).

An ecosystem approach to watershed management (EAWM) is not a formula or a panacea to solve all human-ecological problems, but a strategic framework that can be adapted to suit various issues and their solutions while managing the watershed in an integrated manner. In an ecosystem approach to watershed management, a strong link between biophysical functions of watershed and human well-being is promoted, which is very crucial for the survival of all living organisms that occur in an ecosystem of the watershed. Therefore, in an ecosystem approach to watershed management, we need to take into account that humans, their social and cultural diversity, biophysical and physical units are the integral elements of an ecosystem and should be taken into consideration while managing the watershed through ecosystem approach.

3.4 Importance of Ecosystem Approach to Watershed Management

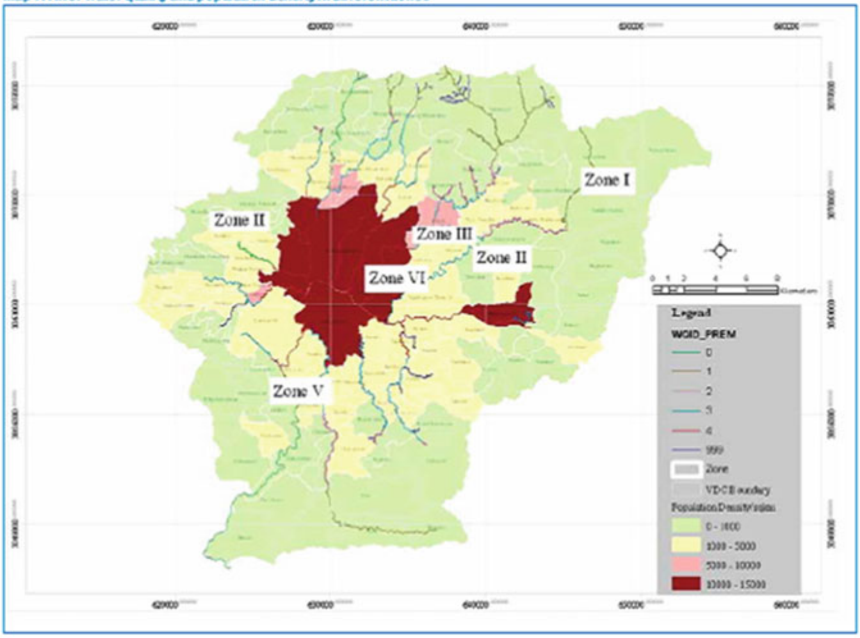
The importance of EAWM to watershed management can be best illustrated through the following example. Let us assume that a conversion of forest ecosystem into agriculture ecosystem is taking place in a process of enhancing enough food to reduce poverty of inhabitants of watershed. In a process of converting forest ecosystem into an agricultural ecosystem, some physical changes occur within the watershed. These physical changes are biodiversity and land cover changes within the watershed that lead to excessive runoff and low infiltration, thereby causing disruption in energy flow/nutrient cycling and nutrient leaching that take place within the altered ecosystem. Such changes within the system lead to ecological response within the watershed. The result of ecological response is biological displacement due to stress and disruption in existing biological communities. Finally, the ecological response leads to the weakening of the quality of life of the people due to erosion, flooding, air and water pollution, land degradation, and loss of productivity of land. Poor quality of life of inhabitants of watershed occurs, which further leads to foster more destruction and change in ecosystem searching for better quality of life.

3.4.1 A Case Study: Shivapuri Nagarjun National Park (SNNP) Watershed, Nepal

3.4.1.1 Brief Description of the SNNP Watershed

The Shivapuri Nagarjun National Park (SNNP) is the only national park located in the Middle Hills or lower Himalayan ecological region of Nepal. Two unique features of this park are (a) indigenous and local communities live within the park along the upstream slopes of the Bagmati River that originates from the uppermost watershed point located within the core area of the park and (b) it is the only national park representing the middle hills region of Nepal. Four major settlements Mulkharka, Chilaune, Kunegaon, and Okhreni inhabit close to 400 households and 1500 people.

Map 7: River water quality and population density in different zones



The indigenous and local communities whose traditional farming and forest products gathering practices have been affected by the declaration of the national park are caught in the vicious cycle of environment conservation, poverty, and habitat destruction since very beginning. The primarily farming people communities are practicing their livelihood activities under a protected area (PA) regime of restricted use of their traditional forest-based resources especially fire wood, fodder and food collection, cultivation of agricultural crops, and use of river and spring water in order to provide good habitat for wild animals and plants.

Shivapuri Nagarjun National Park (SNNP) is the Ninth National Park established in 2002. It was initially established as a protected watershed and wildlife reserve in 1976. It is located in the country's mid-hills on the northern fringe of the Kathmandu Valley and at an altitude between 1350 m and 2732 m. It covers an area of 159 km^2 including parts of Kathmandu, Nuwakot, Dhading, and Sindhupalchowk districts with 23 Village Development Committees (Fig. 3.1). Climatically, the park is located in a transition zone between subtropical and temperate climate. The annual average precipitation is around 1400 mm that occurs mostly from May to September. Temperatures vary from 2 to 17 °C during winter, which rises to 19 to 30 °C during summer. The SNNP watershed has always been an important water catchment area and prime source of drinking water supplying several hundred thousand cubic liters of water daily to the Kathmandu Valley. More than nine tributaries of the main river Bagmati and other small rivulets and streams discharge about 30 million liters of water per day. SNNP is an excellent representative site of the ecosystems of middle hills of Nepal as it is located midway between Eastern and Central Himalaya. It is rich in biodiversity having some of the nationally and globally threatened wild

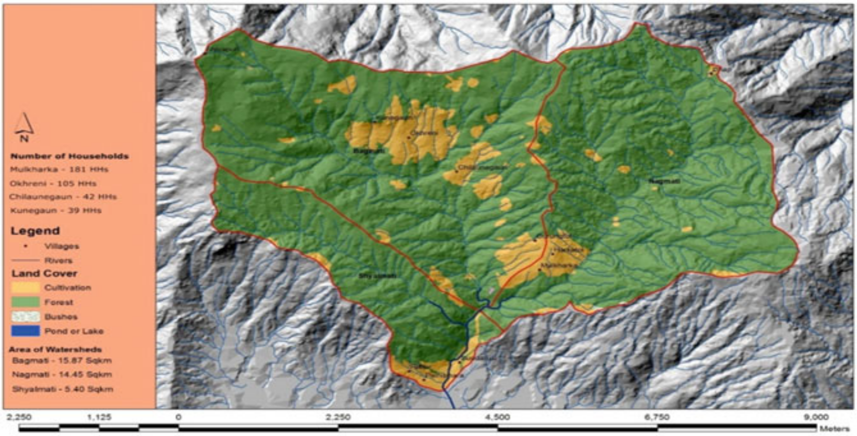


Fig. 3.1 Upstream watershed of Bagmati River focusing the 4 settlements: Mulkharka, Chilaune, Okhreni, and Kunegaon (Source: NGO Package 1—Watershed Management. Project Document, 2016

animals, birds, and butterflies. It has subtropical to lower temperate forests and associated vegetation. It is a good site for research and study in forestry, park management, ecosystem management, socio-ecological interactions, and cultural values of biodiversity especially water as well as hiking, trekking, panoramic views of Himalayan mountain peaks along with meditation, bird watching, and long-term ecological studies. The SNNP is highly important for its cultural and religious heritage—most important of all being the origin of River Bagmati from Baghdwar or Mouth of a Tiger. The River fed by more than five main sub-rivers meanders through the city of Kathmandu with several shrines and temples located along its bank throughout its course in the valley. The people of the Kathmandu valley with its close to three million populations around the park follow Hindu and Buddhist culture. Some important places for cultural and religious importance in the park are Nagi Gumba, Bagdwar, Bishnudwar, Jamacho, Manichur Mahadev, Kageshwori, Sundarimai, Baudeshwor, Tarkeshow, Pachali Bhairav, Mahadevasthan, Shivapuri Peak, and Sundarijal. These are the important pilgrimage destinations for Hindus and Buddhists.

Shivapuri National Park is easily accessible from Kathmandu city, so it attracts many visitors and tourists for hiking, camping, picnic as well as enjoying adventure tourism activities like rock climbing, mountain biking, and some sports events. There are many popular trekking routes within the park. Trekking routes to Gosaikunda, Helambu, Nagarkot, and Langtang National Park pass through this park. Impressive view of the high Himalayan peak towards the North; Nagarkot hills towards the East; Nagarjun hills towards the West; and Kathmandu valley, Phulchowki and Chandragiri hills towards the South can be seen from the Shivapuri Peak (Source: Shivapuri Management Plan; FAO 1996).

Description of the Upper Bagmati Watershed.

The Bagmati River is the main river of the Bagmati basin. The River originates from Baghdwar, which is located in SNNP in 15 km northeast of Kathmandu. The Bagmati River flows through the Kathmandu Valley crisscrossing a number of important religious and cultural sites including Pashupatinath and Gokarneswor temples. Most of the important temples, traditional monuments, ghats, stupas, and shrines are located along the river banks and are used for different cultural and ritual purposes. The Bagmati River is fed by natural springs and monsoon rainfall. The average annual rainfall in the catchment is about 1900 mm, of which about 80% occurs during monsoon (June–September). The Bagmati basin is characterized as medium or dry basin fed by springs and monsoon rainfall (WECS 2008).

SNNP has several watersheds of different sizes ranging from the micro- to sub-watersheds. Nagmati, Bagmati Nadi, and Shyalmati rivers are the main upstream sub-watersheds of main Bagmati River. Bagmati River Basin Improvement Project (BRBIP 2016) had recently contracted the Joint venture of The Centre for Green Economy Development, Nepal (CGED, Nepal), and Integrated Development Society, Nepal (IDS-N), to implement the project titled "NGO Package 1—Watershed Management" in Shivapuri Nagarjun National Park (SNNP). The project had selected upstream watershed of Bagmati River (Bagmati Nadi) within SNNP as a planning and working unit to focus and demonstrate ecosystem-based IWM. Several programs were implemented with due consideration of ecosystem-based IWM.

3.5 Ecosystem Services Provided by the Watershed

Any watershed or sub-watershed or micro-watershed contains several ecosystems. The ecosystems could be forest, grassland (rangeland), shrubland, desert, agriculture, and aquatic ecosystems. The ecosystems of watershed provide direct and indirect benefits in terms of services and goods to the people living both in upstream and downstream of the watershed. The upstream watershed of Bagmati River has forest, agriculture, shrubland/grassland, and aquatic ecosystems. The ecosystems have provided all the four ecosystem services like Provisioning, Regulating, Cultural, and Supporting/Habitat services to the people living in the core area of upstream watershed and the buffer zone of national park (downstream and periphery of watershed).

Among the provisioning services, the most important services are the water, food, and fuel energy. Among the regulating services, hydrological services including weather regulations, reduction of runoff/peak-flow and sedimentation through natural buffering capacity, moderating climate, reduction of water and air pollution, controlling of soil erosion/landslides, and maintaining ground-water recharge are the important services. Similarly, the supporting services include support to wildlife habitat, maintaining ecological integrity, facilitating hydrological cycle, and ensuring ecosystem functioning, and support for soil formation and nutrient cycling. Under cultural services the ecosystem provides recreation, education, aesthetics, adventure, and spiritual services including the enhancement of cultural heritage of people living in the watershed.

The specific ecosystem services provided by SNNP are described as follows:

3.5.1 Provisioning Services (MA 2005)

This include the material products obtained from upstream watershed ecosystems, including food, fiber, fuelwood, timber, grass, fresh water and air, genetic resources, crop, fruit, and livestock productions. There is also legal and illegal hunting of wild animals that provides meat, medicinal plants, and minerals. Equally important is regulating service chief among which are hydrological and river discharge services besides terrestrial and aquatic biodiversity and air, water, and land pollution reduction services. The supporting services include habitat maintenance service (MA 2005).

Management Strategy: The management strategy adapted by the local communities focused on plantation of forest and fodder trees, fruit trees, and grasses, as well as organic farming. As trees and plants grow, they help remove more CO_2 from the atmosphere through photosynthesis and effectively lock it away in their tissues, thus acting as carbon sink or carbon stores. Also, they help provide basic needs of the local people like timber, fuelwood, grass, fruits and nuts, NTFPs, and fresh air and water. Vegetation management and organic farming have increased the soil fertility of the agriculture land and forest floor to supply nutrients to plants communities and increased forest cover also filter and act as watershed improvement treatment.

- Trainings on quality drinking water, water storage, purification of water, ensuring water flow through manipulation of vegetation and trees, organic farming, waste disposal, and clean energy were provided to the local people. Solid waste management activities have been carried out by the local people, which have reduced the pollution level of soil, water, and air inside the upstream watershed.
- Plantation and maintaining the trees and vegetation in the upstream watershed have regulated the pests and vector-borne diseases that attack plants, animals, and people.

3.5.2 Regulating Services

This includes water purification, climate regulation, flood control and mitigation, soil retention and landslide prevention, pollination, and pest and disease control.

Management Strategy: The management strategies focused was: (a) construction of bioengineering-based erosion and landslide prevention, (b) slope failure prevention structures, and (c) trainings on IPM-based organic farming. Biophysical Hazard reduction through these has enhanced the safety of the upstream watershed dwellers from the natural disasters and climate change impacts.

3.5.3 Cultural Services

They are the nonmaterial benefits from ecosystems including recreation, aesthetic experience, spiritual enrichment, and cognitive development, as well as their roles in supporting knowledge systems, social relations, and aesthetic values.

Management Strategy: For this, the management objectives of ecosystem-based IWM were primarily focused on providing training on developing ecotourism through developing ecosystem and biodiversity to attract local and international tourists, thereby increasing the local economics of the people living in the upstream of the watershed.

3.5.4 Habitat Services

Habitat services are those that are necessary for the production of all other ecosystem services including provisioning of habitat for species, primary production, nutrient cycling, and maintenance of genetic pools and evolutionary processes.

3.6 Key EAWM Strategies Adopted

A participatory and integrated ecosystem-based watershed management (EAWM) strategic framework was developed for implementing an adaptive management of the SNNP watershed. The aim was to apply EAWM tools to deal with the complex and dynamic nature of the PA ecosystems inside the watershed and to enhance the knowledge and capability of the park and community leaders to understand both the functions and structure of the socio-ecological production ecosystem (SEPE) within the watershed. This is a strategy for the integrated management of land, water, and living organisms of all kinds—plants, animals, fungi, different pollinators, and micro-organisms that can help promote conservation and sustainable use of natural resources within a watershed in an equitable manner. Thus, the application of an EAWM aimed to help to create a balance among the conservation, sustainable use, and the fair and equitable sharing of the benefits available from the use and management of natural resources of the watershed. The aim was also to improve the degraded habitat and reduce the wildlife damage of crops and properties of the buffer zone community. The approach applied used locally tailored scientific methodologies informed by indigenous and local knowledge and practices focused on the levels of socio-ecological organizations of different components, which encompass the essential structure, processes, functions, and interactions among organisms and their environment (Handbook of the UN Convention on Biological Diversity, second edition, 2003).

Recognizing the vague and complex definitions of watershed and ecosystem, the simplest strategies as stipulated by CBD were adopted while managing the ecosystem based on integrated and participatory management of upstream watershed ecosystem services establishing clear links with the local and downstream users and beneficiaries. The social, cultural, and economic values, benefits, and priorities of watershed communities were clearly identified and livelihood improvement and watershed rehabilitation programs implemented. Designing and working on assisted watershed capital improvement and community management principles to alleviate the vulnerability and poverty of local inhabitants, the first stress was to set priority and develop collective actions to sustainably utilize the essential ecosystem services from the IWM point of view.

Boundary of working unit for such an integrated watershed ecosystem management has to be landscape or catchment that has forest, shrubs, agriculture, and wetlands as land use units. These units are clearly defined in consultation with local people and park authorities within the upstream watershed of Bagmati River. The communities living in upstream watershed of this park landscape were made aware, sensitized to be inclusive in all their actions, and trained to maintain and upgrade the terrestrial and aquatic ecosystems especially agricultural ecosystem of the watershed and to enhance the ecosystems ability to respond to a variety of internal and external stressors and pressures. Changing hydrological regime of the watershed was also studied and considered while designing and implementing intervention programs in the watershed. Scientific information and proven technologies of watershed management were introduced, which were easily adaptable to local conditions and adopted by the inhabitants. These tailored technologies ensured the watershed management interventions were close to the ecosystem integrity that yields social, economic, and cultural benefits.

3.7 Inclusive Approaches

Selection of all activities and management decisions were done based on the principle and good practices of Gender Equality and Social Inclusion (GESI) and empowerment. The approach gave priority to the upstream watershed inhabitants in order to build up natural capital by enhancing social and human capital as well as living quality of local people who were trained as the frontline watershed managers and workers. Indigenous and local skill and knowledge of the inhabitants on ecosystem approaches to watershed management was improved by providing appropriate trainings on ecosystem and IWM. Active and meaningful participation and involvement of upstream watershed inhabitants and stakeholders were pursued while implementing the ecosystem-based watershed management activities.

3.8 Implementation of Ecosystem-Based Integrated Watershed Management Programs

Several ecosystems-based IWM programs have been implemented in the upstream watershed of Bagmati River in SNNP. This is the only ecosystem-based IWM program that has been implemented in the upstream watershed particularly focusing the protected area of the mid-mountain ecological zone. The programs were implemented in the upstream watershed of Bagmati River focusing the four settlements (Mulkharka, Chilaune, Okhreni, and Kunegaon), which are situated in the core area of SNNP. These four settlements were declared as buffer Zone and the project's target group was 367 Households/BZ user groups of the four settlements (Fig. 3.1).

Key ecosystem-based IWM interventions for providing ecosystem and watershed management benefits to the targeted BZ users groups were detailed in the following sections.

3.8.1 Promotion of Green Environment through Mobilization of Local Participation

In this program, efforts were made by the local farmers to minimize erosion from outward sloping agriculture land by planting grass, fodder and fruit trees in the private farmland. About 7748 planting materials have been distributed to the 1045 local farmers freely (Figs. 3.2 and 3.3). The farmers were given adequate trainings on plantation, maintenance, and care of the plants they had planted in their farmland. Almost 367 HHs had planted 6758 seedlings of several winter and summer fruit plants, fodder trees, and grass saplings covering almost 12.5 ha of sloping agriculture land. These programs have raised the awareness of the households in the promotion and maintenance of forest ecosystem and green environment in their settlements. The planted saplings of forest tress, fodder and fruit trees, and grass

Fig. 3.2 Planted Alnus nepalensis and natural regeneration of grass

Fig. 3.3 Napier grass planted by farmers

seedlings have started bearing fruits and forage to the livestock, which have reduced the farmer's dependency on natural forest of national park.

3.8.2 Enhancing Farmer's Capacity on Ecosystem-Based Integrated Watershed Management

Sustainable ecosystem-based IWM requires effective and extensive participation of local people. For their effective and sustained participation, the local people should have adequate knowledge and capacity for ecosystem-based IWM. The NGO Package 1—Watershed Management project had launched several demonstration and hand-on trainings on ecosystem and IWM to the BZUGs of the four settlements of SNNP and park authority.

Some of the key capacity enhancement programs provided to the BZUGs were:

- Training programme on understanding of ecosystem and IWM, construction and demonstration of bioengineering-based check dam and erosion control activities, environmentally sustainable improved cookstoves, plantations techniques of trees, shrubs, and grass, and so on.
- Trainings and awareness program on the integrated watershed and ecosystem to educate the households of the project area regarding the consequences of ecosystem and watershed degradation and benefits of well-managed ecosystem and integrated watershed, and how to minimize the conflicts between park management and community people were provided.
- Trainings to the farmers and households of the four settlements in organic farming, tunnel farming, and ecotourisms.
- For demonstration, about 150 households were supported to adopt organic farming practices by distributing organic seeds and conducted field visit to 30 farmers on organic farming and Integrated Pest Management (IPM).
- Trainings and demonstrations to at least 250 households in the use of more efficient stoves.
- Training and demonstration were conducted to 100 households of the four settlements in adopting eco-friendly household toilets, solar energy, and solid waste management systems.

Fig. 3.4 Farmers participating in various capacity enhancement trainings and demonstrations

- Among the trainees, socially excluded and women groups were given high priority in almost all training and demonstration programs (Fig. 3.4).

3.8.3 Participatory Stakeholder Interactions

There existed an excellent collaboration between and among the multiple stakeholders in the Project. The park staff, the project team, the Buffer Zone User Groups and Committees (BZUGs and BZUCs) were constantly engaged. This built the strong foundation for co-producing a long-term and sustainable upper Bagmati watershed management strategy and action plan. Increased awareness among settlers and leadership of BZUGs and strengthened capacity of BGUC chair helped create a long-term community-based ecosystem-based livelihood and income generating activities for the people. This incentivized the BZUGs to implement the watershed management plan jointly prepared by the project. The farmers are also trained to engage in participatory monitoring and joint planning, peer learning through visiting neighbors' farms, and conducting joint workshops, training, and exposure visits along with park staff. These multidimensional stakeholder engagement efforts created an enabling environment to work in a co-operative and collaborative manner to make the ecosystem-based watershed management a truly integrated and participatory process.

3.8.4 Environment and People-Centered Conservation Measures for Maintaining Land Productivity

This is an important ecosystem-based IWM intervention, in which on-farm conservation practices through applying sustainable and environment friendly cultivation using local resources and traditional knowledge and practices have been used.

On-farm conservation involves management of the farm resource to conserve soil and water and improve production through various measures. The activities conducted by NGO—Pkg 1 Watershed Management Project in Shivapuri Nagarjun National Park (SNNP) included package program of vegetative, structural measures and land surface treatment activities applied in the farmland, which included planting of trees, herbs, or grass on marginal lands or unused lands in between and/or within farmlands, planting grass, fodder and fruit trees and leguminous shrubs on the terrace risers and slopes mainly to reduce erosion, and increase productivity of the outward sloping farmland. Vegetable seeds, grass seeds and saplings, fruit tree seedlings, and bamboos rhizomes were distributed to the farmers for the participatory planting in their own farmlands and degraded land in the vicinities of their settlement (Figs. 3.2 and 3.3).

3.8.5 Degraded Land Rehabilitation

Degraded land rehabilitation was another important ecosystem-based IWM intervention carried out in the upstream watershed of Bagmati River. The activity was implemented through using local resources, traditional knowledge and practices, which have protected the value of the biophysical environment and the ecosystem of the upstream watershed by minimizing the human induced stresses on the existing watershed resources. Also, the activity attempted to bring the deteriorated land back to its original position through conserving and improving soil condition and introducing new flora on the land.

Generally, the activities included tree, shrub, and grass planting with necessary conservation techniques and micro-gully plugging through bioengineering-focused engineering structures. Two gabion wire check dams were constructed at two gullies and bioengineering valued trees, shrubs, and grass were planted at the slopes of the gullies (Fig. 3.5). These two structures have protected tons of soil from being eroded from their micro-catchments, and the deteriorated lands are almost back to their original position.

Fig. 3.5 Construction of bioengineering-based gabion wire check dams to control gully erosion

3.9 Conclusion and Lessons Learned

Shivapuri Nagarjun National Park (SNNP) consists of various watersheds of different sizes ranging from micro-watershed to big watersheds like Bagmati River watershed. Irrespective of the size of watershed, all watersheds are built up with various ecosystems like terrestrial and aquatic ecosystems. Within a watershed there exists a strong relationship between terrestrial and aquatic ecosystems. Any perturbation in the terrestrial ecosystem impacts the life of the organisms living in the aquatic ecosystem. Similarly, in any watershed there exist a strong relationship between upstream and downstream of the watershed. Any destruction in the ecosystem of upstream watershed results in immense impacts in the ecological services available in downstream. Based on the unique relationship between watershed and the users of its ecosystem services, the ecosystem based approach of IWM is considered one of the best strategies for enhancing the sustainability of the watershed management, which, in turn can provide other ecological benefits like fresh air, clean water, regulation of hydrological flows and adaptation to the climate impact, support for soil formation and nutrient cycling, enhancement of cultural, educational, aesthetic, and spiritual services for the survival of all the organisms including the human being inhabiting the watershed.

A number of lessons were learned and some were built in the subsequent activity planning and implementation. The important lessons are:

1. Winning the trust of the people and creating an environment of mutual respect and appreciation between the project staff and the project staff helped the team to achieve the full engagement of farmers and stakeholders in the project activities.
2. Quality of the engagement: We learnt early on that participation not representation has to be ensured for a quality and outcome-oriented engagement that was achieved by launching series of awareness raising sessions that made the BZUGs aware of the value of collective actions wherein the community's collective efforts were shown to be much more than the sum of the individual actions.

3. There is always an issue of prioritization between conservation and sustainable livelihoods—which comes first. Our lesson is clear. The way to sustainable conservation, for that matter harmony between human and nature, starts from sustainable livelihoods. We therefore put a lot of emphasis on organic farming, commercial fruit and vegetable farming, and ecotourism promotion before asking farmers to plant trees and stop felling green trees for cooking and heating.
4. Domestic liquor making and selling in the informal market is a serious and a complex issue which needs an out-of-box solution: providing them with attractive livelihood options through some "smart incentives" such as secure job for one family member of the household whose food security or livelihoods depend on liquor making and selling.
5. Project period matters in environmental projects—Three (3) year period for watershed improvement and management through plantations and livelihood improvement is too short to achieve outcomes and show real impact as the poor and deprived households need to first realize the improvement in their livelihoods (e.g., income rise in real terms) and then only they can be convinced to stop cutting green trees and support conservation measures.

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Chapter 4
Nature-Based Solution for Balancing the Food, Energy, and Environment Trilemma: Lessons from Indonesia

Syed Ajijur Rahman and Himlal Baral

Abstract Demand for food and energy is constantly increasing in line with the global population and there are widespread concerns about environmental conservation. This chapter provides an overview of the identified potential to restore and utilize degraded land through an integrated biofuel- and food-production system that can also conserve the environment. Our findings highlight that the biofuel species Nyamplung (*Calophyllum inophyllum* L.) and Kemiri sunan [*Reutealis trisperma (Blanco) Airy Shaw*] in Indonesia are suitable to grow with local food crops on degraded land. Such integrated systems on degraded land are economically and socially favorable for local farmers. Producing biofuel and food on degraded land can also avoid compromising agricultural land use and production, while minimizing the harmful environmental consequences. However, for long-term sustainability of the system, and due to biodiversity and environmental concerns, there is a need to implement a mixed landscape approach using a "segregation" and "aggregation" land-management strategy, supported by competent government policies and local communities with sufficient social capital.

Keywords Degraded land · Species · Conservation · Land management · Community

4.1 Introduction

Currently, 60% of the world's population resides in Asia (Worldometers 2019; World Population Review [WPR] 2019). It is estimated that the world's population in 2050 will reach more than 9 billion (Vira et al. 2015), increasing the demand for food and energy throughout Asia and the rest of the world. In addition, the

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agricultural expansion caused by continued population growth has quickened the pace of land transformation and degradation (Babigumira et al. 2014). This situation is exacerbated by the agricultural intensification practiced in many parts of the world to increase crop production. As a result, ~40% (20 million km^2) of the global agricultural land area has already been degraded (Hooke and Martín-Duque 2012; Snelder and Lasco 2008).

Land degradation is more severe in tropical countries, like Indonesia, than in other parts of the world. Degraded land accounts for approximately 40% (0.8 million km^2) of the total land area in Indonesia (Indonesia Climate Change Center [ICCC] 2014). There are several interrelated drivers behind such land degradation in Indonesia, including forest fires, agricultural expansion, and illegal logging (Koh et al. 2011; Sharma et al. 2018; Dhyani and Dhyani 2020). It is well documented that land degradation has negative impacts on natural capital and ecosystem services. These impacts include soil erosion, watershed degradation, climate change, desertification, and biodiversity loss (Babigumira et al. 2014; Lawrence and Vandecar 2015).

Considering the very high cost of land restoration—approximately USD 260–2880 per hectare, depending on the condition of the land and the method of restoration—it is questionable whether governments and local communities can embrace such efforts (Rahman et al. 2019). Therefore, as a potential nature-based solution to enhance energy and food production, bioenergy crops—such as Nyamplung and Pongamia—could be cultivated as a restoration crop in different agroforestry systems. This would provide a climate-smart and profitable farming approach by producing bioenergy, food, and other essential farming products while functioning as a method for low-cost land restoration and environmental conservation (Baral and Lee 2016; Borchard et al. 2018; Rahman et al. 2019).

This solution could tackle the socioeconomic and environmental challenges related to land degradation (e.g., declining agricultural production, income loss, water pollution, health risks, and climate change) by employing sustainable management paradigms and using nature. It is a cost-effective and community-based solution that could simultaneously provide environmental, social, and economic benefits while helping to build resilience (Garrity 2004; Roshetko 2013; Schaubroeck 2017).

It has been well documented that agroforestry systems can protect soil from erosion, conserve soil moisture and improve soil fertility by enhancing nutrient cycling and regulating water quality. Agroforestry provides better ecosystem functions on the same land that is generating food and energy (Idol et al. 2011; Lasco et al. 2014; Rahman et al. 2019). Agroforestry can meet financial, social, and environmental goals by diversifying farm products and services for communities (Garrity 2004). Various studies have provided evidence that the net present value (NPV) of different agroforestry systems is much higher than that of seasonal agricultural systems (Alavalapati and Mercer 2004; Rahman et al. 2008; Roshetko 2013; Rahman et al. 2016). Furthermore, by generating some important forest products—such as firewood and timber—agroforestry may relieve pressure on local forests, helping to reduce deforestation and land degradation (Murniati and Gintings 2001; Garrity et al. 2002; Rahman et al. 2017a). Since 2016, the Center for International Forestry Research (CIFOR) and partner institutions have examined a wide range of policy-relevant issues associated with bioenergy, especially social, economic, and environmental aspects. These include how bioenergy crops can be integrated with food crops (such as paddy crops, maize, pineapple, dragon fruit, and peanuts) as part of landscape restoration efforts. Rather than using arable land to produce bioenergy, researchers are identifying and assessing degraded land. In the process, they are building a database of key species that grow well on Indonesia's degraded lands, thereby transforming them back into profitable landscapes.

This chapter assesses the potential of four biofuel species to grow on the degraded land with local food crops, aiming to produce energy and food while conserving the environment. The examples given relate specifically to Indonesia.

4.2 Methods

4.2.1 Study Sites

This study was conducted in Buntoi village (Pulang Pisau, Central Kalimantan) and in Giriwono village (Wonogiri, Central Java); see Fig. 4.1.

Buntoi, with a total land area of 16,262 ha, is dominated by forest and agricultural land. The soil is predominantly peat and alluvial. Buntoi has a tropical and humid climate with a temperature range of 26.5–27.5 °C. It has two distinct seasons: dry (April–October) and rainy (November–March). In late 2015, Buntoi village was

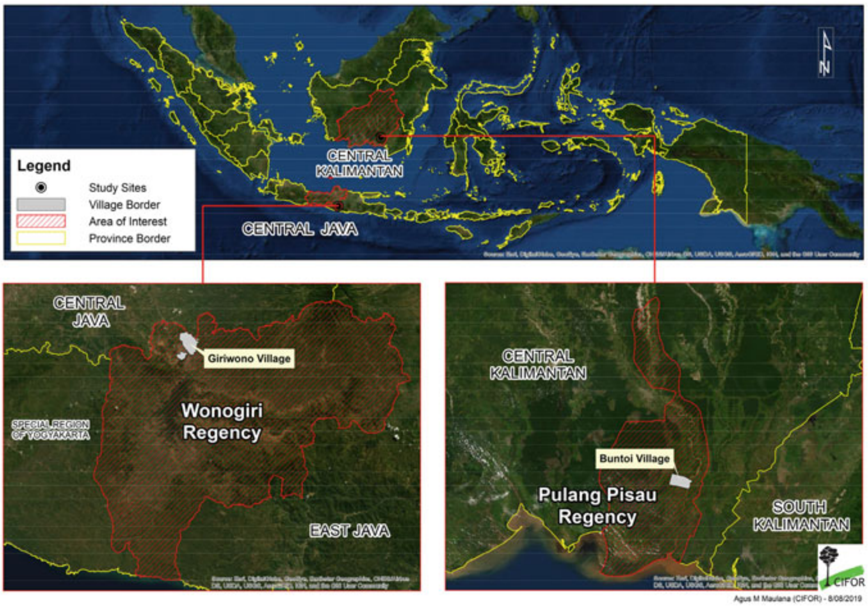

Fig. 4.1 Location of study sites: Buntoi village (Pulang Pisau, Central Kalimantan) and Giriwono village (Wonogiri, Central Java)

affected by peatland and forest fires that burned large areas of farmers' productive land. The burned land has since been abandoned. The village was selected as one of the locations for potential bioenergy crop plantations initiated by the Ministry of Energy and Mineral Resources (ESDM) and the local government, under the Bioenergi Lestari project. Testing the performance of selected biofuel species (see section on data collection) at this site has helped support this initiative.

With a total land area of 1275 ha, Giriwono is also dominated by forest and agricultural land. The site's loam soil slopes range from 0 to 10%. Its equatorial climate contributes average precipitation of 1878 mm, with a temperature range of 20–38 °C. The study site was previously managed by Perum Perhutani (a state-run forestry company working in Java) and is now considered an unproductive, degraded state-owned land area. This site was selected in order to produce the required research data (on the socioeconomic and environmental benefits of Nyamplung-based agroforestry systems) from the farmers already practicing Nyamplung-based agroforestry.[1]

4.2.2 Data Collection

In Buntoi, four biofuel species—Gamal [*Gliricidia sepium* (Jacq.) Walp.], Kaliandra (*Calliandra calothyrsus* Meissner), Kemiri sunan [*Reutealis trisperma (Blanco) Airy Shaw*], and Nyamplung (*Calophyllum inophyllum* L.)—were selected[2] to test their adaptive capability on degraded peatlands. A split plot design (with a total of 16 subplots, categorizing 8 plots in Group A and 8 plots in Group B) on 2 ha of degraded peatland was applied to test the performance of these four species with two different treatments: monoculture and agroforestry (intercropping with pineapple). Parameters used were plant height (in cm) and circular stem growth (in mm), measured from 10 cm above the ground. The survival rate was also observed by counting the total number of surviving saplings in each plot. Data were recorded every month (i.e., March 2016 to February 2017) using the above parameters. In each plot, species were spaced as: Kaliandra and Gamal (2 × 1 m), Kemiri sunan and Nyamplung (8 × 8 m), and pineapple (1 × 1 m). Slow-release NPK fertilizer was used in all of the plots.

In Giriwono, a focus group discussion (FGD) and field observations were used to collect data on two local farming systems: Nyamplung-based agroforestry and monoculture. A total of 10 agroforestry and 10 monoculture farmers attended the FGD. Farmers were selected based on their knowledge of local farming systems as well as the socioeconomic and geographic states of the village and its surroundings. Field observations were conducted in two farming locations, which were selected

[1] A total of 15 farmers in the village are using such Nyamplung-based agroforestry systems.

[2] The species were selected based on their potential to grow on the degraded land in Indonesia, as suggested by the literature (e.g., Borchard et al. 2018; Jaung et al. 2018).

based on information gathered in the FGD. During observations, several photos of Nyamplung-based agroforestry and monoculture were taken, and relevant farming information was noted.

Additionally, secondary data were gathered from a wide range of literature available online and at CIFOR's headquarters in Bogor, West Java, to corroborate the primary data collected from the research sites, as well as for background information and qualitative inputs for the study.

4.2.3 Data Analysis

For the four tested species in Buntoi, descriptive statistics and a nonparametric test—i.e., Kruskal-Wallis and the posthoc results of a Wilcoxon rank sum test in R software (version 3.4.4)—were used to analyze the data.

The NPV was used to assess the overall economic performance of local farming systems in Giriwono, using a 10% discount rate. Qualitative analysis was also conducted through the narrative analysis technique, particularly the social and environmental potential of integrated agroforestry systems based on the data collected from FGDs, field observations, and the relevant literature.

4.3 Producing Energy and Food on Degraded Land: Lessons from Two Case-Study Locations in Indonesia

In order to successfully restore degraded land for biofuel and food production, it is important to identify appropriate species that can survive on such land. In collaboration with the Korean National Institute of Forest Science (NIFoS), CIFOR is conducting research on the potential of growing bioenergy crops on degraded land in combination with local food crops in several case-study locations in Indonesia. This section provides the main findings from two case-study locations in Java and Kalimantan (see Fig. 4.1).

4.3.1 Suitable Species in Pulang Pisau, Central Kalimantan

In a bid to find which plants can grow on burned and degraded peatland in Pulang Pisau, Central Kalimantan, four biofuel species—Gamal, Kaliandra, Nyamplung, and Kemiri sunan—were tested. Nyamplung was found to be the most adaptable species (survival rate 88%), followed by Kemiri sunan (survival rate 48%). Moreover, both of these species performed better under agroforestry treatment with a local food crop—i.e., pineapple (*Ananas comosus*)—when compared with monoculture treatment. However, with specific reference to the Wilcoxon rank sum test, Nyamplung performs better based on tree height and circular stem growth compared with Kemiri sunan (see Fig. 4.4 and 4.5 in the appendix).

Fig. 4.2 Experimental bioenergy plots at Buntoi village (Pulang Pisau, Central Kalimantan)

This can be a win-win result, as growing biofuel with a local crop in an agroforestry system may have the potential to enhance overall farm production and income while also protecting biodiversity and supporting sustainable development (Idol et al. 2011; Dagar et al. 2014). This awareness of the survivability of Nyamplung, Kemiri sunan, and pineapple on burned and degraded peatland, as well as their improved performance using agroforestry, can promote the benefits of agroforestry and enhance farmers' livelihoods, while supporting the local environment (Fig. 4.2).

4.3.2 The Socioeconomics of Food and Energy Integration in Wonogiri, Central Java

On degraded landscape in Wonogiri, Central Java, the intercropping of Nyamplung with various local food crops—i.e., maize, paddy crops, and peanuts—and its use in combination with honey production provide farmers with viable economic options at different scales. Based on the data collected from 10 agroforestry and 10 monoculture farmers, it was found that even though monocultures of paddy crops and peanuts are not financially profitable (having a negative NPV[3]), they become profitable when coupled with Nyamplung production (NPV 66,206,227 IDR ha^{-1} and 62,570,818 IDR ha^{-1}, respectively[4]) due to the high value of Nyamplung seeds (i.e., harvest profit NPV 87,111,478 IDR ha^{-1}) as a bioenergy crop in its calculated 35-year optimal production cycle. Nyamplung intercropped with maize also generates extra

[3]Despite negative profitability, farmers in Wonogiri cultivate paddy crops and peanuts for their subsistence and food security value. It is important to note that the production of rice and peanuts is profitable when compared with purchasing those commodities at local markets.

[4]1 USD = 14,287.57 IDR (Indonesian rupiah), as of 13 August 2019.

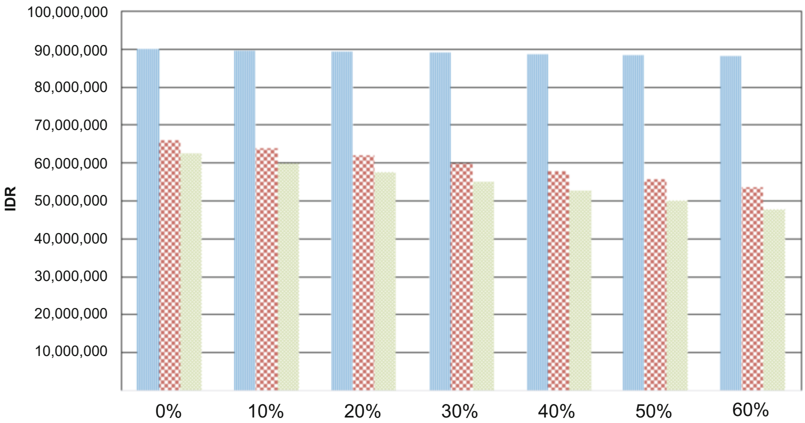

Fig. 4.3 Sensitivity of overall profitability (NPV in IDR ha^{-1}) decreases in production (up to 60%) of Nyamplung and three understory crops, taking into account a 35-year time horizon

profit (NPV 90,073,056 IDR ha^{-1}). The crop yielding the largest economic profit is honey production, which delivers an NPV of 854,592,341 IDR ha^{-1}—nearly 10 times higher than that of Nyamplung alone. Even if this intercropping were to result in losses (e.g., through crop failures due to pests and diseases, or climate change) of as much as 60%, this system would still provide a positive NPV, and thus proves itself to be financially profitable (see Fig. 4.3).

During the FGD, it was demonstrated that Nyamplung cultivation strengthens social solidarity, with farmers sharing tree-planting knowledge. Farmers cultivating Nyamplung are valued in the community, as involvement in such cultivation is more prestigious than farming paddy, maize, and peanut monocultures. Nyamplung-based systems also create employment opportunities (traders as well as seasonal/regular wage laborers for harvesting, sorting, and transporting farm products), thus supporting the emergence of farm-related rural employment and expertise.

4.4 System Expansion through Enhancing Community Participation

It is crucial to recognize that effective land-use planning depends not only on the production of goods and the rehabilitation of the environment, but also on local people's needs and their participation, which can make such planning successful in the longer term (Lamb et al. 2005; Paudyal et al. 2017; Borchard et al. 2018). Restoring degraded land to generate food and energy while conserving the environment will require more than just choosing the appropriate species for their socioeconomic and environmental suitability—it will also involve ensuring the participation of local people (Paudyal et al. 2017; Rahman et al. 2017b).

In our experience, the bioenergy crops Nyamplung and Kemiri sunan have the potential to grow on degraded land as part of land-restoration efforts, in cases where degraded land may otherwise be costly to restore (Tilman et al. 2006; Baral and Lee 2016; Maimunah et al. 2018). For international organizations and governments joining the global land-restoration effort (e.g., the Bonn Challenge, the New York Declaration on Forests, the Sustainable Development Goals (SDGs) Target 15.3 on land degradation neutrality), such bioenergy crops could meet economic, social, and environmental challenges if integrated in agroforestry systems (Rahman et al. 2019). An indicator of this success would be increased community adoption of and participation in such agroforestry systems, and their extension to the wider landscape scale, which can be costly and difficult to implement by external organizations or government.

Even though some farmers have already adopted the Nyamplung systems in Wonogiri, Central Java, the communities can further increase and facilitate such successful uptake by meeting several criteria. First, the land targeted for restoration and management should have clearly defined boundaries. The second criterion should focus on helping village-level institutions to follow rules and processes for monitoring and managing the land. The final criterion involves horizontal and vertical linkages with higher-level authorities—including those with powers over the right to organize—and the need for nested enterprises if the land belongs to larger systems (Ostrom 1990; Watts and Colfer 2011).

4.5 Land-Use Decision-Making Regarding Land Restoration for Energy, Food, and Environmental Conservation

As a nature-based solution to restoring degraded land, an integrated agroforestry farming system could bring economic, social, and environmental benefits. However, there is also a risk that increased adoption of the intensive energy and food cultivation system could compete with other agricultural production, thereby leading to forest clearance and additional pressure on biodiversity (Mooney 2018). Even though intensive farming can provide more production in a smaller area compared with extensive farming, it is unlikely that intensive farming would spare more land for nature conservation. Therefore, to avoid mass extinction and ecosystem collapse, we must integrate biodiversity conservation into the same landscape that we use (Kremen and Merenlender 2018). Otherwise, the result might be an agricultural version of the whole landscape and be similar to the Jevons paradox.[5] As Brazil has shown in recent decades, the Amazon rainforest and Cerrado grasslands have been converted to intensive croplands, not just to feed Brazilians, but for beef and soybean exports that have brought wealth and political influence to a small group of landowners (Phalan 2018).

To ensure better decision-making regarding the cultivation of energy crops and food, and for environmental conservation, there is a need for careful landscape design to counter local land-use challenges. To this end, a mixed land-management approach is required, including elements of both "segregation" and "integration" of land uses. A single approach, such as the "segregation" inherent in the "land sparing" landscape model, is not sufficient to achieve conservation goals alone (Van Noordwijk et al. 2001). In order to sustain biodiversity and environmental conservation, and to protect against human disturbance, a carefully designed "segregation" approach is required that could draw boundaries around protected areas. However, in other areas—such as agricultural land—"integration" through adopting an energy and food cultivation model can enhance farm production, income growth, and environmental conservation. The sustainability of an energy and food cultivation model will enable it to achieve medium- and long-term goals in the provision of valued goods and services (Van Noordwijk et al. 2001).

Nonetheless, this needs to be highly participatory to ensure that it is informed and supported by cohesive local communities, reinforced by competent government policies (Sayer 2009; Lawrence 2010; Watts and Colfer 2011).

4.6 Conclusion and Future Recommendations

To address the increasing demand for fuel and food while conserving the natural environment, the restoration of degraded land through our energy and food cultivation model could be a viable option for Indonesia, and elsewhere in the tropics. As the most adaptive species to grow on degraded land, Nyamplung and Kemiri sunan performed well in our agroforestry experimental plots in Central Kalimantan. Likewise, in degraded and low-fertility soils in Central Java, Nyamplung cultivation with local crops by farmers supports the view that bioenergy crops have low nutritional demands and are therefore suitable for degraded lands.

As a nature-based solution, producing biofuel on degraded land can also avoid compromising agricultural land use and production, while minimizing the harmful environmental consequences. Such a solution can bring more natural features into landscapes through community-based, locally adapted, resource-efficient interventions for the benefit of societies and overall biodiversity. If the bioenergy sector

[5]William Jevons was a nineteenth-century British economist who noticed that more efficient coal-powered engines of his day did not reduce coal burning but massively increased it by kick-starting the Industrial Revolution.

implements such sustainable farming methods, it can also help achieve other national targets, such as food security and reductions in greenhouse gas emissions. However, an effective implementation strategy may be needed to support this "integrated" nature-based land-use approach while ensuring that farmers' financial and human capital is not restricted (Rahman 2019). This could increase the net production and income of farming households in the degraded landscape. Every farmer who has degraded land as well as the capacity to adopt such a system could benefit in the future.

However, for the long-term sustainability of our integrated cultivation model, a mixed land-management approach is required, including elements of both segregation and integration of land uses, supported by competent government policies and local communities with sufficient social capital. The net output of a mixed land-management approach would sustain agricultural production while protecting biodiversity and associated ecosystems at the landscape level; it could also contribute to an increase in these resources, as well as the supply of goods and services that they produce.

Furthermore, supportive and effective policies should be propagated not by temporary projects but by long-term, government-backed institutions that are focused on biofuel-based agroforestry practices that may need adaptation to meet new opportunities and challenges. This is because, even though farmers grow trees under a range of environmental conditions across different landscapes, their decisions to adopt agroforestry are often dependent on favorable conditions (Van Noordwijk et al. 2008).

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Appendix

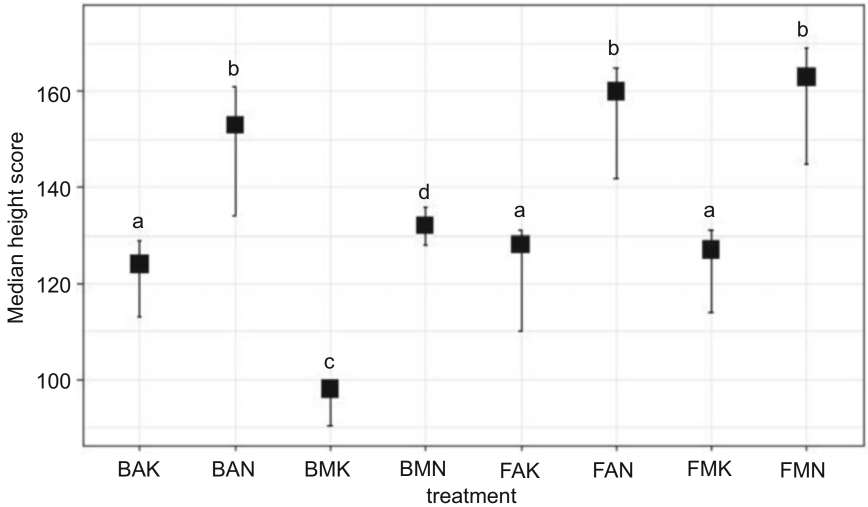

Fig. 4.4 Results of Wilcoxon rank sum test on tree height for Nyamplung and Kemiri sunan (BAK—agroforestry Kemiri sunan plot B; BAN—agroforestry Nyamplung plot B; BMK—monoculture Kemiri sunan plot B; BMN—monoculture Nyamplung plot B; FAK—agroforestry Kemiri sunan plot A; FAN—agroforestry Nyamplung plot A; FMK—monoculture Kemiri sunan plot A; FMN—monoculture Nyamplung plot A). The letters a, b, c, and d on the figure show different performance levels of height

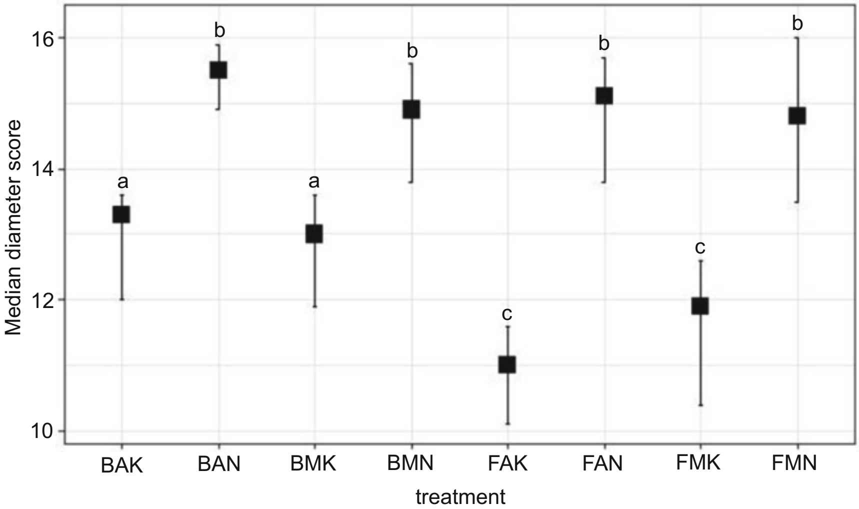

Fig. 4.5 Results of Wilcoxon rank sum test on tree diameter for Nyamplung and Kemiri sunan (BAK—agroforestry Kemiri sunan plot B; BAN—agroforestry Nyamplung plot B; BMK—monoculture Kemiri sunan plot B; BMN—monoculture Nyamplung plot B; FAK—agroforestry Kemiri sunan plot A; FAN—agroforestry Nyamplung plot A; FMK—monoculture Kemiri sunan plot A; FMN—monoculture nyamplung plot A). The letters a, b, and c on the figure show different performance levels of diameter

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Chapter 5
Wetlands as Buffers for Water-Mediated Disaster Risks: Policy and Programming Opportunities in India

Ritesh Kumar, Ridhi Saluja, and Dushyant Mohil

Abstract Building resilience in all forms, including resilience to water-mediated disasters, is imperative for achieving sustainable development. Recognition of role of wetlands in buffering water-mediated risks can diversify disaster risk reduction options as well as contribute to building community as well as ecological resilience. The synergies between international and national policies related to environment, DRR and climate change policy needs to be gainfully utilized to promote higher investment and programming support to initiatives for conservation of wetlands for reducing disaster risk in India. An enabling environment can be created by prioritizing wetlands considering their functions within landscapes, developing and piloting tools linking wetlands functions within hazard-capacity-vulnerability assessments, and creating opportunities of cross-representation within organizations mandated with wetlands and DRR sectors. Oversimplification of the role of wetlands in buffering water-mediated risks will be counter-productive to this agenda. Rather than a polarized policy-making which considers either hard-engineering or nature-based solutions, wetlands should be made a part of portfolios of built and natural capital within a landscape (such as river basin), considering likely outcomes for multiple goals, such as poverty reduction, water-food-energy security, disaster risk reduction, biodiversity conservation and climate resilience, in equitable, efficient and economically and socially viable terms.

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5.1 Addressing Water-Mediated Disaster Risks in India: The Need for Alternative Approaches

Water-mediated disasters (floods, droughts, cyclones, flash floods and storm surge) constitute a significant proportion of disaster events in India, claiming an exorbitant proportion of deaths and damages.[1] High temporal and spatial variability in water resources availability coupled with landscape degradation and unplanned development makes the sub-continent highly vulnerable to frequent floods and droughts (Sharma 2003; Singh and Kumar 2013; Malik et al. 2016; Zhang et al. 2017; Dhyani et al. 2018), and the trends are projected to intensify with climate change (Guhathakurta et al. 2011; Mallya et al. 2015). The Indian coast is routinely battered by landfalls of cyclonic storms forming over North Indian Ocean due to tropical cyclogenesis (Pattanaik and Mohapatra 2016). The water-mediated risks are projected to increase with intensifying climate change and development pressures (Mishra 2014; Malik et al. 2016). The focus of risk management so far has predominantly been structural in nature, such as construction of embankments, dams, barrages and sea-walls, following from the colonial legacy of hydraulic engineering to harness and regulate water (D'Souza 2002; Weil 2006). The efficacy of structural solutions has been intensely debated (Iyer 2008; Sinha 2008), and repeated calls made for considering natural ecosystems within the suite of response options (Shaw 2006; Abbas et al. 2016; Mondal and Patel 2018; Das and DSouza 2019).

The recent shift in emphasis from disaster response to comprehensive disaster management and specifically disaster risk reduction (Palliyaguru et al. 2014; Serrao-Neumann et al. 2015) has created opportunities for considering nature-based solutions—a concept introduced reflecting the possibility of using nature as a means for reducing disaster risk, and more recently climate change mitigation and adaptation (Munang et al. 2013; Renaud et al. 2016; Nesshöver et al. 2017). This opinion piece analyzes the Indian policy and programming context for integrating wetlands as nature-based solutions for buffering communities against water-mediated disaster risks. Following an introduction, the science-base on role of wetlands as buffers for water-mediated risks is discussed. An overview of current programming for wetlands conservation and management follows, leading onto a discussion on policy synergies between wetlands conservation and disaster risk reduction sectors. Specific programme integration opportunities between the two sectors are discussed next. The conclusion section reinforces the role of water and wetlands as core of building resilient societies and highlights the need for joined-up solutions for wetlands conservation and disaster risk reduction.

[1] As per EMDAT Database, during 1916–2019 water-mediated disasters accounted for 78% of the total disaster events and 98% of the population affected.

5.2 Wetlands as Buffers for Water-Mediated Risks

Wetlands buffer water-mediated risks due to their capacity to store water, moderate flow regimes, and influence the way water moves in the landscape and is available in terms of quantity, quality and timing (Bullock and Acreman 2003). There is a considerable body of research that highlights the increasing vulnerability of landscapes wherein wetlands have been degraded or lost (Dewan and Yamaguchi 2008; Acreman and Holden 2013; Marois and Mitsch 2015). This is especially true for major urban areas in India, wherein large swathes of wetlands have been converted to give way for housing and other infrastructure (R. Kumar and Kaul 2018). A positive relationship between an increase in the built-up area, increasing runoff, loss of wetlands and enhanced flood vulnerability has been observed for several cities, such as Nagpur (Dhyani et al. 2018), Mumbai (Zope et al. 2016), Bangalore (Ramachandra et al. 2019) and Chennai (Gupta and Nair 2011). Extensive urbanization of floodplains and conversion of wetlands were identified as critical anthropogenic drivers of extensive damage due to 2014 extreme flooding in Kashmir (Romshoo et al. 2018). Figure 5.1 depicts the changes in downstream hydrological regimes in response to degradation and conversion of Wular in Jhelum Basin of Kashmir. Severe degradation and encroachment in Pallikarnai marshes and other significant wetlands of Chennai have exposed its vulnerability to urban flooding, and a major causative factor for rampant destruction during floods of November and December 2015 (Arabindoo 2016). Studies on August 2018 floods in Kerala unsurprisingly indicated that the areas around the backwaters and adjoining river floodplains received prolonged inundation as these were the natural depressions in the landscape, yet also most heavily populated (Vishnu et al. 2019).

If the floods have brought floodplain and urban wetlands to the limelight, so have tropical cyclones and storm surges to the coastal wetlands. Evidences from the 2004 Tsunami indicated the role of coastal vegetation (primarily mangroves) and physical settings as distance and elevation of human inhabitation from the sea in reducing disaster impacts (Kathiresan and Rajendran 2005). In super-cyclone Kalinga which battered Orissa coast 1999, mangroves were noted to have saved human lives and assets, the opportunity cost of saving a life by retaining mangroves estimated to be INR 11.7 million per life saved (Das and Vincent 2009). Ecosystem degradation and biodiversity loss in Indian Sundarbans have created an economic damage to the state of West Bengal, including increased exposure to cyclones, to the tune of INR 6.2 billion annually at 2009 prices, equivalent to 4.8 per cent of the State's Gross Domestic Product (The World Bank 2014). The rate of surge height reduction has been noted to range between 4 and 48 cm per km of passage through mangroves (McIvor et al. 2012; Zhang et al. 2012).

Reservoirs, a category of human-made wetlands, also form a part of built infrastructure to control floods (Abe and James 2013), as well as meeting other water requirements. However, their performance in achieving flood control has been variable and subject to much debate, also in terms of socio-political issues related to relief and rehabilitation (Bandyopadhyay et al. 2002).

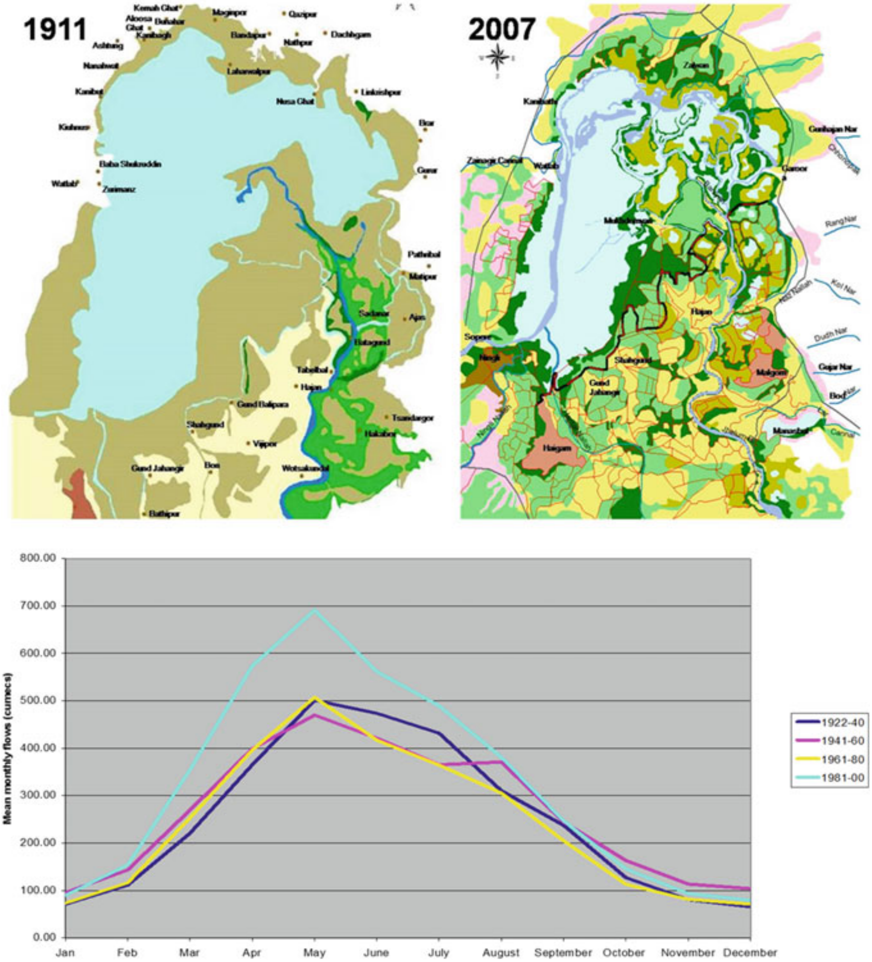

Fig. 5.1 Changes in hydrological regime moderation in landscapes due to loss of wetlands in Jhelum Valley. Wular, a large freshwater (shown in light blue) and fringing marsh of Kashmir Valley have been extensively transformed into plantations, agriculture and settlement areas (shown in dark green, yellow and brown areas in the map in the right). The hydrograph of Jhelum River at Baramulla, downstream of Wular, shows increasing and sharper peaks (indicative of floods) as well as rapid declines towards September–December (indicative of droughts). Source: Redrawn with permission from Wetlands International South Asia (2007)

The risks of oversimplification of the role of wetlands in buffering water-mediated risks has also been highlighted, often resulting from very simplistic extrapolation of site and wetlands specific evidence into more generalized statements (such as McCartney and Finlayson 2017). For example, the ability of wetlands to moderate flow regimes is closely linked with soil condition, in particular, the extent of saturation and relative location within a landscape (Bullock and Acreman 2003).

A highly saturated wetland located in the headwaters may become a source of floods, rather than acting as a sponge, as is widely believed (Acreman and Holden 2013). Similarly, there are non-linearities in storm surge buffering capacity of mangroves, and extreme events with very high water levels and winds speed may actually end up damaging and even destroying mangroves, thus rendering their coastal protection value less effective (Narayan et al. 2016). Knowledge of how wetlands function within a landscape and deliver their buffering services is crucial for managers and policy planners to pursue integrated approaches.

5.3 Wetlands in India: Programming for Conservation and Management

Wetlands is a generic term used for aquatic ecosystems located at the interface of land and water and combining attributes of terrestrial as well as aquatic ecosystems (Keddy 2010). The Ramsar Convention (a globally coordinated institutional framework for conservation of wetlands ratified by 171 contracting parties to date, including India which ratified the Convention in 1982) uses a broad definition of wetlands as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres' (Ramsar Convention Secretariat 2016). To ensure connectivity between different habitats, Article 2.1 of the Convention provides that riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands may also be included within the boundary (Ramsar Convention Secretariat 2016). The broad ranging definition thus covers a large category of inland wetlands (such as ponds, lakes, marshes, swamps and peatlands), coastal and nearshore marine wetlands (such as coral reefs, mangroves, seagrass beds and estuaries) and human-made wetlands (such as rice paddies, fish-ponds, and water storage areas as tanks, reservoirs and dams).

India has a diverse wetland regime on account of wide climatic, geological and topographic variations in the country. The Himalayas are dotted with glaciated lakes, alpine marshes and peatlands, and bordered by the extensive marshes and swamps of the Terai region. Floodplains and ox-bows abound in the Gangetic–Brahmaputra alluvial plains. The arid and semi-arid region is studded with saline flats and lakes, whereas the Deccan region has numerous tanks, often in a cascade arrangement. The coastline is bordered by estuaries, mangrove and saltpans, and interspersed with coral reefs. Their area ranges in areas from small village ponds (having areas less than an acre) to large lagoons such as Chilika and Vembanad backwaters having an expanse of over a thousand square kilometre.

As per the National Wetland Atlas published in 2011, India has 0.77 million wetlands spanning 15.26 million ha, equivalent to 4.63% of her geographical area (Panigrahy et al. 2012). Inland wetlands (including wetlands below the minimum

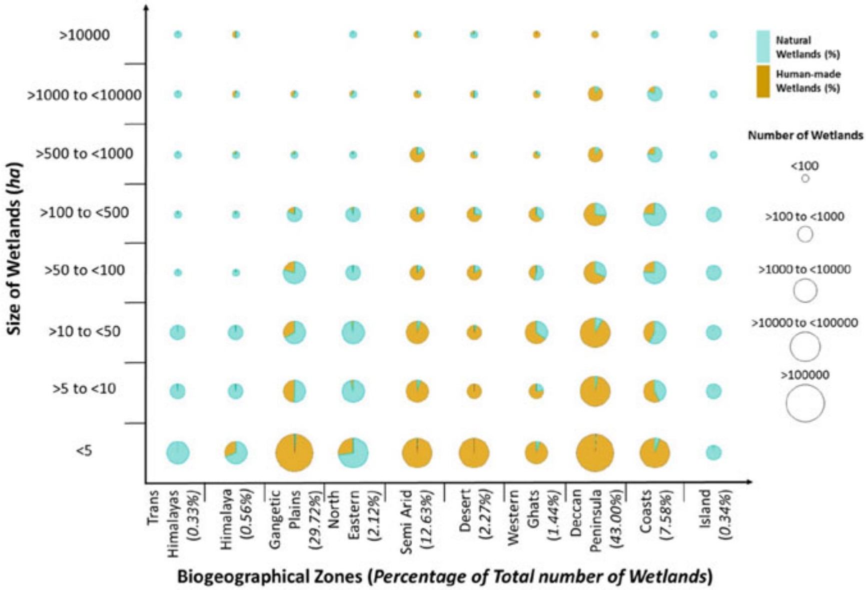

Fig. 5.2 Distribution of wetlands of India in different biogeographic zones (in terms of area and numbers) (Source: Prepared by Wetlands International South Asia using the data from National Wetlands Atlas 2011 (Panigrahy et al. 2012))

mapping unit of 2.25 ha) constitute 69% (10.56 million ha) of the total wetland area. The wetlands make an immense contribution to water, food and climate security of the country, and are inextricably linked with cultural and recreational values, while also providing habitat support to a range of plant and animal species. A discussion on these values is outside the scope of this paper, and for a recent summary on ecosystem services and biodiversity values, the reader is referred to Kumar et al. 2017a, b. The distribution of wetlands in various biogeographic zones of India in terms of their area and number is presented in Fig. 5.2.

Within the federal set-up, policy and programming for wetlands conservation is placed within the mandate of the Ministry of Environment, Forest and Climate Change (MoEFCC 2019). The roots lie in recognition of wetlands as key waterbird habitats, especially for birds migrating within Central Asian Flyway, drawing in parts from waterbird centric-wetlands conservation movements in Europe and North America (Kumar 2019). A number of wetlands supporting large congregation of waterbirds, such as Vedanthangal, Keoladeo, Khijadiya and Ranganathittu were designated as protected areas under the colonial laws and regulation. India's ratification of Ramsar Convention in 1982 and creation of the Ministry of Environment and Forest in 1985 (from a federal Department of Environment in 1980) created conducive backdrop for establishment of a national wetlands programme in 1986 for providing an overarching national policy framework and financial assistance for the implementation of wetland management plans to the state governments (MoEF

1992). Programmes on urban wetlands and mangroves and coral reefs were subsequently carved out from the national programme (MoEF 2008a). The programme is currently known as National Programme for Conservation of Aquatic Ecosystems (NPCA) and has subsumed the programme on urban wetlands (MoEFCC 2019). Mangroves and coral reefs continue as a separate scheme, whereas wetlands located within protected areas are funded under the centrally sponsored scheme titled Integrated Development of Wildlife Habitats. As of December 2019, over 250 wetlands have been covered under these national programmes, a majority of which are protected areas, designated for biodiversity values, primarily waterbirds.

Provisions of the Indian Forest Act, 1927, the Forest (Conservation) Act, 1980 and the Indian Wild Life (Protection) Act, 1972 define the regulatory framework for wetlands located within forests and designated protected areas. This is significant as nearly 62,400 wetlands are located within reserved forest areas of the country (FSI 2019). In 2017, the Wetlands (Conservation and Management) Rules were notified under The Environment (Protection) Act, 1986. These Rules provide for State Wetlands Authorities as the main policy and regulatory bodies within states. Several states governments (notably West Bengal, Odisha, Kerala, Manipur, Assam and Rajasthan) have also enacted legislation on wetlands.

The coastal wetlands are protected under the Coastal Regulation Zone (CRZ) Notification (2018) and its amendments and the Island Protection Zone (IPZ) Notification 2011. The Environment (Protection) Rules, 1986 under the EP Act empowers the Central Government to prohibit or restrict the location of industries and carry out processes and operations in different areas including wetlands. The Indian Fisheries Act, 1897, The Water (Prevention and Control of Pollution) Act, 1974 and The Biological Diversity Act, 2002 provide instruments for regulating various development threats on wetlands. The Coastal Aquaculture Authority Act, 2005 prohibits the conversion of natural coastal wetlands such as mangroves, salt pans, estuaries and lagoons for aquaculture. Under the Biological Diversity Act, 2002, the Central Government can issue directives to State Governments to take immediate ameliorative measures to address threats on any area rich in biological diversity, biological resources and their habitats. The Act also gives State Governments the powers to notify areas of biodiversity importance as biodiversity heritage sites.

The management of wetlands supported under the central government schemes can broadly be placed in two clusters. Wetlands designated as protected areas, or located within the protected area network, are guided by the wildlife management planning framework. The framework in vogue is based on the 2004 Sawarkar guidelines for 'planning wildlife management in protected areas and managed landscapes' (Sawarkar 2005). The plans are focused on species protection and habitat conservation needs and are approved for a duration of ten years. The NPCA provides funding on the basis on integrated management plans, developed based on the diagnostic evaluation of wetlands features and threats, and covering interventions within the entire river basin—coastal zone. Implementation of such plans requires coordination across multiple sectors and significant governance improvements, particularly stakeholder involvement in management. Ecological restoration of Chilika and its transformation from a Ramsar Site enlisted within Montreux Record to an award-winning site namely Ramsar Wetland Conservation Award and Evian Special Prize in 2002 have been possible through an enabling governance mechanism and sound science-based to guide integrated management (Pattnaik and Kumar 2016).

National efforts for wetlands conservation are best characterized as stand-alone projects, mostly designed to conserve biological diversity values. The natural wetlands have continued to degrade in India on account of various anthropogenic pressures, despite a marginal increase in human-made wetlands (Kumar et al. 2017a, b). A significant driver of wetland loss has been a failure in mainstreaming the wetlands ecosystem services and biodiversity in developmental planning. This has led to sectoral approaches being adopted for wetlands management, conversion for other usages, pollution, species invasion and over-extraction of resources.

In the recent times, there have been frequent calls to look into the existing paradigms of water management, and consider the role of wetlands in water security (Shah 2009; Tushaar 2012) and urban resilience (Ramachandra et al. 2019). This has opened up a window of opportunity for promoting a landscape-level wetlands conservation programme, tailored at meeting wider developmental needs.

5.4 Policy Synergies for Integrating Wetlands in Disaster Risk Reduction Plans and Actions

'Resilience' and 'ecosystems' have been identified as recurrent themes for motivating policy integration between the three global agendas for climate change adaptation, sustainable development and disaster risk reduction (Solecki et al. 2011; UNFCCC 2017). Environment-related conventions such as Convention on Biological Diversity and Ramsar Convention on Wetlands have through recent resolutions and guidance encouraged member states to take into account the role of ecosystems in disaster risk reduction (Kumar et al. 2017b; CBD 2019). Nature-based solutions such as use of wetlands for disaster risk reduction find mention in the Sendai Framework on Disaster Risk Reduction (UNISDR 2015). Call for synergies between implementation of climate mitigation and adaptation actions and actions for implementing sustainable development goals and disaster risk reduction find a clear articulation in the United Nations Framework Convention on Climate Change (UNFCCC 2017). India's ratification of all these agreements provides a strong basis for pursing implementation of nature-based solutions within the framework of international commitments made thereunder.

Direct references to nature-based solutions in national policies are few, and in most instances cross-references opportunities have been highlighted. The National Disaster Management Plan takes into account several non-structural measures for flood and cyclone risk reduction measures, and makes direct reference to wetlands (NDMA 2019). The National Water Policy (2012) recommends adoption of a basin approach for water resources management and identifies conservation of river corridors, water bodies and associated ecosystems as an essential action area for reducing water risks (MoWR 2012). The Smart Cities programme of urban transformation includes enhanced water security, sustainable environment and disaster resilience as core elements (MoUD 2015). Development connect in the National Environment Policy of 2006 is highlighted by recognizing wetlands as components of 'freshwater resources', and recommendation for integration of wetlands in developmental planning, and management based on prudent use strategies (MoEF 2006). Mainstreaming the full range of wetlands ecosystem services into developmental planning is listed as the aim of the national wetlands programme (MoEFCC 2019). The National Action Plan for Climate Change includes wetland conservation and sustainable management in the National Water Mission and the Green India Mission (MoEF 2008b). The national indicator framework for monitoring implementation of sustainable development goals provides a mapping of various sectoral programmes towards assessing country's progress on sustainable development goals (MoSPI 2015).

5.5 Integrating Wetlands in Disaster Risk Reduction Programmes

Integrating wetlands in disaster risk reduction programme needs programming innovations, particularly in the way wetlands are identified and prioritized, collaborative planning is conducted and governance for the two sectors bridged.

5.5.1 Prioritizing Wetlands

The National Wetlands Atlas provides the data on wetlands on a geospatial platform, using which the extent of wetlands in a given spatial unit (such as district, state or a river basin boundary) can be determined. This geospatial data is an important beginning point. A major barrier limiting the integration of the role of wetlands in sectoral and river basin scale planning has been the lack of understanding of the way these ecosystems function within the landscape (such as catchment or a river basin), and quantitative information on their functioning (such as extent of smoothening of flood peaks) to enable their incorporation in decision-making. A significant proportion of wetland research in India is devoted to defining their components (such as biota, water quantity and chemistry). This information, however valuable for conservation planning purposes, is of limited use for cross-sectoral planning and decision-making with sectors responsible for disaster risk reduction. A functional assessment of wetlands using frameworks such as hydro-geomorphic classification integrating landscape dynamics elements or ecosystem services assessment can be used to elicit the role of wetlands in delivering specific hydrological and ecological functions (Lisenby et al. 2019; McInnes and Everard 2017) and enable prioritization for various objectives, including disaster risk reduction.

5.5.2 *Joint Assessment Methods and Tools*

Implementation of integrated solutions also requires joined-up assessment tools to enable identification of specific intervention opportunities. The assessment tools commonly used for disaster risk reduction planning (such as hazard-capacity-vulnerability assessment) mostly take a people's perspective, and a socio-political approach to the identification of risks and vulnerabilities (Cadag and Gaillard 2012; Gaillard and Mercer 2013). The ecosystem typologies commonly used for wetlands conservation planning do not necessarily render information on wetlands functions, such as those required for disaster risk reduction (Maltby and Acreman 2011). Assessment tools which can link wetlands condition (to assess the degree to which different wetlands attributes deviate from reference conditions) with wetlands functions (such as hydrological regime moderation, water storage and others) are more relevant (McLaughlin and Cohen 2013). Tools which can link wetlands conditions and functions as part of the hazard-capacity-vulnerability assessment can serve to be the bridge between practitioners in the two sectors. An attempt has been made in the form of a cluster-planning approach demonstrated for Mahanadi Delta, wherein building on inter-relationship between wetlands degradation and increasing water-mediated risks, specific landscape-scale intervention opportunities have been identified (Kumar et al. 2016).

5.5.3 *Collaborative Planning*

For wetlands to be included as part of disaster risk reduction plans, the opportunities for integration exist at the state, district as well as Gram Panchayat levels. Section 31 of the Disaster Management Act 2005 makes it mandatory to have a disaster management plan for every district. The plan envisages to include hazard vulnerability capacity and risk assessment, prevention, mitigation, preparedness measures, response plan and procedures (NDMA 2014). At the village level, the development of Gram Panchayat Development Plan (GPDP) is the responsibility of the Gram Panchayats (MoPR 2018). The GPDP preparation process must include an assessment of wetlands as a part of landscape settings and include wetlands restoration and management as a risk reduction strategy. The MoEFCC has laid down guidelines for the diagnostic evaluation of management planning for wetlands, enabling identification of action plan with due consideration of wetlands values, threats and management needs (MoEFCC 2019). The principles of wetlands management planning can work across various scales and can be gainfully utilized for identifying intervention needs for wetlands lying within the boundaries of various administrative units. For ease of implementation, further simplification of wetlands management guidelines, especially to meet the needs of planners within the district and gram panchayat levels, is required.

5.5.4 *Bridging Governance*

In line with the provisions of the Wetlands (Conservation and Management) Act, 2017, State Wetlands Authorities have been constituted as the nodal policy and regulatory institutions within states. The Authorities have been conceived as multi-sectoral and multi-stakeholder platforms, wherein various issues related to wetlands management can be discussed and operationalized. Individual wetlands are placed within a specific department, in most cases being Forest and Environment, but also within departments of irrigation, fisheries, revenue, urban development and others, depending on the local context. Institutional arrangement for disaster management is defined under The Disaster Management Act 2005. The Act provides for setting up of Stage Disaster Management Authorities under the Chairpersonship of the Chief Minister. District level authorities are to be headed by the Collector/District Magistrate with the elected representative of the local authority as co-chairperson.

In order to enable consideration of wetlands within DRR planning and implementation processes, institutional embedding at state, district and village levels are required. At the state level, a mechanism of cross-representation (i.e. representation of DRR interests in State Wetlands Authorities and vice versa) may enable consideration of interests of the two sectors for mutual advantages. At district levels, the integration may be enabled by bringing in the concerned departments entrusted with wetlands management within the DDMA. At Gram Panchayats, ensuring that the GPDPs consider wetlands conservation and disaster risk reduction within the developmental planning process may address the bridging needs.

5.6 Conclusion

Building resilience in all forms, including resilience to water-mediated disasters, is imperative for achieving sustainable development (Folke et al. 2002). The changing patterns in water availability, in quality and quantity, as well as in space and in time (Jain 2019), will define key pathways for resilience building. Thus requirements for water system resilience must guide human development trajectories (Boltz et al. 2019). Human civilizations, wetlands and water systems have co-evolved as a coupled system, and significant parts of water systems and wetlands transformed and regulated to meet human needs for survival and sustenance. While degradation of wetlands has made landscapes and societies vulnerable, it is also true that a significant part of human population and economic assets currently dwell in highly dynamic, hydrologically variable and ecologically fragile parts of landscapes, such as river floodplains, wetlands shorelines and coastal zones. It is therefore natural that conservation and wise use of wetlands form an integral part of solutions for buffering disaster risks and building resilient societies.

Implementation of nature-based solutions, such as consideration of wetlands as buffers of water-mediated risks, cannot be treated as an additive process wherein the policies and programmes of wetlands conservation and disaster risk reduction sector are simply joined together, but require a more sophisticated and nuanced, collaborative and beyond sectoral disciplinary approaches. The issue at hand is not just about connecting two different policy areas (wetlands conservation and disaster risk reduction) at a single hydrological (catchment) or administrative (district) scale. Given the pervasive uncertainty (such as the manifestation of climate change on wetlands functioning as well as on extreme hydrological events, such as floods and droughts) and contested knowledge claims (such as increased need for hydrological regulation to address variability), the difficulty of joined-up management of wetlands and disaster risk reduction cannot be achieved by various policy and programme actors acting in isolation. The role of collaborative governance solutions is crucial for addressing challenges associated with building coherent conceptual and methodological narratives (such as wetlands degradation not just seen as tantamount to loss of critical ecosystem services, but reduced landscape resiliency to increasing hazards and risks), and developing approaches for joint working that have potential to transform, rather than simply reaffirm segmented ways of research natural systems and landscape vulnerability. An upfront investment of time and trust is required to develop conceptual models, common definitions and working language and methods are required to provide the basis of nature-based solutions in general, including the integration of wetlands in disaster risk reduction (Bracken and Oughton 2006).

Available evidence also indicates that the capacity of wetlands to help mitigate hazards and reduce water-mediated disaster risk depends on landscape settings, ecological conditions as well as socio-political contexts. Rather than a polarized policy-making which considers either hard-engineering or nature-based solutions, the need of the hour is to consider different portfolios of built and natural capital within a landscape (such as river basin), and consider likely outcomes for multiple goals, such as poverty reduction, water-food-energy security, disaster risk reduction, biodiversity conservation and climate resilience, in equitable, efficient and economically and socially viable terms. Nature-based solutions are to be seen as complementary to other risk management measures such as early warning, evacuation and contingency planning.

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Chapter 6
Landscape Character Assessment: A Method to Include Community Perspectives and Ecosystem Services in Land-use Planning

Debbie M. F. Bartlett

Abstract As nature-based solutions (NbS) are increasingly acknowledged as important for restoring and enhancing ecosystems, in both the urban and rural contexts, deciding on the most appropriate for the specific situation is of paramount importance. This chapter introduces the technique of landscape character assessment, an established method to combine both professional and local community views about places and the current environmental, social, and economic issues affecting them. The way in which this was introduced to colleagues in Gujarat, India, to incorporate landscape values and community views into ecosystem service assessment, is described. This process is suggested as a robust, evidence based, method to inform the decision-making process. Successful implementation of nature-based solutions depends firstly on identification of the problem and involving a variety of perspectives, as in the method described, can ensure that this takes place and provides the basis for selection of the most appropriate solution.

6.1 Introduction

The concept of nature-based solutions (NbS) is now widely accepted at global, regional and national scales. The IUCN refers to these as '*Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*'.[1] However, the European Commission, in transposing NbS into policy, gives a subtly different emphasis, stating that

[1] See https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

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'*Nature-based solutions harness the power and sophistication of nature to turn environmental, social and economic challenges into innovation opportunities'* (European Commission 2015).

Fundamental to implementing NbS is understanding exactly what is meant by 'nature', and what 'actions' or 'solutions' the NbS are providing. Bridgewater (2018) explored this issue and suggested that the starting point for implementation must be the identification of the environmental issue—or problem—and then carrying out a review of the potential solutions. At the same time the human context of NbS is crucial, framed as '*societal challenges*' (IUCN) and '*environmental, social and economic challenges*' (European Commission 2015) and must be considered simultaneously. The most effective way to address this is by taking into account the Ecosystem Services any NbS delivers (Diaz et al. 2018) and factoring this into the decision-making process.

Very little—if any—of our environment can be considered as natural. Even highly designated areas for nature conservation are more accurately described as semi-natural, having been subject to human influence over centuries and urban areas are examples of extreme ecosystem modification. Tree planting is generally considered a good and 'natural' action but there are many examples, such as the planting of *Prosopis juliflora* in North West India to reduce the spread of deserts, where has had unintended—and negative—consequences (Bartlett et al. 2017). Current concern about carbon emissions has led to widespread tree planning initiatives but, while effective as a NbS to mitigate climate change, this is not always appropriate and concerns have been raised regarding the negative impact on both biodiversity and ecosystem services of forest expansion into grasslands (e.g. Veldman et al. 2015).

So how then can we ensure that NbS can be effectively implemented to address defined issues and deliver the maximum in terms of societal co-benefits? The first step is to consider the context in which we are using NbS and this means looking in detail at the situation and understanding how it has developed.

Places are very different. The character of a place, whether this is an area of countryside, a village or a town, depends on a complex combination of factors, both 'natural' and related to human activity, and how these have interacted over time. When visiting somewhere unfamiliar, it is often apparent that it is unlike another but precisely what makes it different can be much more challenging to define. Clearly geography plays a major part. Geology, soil, hydrology, climate, elevation and aspect are fundamental but so are cultural influences and land-use practices, both past and present. This combination makes up the 'landscape character', which is defined as the distinct, recognisable and consistent pattern of elements in the landscape that makes one landscape different from another—it is not a value judgement and is not a measure of one being better or worse than another (Tudor 2014; Roe 2007). Whether the aim is restoration or future development, these need to be understood if the most appropriate NbS, which will have maximum overall benefits, are to be identified and implemented.

Landscape character assessment is a well-established technique that can help to do this. It is defined as '*the process of identifying and describing variation in the character of the landscape. It seeks to identify and explain the unique combination of* *elements and features (characteristics) that make landscapes distinctive*' (Landscape Institute 2016). It has provided the context for land-use planning decisions, including environmental impact assessments, and for identifying priorities for environmental restoration and enhancement since the 1990s. As awareness of ecosystem services has developed, this has led to the method being refined in order to inform appropriate management of change, including socio-economic data and future projections, to enable identification of strategic management objectives, resulting in an integrated approach to sustainable development in a changing context. The aim of this chapter is to provide an introduction to the technique and illustrate its application through a case study describing research carried out in Gujarat, North West India.

6.2 How to Carry out a Landscape Character Assessment

The first step is to define the area under consideration. The extent of the landscape (and therefore the scale at which the analysis is carried out) depends on the aim and could be a region, a smaller district, or a town or city. This is followed by a detailed desk-based study, gathering together physical, biological, historic, socio-economic and basically as much data and information about the area as possible. Topographical, geological, hydrological and soil maps as well as any existing plans and policies are useful and can be consulted and used in combination with historic maps, photographs and remote sensing imagery to reveal land cover and how this has changed over time. Literature, whether formal reports, visitor guides or articles in the local press can be helpful in amassing information on livelihoods and socio-economic factors that need to be considered along with attributes such as ecological communities, significant plants and wildlife and any designations. All this data can be combined into an initial report and graphical presentation, and using Geographical Information System (GIS) software[2] is an effective way to enable identification of parts of the study area that are similar and those that are likely to be different. These can be referred to as 'natural areas' and could, for example be uplands versus lowlands, have different geology/soils or, in the case of an urban landscape, have been developed at different times and so be likely to have different building styles.

Once the different 'natural areas', whether extending to kilometers or just a few streets, have been identified on a map base it is time to carry out fieldwork. To enable a systematic approach recording sheets ('field sheets') are used to capture information on features such as topography, land cover, land use, and cultural and natural heritage. These have some standard requirements such as location, date, surveyor and weather conditions, and are then basically a checklist of features, based on those the desk study has suggested likely to be encountered and the level of detail required,

[2]QGIS, free, open source, software available from https://qgis.org/en/site/ is increasingly used but if not available the same result can be achieved using film overlays.

i.e. this is likely to vary according to the scale of the specific project. They should include space for a sketch and for comments on perceptual factors and on condition (e.g. whether building is in good condition or derelict; waterways clear or blocked). Taking photographs is always useful but these need to be carefully numbered so they can be related to the specific field sheet for later analysis. The field sheets should always be tested in a pilot to test whether they work well and are easy to use; they can be modified if necessary, before embarking on the field survey. The number and size of the 'plots', the locations for which field sheets are completed, will depend on the size of the study area but—as in all research—the more the better! The desk study should suggest places to visit, either as they seem typical of the area or are of particular significance, for example there is a historic building, it is where events are held, or there is a particular feature such as a rocky outcrop or waterfall.

Analysis of the field sheets will add detail to the information in the desk study report enabling places with similar features and characteristics to be grouped together and considered separately from others. This will help to confirm the boundaries of the natural areas (although these will always be 'fuzzy') and to identify sub-divisions within them, usually referred to as local character areas. The key features—which could be types of trees, farming practices, evidence of particular livelihoods, building styles or even geometric as opposed to random road layouts—that are characteristic of the different places can be identified, and tentative value judgements begin to be made.

The following are the types of questions that can be used at this point:

- Are these features desirable?
- Are they in good condition or is some restoration needed?
- Should the features identified as contributing to the character of the place be reinforced? (i.e. more trees of the same species planted, or a building style be encouraged in future built development?)
- What are the local drivers (or influences) that are causing change?
- Is this change positive or negative?

The combination of the field and desk studies will enable the first step in identifying priority issues for action, whether restoration or development, that might apply in the different places (or local character areas). These are often referred to as Strategic Environmental Opportunities—or SEOs—and at this stage it is important that these are referred to as 'Draft SEOs'. These might relate to tree planting (to continue with that example) and it could be that a specific species has been planted but all the specimens are now reaching the end of their life so replacement is required or, conversely that one is expanding rapidly and is in need of control. A tree species that is characteristic of a town may not be native to the area but may have cultural significance.

6.3 Participatory Landscape and Ecosystem Service Assessment

It is likely that both the desk-based study and the fieldwork will have been carried out by professionals and these may well be from outside the area. Input from local people is vital to ensure that nothing has been missed, particularly when livelihoods depend on natural resources and not all strata of the community have equal representation in decision-making (Ahmed and Bartlett 2019; Diaz et al. 2018). Local ecological knowledge is vital to both correctly identifying the relative importance of features and understanding drivers of change. It is easy for outsiders—or those from different social groups—to misread situations; what to one person is a pernicious non-native invasive may be a highly valued plant to another (e.g. Bartlett et al. 2018). Participatory ecosystem service assessment enables the human perspective to be incorporated and only when this has been done can the word 'draft' be removed, and the SEOs be formulated. A detailed discussion of the ethics of consultation versus participation is beyond the scope of this chapter but it should be remembered that professionals are paid for their time whereas local people are often expected to attend meetings and contribute their knowledge for no reward, sometimes without even being offered refreshments. The issues around increasing dependence on local community input, 'citizen science', volunteered geographical information, social equity and the lack of social science research with respect to NbS are discussed by Wild et al. (2019). When people either have something to gain or, conversely something to lose, in a situation then they are 'stakeholders'. If some of these can be identified then 'snowballing' can be used, getting them to identify others with an interest in the issue(s) under consideration (Santoro et al. 2019, in the context of NbS for flood alleviation).

All the stages in the landscape assessment process—desk study, fieldwork and finding out what matters to local people—are equally important and combining the results of all these into a report enables the SEOs to be finalised and for these to inform the selection of the most appropriate NbS and—importantly—a robust framework for securing funding, implementation and long-term management.

6.4 Case Study: Introducing Landscape Character Assessment in Gujarat, India

This project was initiated by a former MSc student at the University of Greenwich who, after graduating, had returned to his home in Gujarat and was working at the Gujarat Institute for Desert Ecology (GUIDE). He had been asked to develop a proposal to eradicate *Prosopis juliflora* from Kachchh district. This plant, a non-native species originating in South America, introduced to control the spread of the deserts had, while arguably achieving the original aim, spread across the whole region and become invasive. As all ecologists are aware the species best suited to the environmental conditions will be the most successful and *P. juliflora* thrives in the dry saline conditions, reproducing rapidly and outcompeting other vegetation. It seemed clear that eradication was not an option but that if priority areas could be identified, then limited control might be possible.

This became an opportunity, with support from the British Council UKIERI programme, to explore the potential for introducing landscape character and ecosystem services assessment to land-use planning in India. Students working at GUIDE worked with those on the University of Greenwich MSc in Environmental Conservation to carry out a desk study, which brought together information on the following topics:

- Landscape and nature conservation designations.
- Landform, geology and soils.
- Water bodies and catchments.
- Population statistics.
- Location of settlements.
- Historic sites and features.
- Cultural aspects.
- Landscape and natural habitats.
- Livelihood change.

This exercise resulted in the identification of basic natural areas and one, the coastal plain, was selected for detailed study, as this was where significant development was taking place and there was significant *Prosopis juliflora*. Field sheets were created consisting of two parts, the first recording topography, land cover and land use, the second the surveyor's perceptions, with care taken to use local terminology (Figs. 6.1 and 6.2).

Additional notes were also made while travelling around the area. The data recorded on the field sheets was entered into an Excel spreadsheet in order to produce consensus descriptors. This resulted in five local character areas being identified within the coastal plain natural area.

The next step was to verify the data collected by involving local people. Eight villages were selected from different parts of the coast, and these were profiled with respect to population size, cultural composition and literacy levels, while land-use change, between 1999 and 2014, was determined for each village territory using remote sensing satellite imagery. Visits were arranged in May and June 2015 in order to carry out focus group discussions, an established technique for gathering information (e.g. Kamberelis and Dimitriadis 2013). GUIDE staff made initial contact with each village sarpanch (headman), and an invitation, in both English and Gujarati, was disseminated as widely as possible. The groups were facilitated by a local interpreter and based on a pre-prepared semi-structured interview schedule, addressing the topics of livelihoods, culture, and landscape and wildlife, to standardise (as far as possible) the information collected. The number of attendees, gender and approximate age were recorded, and notes transcribed as soon as possible after each meeting, recording information under the schedule headings. This enabled an outline ecosystem service evaluation and draft analysis of the key issues for each

ANNEX 1

KACHCHH 2015 FIELD SURVEY SHEET

Surveyor:
Time:
View point No:
Photo No:
Weather:

Date:
Location:
Coordinates:
Direction of view:
Visibility:

Topography

Flat	Plain	Broad valley
Undulating	Plateau	Narrow valley
Hills	Steep	Flood plain
Mountains	Scarp\cliffs	Estuary
	Deep gorge	

Annotated Sketch/ Brief Description

LAND COVER

Cropped land
Field crops
Bare ground
With rocks
With stones
Vegetation
Grass
Mixed herbs
Abundant
Sparse
Medicinal plants
Woodland and scrub
Mixed woodland
Group of trees
Isolated trees
Scrub
Isolated shrubs
Mangrove
Prosopis juliflora
Dominant
Abundant
Frequent
Occasional
Rare
Absent
Water and wetland
Lake
Reservoir
Pond
Running water
River
Canal
Wetland
Marsh
Coastal features
Sea and coastal waters
Inter-tidal sand and mud
Salt marsh
Salt pans
Dunes
Coastal rocks and cliffs

LAND USE

Farming
Field crops (name)

Intercropping

Home garden/s
Market garden/s
Orchard

Pasture
Rough grazing
Fallow
Boundaries
Shelterbelt (windbreak)
Walls
Fences

Built forms
Settlement
Industry
Military
School
Temple
Farm buildings
Temporary buildings
Scattered buildings
Infrastructure
Road
Track
Footpaths
Railway

Pylons
Communication masts
Wind turbines
Power station

Drainage ditch/dyke
Dam
Reservoir

Cultural Heritage
Buildings
Vernacular
Historic
Religious

Other;

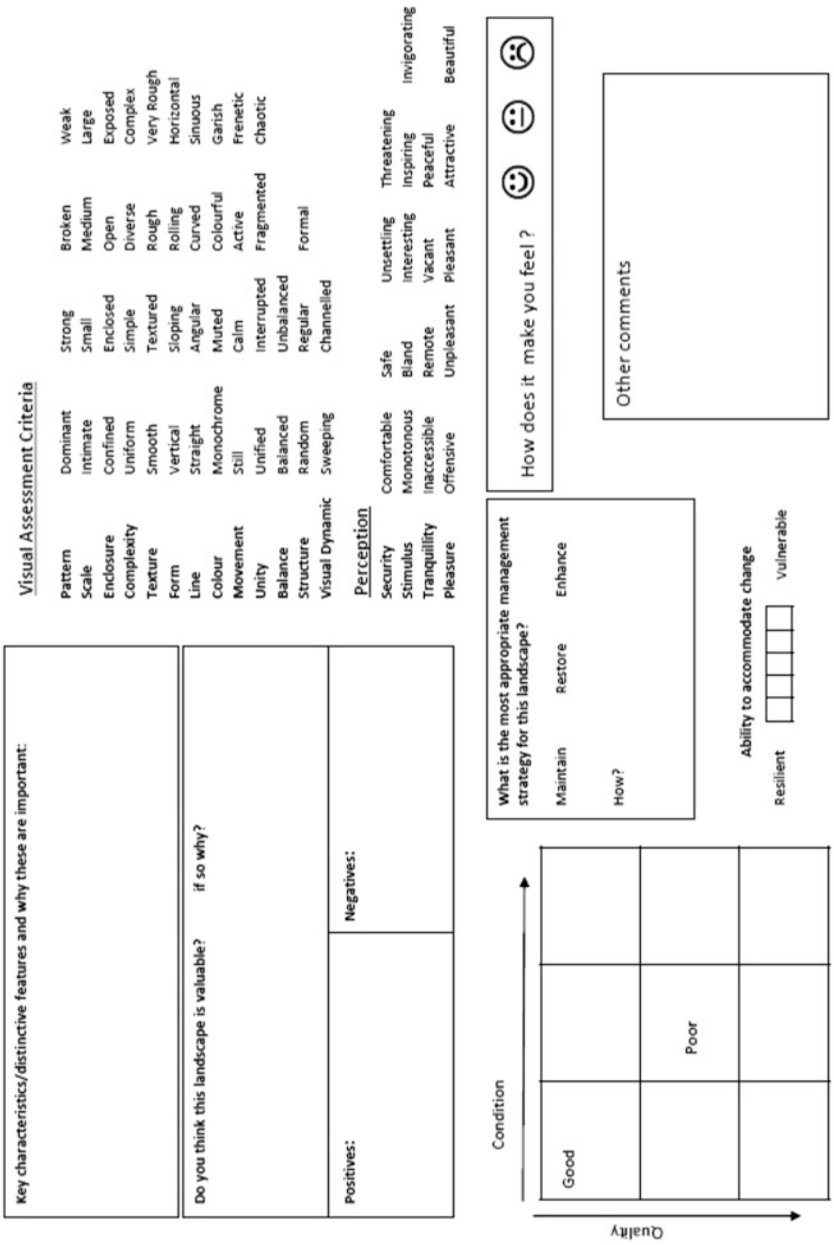
Natural Heritage
Significant trees
Landform features

Other:

Livestock

Sheep
<10 10-100 >100
Cattle
<10 10-100 >100
Buffalo
<10 10-100 >100
Camels
<10 10-100 >100
Goats
<10 10-100 >100
Mixed herds
Draft animals

Fig. 6.1 Field sheet front page


Key characteristics/distinctive features and why these are important:

Do you think this landscape is valuable? if so why?

Positives: Negatives:

Visual Assessment Criteria

Pattern	Dominant	Strong	Broken	Weak	
Scale	Intimate	Small	Medium	Large	
Enclosure	Confined	Enclosed	Open	Exposed	
Complexity	Uniform	Simple	Diverse	Complex	
Texture	Smooth	Textured	Rough	Very Rough	
Form	Vertical	Sloping	Rolling	Horizontal	
Line	Straight	Angular	Curved	Sinuous	
Colour	Monochrome	Muted	Colourful	Garish	
Movement	Still	Calm	Active	Frenetic	
Unity	Unified	Interrupted	Fragmented	Chaotic	
Balance	Balanced	Unbalanced			
Structure	Random	Regular	Formal		
Visual Dynamic	Sweeping	Channelled			

Perception

Security	Comfortable	Safe	Unsettling	Threatening	
Stimulus	Monotonous	Bland	Interesting	Inspiring	Invigorating
Tranquillity	Inaccessible	Remote	Vacant	Peaceful	
Pleasure	Offensive	Unpleasant	Pleasant	Attractive	Beautiful

How does it make you feel ?

What is the most appropriate management strategy for this landscape?

Maintain Restore Enhance

How?

Ability to accommodate change

Resilient Vulnerable

Other comments

Fig. 6.2 Field sheet back page

village. These were displayed on bilingual English/Gujarati posters which were taken on our return visits to each village in December 2015, so that any further comments could be added and to ensure our understanding had been correct; changes were made as necessary to create the final posters (see Fig. 6.3).

A further analysis was then carried out to identify common strands across all the villages. The most pressing concerns of local people were the impact of recent industrial development on the environment, particularly water abstraction and pollution, crop predation by livestock and increasing soil salinity. *P. juliflora* was considered to make a positive contribution as a valuable source of fuel, honey, medicinal gum and fodder and removed from agricultural fields like any other weed.

The results of the whole process were combined into one working document, the Natural Character Area Profile for the Coastal Plain of Kachchh and this was presented and discussed in the final stakeholder workshop. All the contributors, as well as local decision makers, were invited, the final posters were displayed, and everyone was given a good lunch. This document (Fig. 6.4) is available on request and for more details of this project and later developments see Bartlett and Milliken (2019), Bartlett et al. (2018) and Bartlett et al. (2017).

6.4.1 Using this Approach for NbS Decision-Making

The format of the Natural Character Area profile produced as the outcome of preceding case study is based on the National Character Area approach that has been adopted in England as part of the 'access to evidence' initiative to inform planning decisions (Natural England 2014). These have been completed for the whole country and are based on defining landscape character, based on biophysical and cultural factors, rather than administrative boundaries, and describe the key features, explain how and why the landscape has changed, and—importantly—identify drivers likely to influence future change. These documents identify opportunities (the SEOs) based on analysis of ecosystem services and provide a robust context for land-use decision-making, informing the development agenda while minimising negative impacts on the environment. This can provide a robust context for deciding on the most appropriate NbS to be applied in a specific context to address accurately the societal challenges identified during the process in a truly sustainable way.

An important consideration is the rapidly changing environmental context in which we are currently operating. Decision-making must take account of likely future scenarios, not just related to climate change and alteration in weather patterns, but also the effect of increasing population and lifestyles. We are facing serious challenges in environmental management. Engaging with processes to enable informed—rather than haphazard—decision-making such as landscape assessment combined with participatory ecosystem service assessment can assist in selecting the best possible NbS with as much future proofing as possible. To quote Bridgewater (2018) '*To be fully effective NbS must focus on twenty-first century environmental*

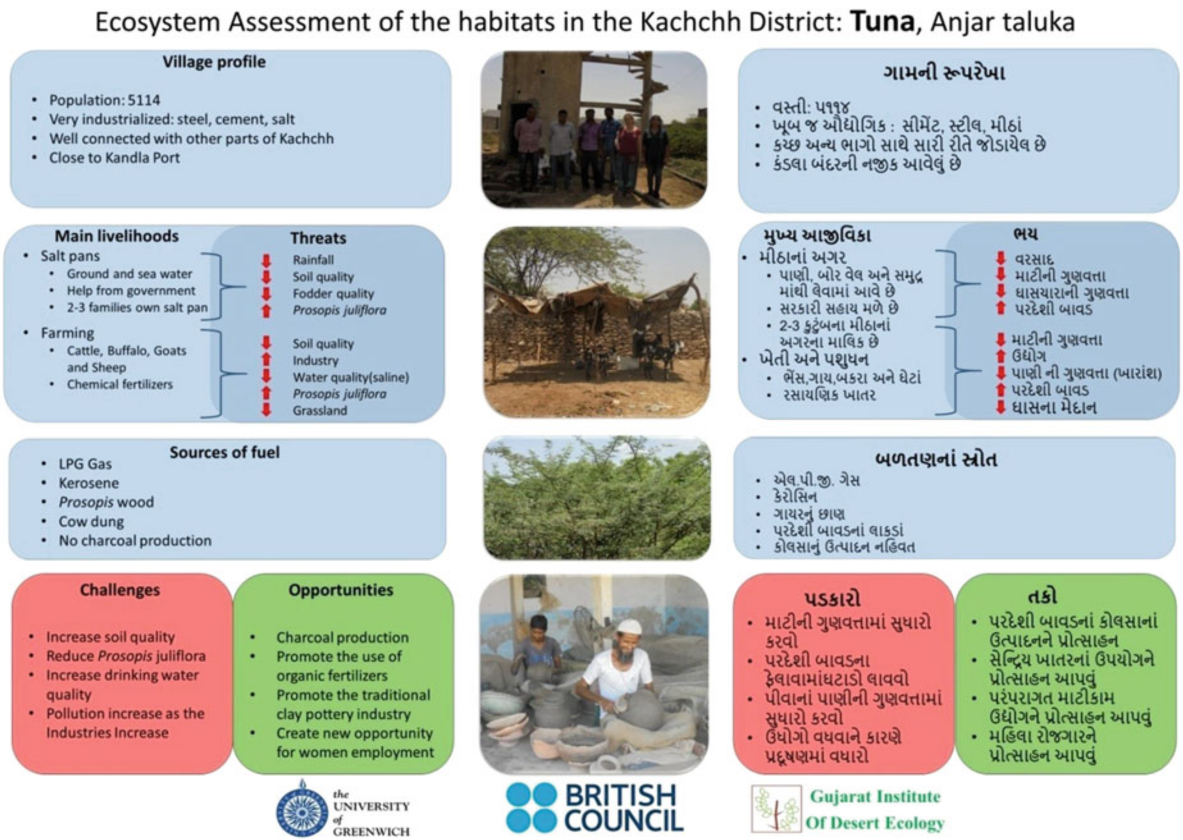


Fig. 6.3 Example poster

Fig. 6.4 Front cover of the Natural Character Area Profile for the Coastal Plain of Kachchh

problems and what solutions nature can contribute in resolving known, known-unknown and unknown-unknown problems'.

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Chapter 7
Linking NbS with Water Management: A Case of South Megacities

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Abstract In fast urbanizing world, megacities, large urban agglomerations of more than ten million people, are drawing attention in the matter of water-related extremes—flooding or scarcity. Even in everyday life, these locations face adequate challenge of basic water provisioning for its habitation in sustainable manner. In global South, where these are proliferating, unmindful dependence of civil engineering solutions has witnessed gradual disconnect of water from its natural surroundings in everyday discourse. This is not sustainable. The consequences of unprecedented urbanization are often familiar to the stakeholders; however, there has been limited efforts in understanding the urban ecosystem and in identifying the interwoven elements those sustain (or have potential to) such ecosystems in sustainable manner and adopting these in policy practices. Globally, there is more emphasis on identification, appreciation, and adoption of nature-based solutions (NbS) in creating water-resilient urban system so that it copes with the risks associated with water. In this chapter, author-duo deploy principles of nature-based solutions (NbS) in megacity environment, in case of historic city of Delhi, and argue that there exists possibilities and opportunities in NbS in the context of global south as it offers cheaper, understandable, durable, climate-adaptive, resilient, and equitable solutions.

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7.1 Introduction

The belief of triumph over nature, a premise of modernity, failed to tame the nature. Flood or drought has periodically demonstrated that abuse or disregard of nature has devastating consequences. Cities, one of the locations of modernity, often witness the consequences of excessive reliance on engineering solutions to master nature. In recent times, the policy makers are becoming more aware of the limitations of the existing approaches and are promoting harmonious relationship with nature in finding out sustainable solutions. Nature-based solutions (NbS) are being advocated to address the concerns of ecological degradation, increase in extreme weather events and compromise with environmental well-being in meeting the goals of sustainable development (Cohen-Shacham et al. 2016; Nesshöver et al. 2017). It is argued that NbS are directly relevant to Sustainable Development Goals (SDG) SDG 2 (food security), SDG 3 (health and well-being), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 13 (climate change), SDG 14 (conservation and sustainable use of oceans, seas, and marine resources), and SDG 15 (protection, restoration, and promotion of sustainable use of terrestrial ecosystem) (Cohen-Shacham et al. 2016). In all these, interface with water is one of the most vital issues of concern for the global community. Water, a finite element for the survival of the living planet, now faces the daunting challenge of urban shift in the habitation pattern on the globe. As the world is witnessing surge in urban population, there is increased focus on the sustained availability of water to the urban dwellers.

In 2015, two out of five people in rural areas had access to piped water supplies (a form of 'improved' supply, but not necessarily a 'safely managed' supply), whereas four out of five people in urban areas had piped supplies; sewer connections dominate in urban areas, where they are used by 63% of the population, compared to only 9% in rural areas.[1] However, the proportion of urban households with access to improved water supply and sanitation services decreases substantially when adjusting for additional indicators related to water (quantity, time, and cost) and sanitation (distance, cleanliness, hand-washing, and safety) (UN-Habitat 2008). Three out of ten people (2.1 billion people, or 29% of the global population) did not use a safely managed drinking water service in 2015, 844 million people still lacked even a basic drinking water service.[2]

Since 2007, when for the first-time half of the human population became urban dwellers, the pace of urbanization has been increasing and by 2050, two-third of world's population will reside in cities.[3] The world population is expected to increase from 7.7 billion in 2017 to between 9.4 and 10.2 billion by 2050, with two-thirds of the population living in cities. More than half of this anticipated growth

[1]https://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf

[2]ibid.

[3]https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html

is expected to occur in Africa (+1.3 billion), with Asia (+0.75 billion) expected to be the second largest contributor to future population growth.[4] In this new urban world, urban agglomerations with more than ten million populations, termed megacities, have acquired enviable space in view of scale, size, and complexity of processes (Dhyani et al. 2018). In 1990, there were 10 cities with more than ten million inhabitants, hosting 153 million people, which represented less than 7% of the global urban population. Today, the number of megacities has tripled to 33, and most of them are in Asia, including five that have recently joined the group: Bangalore, Bangkok, Jakarta, Lahore, and Chennai. Globally, the population of megacities has grown to 529 million, and they now account for 13% of the world's urban dwellers. Such gigantic habitation brings considerable focus and challenges for water management (Gandy 2004, 2011; Bakker 2010; Hosagrahar 2011).

In 2011, the World Wildlife Fund (WWF) produced a report titled "Big Cities, Big Water, Big Challenges" that covers six large cities—Mexico City, Buenos Aires, Nairobi, Kolkata, and Shanghai. Using the concept of "water footprint", the report argues that *"the main threats to urban water are water scarcity, decreasing water quality and pollution, water overuse and associated salt-water intrusion in addition to infrastructural, institutional, and social problems"* (p.5). This narrative of crisis and risk assumes gigantic proportion in case of megacities. It asks for re-strategizing the focus of urban water management by integrating *"a larger proportion of solutions like raising awareness to reduce consumption, law enforcement and controls, reuse and recycling of storm- and wastewater, corporate water stewardship, economic and fiscal incentives and instruments, cost recovery, integrated river basin management, payment for environmental services, and climate change adaptation"* (p.6).

In this chapter, the focus is centred on water supply in Delhi, world's second largest city, which reveals the challenges and the barriers, adopted measures and its consequences, and possible pathways premised on the NbS. Delhi, a megacity, evolved along with nature since first millennium; however, its newer political masters of nineteenth century led down a new water system, where there was no space for water bodies, river, tropical climate, and indigenous technology (Kumar 2013). In this chapter, we demonstrate with evidence of this transition. In the process, it describes how separation of nature from water management system has led to irrevocable consequences and how mainstreaming NbS is necessary for designing a sustainable and just water management system in the megacity. The chapter has five sections besides introduction and conclusion. First section outlines the extent and positioning of megacities in the urban world; second section deals with Delhi and its ever evolving water supply system; third section reveals the loss and consequences in Delhi' water system; fourth section focuses on NbS and its necessity in urban water system; and fifth section suggests possible pathways for sustainable water future.

[4]ibid.

7.1.1 Megacities

Cities with ten million or more inhabitants, termed as megacities, are concentrated in only 20 countries. China alone has six megacities and it will add 2 more megacities and six more large cities by 2030. India has five megacities now, adding two more by 2030 (Ahmadabad and Hyderabad). The two megacities of Brazil are expected to remain the only megacities in the country, as is the case in Japan, Pakistan, and the United States of America. Cairo, Kinshasa, and Lagos are the three megacities in Africa in 2018, but two more are expected to emerge by 2030, Dar es Salaam and Luanda. These are fascinating locations of human interactions with concentration of political power and economy. Any intervention to augment any service in megacities takes gigantic scale and hence occupies greater public imagination. Deploying trains to bring water in Chennai in 2019 made headlines as the city struggled in face of its overdependence on outside supply. Every summer, Delhi, another megacity, struggles to quench the thirst in spite of its setting between river Yamuna and Aravali hills.

Scale, speed, and complexity of a South megacity often make it difficult to identify and to assess the characteristics of the risks concerning water. Conventionally, the approach has been to apply a pre-fixed yardstick (norms and indicators) to locate these risks and prioritize it for policy intervention. A large body of reports by various international agencies are available in this regard (UN-HABITAT 2003, 2008, 2010; World Water Assessment Programme [WWAP] 2003, 2009, 2012). The macro awareness of the risks in water supply in such cities is well described and discussed. This kind of acknowledgement is not a recent phenomenon. World Health Organization published a report in 1963[5] titled *Urban Water Supply Conditions and Needs in Seventy-five Developing Countries* to underline the risk faced in the cities of the developing countries. The scale of these reports, invariably, is at the city level or at the national level.

The risks faced in megacity water management are multilayered and multidimensional. The popular notion of risk originating from arithmetic understanding of supply-demand gap is already under challenge for two reasons: one, it gives less attention to intra-city differences in distribution and availability (Satterthwaite 2004; McGranahan and Owen 2006; United Nations Development Programme [UNDP] 2006; UN-Habitat 2003, 2008, 2010); and two, the cities, which have achieved the goal of universal supply, are staring at the challenges of climate change and other uncertainties (Brown and Clarke 2007; Brooks et al. 2009). World Wildlife Fund [WWF] (2011) in a report titled 'Big Cities, Big Water, Big Challenges' discusses the risks in water supply in six big cities from global South:

- *Mexico City, Mexico:* Over-exploitation of aquifers has contributed to the continued subsidence within the city (5–40 cm per year), increasing the chance of catastrophic flooding.

[5]Available at http://whqlibdoc.who.int/php/WHO_PHP_23.pdf (accessed on 20/06/2012).

- *Buenos Aires, Argentina:* One of the most polluted waters in the world contains levels of lead, zinc, and chrome 50 times higher than the legal limit in Argentina.
- *Nairobi, Kenya*: Sixty per cent of the inhabitants lives in informal settlements with inadequate access to quality water and is forced to buy highly priced water at kiosks.
- *Karachi, Pakistan:* Eighty per cent of untreated wastewater is discharged into the Arabian Sea and around 30,000 people, mostly children, die each year in the city due to consumption of contaminated water.
- *Kolkata, India*: The city is struggling to contend with faecal contamination of municipal water and arsenic pollution of groundwater.
- *Shanghai, China:* The city already experiences high water stress due to the rising demand of 23 million inhabitants.

Megacity is not confined to its territorial limit. With the concentration of power (political, economic, judicial, bureaucratic, media amongst others), a megacity water management system has far reaching consequences for the region and for the country. Unable to deal with the scarcity, inequity, wastage, stress, theft, etc. effectively, a megacity affects the behaviour and the capacity of a generation of population, at a large scale, in a manner, which is not water-conducive. Kumar (2013) analyses these consequences in a framework of multiple layers of risks in the setting of megacity water. Before appreciating these layers, it is worthwhile to examine it in the context of a specific megacity in detail. In this chapter, this megacity is Delhi for various reasons. A capital city with a history of more than thousand years, Delhi has witnessed its transition from water-conducive to water-stressed city in last two centuries.

7.2 Delhi and its Waters

"(Indian cities) *form an inseparably interwoven structure"*, (not) "*as an involved network of thoroughfares dividing masses of building blocks, but as a great chess-board on which the manifold game of life is in active progress*" (Geddes, Patrick quoted in Tyrwhitt 1947).

Delhi is a historic city. At least eight political capitals are identifiable within the current territorial limit of the city. Yamuna and Aravali hills guided the hydraulic behaviour of the city, which further influenced the shifting of capital from time to time. With an area of 1483 square kilometre, the city boasted a population of 16.8 million in 2011 (Census of India 2011), which was estimated to be 19 million in 2017.[6] A government report suggests that close to 76% of the population reside in

[6] http://delhiplanning.nic.in/sites/default/files/2%29%20Demographic%20Profile.pdf (accessed on 25/12/2019).

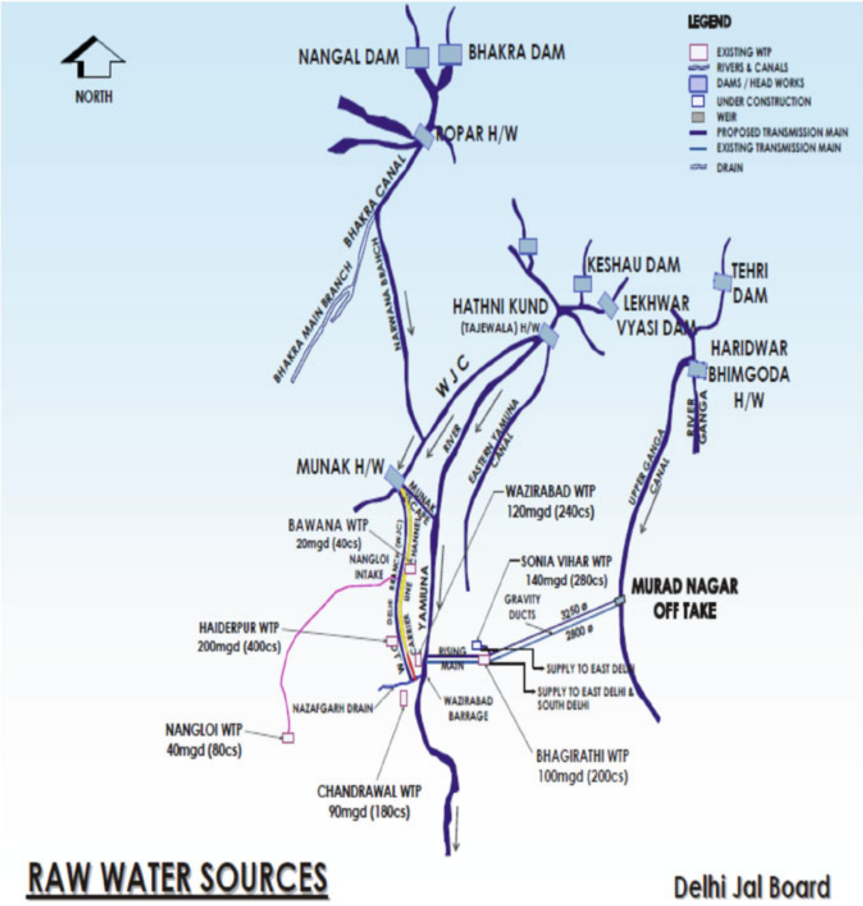

Fig. 7.1 Functional map of water supply, treatment plants for Delhi (Source: DJB, 2010)

the unplanned habitation in the city.[7] For providing water to its diverse habitation, it is dependent upon an arrangement in the Supreme Court of India with the neighbouring states including Himalayan states to facilitate specific quantity of water for the city (Fig. 7.1).

Evolution of water management in Delhi has a long history. As a capital city, it has witnessed at least three different periods in its handling of water. First, until 1858, the fall of Mughals; second, thereafter until 1947, the year of independence; and third, post-independence period. The literature concerning the pre-colonial period (before nineteenth century AD) is quite descriptive in nature. Lort (1995)

[7] https://www.cprindia.org/sites/default/files/policy-briefs/Categorisation-of-Settlement-in-Delhi.pdf

unearths the presence of seventeen stepwells in various locations in Delhi and discusses its architecture, purposes, and the inscriptions recorded on these historical buildings. These wells, unique to India, create *"a link between underground water and surface life is as rich, colorful, and textured as India itself"*, claims American photographer Morna Livingston, the author of *Steps to Water*. Her vivid photographic work focuses on stepwells in western India. These wells follow a common structural design: *"an excavation lined with stone allows the water level inside the cavity to fluctuate freely with surrounding water table. Continuous steps from ground level to the bottom of the structure lead to water, no matter how great the variation in the water table"* (Livingston 2002). These stepwells survived in the landscape of the city amidst the changes in kings and emperors. This must have been possible due to local management, community engagement, and continuous utility for the people. Here nature, culture, and society seem to work in harmony at a specific location. It was an example of *collective consumption* that made the city of Delhi. Lort (1995; 132 pg) argues that "These imperial commissions were an integral part of the growth of the city: they supplied water for the urban population, contributed to imperial prosperity and fulfilled charitable and religious duty".

Cherian (2004) travels through the hydrological map of the city and describes the significance of natural drainages in creating a megacity water network. His analysis is in the background of various construction works being taken up for the Commonwealth Games, 2010. These works provide an excellent setting to situate the discussion on the megacity water.

Based on the ancient text of *Manasara*[8] (400 AD–600 AD) concerning *Vaastu shastra,* the new city of *Shahjahanabad* (seventeenth century) took a shape of *karmuka* or bow (semi-elliptic design) fronting a river. It was the urban conclusion to the patrimonial-bureaucratic premise of the state and simultaneously following the previous traditions in India, it was a*xis mundi,* symbol of centre as a zone of the sacred, which acted as meeting place of heaven, hell, and earth for the rulers and the priests to communicate with the divine (Blake 1991). Ali Mardan Khan realigned the Yamuna canal, constructed during Firuz-Shah Tughlaq (1351–1388), extended it from Hisar and brought water to this new city in 1639. Hailed as Nahr-*i-Bihisht* (paradise canal), the longest and the largest canal, is a remarkable example of engineering excellence in the Mughal empire. The canal provided regular water from the Yamuna to the city except for brief interruptions during 1707 and 1740 though the canal dried up in the late eighteenth century. It was reopened in AD 1820 and continued to nurture the urban areas of Delhi till mid-nineteenth century (Gupta 1981).

Nature was still an ally in the city not as an outsider, but as an insider. Cultural meanings were still part of state discourses while harnessing and utilizing various

[8]**Manasara** Silpa Sastram is a definitive Indian treatise on Vastu Sasthram, an ancient building code which was used for designing houses, planning cities and communities for centuries in India. This document was used as a prescriptive building code dealing with architecture and spatial organization of residential quarters. It is written by a sage named Manasara. It is one of the 5 documents that exists now which deals with Vastu Sasthram. (Dutt 1925).

forms of water. Socially, it continued to shape the daily life through various practices. These practices on one side reflected the deep-rooted social stratification based on caste, race, and religion and on the other side, it remained a vehicle to attain prestige, salvation, and *punya* (goodness). Its political significance cannot be underestimated as evident in various inscriptions on stepwells in Delhi suggests the aspiration to gain stature by doing goodwill (Lort 1995).

However, during nineteenth century, a shift in political power structure from Mughals to Britishers proved decisive for the city's waters. These new protectors of the canal introduced three new factors in the system: *one,* government as the sole authority in carrying out such works; *two,* from the very beginning, after the reopening of the canal, the element of inequality in the distribution (the British Residency and the garrisons were preferred) of canal water was inbuilt in the system (Prakash 1999); and *three,* the wells were not given due attention. Gupta (1981) notes: "*During the eighteen-twenties and eighteen thirties, when the canal did provide potable water, the wells were neglected. This was possibly why in 1843 as many as 555 of the 607 in the city were pronounced to be brackish*".

The scholarships concerning colonial times (from nineteenth century until 1947, the year of independence) serve two broad purposes: one, these provide descriptive information on the events leading to the introduction of modern water supply; and two, these show the working of politics, science, and capital that facilitated its shaping in the city. Gupta (1981) uses broad canvas of historical account of the empires during the nineteenth century (however her discussion travels upto 1947) to convey the shaping of the water supply, whereas Prashad (2001), Mann (2007), and Sharan (2006) centre their works on the water supply and sanitation. Another significant work is of Prakash (1999) which discusses the import of colonial science in India. Headrick (1988) discusses the ideological design in the tentacles of progress in the colonial cities that includes water management. These scholarships unpack the layers of decision making (in the government and in the political set-up) that laid the foundation of the modern water system in Delhi. All these works identify segregation, selective modernization, and neglect of indigenous system integral to the colonial water system. Surprisingly these works do not identify the significance of institutional design that guided the colonial system and created a legacy for the post-independence state. Another crucial element missing in these discussions is of the importance of season in the tropical setting. Headrick (1988) does talk about tropical countries but the linkage between the tropics and the modern water supply is absent. In 1892, the city witnessed its first piped water supply. However, the discharge of waste water continued to be without any control unlike the cities of the western world of that time (Mann 2007). As the new water management system needed to cater to the needs of the seat of the government, the habitation outside the capital area was either left to fend off for itself or made to survive on the new but broken arrangements.

In the contemporary literature, two broad trends were identified: one, the focus on the failure of the current water supply system; and two, the discussion on the coping strategies for the purpose of calculation of opportunity cost. Zerah (1998, 2000a, 2000b) focuses on her works on the failure of the municipal water supply system and its implications in the form of coping strategies for the households. Llorente (2005) takes up this discussion further and discusses the institutional and organizational aspects of Delhi's water; but surprisingly the discussion on the DJB Act, 1998 is absent. Soni (2003) focuses the works on supply side aspects of the megacity water management and advocates integrated water management for the city.

Mehta (2012) in her work on water in the resettlement colonies discusses the lack of inter-agency coordination and cooperation that results in fragmentation of the state, and she argues that this places the potable water at the centre of politics in the city. Truelove (2011) focuses on the position of women in the case of water in three different types of habitations and re-conceptualizes the concept of water inequality in the city. Tovey (2002) in her works on the institutional dimension of water supply in Delhi's slums finds the emergence of new social arrangements based on geographical proximity and vertical networks to promote the collective action. Mostly these rich works base its analyses on the empirical results derived through the application of econometrics. The focus of these works is on the contemporary conditions without considering the historical past of the city's water supply. Hosagrahar (2011) suggests that there is an urgent need to revisit the historical and cultural landscape of water in Delhi to find the solution to the present problems.

The desire for the piped water supply, a new symbol of modernity, gradually shifted the provisioning of water from individual/community to the state. This transition also witnessed the shift from nature to tap! As a consequence, the whole ecosystem of traditional water system collapsed/lost. Individuals/communities increasingly lost touch from its neighbourhood pond or well or river. In the process, it lost its capacity to navigate the vagaries of seasons. State, which earlier valued the nature in tropics and thus designed its hydraulic system in consonance, now armed with tools of modernity believed in triumph over tradition and hence propagated and aspired for techno-hydraulic system with scant regard for the nature (Giddens 1999). Next section demonstrates the loss and the risks in the new system.

7.2.1 Loss and Consequences in Delhi's Waters

Delhi receives average annual rainfall of 611.8 mm with 20–30 rainy days.[9] The political masters of the city realizing the hydrological conditions and limitations focused on multi-pronged approaches to negotiate the requirements of the city and its inhabitants. Limitation and uncertainty of surface water availability made the people reliant on the practices of capture of rainwater, promotion of water bodies—natural and stepwells (baolis)—suited to local climatic conditions, and evolved coping mechanism guided by the sacred connect with water.

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[9]http://naturalheritage.intach.org/wp-content/uploads/2018/07/DWP-2018-july.pdf (accessed on 25/12/2019).

In the era of piped water supply system, Delhi gradually lost its appreciation for the local hydraulics like water bodies, river, and Aravali (Kumar 2013). State, as a water provider, pursued its water strategy premised on supply-demand narrative, which contributed to the loss of city's ecosystems. It made the city dependent on outside supply and thus exposed the city to more risks, beyond its control (ibid). This created a situation which witnessed inequity, inaccessibility, denial, wastage, and political strife in the capital city (ibid). It led to disconnect with nature-based strategy of water management.

One such consequence has been the loss of water bodies in the city. As Delhi engulfed its hinterland in the process of mega-urbanization, it impacted the existing water bodies in the villages at three levels: ignorance of physical structure; deemed transfer of ownership from village community to the state; and consequent loss of stake and capacity of the neighbourhood.

In 2000, Delhi government was dragged into the High Court of Delhi on the issue of revival of 629 water bodies located within the boundary of the megacity.[10] After various committees, reports, and judicial directions, the government came to the conclusion, in 2011, that 232 of these are beyond revival because of human encroachment or waste dumping.[11] For remaining, which are mostly located in villages, the feasibility of revival is explored through civil engineering methods by the concerned owner departments (INTACH 2010). These facts reveal following issues: the ownership of these water bodies rests with the government (as so called gram sabha,[12] the intended owner, is dysfunctional in the absence of local body); the neighbouring community is not a genuine stakeholder in the process; the hardware approach to revive the water bodies is unsustainable (ibid); the process of urbanization itself is the reason for the loss of water bodies. Revival of water bodies is linked to the overall megacity water management for three reasons: it helps in recharging the groundwater; it increases the blue cover; it allows the participation of local in management (ibid).

The current status of water bodies in Delhi indicates a curious mix of three processes—commodification of land for habitation, disempowerment of community to regulate, organized irresponsibility of state. However, increased awareness through judicial interventions and civil societies' engagements may influence these processes, so that the harvesting of rainwater becomes fruitful. Bringing water bodies back into overall water management strategy is one of the ways to find nature-based solutions in Delhi's water. In the next section, we discuss these solutions in the context of megacities, which pose the challenges of scale, efficiency, and sustainability.

[10] Tapas, a voluntary organization has filed a number of PILs on the subject of water in Delhi.

[11] http://www.hindustantimes.com/India-news/NewDelhi/Delhi-water-bodies-go-under-almost/Article1-657793.aspx accessed on 23/06/2012.

[12] Gram sabha is the smallest democratic form of governance at the village level in India.

7.3 NbS in the Context of Megacities

Nature-based solutions (NbS) to address the concerns of risks related to natural resources are age-old phenomena. In urban locations, the political masters and the economic entrepreneurs used NbS to design the urban ecosystems to harness the water in harmony with nature. The remnants of the hydraulic structures of the past suggest that such water designs were integral to the urban habitation patterns. In addition to current ecosystem services, it also helped in improving coping mechanism, hence resilience, to face the vagaries of nature. As colonial masters shifted focus to urban water and drainage system in the mid-nineteenth century, the connect with nature, by the twentieth century, got lost. The desire and goal of provisioning water supply to all, through the state, promoted large engineering solutions, not in consonance with the nature, which has been proved ineffective and insufficient (Kumar 2013).

Cohen-Shacham et al. (2016) and Keeler et al. (2019) note that NbS terminology emerged around 2000, but the application of natural processes to manage water probably spans millennia. Nature-based solutions (NbS) are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water. The defining feature of an NbS is, therefore, not whether an ecosystem used is 'natural' but whether natural processes are being proactively managed to achieve a water-related objective. In 2018, UN-Water released its World Water Development Report focused on 'nature-based solution for water'. The report argued that NbS serve three inter-related purposes: mimicking natural processes to enhance water availability; improving quality of water; and reducing risks associated with water-related disasters and climate change. It advocates working for appropriate blending of grey and green investments to 'maximize benefits and system efficiency while minimizing costs and trade-offs'.[13]

In urban context, the efforts of integration of NbS with the ongoing water management have not been successful due to entrenched sectoral interests, political and governance barriers (Jønch-Clausen 2004), and the lack of collective responsibility (Goldin et al. 2008). Gradually, the enhanced understanding about the connect between NbS and ecosystem services is helping in creating an environment more conducive for integration of NbS in the existing urban water management system.

In China, a concept of 'sponge city' has been initiated to improve water availability in urban settlements. This concept relies on the application of NbS and its integration in the urban water system with quantifiable objectives. The project's objective is "70% of rain water to be absorbed and reused through improved water permeation, retention and storage, purification and drainage, as well as water saving and reuse. This goal should be met by 20% of urban areas by the year 2020 and by 80% of urban areas by the year 2030" (Embassy of the Kingdom of the Netherlands in China, 2016, p. 1 as quoted in Water 2018).

[13] https://www.unwater.org/publications/world-water-development-report-2018/ (accessed on 25/12/2019).

In India, a new Wetland (Conservation and Management) Rules, 2017[14] was framed, which facilitated the constituted State level Wetland (Conservation and Management) Authority. Amongst other powers, this Authority will also "define strategies for conservation and wise use of wetlands within their jurisdiction; wise use being a principle for managing these ecosystems which incorporates sustainable uses (such as capture fisheries at subsistence level or harvest of aquatic plants) as being compatible with conservation, if ecosystem functions (such as water storage, groundwater recharge, flood buffering) and values (such as recreation and cultural) are maintained or enhanced" (Rule 4(g) of these Rules).

Enhanced awareness of NbS combined with the efforts putting up institutional arrangements for NbS bodes well for the future. The challenge of sustaining the efforts and scaling up the local solutions at the megacity level is not going to be easy. It would require convergence of actions of various agencies concerned with NbS simultaneously. Continuous updation of knowledge base and enhancing the capacity to ensure appropriate linkages between the grey and the green infrastructures would be the key for mainstreaming NbS in urban water.

7.4 Possible Pathways for Delhi's Waters Premised on NbS

The limitation of supply-demand approach coupled with growing awareness of crucial role of nature in the hydrological governance of Delhi has brought nature back in business. Capture, conservation, and revival, at least in last two decades, seem to draw attention of civil society, judiciary, and government in the city. As discussed earlier, judicial interventions, since 2000, played significant role in putting water bodies and rainwater harvesting on the agenda of Delhi's water. In 2018, Indian National Trust for Art and Cultural Heritage (INTACH in short) came out with the first Water Policy for the city. These developments indicate a paradigm shift in the water management strategy in the city, where nature is treated as integral to the future of Delhi's water. In this section, we focus on one of the important elements of nature-based solutions—revival of water bodies to demonstrate the shift.

7.4.1 Revival of Water Bodies

In urban landscape, the presence of water bodies has been integral to urban sustainability. In the scheme of nature-based solutions for urban water, these water bodies serve multiple purposes including capturing rainwater, recharging groundwater, protecting soil erosion, and enhancing landscape restoration. The Centre for Science

[14]http://www.indiaenvironmentportal.org.in/files/file/Wetlands%20(Conservation%20and%20Management)%20Rules,%202017.pdf (accessed on 25/12/2019).

and Environment [CSE] (2012) notes that water bodies perform diverse functions "*like providing drinking water, fish, fodder, supporting wildlife and controlling the rate of run-off in urban areas which subsequently control flooding in these areas. There are historical evidences that the areas around lakes, ponds and tanks always provided recreational spaces to the societies. These bodies of water also help in recharging the groundwater. The urban water bodies of India, whether man-made or natural, fresh water or brackish play a very vital role in managing the ecological balance like maintaining water balance, flood prevention, biodiversity and support food security and livelihoods*". (p. 2).

Waterbodies are of various types in the city. Delhi as a political capital grew up as fortified medieval city surrounded with the villages. Within the fortified space, the state created waterbodies like Hauz Khas, and Old Fort Lake. And outside it, every village developed and preserved its own small ponds, which were managed by local communities. These village ponds, large in numbers, worked as local catchment area for gathering rainwater. These ponds gradually disappeared due to urbanization and lack of ownership. Lakes, larger in size, witnessed shifting attention due to regular change in location of political capital. Some of these still survive. Most prominent amongst these are Bhalswa lake (a freshwater oxbow lake on the river floodplain) and Sanjay lake. Marshes are another group of waterbodies, mostly found within the floodplain embankments. Jahangirpuri marshes, presently the largest waterbody in the city, are outside the floodplain embankments.[15] Another set of waterbodies, called baolis (stepwell), mostly created by individuals for the purposes of drinking water, on the lines of western India (Lort 1995) are within the control of Archaeological Survey of India.

Historically, the community and the city knew the necessity and the significance of water bodies. With the separation of nature from water in the city, it lost the presence and the significance of its age-old tradition of water bodies. Faced with the water concerns, civil societies, judiciary, media and state started invoking and revisiting its hydraulic past. In 2000, Tapas, a voluntary organization filed a case in the High Court of Delhi for the revival of water bodies in Delhi.[16] This led to series of activities including formation of committees, identification of water bodies, its documentation, and marshalling of various land-owning agencies. Revival of water bodies found space in public discourse in the city.

In view of ownership of the waterbodies by multiple agencies in Delhi, an apex body, headed by the Chief Secretary, was constituted to monitor the progress of revival of waterbodies in the city regularly. This body is represented by all concerned agencies along with Tapas, a voluntary organization. A steering committee to monitor the progress and intervene as and when required during the time of execution of various programmes in the improvement of water bodies and provide it

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[15] http://pwd.delhigovt.nic.in/wps/wcm/connect/7e8d0a0049b7df8da347bb26edbf4824/Water+Bodies+Presentation.pdf?MOD=AJPERES&lmod=1827942602&CACHEID=7e8d0a0049b7df8da347bb26edbf4824 (accessed on 25/12/2019).

[16] W.P.(C) 3502/2000 (VINOD KUMAR JAIN – Petitioner Versus Govt. of NCT of Delhi).

suggestions is also constituted. These institutional arrangements are helpful in putting waterbodies in the forefront of water management in Delhi. Subsequently, a wetland authority for the city was notified on April 23, 2019 under the Wetland (conservation and management) Rules, 2017 to look after conservation and management of all wetlands including waterbodies in the city.[17]

In last two decades, Delhi Jal Board, the focal agency of water provisioning in the city, has consistently talked about the status of revival of these water bodies. However, in 2018, it informed the Supreme Court of India, which noted[18] that.

"It is further stated that even though 1011 water bodies have been identified in Delhi, steps have apparently been taken to prepare an action plan for rejuvenation of 201 water bodies. It is further stated that with regard to pilot project in Rajokri and Gogha villages, the details have not been given including when the pilot project was initiated and when it is likely to be completed. A report indicating all time-lines in this regard must be made available to the learned Amicus Curiae. Finally, it is submitted that the Delhi Jal Board has given a contract to the Government Corporation that is Water and Power Consultancy Services with regard to rejuvenation of 12 water bodies and consultancy assignment has been given for 93 water bodies to IIT Delhi.

As far as the remaining water bodies (201–12-93) are concerned, they have been taken up through NEERI and other empanelled consultants".

There has been continuous monitoring of the status of water bodies by Supreme Court of India, Delhi High Court, and National Green Tribunal. In 2018, National Green Tribunal constituted a monitoring committee, headed by a retired High Court Judge Mr. S.P. Garg, to monitor various action plans of recharge of groundwater in the city.[19]

Revival of water bodies is long drawn process. Advantage of availability of dense habitation in a megacity, which advocates centralized allocation of resources like water for the reasons of efficiency, often tests the necessity of continued attention and resources on NbS. However, awareness of NbS-associated multiple benefits like landscape development, groundwater recharge, storm water management, community engagement, recreation and tourism potential, ecosystem services, and healthy living in an urban neighbourhood will help in dispelling any view against the continued attention on NbS like water bodies in a megacity.

In Delhi, revival of series of water bodies is now visible on ground in some cases.[20] This indicates acknowledgment of significance of these by various agencies. Identification of water bodies and its current status in the city has made the

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[17]https://www.pressreader.com/india/hindustan-times-st-noida/20190705/281698321303949 (accessed on 25/12/2019).

[18]Writ Petition(s(Civil) No(s). 4677/1985 (available at http://www.indiaenvironmentportal.org.in/files/file/water_body_revival_Supreme_Court.pdf).

[19]https://www.business-standard.com/article/pti-stories/ngt-forms-monitoring-committee-to-prepare-action-plan-on-groundwater-recharge-in-delhi-118090501082_1.html

[20]SANDRP notes this at https://sandrp.in/2019/04/06/wetlands-overview-2019-north-india-no-land-for-wetlands/ (accessed on 25/12/2019).

stakeholders aware of the need for revival of these water bodies. Revival of water body like Hauz Khas lake has demonstrated the tangible and intangible benefits of ecosystem services.[21]

However, the presence of multiplicity of authorities in the city is a major barrier in making water bodies as an idea integral to the city's water management system. A number of water bodies are found to be encroached for habitation or civic amenities in the city. Various agencies are working on its revival as stand-alone activities in silos (Kumar 2013). The informal character of Delhi makes it unattractive for the political executives to invest in such long-term measures.

7.4.2 Rainwater Harvesting

Despite the prevalent belief that Delhi receives its raw water from outside sources, almost one-tenth of its requirement is met from the groundwater.[22] Almost 22% of the households in Delhi (561,913) were extracting groundwater for drinking water in 2001; in 2011, 13.7% households (457,654) were still dependent on such extraction (Census of India 2011). Groundwater also becomes handy to overcome the risk of inadequacy and intermittent supply in the city which eventually put enormous pressure on the quantity and quality of the groundwater. Since rainwater harvesting is considered integral to the improvement in groundwater scenario in the megacity, this section first looks into various efforts of harvesting and second examines the barriers in the harvesting of rain.

Rainwater harvesting consists of a wide range of technologies used to collect, store, and provide water with the particular aim of meeting demand of human and/or human activities (Malesu et al. 2008). Two approaches are prevalent: first, in situ rainwater harvesting system (relatively small in scale); second, ex situ rainwater harvesting system (capture area is external to the point of storage). Without using distinction, this section discusses three types of physical structures—water bodies, rainwater harvesting structures (popularly referred to planned harvesting at the colony/institutional level), and storm water drain. First two of these are intended to harvest water to recharge the groundwater or to use for various purposes, whereas the third one is primarily built to allow the run-off with the sole purpose of avoiding water logging.

The Centre for Science and Environment argues that the harvesting of 50% of the rainwater may be sufficient to bridge the existing supply-demand gap in Delhi.[23]

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[21] Roy, Deya. (2016). Revival of Hauz Khas Lake in Delhi: Approaches to Urban Water Resource Management in India. Journal of Management and Sustainability. 6. 73. https://doi.org/10.5539/jms.v6n4p73

[22] http://delhiplanning.nic.in/sites/default/files/Ch-3%2BWater%2BSupply.pdf

[23] Available at http://www.rainwaterharvesting.org/ (accessed on 23/06/2012).

Three main actors—state, voluntary organizations, and neighbourhood committees—are involved in creating rainwater harvesting structures in the institutions or colonies. The DJB (Delhi Jal Board) has created a cell to guide the rainwater harvesting efforts throughout the city. In its released guideline,[24] it claims that rainwater harvesting is critical for the water security of Delhi. Simultaneously CSE (Centre for Science and Environment [CSE] 2012), an environmental organization vigorously pursued it using three tools—live demonstration; development of a manual of urban rainwater harvesting; and awareness campaign through environmental writing. The state encouraged these efforts by introducing financial incentives and annual reward schemes since 2002. However, its spread has been guided by the legality of habitation,[25] which remains a major barrier against the desire for making such efforts inclusive to each and everybody in the megacity.

The megacities need political will to legislate (specific byelaws for mandating the harvesting and incentivizing it), to promote (creating a culture of rainwater harvesting), and to overcome the barriers (of integration).

Nature-based solutions that protect or restore the natural infiltration capacity of a watershed will increase the water supply service: these solutions include, to various extents, street trees, parks and open space, community gardens, and engineered devices such as raingardens, bioswales, or retention ponds that are designed to increase storm water infiltration. Conversely, the use of water by vegetation through transpiration decreases the water supply service (Keeler et al. 2019). Access to water is a key development objective as outlined in the UN Sustainable Development Goals (United Nations 2014, 2015) and changes in water supply affect domestic, industrial, agricultural, and environmental water availability. The benefits of increased water supply can be direct, e.g. through economic gains related to the use of groundwater. They can also be indirect, such as education and social capital involved in the implementation of the nature-based solutions. However, given the availability of substitutes and the limited magnitude of the net recharge, due to the trade-off between infiltration and evapotranspiration, it is likely that improved water supply will be a co-benefit of nature-based solutions such as parks or raingardens, rather than a primary objective.

7.5 Conclusion

In more than 55% urbanized world, water services, premised on supply-demand narratives, have not given the desired results. As water is essential element to achieve a number of SDG goals, it is imperative that urban water gets due attention in policy discourses. Unfortunately, the study of water supply in the world's

[24] http://delhijalboard.nic.in/sites/default/files/RWH_Guidline_13072016.pdf (accessed on 24/12/2019).

[25] Only registered associations are allowed to take this support.

megacities, urban agglomerations with more than ten million inhabitants, has not been encouraging. Flood or drought situations have increased. Overdependence on outside supply coupled with loss of natural ecosystem of the urban areas has made the water situation troubling.

The chapter using Delhi as case study demonstrated the evolution of the city along with nature, which got snapped in the age of modern water supply system. It has enhanced the risks, increased the political strife, endangered the city's water ecosystem, and made people ignorant of its connect with nature.

Premising NbS in megacity water system is important as it achieves a number of goals: (a) Megacity, being large agglomeration, provides an opportunity to scale up the applications of NbS; (b) As role model for other cities, it helps in better acceptability and adaptability; (c) Its overdependence on outside water source gets reduced, which helps in diversification of risks and also lesser regional conflict over resources; (d) The policy makers, whose concentration is invariable in these locations, are able to mainstream NbS in future water strategy, which is more in conformity with its natural surroundings; (e) Since NbS are culturally prevalent and understood amongst the stakeholders, its mainstreaming in the overall water management is acceptable; and (f) it makes system more resilient.

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Part II
Evidence and Examples of NbS Implementation

Chapter 8
Forest Landscape Restoration as a NbS Strategy for Achieving Bonn Challenge Pledge: Lessons from India's Restoration Efforts

Anushree Bhattacharjee

Abstract Bonn Challenge is an ambitious global restoration pledge that was launched in 2011, with the nature-based solutions (NbS) strategy of forest landscape restoration (FLR) as its underlying principle. India has one of the largest pledges from Asia with the aim of bringing 13 million hectares of degraded land into restoration by the year 2020, and an additional eight million hectares by 2030, and thus should maintain a leadership position in South Asia on Bonn Challenge and landscape restoration. Government of India (GoI) and IUCN have prepared the first country progress report towards the Bonn Challenge pledge in 2018 which showed that India has already brought 9.8 million hectares into restoration. This report is the first progress report from any Bonn Challenge country and is also unique as it includes restoration efforts undertaken by the government, NGOs and the private sector. Although the government was the majority contributor (94.4%), the efforts of NGOs (3.6%) and private companies (2%) are important as they have the technical expertise to guarantee success. Three best practices of landscape restoration from across different ecosystems of India have been detailed here so that they may act as learnings for future restoration efforts. Lessons learnt from past restoration efforts have informed the design of a flagship project on FLR launched in five Indian States by GoI and IUCN, which will maintain India's leadership on Bonn Challenge across South Asia.

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8.1 Introduction

8.1.1 The Global Challenge of Land Degradation

Land degradation is a global crisis of grave magnitude. Logging is one of the major causes of forest degradation (Lewis et al. 2015), while conversion of forest land to farmland also affects the function and health, especially of tropical forests across the world (Hansen et al. 2013). Degradation affects the delivery of ecosystem services, thus affecting human livelihoods (Campbell et al. 2001). Globally, the loss of biodiversity and ecosystem services due to land degradation has been calculated to be more than 10% of the annual global gross domestic product (IPBES 2018). Degradation affects the productivity of agricultural and pastoral land across the world, causing major food security challenges (FAO and OECD 2018). Globally, more than 3.2 billion people have been affected by land degradation (IPBES 2018).

The Global Partnership for Forest Landscape Restoration (GPFLR) commissioned an assessment of restoration potential across the world in 2010. The study produced a World of Opportunity Map, which revealed that there was approximately 2 billion hectares of degraded land globally which could benefit from some form of restoration (Laestadius et al. 2011). Interesting new studies have since suggested that the cost of reclaiming degraded land is much less than the economic cost of land degradation (Chazdon et al. 2015; TERI 2018), thus championing economic sense in mitigating land degradation. However, it is being recognized that a long-term solution to this problem is much more nuanced than simply planting trees (Mansourian et al. 2005; Chazdon 2008). A successful long-term solution needs to strengthen the resilience of landscapes as well as that of the communities that inhabit these landscapes (Sunderlin et al. 2008; IUCN and WRI 2014).

Nature-based solutions (NbS) is a practical strategy for restoring the productivity of the world's degraded lands. The International Union for Conservation of Nature (IUCN) defines NbS as 'actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham et al. 2016; Dhyani et al. 2018). Forest landscape restoration (FLR) is one such NbS strategy. While ecological restoration used to historically refer to the act of bringing back the state of a degraded land to its original condition prior to degradation (Hobbs and Norton 1996), forest landscape restoration is a more forward-looking dynamic approach. It aims to restore an entire landscape to meet present and future needs while offering multiple benefits and land uses over time. Forest landscape restoration is defined as the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes (IUCN and WRI 2014). It is not limited to forests, but also extends to other landscapes. It is being increasingly demonstrated that for restoration to have long-term benefits it needs to be carried out at a large scale, hence the urgency to move beyond site-specific restoration efforts to landscape-level efforts.

8.1.2 Bonn Challenge: A Global Collective Effort to Combat Deforestation and Degradation

In order to accelerate landscape restoration efforts globally, the Bonn Challenge was launched by the Government of Germany and IUCN in 2011 (Laestadius et al. 2015). The Bonn Challenge is a global effort to bring 150 million hectares of the world's deforested and degraded land into restoration by the year 2020 (Bonn Challenge 2019). This was later extended to bringing 350 million hectares into restoration by the year 2030 by the New York Declaration on Forests at the 2014 UN Climate Summit (infoFLR 2019). IUCN is the secretariat for the challenge. It has been calculated that achieving the 350 million hectares target will not only generate approximately US$ 170 billion per year in net benefits, but also sequester up to 1.7 gigatonnes of carbon dioxide equivalent annually (Bonn Challenge 2019). The forest landscape restoration approach underlies the Bonn Challenge pledge. Achieving the Bonn Challenge pledge will also help in meeting several international commitments under the Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention to Combat Desertification (UNCCD), as well as support the countries in meeting their Sustainable Development Goals (SDGs). Presently, Bonn Challenge has garnered 62 global commitments, thus reaching a total commitment of bringing into restoration 170.9 million hectares (Bonn Challenge 2019). There are several regional initiatives to support and promote Bonn Challenge, such as the African Forest Landscape Restoration Initiative (AFR100) in Africa and the Initiative 20×20 in Latin America (IUCN and WRI 2014). In September 2019, ECCA30 was launched (InfoFLR 2019). It is a country-led initiative to bring 30 million hectares of degraded and deforested landscapes into restoration in Europe, Caucasus and Central Asia by 2030. Bonn Challenge is gaining momentum with several high-level ministerial roundtables happening in various parts of the world. These include Asia's first Bonn Challenge roundtable that was held in May 2017 in South Sumatra (IUCN 2017).

India joined the Bonn Challenge pledge in the year 2015 during the UNFCCC Conference of Parties (COP) at Paris. India's pledge is one of the largest from Asia, with a commitment to bring 13 million hectares of deforested and degraded land into restoration by 2020, and an additional eight million hectares by the year 2030 (Bonn Challenge 2019). In view of this large commitment, India needs to take a leadership role on Bonn Challenge and restoration in Asia, particularly South Asia. Presently, the green cover of India is 24.56% of the total geographic area of the country (FSI 2019). However, this includes all green cover including mono plantations. Thus, India needs to have a better reporting protocol for the Bonn Challenge. This chapter details the leadership role taken by India till date towards the Bonn Challenge in South Asia. It also details a few case studies from across the country that have been identified as best practices of restoration. It is hoped that the lessons learnt from these case studies can be used by other restoration practitioners to better design future restoration efforts.

8.2 Methodology

Existing publications on Bonn Challenge and India were reviewed in detail and analysed. Reports published by IUCN India since 2015, the year Government of India joined the Bonn Challenge pledge, were given special focus. The major highlights of India's leadership role in Bonn Challenge were identified and distilled, and have been presented in the results and discussion section of this chapter. The restoration data from India's first progress report towards the Bonn Challenge pledge was referred to and the key findings have been presented in the discussion section. The progress report had also mentioned a few best practices of restoration being practised by different agencies across India. Of these case studies, three were selected for further elaboration for the purpose of this chapter. These have all used local indigenous tree species towards the restoration of landscapes and are all examples of engagement with multiple stakeholder agencies. They also showcase diversity in terms of geography and ecosystem types. The lead agency for each of these restoration efforts were contacted for further details of the restoration efforts. The details provided by the lead restoration agencies were studied and analysed, clarifications and more details were sought wherever required, and the final case studies have been presented in the following sections of this chapter. Although the review was carried out on the basis of secondary data, care was taken to select case studies that have been mentioned and appreciated across the years, by multiple sources, both government as well as non-government.

8.3 Results and Discussion

8.3.1 India and the Bonn Challenge Pledge

8.3.1.1 First South Asia Regional Consultation on FLR and Bonn Challenge

On August 29–30, 2017, the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India organized the 'Forests and Beyond: South Asia regional consultation on forest landscape restoration: Challenges, Opportunities and Way Forward towards the Bonn Challenge Pledge' at New Delhi, India, in partnership with IUCN and the Indian Council of Forestry Research and Education (ICFRE). It was attended by 85 delegates from India, Bhutan, Nepal, Sri Lanka and Bangladesh, representing government, non-government organizations (NGOs), private sector companies, as well as bilateral and multilateral organizations (Bhattacharjee et al. 2017). The objective of the regional consultation was to showcase the progress made by the participating countries towards their restoration commitments, as well as sharing of experiences on restoration, with a special focus on the tools, financial mechanisms and policies developed to support forest landscape restoration. The consultation also aimed to identify gaps in communication, technical support and partnerships needed for accelerating action on forest landscape restoration in the region. The two-day deliberations revealed the tremendous potential that existed in South Asia for implementing restoration at a landscape scale. The key recommendations from the consultation were to start the shift from planning and pledging to actual implementation and achievement of restoration targets, while prioritizing restoration potential at national and sub-national levels using tools such as Restoration Opportunities Assessment Methodology (ROAM). ROAM is a flexible and affordable framework for countries to rapidly identify and analyse FLR potential at a national or sub-national level (IUCN and WRI 2014). The need for adopting robust monitoring protocols as well as exploring strategies for continued knowledge exchange between the South Asian countries was also suggested. It was proposed that India could take the lead from the region on creating this knowledge sharing platform.

8.3.1.2 India's Progress Report on the Bonn Challenge: First of its Kind in the World

The Government of India with IUCN's technical support started working on a country progress report towards the Bonn Challenge pledge in 2017. This report was published in 2018, and along with data on government efforts also included restoration efforts carried out by NGOs and private companies (Borah et al. 2018). This is the first progress report from any Bonn Challenge country. Data was collected from various agencies practising restoration across India. Since the National Afforestation and Eco-Development Board (NAEB) of the MoEFCC is the focal agency for restoration, they were the focal point for collating and compiling the data on government restoration efforts. Online survey forms and interview questionnaires were used to collect restoration data from NGOs and private sector companies. Restoration data was collected from the year 2011 (year of Bonn Challenge inception) till 2016–2017, except in a few cases where it was not possible to differentiate the data of 2010–2011. The analysis considered restoration data from 14 NGOs and 11 private companies. Thus, this remains a dynamic report and IUCN will need to continue to engage and collect data from more stakeholders in the next phase of reporting.

The analysis revealed that approximately 9.8 million hectares of land was brought into restoration across India from 2011 till 2016–2017. Of the total area, 94.4% of land was restored by government agencies, while 3.6% and 2% of restoration efforts were by NGOs and private companies, respectively (Fig. 8.1). Here, it is important to remember that while the government efforts far outweigh the others in magnitude, there are many learnings that can be gleaned from the technical expertise and local knowledge of the non-government organizations. Hence, best results can be obtained through collaborations between public and private agencies. Additionally, while the data obtained from NGOs and private companies contained details of species used for plantation and cost of restoration efforts, this level of detailed information was

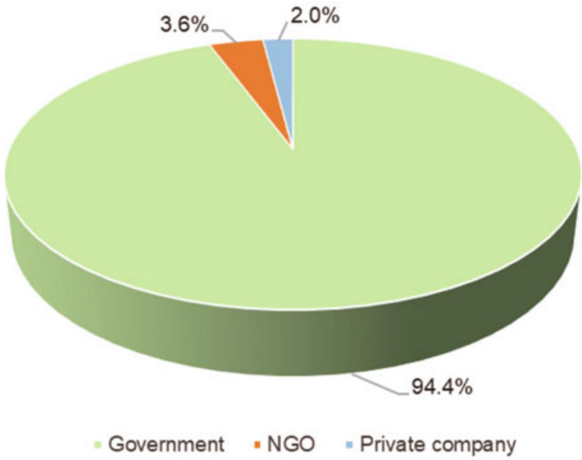

Fig. 8.1 Percentage of restoration efforts by the three major stakeholders in India

not available for the government data. Future efforts to report progress towards the Bonn Challenge would have to work with State governments directly to obtain more detailed information of the restoration efforts.

Majority of the area restored by private companies (97.4%) used mixed plantation methods of various types while only a small percentage (2.6%) was restored using mono plantations. The mono plantations mostly comprised of cash crop species which would be of economic value for the growers. Future restoration efforts will have to ensure a shift from mono to mixed plantation methods in order to ensure better ecosystem and biodiversity benefits from the restored land. A major concern was the use of exotic varieties such as *Leucaena* spp. and *Casuarina* spp. by private companies. Such practices would need to be checked and rectified immediately as it is well known that exotics can proliferate rapidly and edge out native species eventually (Vitousek et al. 1997; Wilcove et al. 1998; Gooden et al. 2009). Of the total area restored by NGOs, the analysis revealed that 91.5% was by using mixed plantation method while 8.5% of the total area was restored using mono plantation method. However, the mono plantation percentage of the restoration was largely due to the use of only one species of mangroves, i.e. *Avicennia* spp., for restoring coastal areas. Not a single instance of use of exotic species was reported in the restoration efforts undertaken by NGOs. The government and private sector can benefit from the technical knowledge and applied research practices of the NGOs to improve future restoration design. NGOs can also serve as a conduit between the government partners and local communities.

8.3.2 Best Practices of Restoration from across India

The IUCN-MoEFCC report highlighted some best practices of restoration with the hope that these would serve as learnings for future restoration efforts in the country.

Three of the case studies are elaborated upon in this chapter. They are each unique in their approach and geographical distribution as well as ecosystem type and can serve as good templates for planning future restoration activities. A distinguishing feature of the case studies is that they are all multi-stakeholder driven efforts, irrespective of whether the lead agency is an NGO, a government department or the local community.

8.3.2.1 Restoration of Tropical Rainforest Fragments in Plantation Landscapes

Established in 1996 as a public charitable trust, Nature Conservation Foundation (NCF) works towards conserving India's unique wildlife heritage using innovative science and research. NCF's Western Ghats programme has been active in the Anamalai hill range of South India for many years. Located in Valparai, Tamil Nadu, NCF's long-running programme on restoration of tropical rainforest fragments began in 2000 in collaboration with the then Hindustan Lever Limited which owned commercial plantations in the landscape and wished to adopt a company policy of sustainability and biodiversity conservation in their production landscapes (Mudappa and Raman 2007). The NCF team used this opportunity to convince the senior management of the company to set aside forest fragments within the landscape as biodiversity plots and restore the fragments using native tree species. NCF initiated similar partnerships with other plantation companies working in the region such as Bombay Burmah Trading Corporation Ltd. (BBTC), Tata Tea and Coffee, and Parry Agro by signing Memorandum of Understandings (MoUs) with the companies. NCF also carried out native shade tree enhancement in coffee, cardamom and vanilla plantations.

These rainforest fragments provide important ecosystem services as they are catchment areas for many streams (Raman et al. 2009). They are also the habitats for many flagship wildlife species such as the Asian elephant, the leopard, the great hornbill as well as many indigenous varieties such as the lion-tailed macaque and Nilgiri langur (Mudappa and Raman 2009; Sridhar et al. 2009). The fragments serve as important ecological corridors for many of these species and, hence, restoration of these fragmented rainforest patches is of vital importance for the entire landscape (Fig. 8.2).

NCF scientists started the restoration efforts in a scientific manner by carefully selecting plots and building reference systems for restoration based on intact forests nearby, thereby establishing clear targets before embarking on the restoration projects. Nurseries of native plants such as *Dimocarpus longan*, *Filicium decipiens*, *Trichilia connaroides*, *Toona ciliata* and *Ormosia travancorica*, among others were established. The plantation companies assisted by providing labour and land for these nurseries. The nurseries provided native plant sources for the restoration activities. Invasive species such as *Lantana camara* were first cleared from the plots before the native species were planted. NCF reported an impressive 70% survival rate in their restoration plots. A recently published study from NCF

Fig. 8.2 A top view of one of NCF's restored forest fragments in the mosaic landscape © Kalyan Varma

demonstrates that the tree diversity, late-successional species density and carbon storage rates were higher in actively restored fragmented patches than in comparable plots that were left for natural regeneration (Osuri et al. 2019).

In order to strengthen this partnership with the plantation companies and ensure their sustained interest in continuing the restoration programme, NCF began collaborating with Rainforest Alliance and Sustainable Agriculture Network in 2006–2007. They introduced sustainable certification to the tea and coffee sector companies they were collaborating with and most of the plantations in the area are currently Rainforest Alliance certified. The certification has become quite popular among the environmentally conscious customers, and therefore many companies are now investing in getting their products certified. This act of linking restoration and conservation efforts to certification, thereby providing market benefits, has further strengthened the collaboration with the private companies of the landscape.

NCF's engagement with local communities for the restoration efforts was largely limited to manpower for carrying out the restoration efforts. This is largely because most of the locals work as labourers in the plantations, and hence only depend on the forest fragments for obtaining fuelwood. NCF reported that there was no major collection of non-timber forest produce (NTFPs) from the fragments, thus limiting the dependence of the communities on the fragments for their livelihoods. A possible alternate solution for fuelwood could be providing all the plantation labourers with liquid petroleum gas (LPG) for free or at subsidized rates as has been done in States such as Uttarakhand, where villagers have been provided LPG cylinders to reduce their dependence on fuelwood for cooking (Nautiyal 2013).

NCF's engagement with the forest department was largely limited to obtaining research permits for carrying out scientific research on the protected areas, and on larger issues of habitat protection and wildlife conservation. The funding for the restoration activities were obtained through competitive grants from conservation organizations. This created some issues of continuity as most conservation organizations do not provide long-term funding. A possible solution could be integrating these restoration efforts into the plantation companies' annual biodiversity management plans.

NCF's presence in the landscape and work on other conservation projects including a long-running project on human-elephant coexistence in the Valparai plateau has also helped improve the local perception towards wildlife and biodiversity conservation. There is better tolerance among local communities and plantation managers towards the wildlife that share the same habitats with them, and now they actively engage in conservation efforts. It is hoped that these indirect benefits of the rainforest restoration programme continue to accrue and help bring about persistent positive changes in the landscape.

This case study is a unique example of an NGO collaborating with private companies across a mosaic landscape to restore fragmented and degraded forest patches using the best of scientific knowledge and research techniques.

8.3.2.2 Restoration of Banni Grasslands in Gujarat

Grasslands are unique and important ecosystems, covering nearly one-third of the earth's terrestrial area (Suttie et al. 2005; Lemaire et al. 2011). They are given low conservation priority as compared to forest ecosystems even though they can store as much carbon as forests (Baer et al. 2002; FAO 2010). Grasslands support many varieties of fauna globally, including some endemic varieties, as well as many biodiversity hotspots. Twenty-four percent of India's geographical area used to be covered with grasslands (Dabadghao and Shankarnarayan 1973) and they still support a variety of unique fauna ranging from the Indian rhinoceros, swamp deer, hog deer, wild buffalo, Nilgiri Tahr, lesser florican to the critically endangered Great Indian Bustard. However, grasslands are often wrongly classified as wastelands in India (Vanak et al. 2015; Ghosh 2017).

Banni grasslands found in the Kachchh district of Gujarat are India's largest natural grasslands (Dayal et al. 2015). Spread over an approximate area of 2500 sq. km. (Koladiya et al. 2016), Banni is a dry savannah type grassland and harbours a rich faunal diversity of browsers and grazers such as Indian gazelle and nilgai, as well as carnivores such as Indian wolf, golden jackal, Indian fox and desert fox, among others. There are approximately 262 species of birds that have been recorded from Banni (Koladiya et al. 2016). The grasslands also support several different groups of nomadic pastoralists commonly known as *maldharis*, who are dependent on the grassland for supporting their indigenous varieties of cattle such as the Banni buffalo and *Kankrej* cattle (Bharwada and Mahajan 2012; Dayal et al. 2015). However, the Banni grasslands have been facing serious threats and are no longer the lush grass biomes that supported the nomadic pastoralists and their indigenous cattle (Dayal et al. 2015). Many of the rivers running towards the grasslands have been diverted or dammed to supply surrounding agricultural lands. This has led to the incursion of seawater into the area and increased the salinity of the grasslands. Presently, approximately half of the area of Banni is considered highly saline. The decline of the grasslands has been further exacerbated by the introduction of

Fig. 8.3 Removal of *Prosopis juliflora* and restoration of Banni grasslands with local community involvement © GUIDE

Prosopis juliflora by the government with the objective of combatting the problem of high salinity. A fast-growing exotic species with allelopathic properties, *Prosopis* has quickly taken over majority of the grasslands by killing native species of grasses. The *maldharis* believe the invasion of *Prosopis* is one of the major causes of the degradation of Banni grasslands. Additionally, the grasslands are under threat due to construction of roadways, land diversion for agricultural practices as well as changes in the lifestyle of the nomadic *maldharis* to a more settled lifestyle, which has increased the anthropogenic pressure on the grasslands.

In the 1990s, a local NGO, Gujarat Institute of Desert Ecology (GUIDE) initiated restoration efforts in Banni. GUIDE initiated discussion with the local villagers at the gram panchayat (village council) level and designed mitigation strategies with inputs from all relevant stakeholders. This inclusive approach was one of the success factors of this effort. Restoration was carried out with the help of the forest department, other local NGOs and the community. GUIDE carried out restoration in two phases, from 1995 till 2000, and a second phase starting in 2007. With the objective of improving ecosystem services through enhanced land productivity, GUIDE carried out detailed baseline studies before starting the restoration efforts using only native species. Several sites of 50–100 hectares size were selected across the Banni grasslands in consultation with the local villagers. The *Prosopis* was manually uprooted and native species of plants as well as leguminous species were planted after fencing the selected sites to protect them from grazers (Fig. 8.3). Farmyard manure was used to add nutrient to the soil, while various soil treatments were carried out to reduce the salinity. Regular monitoring was carried out throughout the project across all parameters including soil quality, biodiversity, biomass generation and species richness, among others.

There have been positive results observed such as increased native species growing in the restored plots and enhanced interest and engagement of local communities in the restoration efforts. Local villagers have started implementing restoration efforts on small grassland patches on their own initiative. Another local NGO called Sahjeevan has also started restoration efforts in the Banni grasslands since 2017, along with local pastoral communities and the Banni Breeders' Association. A collaboration of Banni Breeders' Association, Sahjeevan, Ashoka Trust for Research in Ecology and the Environment (ATREE), the National Centre for

Biological Sciences (NCBS), KSKV Kachchh University (KU), Ambedkar University Delhi (AUD) and Shiv Nadar University (SNU) called Research And Monitoring in the Banni Landscape (RAMBLE) has been launched. The RAMBLE's main objective is to understand the complex socio-ecological dynamics of the Banni ecosystem, and to generate information that would inform and aid the *maldharis* in formulating a Banni conservation and management plan.

Such scientifically planned restoration efforts involving all concerned stakeholders with proper monitoring protocols are the only hope for restoring Banni to its past glory.

8.3.2.3 Restoring Degraded Forests in Nagaland through Joint Forest Management Practice

Joint Forest Management (JFM) is the participatory approach of managing forests that is practised in India with the involvement of local forest fringe communities (Bhattacharya et al. 2010). It was institutionalized in the National Forest Policy 1988 which spoke of involving communities in the protection and management of forests and laid the path for community forest management in the country. This was further strengthened by then Ministry of Environment and Forest's JFM circular in 1990 which provided an enabling mechanism for community engagement and benefit sharing as well as highlighting the need to consult local communities while preparing the forest department's working plans. While joint forest management committees (JFMCs) are formed with representation of both the local community and the forest department for management of reserve forests, eco-development committees (EDCs) are formed for the protected areas such as national parks and wildlife sanctuaries (GoI 2010). The NAEB's national afforestation programme (NAP) works very closely with JFMCs across all States. There are many success stories of JFMCs restoring and managing forests and forest resources. One such success story from Nagaland in the north-eastern region of India is detailed here. It is a great example of what can be achieved through collaboration between forest department, local community and community institutions.

Old Jalukie in Nagaland is a village of the tribe *Zeliang Nagas,* and an important watershed area with five rivers flowing through the area. The villagers practise the traditional slash and burn form of agriculture known as *jhum* and are also dependent on the surrounding forests for NTFPs. Hunting is a common practice. Over time, the surrounding forests have become degraded due to the various anthropogenic pressures.

The Old Jalukie JFMC was formed in 2002 as a quasi-regulatory body under the aegis of the village council. In 2012, the village council created a community biodiversity reserve of 370 hectares, where all extractive practices such as *jhum,* logging and hunting were banned. The JFMC employed the local youth to enforce this ban. The JFMC also initiated plantation activities using local species such as *Aquilaria agallocha*, *Terminalia myriocarpa* and *Parkia speciosa* in the fallow lands created by *jhum* cultivation. These species were of commercial value and therefore supplemented the villagers' livelihood opportunities. A nursery was created in the village using seeds collected from surrounding forests. This provided planting material for the restoration activities. The JFMC also generated employment for the villagers as they were remunerated for maintaining the nursery as well as the newly restored forested areas. The JFMC has also tried to introduce alternate livelihood options such as animal husbandry and kitchen garden farming to reduce the villagers' dependence on the surrounding forests. A significant achievement has been the provision of LPG connections to the villagers as it has significantly reduced the extraction of fuelwood from the forests. The JFMC has been supported by the forest department, the village council as well as the local community institutions of the village. This collaborative approach has ensured the smooth transitioning from the old ways to the new and less extractive lifestyles now practised in Old Jalukie.

Even though the JFMC had not assessed the initial baseline data, the JFMC and forest department have reported marked improvement in the forest density, canopy cover as well as biodiversity and species richness at the restored sites over time. Soil quality and water availability have also been reported to have improved while the hunting ban has increased the wildlife sightings in the surrounding forests with recent sightings of animals such as sambar, barking deer, wild boar, leopard cat, pangolin, slow loris and jungle cat reported from the area. The forest department also reported the sighting of many bird species from these restored sites. The forests are being dominated by multi-storey canopy tree species such as *Juglans regia*, *Eugenia jambolana*, *Bischofia javanica*, *Ficus* spp., *Schima wallichii* and *Bombax ceiba* while shrubs like *Clerodendron* spp., and *Dracaena* spp. as well as herbs like *Curcuma caesia* have made a comeback. Orchids of *Cymbidium* spp. and *Vanda* spp. have also been observed.

The awareness and outreach programmes carried out by the JFMC have been successful in changing the attitude of the local community towards restoration of forests and conservation of wildlife. There has been a marked decrease in practices such as hunting, logging and *jhum* cultivation. The Old Jalukie JFMC has been recognized for its notable efforts and was awarded the Governor's Award in 2014. It also won the prestigious India Biodiversity Award 2014, awarded by the Ministry of Environment, Forest and Climate Change and United Nations Development Programme (UNDP).

8.4 Conclusion

The Government of India has always demonstrated its commitment towards national and international commitments such as the Nationally Determined Contribution (NDC), the SDGs, the National Biodiversity Targets (NBTs) aligned with the global Aichi targets, Bonn Challenge, as well as the recently prepared Land Degradation Neutrality (LDN) targets that were launched at the UNCCD COP14 held in September 2019 at New Delhi. However, meeting these ambitious targets is a challenge that will require significant efforts from both government and non-government agencies. While there are several monitoring and reporting protocols available globally, these need to be adapted and modified to be suitable for the local conditions in India. As per India's first Bonn Challenge report, the country appears to be on track to meet its Bonn Challenge pledge. However, the reporting for the first progress report was based on secondary data collection, while future efforts should focus on collecting primary data from the States directly, as well as verifying the data wherever possible. The data should include not just plantation, but all forms of nature-based solutions applied to restore degraded landscapes. Efforts of NGOs and private companies need to be consistently captured.

Since India is the first country to prepare a country progress report for Bonn Challenge, it is important that India retains its leadership role from the region towards the Bonn Challenge pledge. Therefore, the Government of India with IUCN support has designed and launched a flagship project called 'Enhanced capacity on forest landscape restoration (FLR) and Bonn Challenge in India' in June 2019. With the objective of creating a holistic country-level focus on forest landscape restoration and Bonn Challenge, the proposed project aims to develop and adapt best practices and monitoring protocols for the Indian States, and build capacity for the same within five pilot States of Haryana, Madhya Pradesh, Maharashtra, Nagaland and Karnataka. It is proposed that the project will be eventually rolled out across the country in all States in subsequent phases. This flagship project of 3.5 years was launched on June 17, 2019 during the World Day to Combat Desertification (WDCD) celebrations at Vigyan Bhawan, New Delhi by India's Minister of Environment, Mr. Prakash Javadekar and other dignitaries from MoEFCC and UN. Among the expected outcomes, the preparation of India's second progress report on Bonn Challenge, as well as the second South Asia regional consultation on forest landscape restoration and Bonn Challenge is included. Development of monitoring and reporting protocols for the States is also part of the workplan along with capacity building of the relevant stakeholders in the five pilot States on these protocols. If implemented successfully, this flagship project can elevate India to a leadership role on the Bonn Challenge pledge across South Asia.

At a time when development and environmental conservation are often at loggerheads, having a transparent and scientific forest landscape restoration strategy which promotes mixed plantations of indigenous species as well as other soil and water conservations efforts tailored for the various ecological zones across the country is the need of the hour. Unique ecosystems would require unique restoration strategies (IUCN and WRI 2014), therefore specific strategies for restoring unique ecosystems such as grasslands and mangroves need to be included within this country strategy. The expertise of NGOs and research institutions need to be acknowledged and utilized by both the government and the private companies. A multi-stakeholder restoration approach is the best way forward strategy.

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Chapter 9
Guns and Roses: Forest Landscape Restoration as a Nature-Based Solution in Areas of Armed Conflict

Sonali Ghosh and C. Ramesh

Abstract Nature-based solutions including forest landscape restoration are part of the key objectives that make up the Bonn challenge. This is a global effort that is committed to by several countries including India that aims to restore 150 million hectares of degraded and deforested land by 2020 and 350 million hectares by 2030. It is expected that the effects of deforestation and degradation providing ecological, social, climatic, and economic benefits would be achieved as part of this ambitious program. Forests in tropics are a rich source of water and other natural resources including wild flora and fauna. It is likely that such natural resources also face the burden of civil unrest and illegal harvest including poaching and extraction of other economically valuable resources under the illegal wildlife trade. Post-armed conflict restoration of such forest areas remains a challenge and requires complex models of landscape-level interventions and includes community-based initiatives. In this chapter, the authors describe one such large-scale nature-based intervention that has been attempted with support of the armed forces. This is therefore one of the first successful case studies to be documented from Asia wherein a unique model of tripartite collaboration (state-military-local community) yields forest restoration results in record time. We discuss that man-made disasters such as armed conflict and wars can be prevented by taking large-scale forest restoration works, besides serving towards poverty reduction and as a means for climate-based adaptation.

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9.1 Introduction

9.1.1 The Crisis of Land Degradation and Forest Fragmentation in the Tropics

Tropical forests as in Asia are a known repository of biodiversity, a home to several indigenous tribes and communities that have been using the natural resource for their own survival. It is well established that forests provide multiple ecosystem services, such as provision of food and water, soak carbon and protect from floods, cyclones, and other natural hazards. At regional and global scales, tropical forests also have a major influence on carbon storage and climate (Laurance 1999). Tropical forests are the most ancient, the most diverse, and the most ecologically complex of land communities (Myers 1988). Though occupying only 7% of the earth's land surface, they probably sustain over half of the planet's life forms. In virtually every biological discipline, tropical forests have been grossly understudied (Giam 2017). Tropical forests are being cleared, burned, logged, fragmented, and overhunted on scales that lack historical precedent. An estimated 350 million hectares have been deforested, and another 500 million hectares of secondary and primary tropical forests have been degraded.[1] One of the most detrimental results of this includes the loss of ecosystem services (such as availability of natural food resources and water) and the loss of livelihood mechanisms for forest-dependent communities. These losses have fallen particularly heavily on the rural poor in tropical countries, where the livelihoods of at least 300 million people now depend upon these degraded or secondary forests (Lamb et al. 2005; Goldewijk 2001; Geist and Lambin 2002).

Forest and deforestation has been interpreted at several levels across countries and organizations (Reddy et al. 2016). For the benefit of this paper, we take the FAO definition that defines "forest as a land spanning more than 1 ha, dominated with native tree species having a minimum stand height of 5 m with an overstorey canopy cover greater than 10 %." Food and Agricultural Organization considers deforestation as replacement of forest by other land use and/or depletion of forest canopy cover to less than 10% (Sasaki and Putz 2009; Food and Agriculture Organisation of the United Nations 2010).

In case of India, satellite-based studies indicate that forests covered an area of 869,012 sq. km in 1930 which has decreased to 625,565 sq. km in 2013, a net loss of 243,447 sq. km (28%) in eight decades (Table 9.1).

The decadal rate of forest cover change was found to be highest in pre-independent India (Gadgil 1990) and has seen a gradual decline due to a paradigm shift in forest policies and legal interventions (Rosencranz and Lele 2008). As per law, no clear felling is permitted besides, India continues to add forest

[1]https://www.iucn.org/resources/issues-briefs/deforestation-and-forest-degradation. Accessed on 30.08.2019.

Table 9.1 Annual rate of forest cover change in India (source: Reddy et al. 2016)

Time Period	Gross rate of deforestation	Net Rate of deforestation	Rate of afforestation/ reforestation
1930–1975	0.77	0.63	0.1
1975–1985	0.29	0.23	0.06
1985–1995	0.14	0.12	0.02
1995–2005	0.07	0.06	0.01
2005–2013	0.05	0.03	0.02

cover through tree plantation programs (Food and Agriculture Organisation of the United Nations 2010).

At the same time, Vásquez-Grandón et al. (2018) mention that the primary drivers of degradation in the tropics have largely been macroeconomic, demographic, technological, institutional, and political factors and may include any or all localized factors such as conversion for infrastructure development, agriculture/settlements, shifting cultivation, commercial plantations, logging, and mining. Coasts and islands have witnessed loss in forest cover and degradation in land quality primarily due to human-induced activities of tourism and infrastructure development, aquaculture practices, land reclamation and also due to occurrence of natural calamities like tsunami, storms, and cyclones (Jha et al. 2000; Kushwaha et al. 2011; Krishna et al. 2014; Roy et al. 2015; Reddy et al. 2016).

It is with this background that it is reiterated that conservation practices and afforestation programs must focus on to reduce/halt forest degradation and subsequent loss of forests. The major challenge remains to focus on vulnerable areas that may require out-of-box solutions including large-scale ecological restoration as an acceptable means of nature-based solution (Lamb et al. 2005).

9.1.2 Deconstructing Armed Conflict and Forest Degradation Nexus

The effects of armed conflict on loss of natural resources is a growing concern across the world, especially in areas of biodiversity hotspots that have witnessed prolonged civil society strife and wars as in parts of Africa, Latin America, and Asia (Le Billon 2000; McNeely 2003; Dávalos et al. 2011; Kushwaha et al. 2011; Ordway 2015; Castro-Nunez et al. 2016a, b; Stevens et al. 2011). Natural resources and armed conflict are intrinsically linked, as conflict increases, natural resources are depleted, with a temporary intermediate phase where they are also protected (as being out of bounds for others) and then again re-utilized through different governance regimes as established in a post-conflict situation (Stevens et al. 2011).

In addition, increased exploitation of resources is known to occur immediately following conflict as weakened governance regimes and transitional state of societies may result in ineffective management. At the same time, natural resources can also be used as a tool for peace building and fostering cooperation (Le Billon 2000; Hatton et al. 2001; Conca and Wallace 2009). It is therefore well established that conflict and forest degradation are linked and conflict may facilitate or prevent large-scale (e.g., industrial) exploitation of forests (Aguilar et al. 2015; Young and Goldman 2015; Bruch et al. 2016; Castro-Nunez et al. 2016a, b).

9.1.3 Forest Landscape Restoration as a Nature-Based Solution

Ecological restoration has been practiced in multiple forms and multiple scales. For instance, traditional ecological knowledge has helped sustain natural ecosystem services, such as production of handicrafts, food and fiber, herbal medicinal products, dyes for self-consumption in rural communities and also increasingly as an income-generation activity (Stevens et al. 2011). Today, the practice of ecological restoration is receiving immense attention because it offers the hope of recovery from much of the environmental damage and also to supplement the use of technological solutions that may not be viable in the long run (Palmer et al. 2016). In many ways, ecological restoration is an attempt to return a system to its near-natural historical state, using a combination of socio-scientific methods (Adams et al. 2004). A more realistic goal may be to restore the quality of the system to an ecological state to an acceptable limit as set at the start of the project. Restoration is therefore a skill that requires learning by experience and involves a multitude of stakeholders, and science-based restorations are those projects that benefit from the infusion of ecological theory and application of the scientific method (ITTO 2002). Science-based restorations follow explicitly stated goals, a restoration design informed by ecological knowledge, and quantitative assessment of system responses employing pre- and post-restoration data collection. Restoration becomes adaptive when a fourth step is followed, i.e., analysis and application of results to inform subsequent efforts (Palmer et al. 2016). At the same time, elimination of poverty is closely linked to restoration of natural ecosystems (Adams et al. 2004). Many rural communities are able to carry restoration once appropriate government policies have been developed. But natural recovery is not always possible, and there are a variety of nature-based solutions proposed for areas that are currently deforested (ITTO 2002; Adams et al. 2004). A number of these have the potential to enhance biodiversity, improve ecological functioning and hence improve human livelihoods. The biggest challenge remains for moving restoration from a site-based activity to a landscape activity and includes these as a recognized tool under nature-based solutions.

Poverty and deforestation issues need to be addressed with equal impetus. It is only at the landscape level that a restoration of a degraded ecosystem can supplement the habitat connectivity offered through protected areas and address the issues of livelihood support (Adams et al. 2004; Nath and Mwchahary 2012).

Recent global initiatives (IUCN 2017) under the Bonn challenge expand the science-based restoration to introduce the term of forest landscape restoration (FLR). It has been defined as "as a nature-based solution that brings people together to identify and implement the most appropriate restoration interventions in a landscape. It seeks to accommodate the needs of all land users and multiple land uses. This large-scale restoration is not just about planting trees as it can include multiple activities like agroforestry, erosion control and natural forest regeneration as it aims to address the underlying drivers of forest loss."

FLR has been found to be effective in providing farming communities living in and around forests with knowledge on sustainable agricultural methods that help reduce the pressure on forests for timber and land clearance activities. Government of countries across the world as well as other private or community landowners have committed to FLR through the Bonn Challenge. Current goals are set to restore 150 million hectares of degraded and deforested land by 2020 and 350 million hectares by 2030 through the Bonn challenge. It has so far generated pledges from governments and organizations to restore over 170.63 million hectares, creating approximately USD 84 billion per year in net benefits that could bring direct additional income opportunities for rural communities.[2]

9.2 Study Area: Manas Tiger Reserve

Manas Tiger Reserve is situated at the foothills of the Bhutan Himalayas in four districts of Bodoland Territorial Council, Assam, India. It is one of the first tiger reserves to be taken under India's flagship Project Tiger scheme in 1973, and the boundary of Manas Tiger Reserve extends from the point where the Sankosh river cuts the Indo-Bhutan International Boundary and separates Assam from West Bengal to the Eastern boundary in Udalguri District. The southern boundary runs across the four districts of Kokrajhar, Chirang, Buxa, and Udalguri of the Bodoland Territorial Areas Council (BTAD), a notified Schedule VI area as per the Indian Constitution (Nath and Mwchahary 2013). The total area of the Tiger Reserve is 2837.10 Sq. km (Fig. 9.1).

From biodiversity point of view, it forms an integral part of Indo-Bhutan Manas Tiger Conservation Landscape (IBMTCL). IBMTCL lies at the critical juncture of the Indo-Malayan and the Indo-Gangetic bio-geographical pathways and was recently lauded for its outstanding natural beauty and unparalleled diversity (UNESCO 2008). The IBMTCL forms an important connecting link between the Buxa, Nameri, and Pakke Tiger Reserves in India, and the Hukaung Valley Tiger Reserve in Myanmar. Within this region, a number of Park Areas (PAs) exist,

[2]http://www.bonnchallenge.org/content/challenge accessed on 30.08.2019.

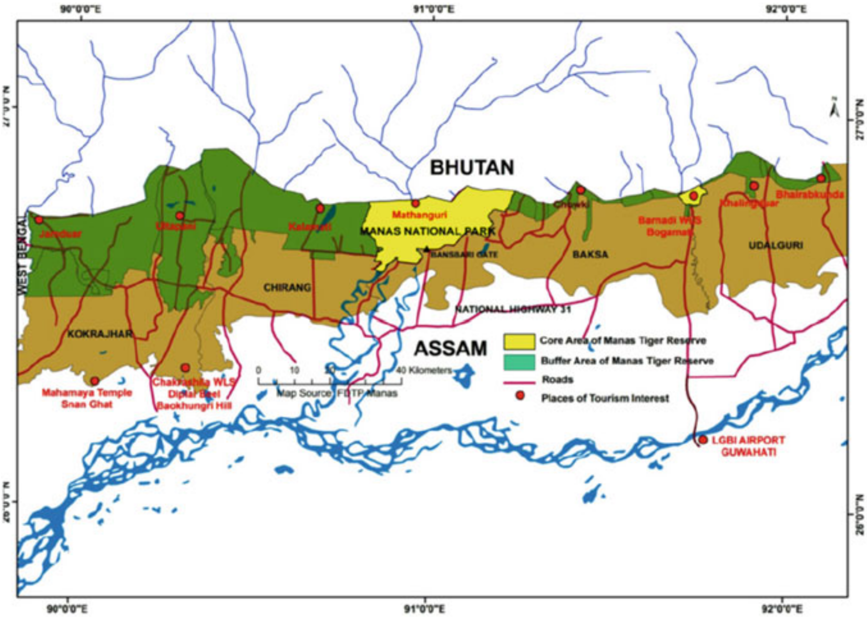

Fig. 9.1 Map of Manas Tiger Reserve (source: Draft Tiger Conservation Plan, Manas Tiger Reserve 2014–2024)

including Jigme Singye National Park (NP), Royal Manas NP, Phibsoo Wildlife Sanctuary (WLS), the Khaling WLS in Bhutan, and the Manas Tiger Reserve in India. Together, they form the single-largest Tiger Conservation Landscape (TCL) for Bengal tigers (*Panthera tigris tigris*) in the world (Sanderson et al. 2010). The IBMTCL has a total area of more than 6541.58 sq. km and, within this area, tigers are known to inhabit the low lying (50 m above sea level) savannah woodlands, sub-tropical moist deciduous and semi-evergreen forests as well as the mid-altitude temperate broadleaf and sub-alpine forests (upto 4100 m.a.s.l). These diverse and extensive habitats and the low density of human populations (in Bhutan) make the area an ideal refuge for tigers as well as other large-bodied animals such as elephants (Talukdar and Gupta 2018).

The landscape also has a marred history of governance with prolonged periods of civil unrest and violence as the native indigenous tribes (Bodo) revolted against the nationalization of forests and other natural resources since colonial times and subsequently with the Indian Government (Srivastava et al. 2002). Militancy and violence marred the conservation scenario as the dense forests and inaccessible locations along the international border served as refuge to several armed rebel groups (Eriksson et al. 2003; Vandekerckhove and Suykens 2008; Lahkar et al. 2018). It was only in 2005 that self-government became possible and law and order was slowly restored, though stray incidents of civil strife still mar the landscape.

The Ripu-Chirang Reserved Forests (RF) form the buffer of Manas Tiger Reserve and were stated to be one of the largest reserved forests in South Asia (Table 9.2).

Table 9.2 Encroachment reported in reserved forest areas in Kokrajhar and Chirang Districts of Assam (source: TCP 2014)

Name of Forest Division	Name of Reserved Forest	Area (Ha)	Area (Ha) under encroachment
Haltugaon	Chirang	59254.12	15000.00
	Manas (pt)	2962.00	100.00
	Bengtol	1071.00	60.00
Kachugaon	Ripu	60526.89	2172.00
	Kachugaon	21445.00	90.00

The Bhabhar tract Sal (*Shorea robusta*) forests were silviculturally worked to produce some of the best quality timber valued for its use in ship building and railway carriages. Such was the importance of the forest tract that immigrants from outside the state were brought in to specially work in the plantation coupes. A tramline connected the remotest part of the forest to the nearest railway head in Sapatgram from where the timber was loaded. During the insurgency years, the biggest aftermath of the political unrest was felt in these reserved forests where illegal logging and encroachment resulted in deforestation like scenario by mid 1980s (Talukdar and Gupta 2018).

Satellite-based studies have investigated the loss of forest and grassland habitat along West Bengal, Bhutan, Arunachal Pradesh, and Assam border in northeastern India falling in Eastern Himalaya (Sarma et al. 2008; Kushwaha et al. 2011). They report significant loss in majority of the forest types and progressive loss of forests in the study area between 1975 and 2009 through 1990 and predict that, unless checked, the area is in for further depletion of the invaluable climax forests in the region, especially the tropical moist deciduous forests.

9.2.1 Deploying a Green Army

The Eco Task Force is a designated green army of the Indian Military and comprises of specially recruited army personnel who undertake massive restoration projects in hostile or complex landscapes requiring large-scale interventions. In recent times, the primary aim of such a force is not only to undertake plantations, but also to maintain and restore law and order in erstwhile politically volatile areas. The first ecological task force (also known as Ecological Battalion) was set up in 1982, after the government felt that the problem of unemployment among retired defense employees could be checked by meaningfully engaging them in large-scale projects of restoring degraded forests post-mining or in areas of armed conflict. The 127 Infantry Battalion was put to task on the Shivalik hills around Mussoorie, where rampant mining had caused severe damage to the local ecosystem. The results were impressive as captured by satellite data in the subsequent years. Soon Eco Task Forces were set up in Rajasthan, Jammu & Kashmir, Nagaland as well as additional battalions in Uttarakhand. At present, there are six ETF battalions working in Uttarakhand, Assam, and Rajasthan, respectively.

9.3 Encouraging Results in Forest Landscape Restoration

Faced with the devastating rate of deforestation leading to severe environmental degradation in the state of Assam, the Government of Assam in 2002 mooted a proposal to raise two Eco Task Force (ETF) units for which sanction was accorded in the month of Feb 2007. The Battalion (Bn) was formally raised on 20 Sep 2007 and was based in Kokrajhar district of western Assam. The unit's primary objective is to carry out afforestation and related holistic ecological improvement in the degraded Manas Tiger Reserve buffer areas (Chirang-Ripu Reserved Forests under Haltugaon and Kachugaon Forest Division) in cooperation with the State Forest Department and the local communities (e.g., NGOs and Joint Forest Management Committees). The unit was also entrusted with plantation of degraded forest land in another forest landscape (outside Manas Tiger Reserve) in Parbatjhora Forest Division, south of Kokrajhar.

ETF comprises of ex-army personnel and therefore a character of discipline and sincerity is an inherent trait. This quality helps them in learning the forestry skills and implementing the plantation works with ease. The retired army personnel are also commanded by a serving officer of Army on deputation. This arrangement also gives the ETF its hierarchical order and obedience.

The ETF based at Kokrajhar comprised of soldiers from the 135 Infantry Battalion (TA) Eco Task Force. They were provided field-level orientation and training with local plant species by the Haltugaon Forest Division.

A few personnel were also deputed for short-term training at Forest Research Institute, Dehradun for learning nursery management and plantation works. While learning and gaining experience was on the job, the soldiers felt that raising plantation was equally tough as their army duty on the country's borders.

As a good practice, plantation target area was assigned to ETF in the month of December every year. This enabled them to do advance plantation works like clearing the invasive and unwanted bushes, field preparation, and firelinemaking. All this could be achieved well before the plantation period of May–July. This advanced preparation enabled them to start the seedling plantation at the onset of monsoons. This resulted in successful establishment of the plantation within a year. Through proper weeding and vacancy filling, the survival rate of plantations was more than 80% at the end of 3 years, when it is officially handed over to the forest department.

With the support of the forest department, ETF could set up nurseries at their camp area that helped reduce carriage costs and also gave sufficient stock for gap filling and replacements. ETF also established a greenhouse for exhibiting local orchids and a vermicomposting unit to prepare organic manure for the nursery. Even approach roads and culverts were constructed for easy access to the plantation sites.

ETF also continuously engaged the local forest villagers in all their ceremonial activities and participated with forest department in celebrations like World Environment Day, Wildlife Week Celebration, etc. These activities helped in garnering the support and trust of local villagers who in turn helped in protecting the plantation from illegal grazing and theft. Awareness meeting programs were also conducted in local schools and colleges to engage the children and youth.

In addition to these works, ETF also assisted the forest department in controlling illegalities in forest by backing up with their force in times of need. This uniformed force in support of the department gave a greater confidence to the field staff to tread in militancy effected encroached areas. Also, the discipline and sincerity of the ETF was gradually imbibed by the field staff of the forest department for whom they were friends and role models.

The results of this collaborative efforts bore fruits when a Guinness World Record was made by the joint effort of the ETF and Haltugaon Forest Division. On April 29, 2012, with the participation of 100 people, a total of 40,885 saplings were planted in 1 h, thereby creating a record for "Most trees planted in an hour by a team."[3,4]

Due to improved protection and plantation in the Chirang-Ripu Elephant Reserve Area, there was a noticeable reduction in elephant depredation into the nearby agricultural fields and villages. This reduction in elephant conflict also gained the support of the people for the forest protection.

As a result of systematic interventions including creation of nurseries of local and indigenous tree species, revival of erstwhile destroyed in-situ forest camps, to engaging with local communities and forest department to carry out invasive species eradication, preparing of soil beds, etc., the Eco Task force could successfully restore a significant part of the encroached area with its native forests.

The predominant species planted included associates of Sal such as *Terminalia bellirica, Sterculia villosa, Lagerstroemia parviflora, Dillenia pentagyna, Michelia champaca, Albizia lebbeck, Stereospermum personatum, Bombax ceiba, Cedrela toona,* etc.

The Task force was not only involved in plantation activities but they were also able to create a sense of security and peace in an erstwhile hostile environment. It also created mass awareness campaigns besides providing ready employment to local people.

Since the activities began, the total number of saplings planted since raising, i.e., Aug 2008 and as on 31 Mar 2018 was reported to be 55,27,739 saplings across an area of more than 2000 ha with an average survival rate of 80–90%.

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[3]https://www.deccanherald.com/content/246068/assamese-team-bids-record-sapling.htmlaccomplished jointly by the troops of 135 Infantry Battalion (TA) Eco Task Force and 15th Battalion of Dogra Regiment and Haltugaon Forest Division in Kokrajhar. (access date 30.08.2019].

[4]https://pnrd.assam.gov.in/information-services/awards-0

9.4 Discussion

The case study of engaging the military for large-scale forest restoration implies some best practices that helped in the speedy recovery of the ecosystem. These can broadly be categorized as below (as adapted from ITTO 2002):

- **Adapt to local context and scale:** It is well established that restoration must use a multitude of approaches that are adapted to local, social, cultural, economic, and ecological values of the site. Setting up historical benchmarks (especially to the degree of restoration required) makes it useful for set measurable targets and indicators. Restoration must be based on updated scientific techniques (e.g., in raising nursery species, choice of planting material, etc.) at the same time respect for traditional and indigenous knowledge helps in recreating the historical timelines for the area. In case of Manas, the use of seed balls for speedier germination was found to be successful. At the same time, fruit and fodder bearing tree species were favored as they would ultimately be supported by Joint Forest Management Committees of the local communities.
- **Shift in approach to focus on landscapes:** Restoration must be viewed as an activity that takes place within and across entire landscapes and not individual sites. At the same time, species for restoration must be given primary importance but should not predominate over the landscape protection. It is at this scale that ecological, social, and economic priorities can be balanced. In case of Manas, large tracts (more than 300 ha) were planned for annual operations so as to increase the survival rates of the plants and also to prevent further encroachment.
- **Enhancement of natural and near-natural conditions within landscapes:** Restoration enhances the conservation, recovery, and sustainable management of forests and other ecosystems. In case of Manas, natural regeneration and afforestation techniques were encouraged without the use of any artificial means such as fertilizers or mechanical appendages.
- **Recognize and engage with multiple stakeholders and encourage shared governance:** Restoration needs active engagement of stakeholders at different scales in planning and decision-making, active implementation, and sharing of benefits. In case of Manas, local communities, especially post-conflict adolescent youth that were semi-literate and unemployed were engaged for patrolling and surveillance through community conservation models (Horwich et al. 2010; Allendorf et al. 2013). This also provided an alternative to taking up arms and joining rebel groups.
- **Aim for multiple benefits for multiple stakeholders:** Landscape-level interventions aim to restore multiple ecological, social, and economic functions across a landscape and generate a range of ecosystem goods and services that benefit multiple stakeholder groups. This can be clearly demonstrated by the eco task force plantation model at Manas wherein the local communities benefitted from better soil and moisture conservation, thereby preventing erosion in their crop fields, manpower generated and secondary livelihood opportunities increased.

- **Ensure long-term resilience as part of nature-based solutions:** Restoration seeks to enhance the resilience of the landscape and its stakeholders over the medium and long term. Restoration approaches should enhance species and genetic diversity and be adjusted over time to reflect changes in climate and other environmental conditions, knowledge, capacities, stakeholder needs, and societal values. As restoration progresses, information from monitoring activities, research, and stakeholder guidance should be integrated into management plans.

9.5 Conclusion

FLR is one of the most accepted ways to arrest the rate of forest degradation in the tropical regions and the Manas model sets an example of how this can be accelerated to achieve better results.

Globally, it is now well established that the scale of land degradation in the tropics can only be altered if an equally large-scale level of restoration activities are undertaken (Tian et al. 2014). While individual landowners or land managers may become involved in restoration activities, tree or forest plantation may not be undertaken by local communities unless they are incentivized (through subsidies) and trained to do so (Lamb et al. 2005). This becomes especially true in cases where governance regimes are weak and the forest has been exploited in recent memory for income generation only. Insecure land tenures and lack of capacities to take up sustainable forestry activities have also been identified as the main hindrances.

Degradation of state-owned forests can be an indicator of a weak or transitional governance system and is prominent in regions of armed conflict. Here the local communities may be even more disenchanted to carry out semi-scientific restoration works. At the same time, large-scale restoration can also be unattractive because the initial costs are high, whereas the direct financial benefits are delayed in comparison with a variety of other possible land uses the landowner might adopt. Even when tree planting is undertaken, most local community owners have often found it easier to use fast-growing exotic tree species than native species, about which there is much less ecological or silvicultural knowledge (Lamb et al. 2005).

In Asia, the post-colonial governments may have inadvertently contributed to conflict, as forests became nationalized and the original forest inhabitants marginalized (Tucker 1987; Gadgil 1990; McNeely 2003). Forests have sometimes been part of the cause of conflict but more often victims of it. Deployment of military services to undertake afforestation/reforestation activities and also for protection of species, as in case of Chitwan National Park wherein army was called in to prevent insurgency-led poaching have yielded results, though they need to be analyzed for efficacy in the long run (Shrestha and Lapeyre 2018; Duffy et al. 2019). However, forest landscape restoration as in case of Manas has proved that scaling up habitat restoration can be supplemented through military-style regimen and focus in combination with science-based plantation techniques to achieve greater results.

Forest landscape restoration for biodiversity is a useful tool to strengthen ecosystem functioning and resilience, besides providing an opportunity for sustaining human livelihoods (Adams et al. 2004; IUCN 2017). Forest landscape restoration can only complement other approaches to improving food security and climate change mitigation and adaptation, including climate-smart agriculture and REDD+ (Reducing Emissions from Deforestation and Forest Degradation) (IUCN 2017).

We further establish that it also provides innovative solutions to restore peace, law and order in areas of post-armed conflict societies. Avoiding deforestation and degradation is critically important for the tropics in Asia and science-based forest restoration is one of the best ways to achieve it under the multiple tools available through nature-based solutions.

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Disclaimer. All views expressed in this paper are personal.

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Chapter 10
Leveraging Conservation Benefits through Ecosystem-Based Services Approach and Community Engagement in Wetland and Riparian Ecosystems: The Case of Conserving Black-Necked Crane and White-Bellied Heron in Bhutan

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Abstract The ecosystem services approach is increasingly being used to restore, enhance, and protect the resilience of an ecosystem in order to conserve biodiversity while considering nature and social-ecological system. The review of the ongoing projects on black-necked crane and white-bellied heron conservation in Bhutan demonstrated that the wetland, riparian, and forest ecosystems are subjected to a range of pressures from development and human interventions. Despite undertaking various interventions to address the challenges of protecting and conserving bird species, especially the white-bellied heron, population has remained dismally low (25) over the last 17 years. The communities living in and around the project areas are largely dependent on natural resources and are vulnerable to any change on natural resources as a result of interventions. Attempts have been made to increase community engagement and participation in conservation activities. The lessons learned from the ongoing projects show that maintaining the interrelationship of the wetland, riparian, and forest ecosystems and the communities is crucial to enhance sustainable conservation of forestry and farming practices, integrated soil and water management, physical infrastructure planning, and livelihood-based conservation. This integrated approach to conserve and manage the natural ecosystems needs involvement of stakeholders from different sectors including communities. The way forward is suggested to establish a landscape-level framework to coordinate and integrate the inter-sectoral interventions and actions. In order to realize the adoption and integration of these actions within this holistic umbrella, various appropriate management and strategy actions are recommended that can lead to win-win situation.

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10.1 Introduction

10.1.1 Biodiversity Conservation

Biodiversity conservation movement started with the late nineteenth century in response to increasing pressure on natural resources and fundamental change of public views regarding the nature of relationship between human and nature (Jepson and Whittaker 2002). In the early days of biodiversity conservation, the aim to protect and preserve nature was mainly connected to exploitation for intellectual and aesthetic contemplation with few moral responsibilities to ensure the survival of threatened life form (Ladle and Whittaker 2011). Over the past years, a wide array of different conservation-oriented approaches, based on multiple values of biodiversity, have been developed and enacted from local and regional activities, such as protected area establishment, ex-situ conservation, recovery planning for species, and specific threat management to the global scale inter-governmental policy developments such as Convention on Biological Diversity (CBD) and Convention on International Trade on Endangered Species (CITES) (Whittakar et al. 2005; Ingram et al. 2012). The ecosystem-based approach is used worldwide to restore, enhance, and protect the resilience of an ecosystem so as to protect biodiversity while considering nature and social-ecological system (Lanhgans et al. 2019). The ecosystem services concept in biodiversity conservation is pursued to understand the way in which natural resources benefit people, and it is increasingly being used to support sustainable management of biodiversity and ecosystems (Ingram et al. 2012).

Bhutan's policy on environment and biodiversity is enshrined by the constitutional mandate, committing the country to maintain 60% forest cover in perpetuity. Forest Policy 2011, Forest and Nature Conservation Act 1995, and National Biodiversity 2015 provide an enabling environment to manage biodiversity, meeting the long-term needs of the people. The Renewable Natural Resources (RNR) sector comprising forest, agriculture, and livestock is the second largest contributor to Gross Domestic Product (GDP) at 15.7% (MoAF 2015). It is accorded high priority since it directly contributes to poverty alleviation, sustainable rural livelihood, food and nutritional security, and other environmental services. Forest Policy and National Biodiversity Strategies and Action Plan of Bhutan 2014 promotes integrated approach to biodiversity management using ecosystem services approach to benefit people by identifying, assessing key ecosystems and ecosystem services and safeguarding for human well-being. In the international front, Bhutan committed to remain carbon neutral at the 15th UNFCCC Conference of Parties (COP) in 2009 in Copenhagen, Denmark. In addition, Bhutan submitted the Intended Nationally Determined Contribution (NDC) in September 2015 towards the Paris Agreement, re-iterating Bhutan's pledge to remain carbon neutral.

10.1.2 Applying Ecosystem Services Approaches to Biodiversity Conservation in Bhutan

Bhutan is rich in natural resource with 70.6% of the total land area under forest cover (MoAF 2017a, b). More than 51.56% Bhutan's forest is conserved through a network of Protected Areas (PA) which are ecologically representative of the major ecosystems ranging from sub-tropical grasslands and mixed deciduous forests to the Alpine ecosystem (MoAF 2015). Humans are an integral part of the PA landscape that poses a challenge to operate the protected areas at the highest standard while maintaining a balance between conservation and sustainable utilization. Integrated Conservation Developed Programme (ICDP) was first initiated in the PA management plans of the protected area in 1990s that attempted to strike balance between conservation and livelihood enhancement in the PA landscape. Grierson and Long (1983) described 11 vegetation zones and sub-zones including a list of common species found in each floristic zone based on elevations and precipitation. Forest ecosystem based on Ohswa (1987) can be broadly divided into three eco-floristic zones—the sub-tropical, temperate, and alpine zones. These natural resources and rural landscapes have huge potential to sustain industries, hydropower, tourism, and rural livelihoods. Forest, agriculture, and livestock are the dominant sectors that provide livelihood, income, and employment to 65% of the population. Numerous glaciers and lakes, rivers, marshes, and springs comprising extensive aquatic ecosystem, besides providing habitats for plants, animals, birds, and insects, are the sources for huge volume of water, accounting to more than 100,000 m^3 per capita availability of water annually (Wangda and Norbu 2013; Watershed Management Division [WMD] 2018). Water is mainly used for agriculture and hydropower production. The tourism sector, much of it accruing from the pristine natural environment, is also gaining importance as the main contributor to export revenue. The diverse biodiversity resources are represented by three broad ecosystems, namely forest, aquatic, and agriculture ecosystems (Fig. 10.1).

A significant part of the current and prospective economic gains is derived from the use of natural capital such as forest and other natural ecosystem services. While the direct benefits and provisioning services provided by the forest ecosystem, i.e., food, timber, NWFPs are tangible and have tagged market values, the cultural, regulation, and support services provided by forest ecosystem (e.g., watershed services, biodiversity conservation, natural landscape, and carbon sequestration) are less visible. The apparent and hidden costs of up-keeping watershed services, biodiversity conservation, natural landscapes, drinking/irrigation water and carbon sequestration are borne by Ministry of Agriculture (Ministry of Agriculture [MoA] 2012), and rural people living in and around the natural landscapes but unfortunately many stakeholders including local communities remain unaware of these vital ecosystem services being provided by forest and other natural ecosystems. Recently, an effort has been made to develop an ecosystem valuation system to put monetary values to those intangible ecosystem services (e.g., carbon sequestration, soil protection, climate regulation) and to create awareness about their contribution of

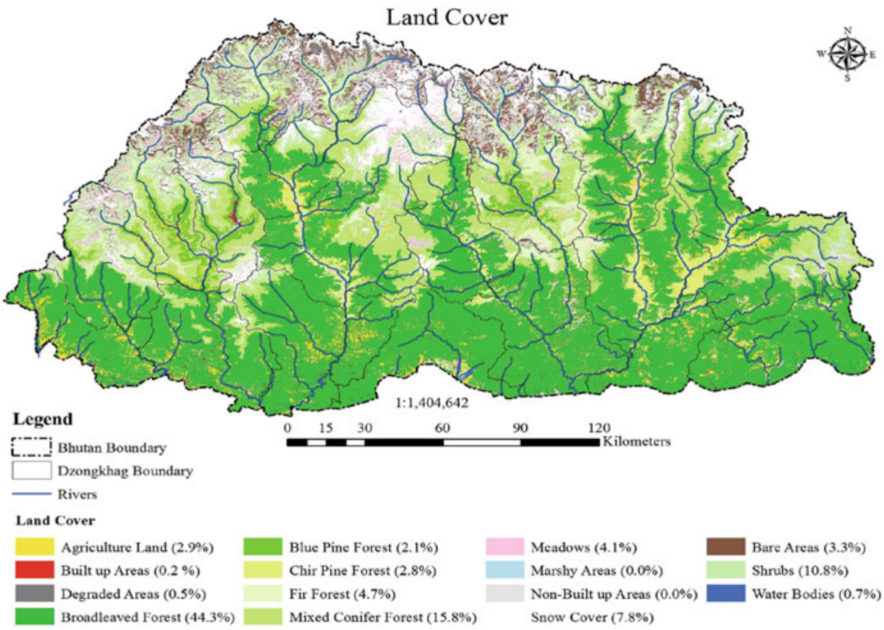


Fig. 10.1 Bhutan land cover classification. Source: Land Use Cover and Mapping Project [LCMP] (2010)

environment service to society (Kubiszewski 2013; Sears et al. 2017; Watershed Management Division [WMD] 2018). Also the human capacity building needs are evident in the areas of mainstreaming contribution of all ecosystem services including regulating services, cultural services, and supporting services into natural capital accounting in the context of national development planning and national income accounting (Watershed Management Division [WMD] 2018). While working on benefit sharing mechanism in the national REDD+ Strategy in 2019, a scoping to link the resources and activate Payment for Ecosystem Service (PES) schemes, between the downstream residents who could derive benefits from forested land and protected watersheds, and those upstream communities managing these resources, was recognized and many actions initiated. One of the options was to invest in the upstream forest and land management in order to reduce soil erosion and sediment flow into streams and rivers. In addition, many of these forestland management options would generate on-farm benefits by maintaining soil fertility and increasing water availability for crop production, leading to improvement in food security and nutrition. The PES has been established for three water drinking schemes across three sites, they are faring well and lessons drawn from them are being used to scale up other PES Schemes (Norbu 2017, Watershed Management Division [WMD] 2018).

10.2 Overview of RSPN's Species Conservation Projects

The Royal Society for Protection of Nature (RSPN) since its establishment in 1987 has been supporting Department of Forest and Park Services (DoFPS), to manage the wetland ecosystem of the Phobjikha as the Phobjikha Conservation Area (PCA) for Black-Necked Crane (BNC) conservation (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014; RSPN 2015) and Riparian Ecosystem of Puna Tsangchu river basin through white-bellied heron conservation program (Fig. 10.2), in collaboration with several international organizations like International Crane Foundation (ICF), ICIMOD, Synchronicity Earth, Mava Foundation, and Bhutan Trust Fund for Conservation (BTF). The collaboration and networking program are done to understand the linkages between conservation and development (Dorji 1998), and to protect endemic and endangered flora and fauna and to maintain sanctity of the unique ecosystems. The conservation works with these two ecosystems have evolved to a multi-faceted initiative, guided by the concept of integrating biodiversity conservation and socio-economic development (Norbu 2012). This concept is congruous with the local tradition and way of life of harmonious co-existence between the local communities and nature (Pradhan 2011).

10.2.1 The Phobjikha Conservation Area

The Phobjikha Conservation Area (PCA) is a high altitude wetland covering an area of 1200 ha and it is an important wintering habitat for the endangered BNC (Fig. 10.3). The core wetland (985 ha) at the bottom of the valley was declared as the Ramsar site in 2015. Historically, the communities here practiced transhumance herding system, using the valley as summer pasture while migrating to the lower

Fig. 10.2 Black-neck Crane and White-bellied Heron in Phobjikha and Puna Tsangchu Basin

Fig. 10.3 Black-Necked Crane Festival and BNC foraging at Phobjikha, one of the wintering sites in Bhutan

valley in winter. The subsistence "pangzhing" cultivation involving burning off open grassland every year to grow buckwheat was prevalent then. This traditional system of food production was gradually phased out to give a way to sedentary mixed-farming, on introduction of potato in 1980s. The majority of farmers grow potato, buckwheat, wheat, and root vegetables. Livestock that include cattle, yak, sheep, pig, and poultry make use of agriculture land, forests, natural wetlands, and scrub meadows.

The BNC (*Grus nigricollis*) is categorized as a vulnerable species on the World Conservation Union's (IUCN) Red List of Threatened Species and is listed as a totally protected species under Forests and Nature Conservation Act 1995. The bird is endemic to the Tibetan plateau and migrates to the lower regions of the Himalaya in India and Bhutan during winters. In 2019, the number of black-necked cranes that visited. In 2019, a total of 609 black- nected crane overwinteried in Bhutan (Tshering 2019). Of these, two-third of them (458) found their winter home in Phobjikha valley, making PCA the most important habitat in Bhutan. The BNC has become part of the community's cultures and everyday life as evident from the reference in the folklores, dances, and stories. The PCA has several interesting biodiversity features that provide diverse ecosystem services. The dwarf bamboos (*Yushania microphylla*) dominate the core wetland area of the valley bottom and serve as roosting habitat for BNC. A relatively wider valley is the main wetland area and is surrounded by moderate to steep slopes of agricultural lands and forests with pure stands of blue pines and junipers supporting some 4700 people (Norbu 2012).

The Phobjikha wetland ecosystem services appear interlinked among the provisional, supporting, regulating, and cultural services, as well as immensely important to people's livelihoods and the well-being of the wetland ecosystem (Phuntso 2010; International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). Local people considered recreation and tourism highly valued ecosystem services (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). As per the ecosystem services assessment (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014), the highest value was given to provisioning services, followed by cultural services. Cultural services are increasingly gaining importance because the unique scenic landscape and rich cultural heritage provide base for tourism and recreational activities. The overall economic benefits generated from the major types of provisioning, supporting, regulating, and cultural services considered in the study worked to around Nu 191.72 million (US$ 3.6 million) per year (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014).

10.2.2 Puna Tsangchu Riparian Ecosystem

The white-bellied heron (*Ardea insignis*), historically known from the Eastern Himalayan foothills, is presently not reported from many of its home ranges in Burma, Nepal and Bangladesh. Currently, only about 60 individual birds are reported worldwide with the highest from Bhutan (25 individuals in 2019). Bhutan's WBH population in 2019 is recorded as 25 indicating a critically low trend (Pradhan 2019). The WBH is enlisted in schedule I as the protected species by Forests and Nature Conservation Act 1995 and is categorized as a critically endangered species in the World Conservation Union's (IUCN) Red List of Threatened Species 2018. This present state of dwindling population is attributed to the shrinking habitats of WBH, owing to increasing anthropogenic pressures in the face of changing climate. The ecology, biology, and population dynamic of WBH is little known and is restricted to the study carried out by RSPN (RSPN 2015). The best known WBH habitat is found along the Puna Tsangchu and Mangdichu basins and the habitat mainly consists of riparian forest and wetland ecosystems between 100 and 1200 m above sea level (Fig. 10.4). Lately, the sightings were also reported from Doksum and Yangbari along the Gongri–Kurichhu and Drangmechhu basins, in the eastern part of the country. The WBH habitat is mostly scattered and fragmented, due to developmental and anthropogenic activities, such as construction of massive infrastructure for hydropower plants, road and sand mining, and other economic activities along the river basins. The communities living along these river basins practice subsistence agriculture farming and they are highly reliant on forest, rivers, pastures,

Fig. 10.4 Typical WBH habitat and nesting sites along the Puna Tsangchu Basin

and wetlands for their living. These increasing development and anthropogenic activities pose serious threats to the endangered WBH habitat and community's livelihood as well. As various pressures mount on WBH habitat and forests, community's access to local resource use is restricted by forest rules and regulation in order to avoid overuse of resources. In such situation, communities often resort to illegal timber/NWFP collection and fishing from forests and rivers to take out their livings which further deteriorate the WBH habitat. To provide alternative economic and employment opportunities and to earn support for WBH conservation activities (e.g., plantation, safeguarding/monitoring WBH population), community incentive-based participatory approach to WBH conservation is underway in the Puna Tsangchu Basin (RSPN 2019b).

Considering the fact that co-existence of WBH and local communities along these rivers is dependent on keeping all natural ecosystems intact and healthy, the communities of the Puna Tsangchu are also taken on-boards to assist RSPN in conservation activities by engaging them in population survey, habitat mapping, advocacy, and educational program. The ongoing RSPN study on population dynamic including genetic and captive breeding activities will add new knowledge to bring about sustainable protection and conservation measures and actions to WBH conservation. Recognizing the importance of community participation for success of WBH conservation program, the focus is on community involvement of community right from project planning, implementation to monitoring. This community participatory approach to conservation is expected to empower the communities and increase their ownership and participation in WBH conservation.

10.3 Projects' Issues, Challenges, and Interventions

The ongoing projects at Phobjikha, Bumthang, Lhuntse, Khotokha, and Bumdeling on Black-Necked Crane (BNC) conservation and white-bellied heron conservation in Puna Tsangchu and Mangdichu river basins are supported by international organizations like International Crane Foundation (ICF), Krupp foundation, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), NABU International, Mava Foundation, Puna Tsangchuu 1 & 2, Synchronicity Earth, Alice C. Taylor Trust, Mava Foundation, NatGeo, and Bhutan Trust Fund for Conservation (BTF). The projects' biodiversity conservation and management issues and challenges are attributed mainly to inadequate knowledge and lack of understanding on BNC and WBH ecology and human–bird interaction, habitat degradation, and lack of coordination and participation amongst stakeholders. The interventions are selected and strategized to address a combination of social, ecological, and technical issues and constraints with emphasis on community-based and nature-based solutions (Tables 10.1 and 10.2).

Table 10.1 A summary of project issues, challenges, and interventions in Wetland Phobjikha Conservation Area and other areas (Bumdeling and Bumthang)

	Project Interventions		
Challenges	Research	Conservation and livelihood activities	Community engagement
– Inadequate knowledge on wintering BNC ecology – Habitat (wetland) degradation—Anthropogenic and Natural – development pressures – Encroachment – Direct threats posed by stray dogs/natural predators – Lack of coordination among stakeholders – Lack of coordination among BNC regions	– Wetland Ecology – Community perception study – Mapping migration routes and breeding/wintering habitats (Fig. 10.5) – dietary composition	– Community-based sustainable tourism (CBST) – Electric fencing – Solid waste management – BNC festival – Roost maintenance (Fig. 10.6) – Annual BNC census, installation of flight diverter on the power lines	– Community consultation in perception studies – Mapping resources – Collecting issue/constraints – Frame conservation and livelihood program

Source: Tshering (2019)

Table 10.2 A summary of issues, challenges, and project interventions in Puna Tsangchu and Mangdichu Riparian Ecosystems

Challenges	Project Interventions		
	Research	Conservation and livelihood activities	Community engagement
– Inadequate knowledge on WBH habitat ecology, biology, and population dynamic of WBH – Infrastructure Development such as hydropower projects put pressure and loss of habitats (Fig. 10.7) – Touristic activities such as rafting and camping along rivers disturb herons during feeding and roosting (Fig. 10.7) – Illegal fishing activities (Fig. 10.7)	– Riparian Ecology – WBH population survey and monitoring – Nesting biology – Ex-situ conservation (captive breeding)	– Education and awareness program – Sustainable livelihood and partnership with stakeholders. Fishery pond, piggery, poultry, organic agriculture, Horticulture, drinking water, and apiculture provided – Eco-restoration – Community protection (patrolling) and monitoring	– Established local conservation support group community group) LCSG and resource group (RG), DoFPS – LCSG monitors the WBH population – Any illegal activities occurring in the WBH habitats are reported to RG. – The RG helps the LCSG to settle the case, Implement project activities

Source: Pradhan (2019)

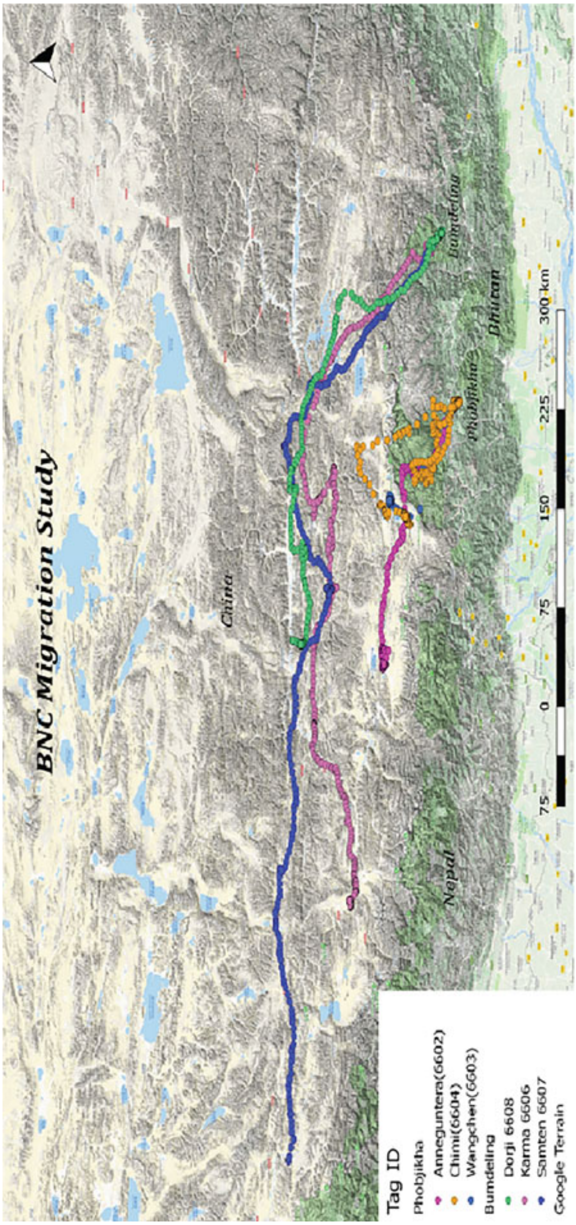


Fig. 10.5 Bhutan–Tibet BNC transmigration routes (Source: Tshering 2019)

Fig. 10.6 Restoring BNC roosting areas at Phobjikha (removing *Berberis* and *Juncus* species)

Fig. 10.7 Human-induced risks and disturbances on WBH and its habitat along the Puna Tsangchu (Basin hydropower development, WBH juvenile crashing against a transmission line, fishing, and rafting)

10.4 Experiences and Lessons Drawn from Project Implementation

1. The wetland and riparian ecosystems in the project areas are subjected to a range of pressures from development and human interventions such as hydropower, roads and hotel construction, tourism, intensive farming practices, insufficient infrastructure planning, and uncontrolled grazing, which have led to degradation of riparian and forest ecosystems, drying up of wetland, agricultural land fragmentation, and increasing waste. Threat of invasive flora species on the wetland ecosystem in Phobjikha due to human interference is evident that is making WBH feeding and roosting areas overgrown with bamboo, Berberis, and Juncus Spp. (Photo Plate 4 Fig 10.6, Wangda et al. 2011). Maintaining the interrelationship of

the wetland, riparian and forest ecosystems, and the communities is essential to enhance sustainable conservation of farming and forestry practices, integrated soil and water management, physical infrastructure planning, and livelihood-based conservation interventions, that will further add values to the wetland and riparian ecosystem services provision. Such integrated approach to conserving and managing natural ecosystem needs involvement of stakeholders from different sectors including communities starting from project activity planning, implementation to monitoring.

2. Potato farming has become the main income earner for Phobjikha farmers and the majority of them grow potato as a single cash crop. The increasing use of chemical fertilizers to enhance potato production has resulted to contamination of land, soil, and water quality, that can lead to pollution and possible health problems. Livelihood diversification is seen as a part of adaptation strategy in the project areas and should be promoted over economic dependence on monoculture crop such as potato. One potential option is to promote nature-based farming that connects communities to the tourism supply of food and other products (home stay and handicrafts) (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014).
3. Endowed with beautiful landscape and conditioned by occasional chance to see the BNC every winter, Phobjikha valley is increasingly becoming an attractive tourist destination. There is a huge potential for ecotourism, particularly low volume, high quality/end tourism. Revenue generated from the recreational services (tourism) ranks first in terms of its contribution to total economic value of Phobjikha wetland ecosystem, followed by provisioning services and regulating services (carbon sequestration) (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). In Puna Tsangchu Basin too, the increasing development activities (e.g., hydropower and tourism) are gradually influencing the natural landscape dynamics, affecting the fragile WBH habitat and local people livelihoods. While the tourism can bring about development, the unregulated tourism can have adverse impact on the natural ecosystem and community well-being. Thus, promoting inclusive forms of ecotourism that integrates local community development and nature conservation is vital in these project areas.
4. The number of BNC visiting Phobjikha valley annually has increased over last 32 years, but it has decreased at Bumdeling, which is the other important wintering wetland for BNC (Fig. 10.8). A small number of BNC visiting Khotokha, Bumthang, and Lhuntse has remained steady over the years. There is a concern that the increasing human-induced activities at the roosting and feeding places can alter the BNC habitats leading to reduction of the values and usefulness of the associated ecosystem services. This change warrants for actions to restore and maintain roost and feeding areas at Phobjikha and other wintering sites. As BNC breeds and lives the major part of the year in China (Tibet), the trans-boundary networking and collaborative research to understand its habitat ecology and transmigration and movement in totality are essential (Tshering 2019).

Fig. 10.8 BNC population trend in Bhutan (Tshering 2019)

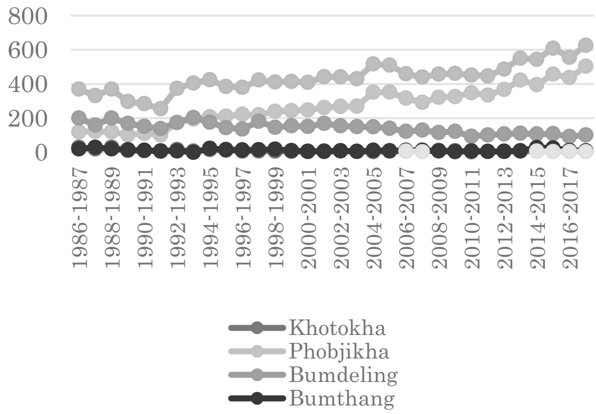
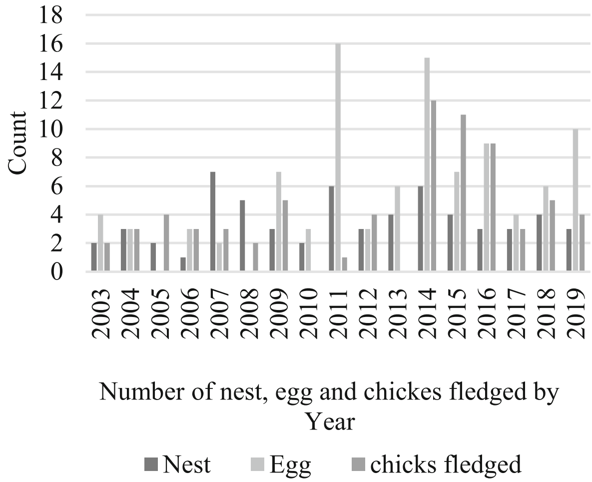


Fig. 10.9 WBH Nest statistics from 2003 to 2019 (Pradhan 2019)



5. The growing concern on low population of WBH continues and looms over WBH future, despites various works undertaken on awareness and advocacy, eco-restoration, population survey, and monitoring. Research works on habitat ecology, population and nesting biology, ex-situ conservation including captive breeding need up-scaling and intensification. The WBH annual monitoring record from 2003 to 2019 on eggs and chick fledging suggests that there is a huge mortality during egg hatching and chick fledging and researchers need to be more vigilant during these critical periods (Fig. 10.9, Pradhan 2019). There is a need to intensify the above works with focus on community engagement through active participation of established Local Conservation Support Group (LCSG).

10.5 Way Forward towards Sustainable BNC and WBH Conservation

Communities in Phobjikha and Puna Tsangchu basin are directly dependent on natural resources and their services for their living. Hence, any change in natural system of these areas can jeopardize the livelihood of the communities. At the other end, the change in the wetland and riparian ecosystems can pose serious challenge to the survival of the vulnerable and critically endangered BNC and WBH species. Further, the impact of changing climate on lives and livelihoods of communities will be more severe, as the majority of the communities are poor and live in remote areas with a few accessibilities to modern facilities such as road, markets, and education. Therefore, reducing pressures and vulnerabilities on natural resources use and community livelihoods, require a holistic approach in which intervention strategies are adapted alongside strategies for poverty reduction, biodiversity conservation, and community development. This calls for a landscape approach (Fig. 10.10) to address inter-sectoral vulnerabilities and constraints by aligning the objectives of conservation and sustainable development within the framework of Nature-based Solution (NbS) (Shacham-Cohen et al. 2019; Dhyani et al. 2018) in order to bring about win-win situations for both conservation and communities well-being. The application of this holistic approach to BNC and WBH protection conservation will require the integration of the following management and adaptation strategies:

10.5.1 Introducing the Ecosystem and Socio-Economic Resilience Analysis and Mapping (ESRAM) Tools

As climate change impact is becoming more pronounced on biodiversity conservation and communities well-being (Choden and Norb 2013), the ESRAM framework is a potential framework to be introduced as a planning tool to guide assessments of social-ecological resilience in the context of climate change adaptation in the project areas. ESRAM analyzes and maps resilience linked to ecosystem and socio-economic systems taking into account climate, ecological, social, economic, cultural, political, and institutional factors (SREP 2017, 2018). The ESRAM study will help in identifying the relevant ecosystem-based adaptation (EBA) measures and intervention activities that will guide in EBA activity implementation. The information and knowledge gained through ESRAM will be shared to support establishment of similar holistic planning, conservation and management approach to other biodiversity programs.

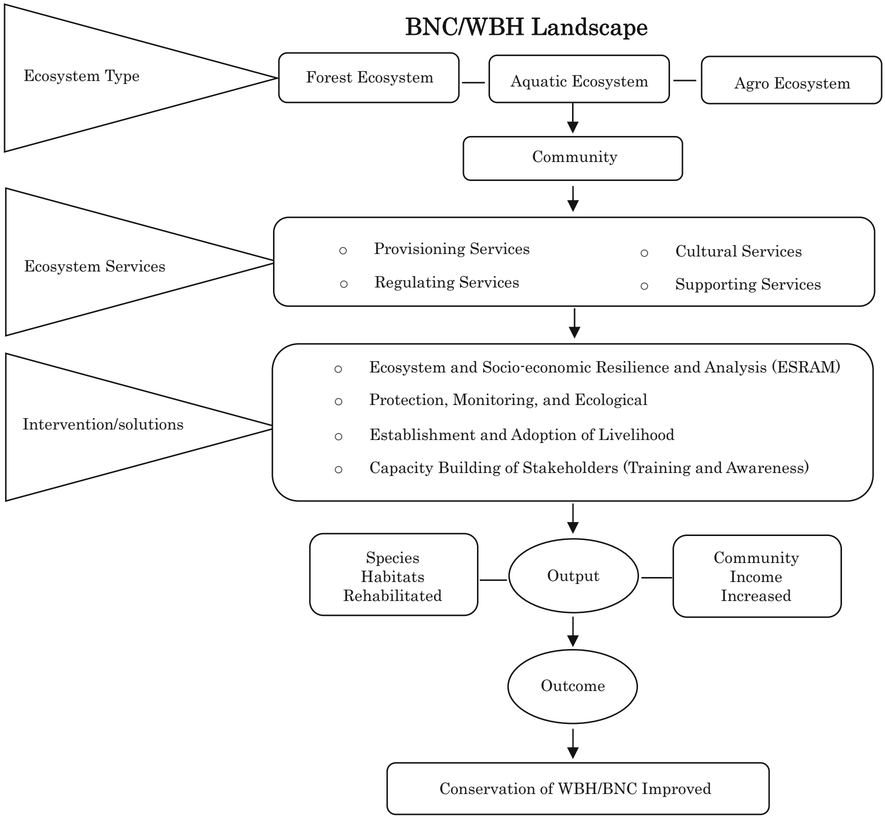


Fig. 10.10 Landscape ecosystem approach framework to BNC and WBH conservation (adapted from Ecosystem Approach, Shacham-Cohen et al. 2019)

10.5.2 Managing Natural Ecosystem for Sustained Ecosystem Services

The majority of communities (e.g., in Phobjikha) perceived that the forest cover and availability of fodder, fuel wood, and other NWFP have decreased over the last 10 years due to population growth and overuse of forest resources (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). Increasing unplanned development activities and intensive farming practices has resulted to degradation of riparian and forest ecosystems, drying up of wetland, fragmentation of agricultural land, and increasing wastes that have put at risk the sustained provision of ecosystem services. Local land use planning with zoning and the zone-specific management plans and guidelines will be prepared and managed to enhance systematic utilization of resources according to land and forest use capabilities and community needs. This calls for an integrated ecosystem approach to maintain inter-linkages between conservation and development for ensuring ecosystem sustainability and people's well-being.

10.5.3 Diversifying Livelihood Options to Enhance Livelihoods

The mainstay of rural livelihood everywhere in Bhutan is agricultural farming. The rural livelihood assessment at Phobjikha shows that the households are dependent on a single potato cash crop. In the context of climate change and its impact on decreasing crop productivity, depending on single crop such as potato may make the communities more vulnerable and poorer. To address the different coping situations, livelihood diversification should be a strategy to adapt to the changing situations and sites including climate change. Livelihood options (e.g., vegetable growing, apiculture, fishery and piggery), climate-smart agriculture (e.g., organic agriculture, agroforestry, conservation agriculture) and traditional crops such as buckwheat, wheat and other cash crop intensifying growing of traditional crops such as buckwheat and wheat, by farmers are some cilmate-smart initiatives. Livestock rearing is also an important conventional activity that is good both for wetland management and for livestock products (cheese and butter). The climate impact reduction strategies related to NbS such as ecosystem-based adaptation, eco-restoration, forest landscape restoration, sustainable land management, and nature-based tourism are some of the livelihood options planned for implementation in the proposed project (RSPN 2019b).

10.5.4 Linking Ecotourism Services to Biodiversity Conservation and Development

The tourism industry in Bhutan is to operate on the principle on environmentally friendly, socially acceptable and economically viable. The information from Phobjikha shows that the major benefits generated from tourism go outside local economy (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). This suggest that there is a potential to mobilize resources for financing conservation and development needs by creating values through, e.g., carbon trading and Payment for Environmental Services (PES) and connecting ecotourism to home stay and local products sale in order to benefit local economy. The ecosystem-based services relating to ecotourism are:

(i) Eco-recreation through community-based management of culture and nature for tourism.

In Phobjikha, a few of these trails such as the Gangtey trek and the annual Black-Necked Crane Festival on 11 November are already popular among tourists. The

Fig. 10.11 Promoting ecotourism (BNC dance and birding) for BNC and WBH conservation

local communities will manage a network of nature trails with government and tourism (Fig. 10.11). For Puna Tsangchu River Basin, limited and controlled ecotourism initiatives (e.g., birding and trekking) to popularize and promote WBH conservation can be possible. The brunt of touristic activities (e.g., birding, rafting, camping) on environment and WBH conservation is already visible at the upper Punakha Tsangchu (Pradhan 2019).

(ii) Sanitary services through community-based management of solid waste.

Solid waste management activities were first introduced in Phobjikha in 2003 with public awareness campaigns and distribution of waste bins to shops. Later, some basic infrastructures (land fill, collection facilities, and tractors) were established in collaboration with the local communities and RSPN. Recognizing the potential adverse impacts of solid waste on people's health and on tourism, a community-based solid waste management system will be established and implemented to keep the valley free of haphazard and unsafe waste disposal. Sewerage treatments need to be in place and use of chemicals (soaps, shampoos, etc.) should be discouraged. Besides communities, hotels need to have proper sewerage facilities and should be discouraged to use chemicals that will have detrimental effects on the wetland and its associated species.

10.5.5 Scaling-up Advocacy and Awareness to Raise the Ecological and Cultural Significance of the BNC and WBH Conservation

Although a number of awareness, advocacy, and education programs have been conducted, there is still a need to work more on awareness creation and the gaining recognition of the Phobjikha Valley and Puna Tsangchu river basin as a Community Conserved Areas (CCA) (International Centre for Integrated Mountain Development [ICIMOD] and Royal Society for Protection of Nature [RSPN] 2014). In general, the CCA designation will provide opportunity to build good rapport with rural communities and gain support in leveraging biodiversity and ecosystem conservation. Specifically, the CCA will determine to what extent the ecological, cultural, and religious values of the BNC and WBH can support the conservation of the landscape and reduce the risk of depleting the wetland and riparian ecosystems. The value of wetland and riparian ecosystem must be assessed and explored in terms of its local, regional, and global significance. Research and monitoring need to be continued and the information shared through systematic database management and dissemination system to a wider audience. Further development and promotion of BNC visitor Centre, Phobjikha, and WBH Captive Breeding Centre, Changchey, will facilitate enhanced understanding about wetland and riparian ecosystems conservation as well as facilitate BNC and WBH related research.

10.5.6 Motivating Community Engagement in Biodiversity Conservation

Community perception towards conservation is changing in the light of increasing human-wildlife conflict incidences (RSPN 2019a, b, c). Local communities in Phobjikha and Puna Tsangchu basin and elsewhere in the rural areas live with numerous conservation costs. They are subjected to state restrictions on natural resource use so as to maintain the natural ecosystem in a healthy state. The positive state of natural ecosystem has meant increase in wildlife population, which in turn has led to increased crop and livestock depredation. Crop depredation by wildlife is rated by the Phobjikha communities as the most critical constraint to farming (Norbu 2012).

The experiences from other countries show that a community's seriousness to engage in conservation activities is influenced by the tangible social and economic benefits they are offered for the conservative activities they render (Ingram et al. 2012). As a learning process, undertaking ecosystem-based adaptation activities in the ongoing incentive-based conservation program (RSPN 2019b) is expected to enhance income and livelihoods in Puna Tsangchu basin through engagement in vegetable growing, fish farming, bee-keeping, and piggery activities (Fig. 10.12).

Fig. 10.12 Livelihood and conservation activities (electric fencing and fish pond) through community engagement

There are plans to work on ecosystem-based adaptation livelihood options such as organic farming and insurance-based HWC solution to compensate livestock loss and crop depredation (RSPN 2019a). Community engagement is the key to the success of the project and it will continue to work through LCSG participation, right from planning, implementation to monitoring of all projects. These arrangements will motivate the local communities and enhance their sense of ownership of the natural ecosystem and active engagement is expected as they will be receiving direct benefits from the conservation and livelihood activities.

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Chapter 11
Geo-Information Tools in Implementing Nature-Based Solutions from High Altitude Wetlands: From Mapping to Decision-Making Support for Disaster Risk Reduction

Parul Srivastava and Neeraj Agarwal

Abstract Wetlands hold back their rich plant diversity, take up surplus nutrients, filter out suspended solids and hold back a large volume of water, creating buffering impact into downstream that can delay the extreme events. In the last few decades with the advancement in the technology and availability of near real-time high-resolution satellite data, mapping and monitoring of these wetlands especially in the higher altitude zones, e.g. Himalayas, have become easier for disaster management. The integration of tools like machine learning and remote sensing leverages mitigation risk and adaptation measures arising out of disasters in the high altitude regions. In India in the high altitude regions especially in the Himalayas, disasters like Glacial Lakes Outburst Floods (GLOF) are posing challenges for the communities and other biodiverse resources in the downstream regions. Thus, the management of such wetlands needs a holistic approach with inclusion of technology and historical data analysis for the preparedness against disaster. Considering such significance of the high altitude wetlands as natural solution for mitigation of disasters in the high altitude regions, the present study provides various geospatial and other technological approaches that can help in identifying the risk by quantifying the area through mapping and temporal monitoring of high altitude lakes.

11.1 Introduction

High Altitude Wetlands (HAWs—the water bodies like lakes; ponds and rivers; found at altitudes higher than 3000 m above mean sea level, often fed by glaciers or snow from the surrounding mountains) caused by glacial activity (also tarns that are

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mostly present in the upper reaches of the Himalaya, above 5500 m) in South Asian region are present within the Hindu Kush Himalayan Region that extends over 3500 km (covering approximately 3.5 million Km^2) and act as a freshwater reservoir to the major river basins such as the Ganges, Indus, Yangtze, Mekong, Amu Darya and Hillmand (Kumar and Lamsal 2016). Fragile geology of the region and its susceptibility to glacial lake outburst floods (GLOFs) make them more vulnerable. In such cases, mapping and monitoring of these major resources become essential to address the conservation needs of precious natural resources. A detailed inventory of these wetlands and baseline information is essential to determine their ecological characters and ecosystem services that it provides to conserve high altitude wetlands.

These high altitude wetlands in the South Asian region have significance as they provide livelihood and are also used as pastureland for grazing livestock by the people living in the fringes. Most of the high altitude wetlands are considered as sacred (O'Neill et al. 2020). The area surrounding wetlands, especially in the Himalayan region, is also home to several rare endemic species of birds, medicinal plants and mammals. The high altitude wetland complex provides several types of intangible (amenity, recreation, aesthetic) ecosystem services to the region. The wetlands offer regulating, provisioning of water supply like filtering, retention, and storage of fresh water in the lakes, supporting, recreational as well as religious and cultural services to the region. Besides, these Himalayan wetlands play an essential role in the hydrological regime of mighty rivers like the Ganges, Brahmaputra and Indus and act as a buffer between glacial meltwaters and outflows to smaller rivers and streams. The major threat to the lakes is unregulated tourism, decaying névé field from mountain peaks under the stress of contemporary climate change, as well as offering items used by the pilgrims into the lake (as observed from the field).

Due to the significant provision services that wetland ecosystem provides, it has a great potential to be categorized as nature-based solutions to address a variety of environmental, social and economic challenges (Cohen-Shacham et al. 2016). The multiple benefits derived from wetlands as ecosystem service include carbon sequestration (Mitsch et al. 2013; Bridgham et al. 2006), maintenance of hydrological characters (Hefting et al. 2004; Xiong et al. 2003), flood regulation (de Groot et al. 2002; Acreman and Holden 2013) and maintenance of biodiversity (Gibbs 2000; Dudgeon et al. 2006). However, despite their enormous potential of providing various ecosystem services, there has been a continued and rapid decline in wetland areas globally (Thorslund et al. 2017). Though there is not much scientific resource available which can give an absolute number for the loss of wetlands, some regions such as the USA and Europe have made substantial effort to slow down the rate of wetland loss over the last decades. Still, there are many regions, which are experiencing rapid wetland loss (Mitsch and Gosselink 2015; Davidson 2014). This highlights the need for mapping, assessment and evaluation to protect and sustain the crucial ecosystem for nature-based solutions to a range of current and future challenges.

Considering HAWs are sensitive to climate change because of their small catchment size, scant vegetative cover, low nutrient content in surface water, and shallow soil and low bedrock weathering rate (Strang et al. 2010), periodic monitoring of these resources is a challenge economically and needs the engagement of huge workforce for field-based monitoring. The information on habitat and species condition, the distribution of the species along with the biodiversity in the zone of influence of HAWs in South Asian Himalayan region are critical to assess the conservation need and status. Remote sensing through its synoptic view and Geographic Information Systems (GIS) together with mobile apps can act as a tool for these spatially explicit environmental data analysis and also for the collection of real- to near real-time data for monitoring, mapping and planning for the better management of natural ecosystems. GIS as a tool can also help measure the environmental impact of NbS.

11.2 Disaster Risks in the High Altitude Wetlands

Wetlands are considered as a natural phenomenon for mitigation of the disaster risks. Degradation of these natural support increases the risk of water-related hazards such as floods, droughts and storm surges. Integrating wetlands as natural phenomena for disaster risk reduction (DRR) either individually or together with physically constructed structures such as the dam can mitigate hazards and intensify the resilience of the communities downstream (RAMSAR Policy Brief No. 1). The wetlands in the high latitude zones are critical as they act as water storage basins that reduce runoff intensity (O'Neill et al. 2020) from snowmelt and affect the communities and resources (especially floral and faunal habitat) in the downstream.

In the past, there have been work dealing with the occurrences of hazards and disasters and also their impact on people in the Eastern Himalayas. But considering that ecosystem-based solutions solely may not address all forms and scales of disaster risks, there is a need to integrate technological (geospatial solutions, MaxEnt—for extent mapping); and model-based solutions (Scenario-based Hydrological Modeling; GIS-based water balance model which provides input and output scenarios) for risk management such as early warning, evacuation and contingency planning, and physical infrastructure such as dams, dykes and seawalls to be applied together to reduce the risks.

The drastic geo-hydrological changes of glaciers due to climate change enhance glacial hazards like glacial lake outburst floods (GLOFs). Moraine-dammed glacial lakes are highly unstable and therefore susceptible to failures which may result in GLOFs affecting downstream regions. To conserve and manage wetlands, and also from the view of disaster preparedness from GLOF, an inventory of wetlands and their catchments is necessary. Digital maps in such cases are very powerful inventory tools as they relate the feature to any given geographical location that has a strong visual impact. The case study presented in the subsequent section is an attempt to map wetlands by using geospatial techniques, ground-truthing and habitat assessments (physical, chemical, biodiversity ecosystem services).

Quantification of high altitude wetlands and their spatial distribution using an inventory approach engaging remote sensing and GIS application is essential not only for wildlife species conservation but also for the biodiversity conservation and sustainable use of natural resources. The study in parts of Eastern Himalayas in Sikkim, India applies remote sensing-based approach and is based on IUCN/RAMSAR definition and amenable from remotely sensed data.

11.3 Geospatial Inventory of Wetlands in High Altitude in India

Some initial attempts were made to inventorize the wetlands during the 1980s and early 1990s. Machine learning approach like maximum entropy has been applied (Phillips et al. 2006; Phillips and Dudík 2008) to assess the extent of wetlands as this approach is a non-parametric approach that can discriminate biotic and abiotic features and can determine the wetland position without repeated measurements, unlike other hydrological models that demand seasonal and temporal measurements.

However, the first scientific mapping of wetlands in India was carried out during 1992–1993 by Space Applications Centre (SAC 2011), Ahmedabad. It was the first extensive inventory exercise at 1:50,000 scale for the classification of wetlands as defined under the Ramsar Convention. According to this inventory estimate, the areal extent of wetlands is about 7.6 m ha (Garg et al. 1998). The satellite data-based estimates show that India has a total 201,503 wetlands having an area greater than 2.25 ha covering nearly 4.7% of the total geographic area of the country.

In one such studies in the subsequent section, a mapping attempt has been done to quantify the wetland area which can be helpful in decision-making in the extreme events for the downstream communities. The study uses both optical and SAR data along with water index to segregate moisture class from other land uses to identify the extent of the wetland.

11.4 Description of the Study Area

Sikkim, a north-eastern Himalayan State in India, is globally renowned for its rich biological diversity that contains approximately 4500 species of flowering plants (Pradhan and Lachungpa 2015). The forest in the state occupies a total of 82.31% of the total geographical area that harbours several endemic floral species. Sikkim is also home to around 534 HAW with 3325 ha area (accounting for approx. 40.79% of the total wetland area) (SAC 2011). Of the several lakes in Sikkim, Gurudongmar Lake Complex (5263 m), Tso Lhamu (5300 m) and Tsomgo Lake (3547 m) are the few prominent lakes that attract a lot of tourists across the globe. In 2006, five important wetlands of the state: (1) Tsomgo lake, (2) Khecheopalri Lake, (3) Gurudongmar Lake complex, (4) Tamzey Lake Complex and (5) Tembava Lake complex—were included under the National Wetland Conservation Programme of the Ministry of Environment, Forest and Climate Change, Govt of

India. The unique geomorphology in the Eastern Himalayas has resulted in more than 315 glacial lake formations, with most of them located above 4000 m.

11.5 Mapping the Extent of the Wetland

The study used both optical (Sentinel 2A) and SAR (Sentinel 1A) satellite to assess the spread of water in the high altitude wetlands as well as land use and land cover in two km radius around the lake. The basis for selection of 2 km buffer around the wetland was to assess the influence of various land use and land cover around the wetland at a finer scale. The water spread areas of wetlands vary greatly in pre- and post-monsoon season.

With a view to this, the spatial extent of the wetland boundary, both pre- and post-monsoon satellite data was utilized for the delineation of boundaries to see the seasonal changes in the wetlands. Potential of SAR data has also been utilized in order to map high altitude wetlands where cloud-free optical data was not available to explore SAR data's capability. For the digital demarcation of the wetland boundary, following exercise was carried out:

11.5.1 Lake Extent Mapping

Normalized difference water index (NDWI, McFeeters 1996) was calculated with optical satellite data of Sentinel 2A where two spectral bands with a spatial resolution of 10 metres corresponding to green and near infrared wavelengths were used:

$$\mathbf{NDWI} = (\mathbf{Green} - \mathbf{NIR})/(\mathbf{Green} + \mathbf{NIR}) \tag{11.1}$$

The above equation generated a continuous raster layer with values -1 to +1, where values near +1 denoted high probability of water pixels (Fig. 11.1). Different threshold values were analysed for the above raster to get the maximum extent of water bodies. Finally, a threshold value of 0.21 was used, which separated waterbodies from non-water class (Fig. 11.2).

A focal majority filter of size $3*3$ window was applied on the classified image to remove speckle noises and to get the final extent of the wetlands for the post-monsoon season. The result shows that the extent of water is more during the post-monsoon season as opposed to many other wetlands in the country (Figs. 11.3 and 11.4) (Bassi et al. 2014). The optical data further classified using a hybrid approach of classification for the assessment of land use and land cover around the wetland (Fig. 11.4). A total of eight classes were delineated and verified through post-classification survey within the zone of influence within the micro-watershed. Land use data analysis will mainly lead to the assessment of the various land use has on the wetlands. Similarly, SAR data was also used to demarcate the

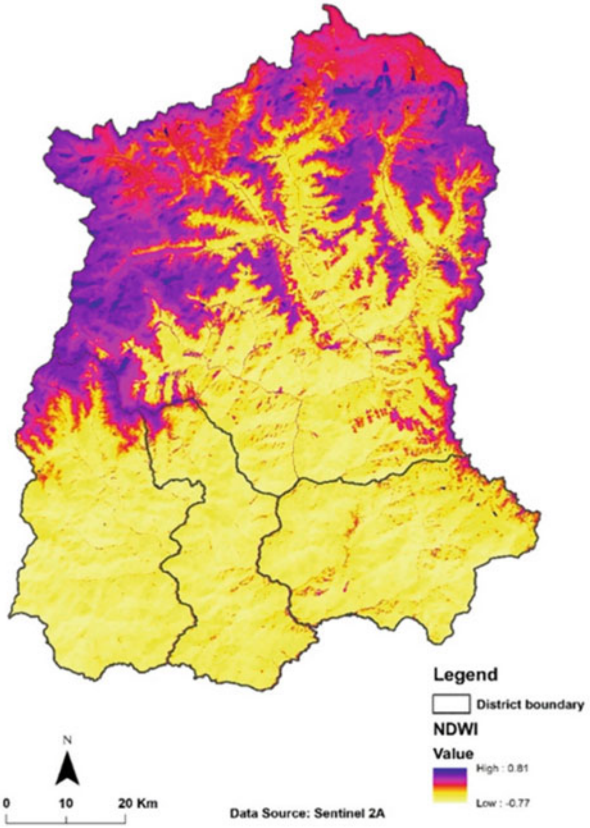

Fig. 11.1 Normalized difference water index, post-monsoon season

wetland boundary in those areas where cloud-free data was not available. As opposed to the optical sensors, which collect ground target information at the cellular and molecular level, SAR sensors are responsive to physical characters, such as water content, and size and structural, such as roughness, characteristics of ground targets (Lang et al. 2015). An iterative exercise is needed to substantiate the findings from this mapping. For the present study, the outputs of SAR data were found to be in sync with the results of the optical data analyses.

11.5.2 Delineation of Watershed and Identification of Zone of Influence

One more critical aspect in the wetland mapping and assessment is the delineation of the zone of influence around the wetland. Given the significance of the wetlands in the high altitude region, it is necessary to see the impact that various land use has on the wetlands. Though any developmental activity in a catchment affects the wetlands

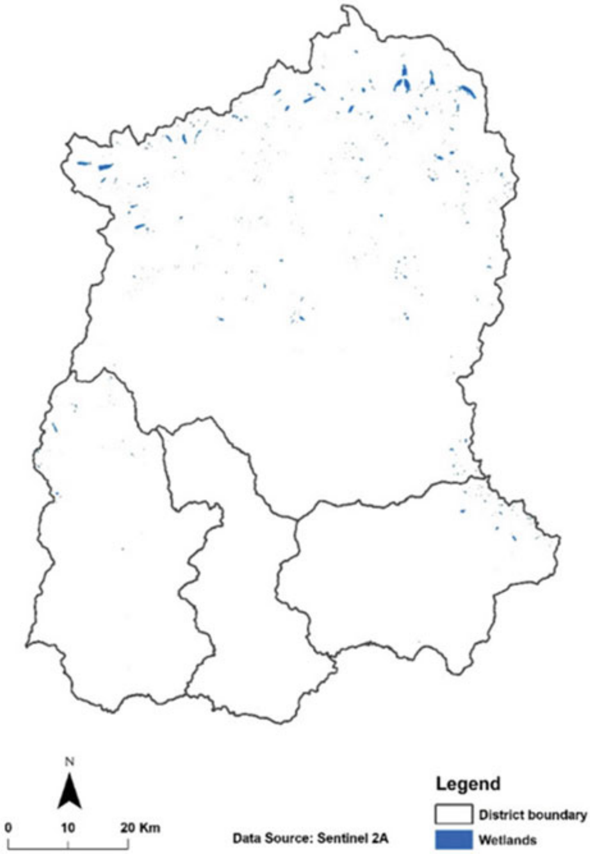

Fig. 11.2 Extent of the wetland

and is considered as the zone of influence for that wetland. However, any change in the land use in a watershed as small as micro-watershed in the high altitudes can have a direct effect on the downstream. Considering its significance, the micro-watershed boundary has been delineated using ArcGIS hydro-analysis tool and ASTER DEM with 30 m spatial resolution. The wetlands with area >0.5 ha were further surveyed to assess the land use and land cover and other characteristics of the wetlands. A total of 5 micro-watersheds identified in Sikkim with East District consists of two—Dik Chhu and Rangpo Rongli Khola micro-watershed. The total number of wetlands found in Sikkim is approximately 534 covering 3325 ha area (SAC 2011). There also 276 wetlands with small to very small size (<0.5 ha) (Table 11.1).

Most of these wetlands in the region are permanent, which mostly feed the groundwater and also to the catchment in the downstream. Also, most of the lakes in Sikkim are at an altitude above 4000 m with only six wetlands between an altitude 3000 and 4000 m. Although there have been many regulatory efforts made both by the government as well as non-governmental institutions through consultative and collaborative efforts, knowledge in many cases is still limited. Some evidence

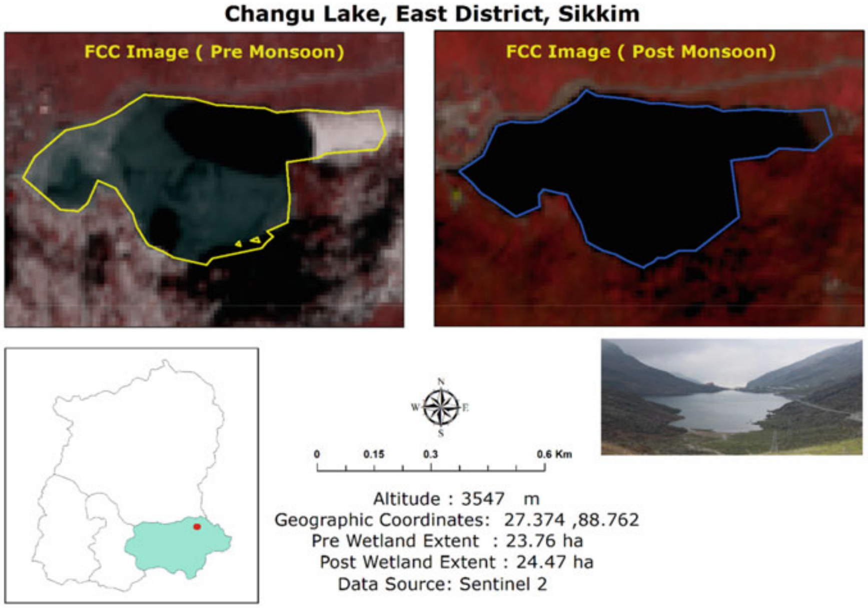

Fig. 11.3 Pre- and post-monsoon wetland extent

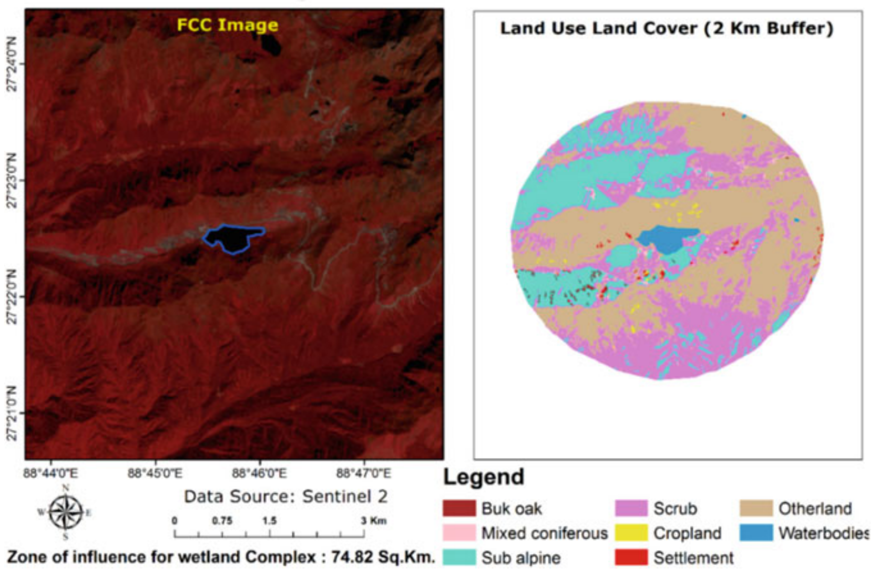

Fig. 11.4 Land use land cover map of Changu Lake in Sikkim part of Eastern Himalaya

Table 11.1 Micro-watershed in East District of Sikkim (parts of Eastern Himalaya)

S.No.	Micro-watershed in parts of Eastern Himalaya
1	Dik Chhu
2	Rangpo Rongli Khola
3	Prek Chhu
4	Rathong Rimbhi Khola
5	Zemu Chhu

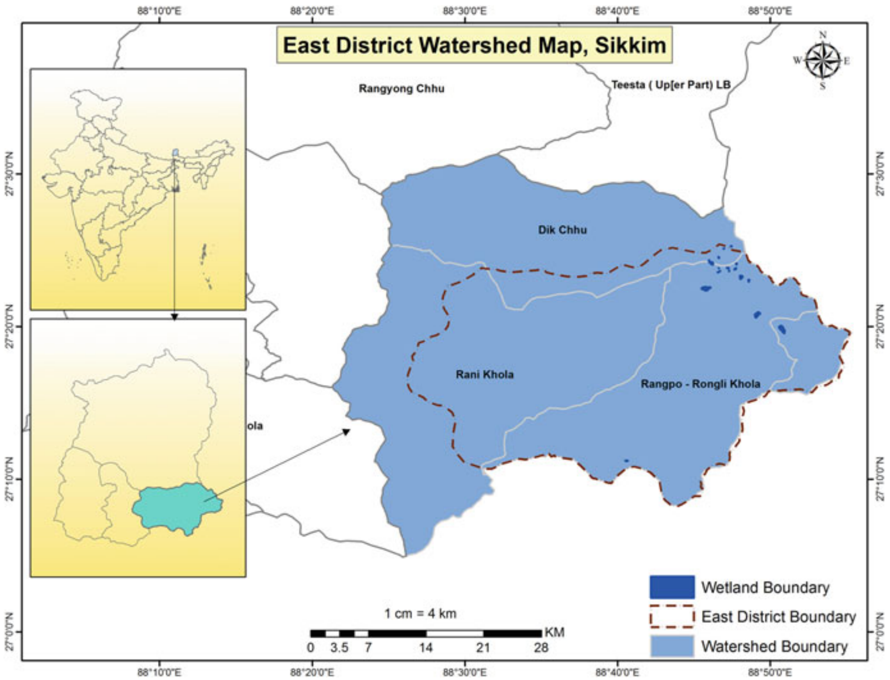

Fig. 11.5 Micro-watershed in East District of Sikkim

landscape can differ considerably from the functions observed at individual wetland scales. This applies to the provisioning of ecosystem services such as biodiversity support, groundwater level and soil moisture regulation, flood regulation and contaminant retention and in such cases, the function or the services arising out of the lakes needs to be assessed individually or at a micro-watershed level (Fig. 11.5).

11.6 The Way Forward: Wetland Management—Integration of Technology and Natural Processes

A key point that the Ramsar action plan roles out in response to the wetland degradation is “Improve national wetland inventories and track wetlands’ extent”.[1] It makes monitoring, management and restoration of the wetlands essential to secure a sustainable supply of water to the entire region and also to safeguard communities and biodiversity that depend on these freshwater sources. That can only be facilitated by the advanced technological interventions including mapping using earth observation monitoring integrated with GIS that provides a reliable tool to account for ecosystem loss, and may also help to address some of the gaps in the availability of the spatial data on ecosystem condition. As far as the spatial database in high altitude region is concerned, the mapping and inventory are yet not complete to support the management activities. Also, there must be sufficient scientific investigation together with analytics (hydrological modelling) that can guide the technological interventions in the management regimes of the wetland. Further, a GIS-based approach is being identified as the most useful technique for wetland risk assessment, as it incorporates a spatial dimension that is useful for monitoring adverse impacts on wetlands.

Many methods have been used that were either based on the individual analysis of the moderate to high-resolution optical data or in combination with SAR (Synthetic Aperture Radar) and DEM (Digital Elevation Model) for the mapping and assessment of the wetlands (Dechka et al. 2002; Grenier et al. 2007; Grenier et al. 2007; Frohn et al. 2009; Bourgeau-Chavez et al. 2009; Corcoran et al. 2012; Baker et al. 2019). For swamp detection, studies show that in the multispectral data, visible to shortwave infrared provides information on wetland vegetation and moisture content, whereas radar offers discrimination of vegetation structure and ground penetration (Henderson and Lewis 2008; Bourgeau-Chavez et al. 2009). However, topographic data only provides information on the pour points for water accumulation and is often used in combination with optical and radar data to improve accuracy (Li and Chen 2005; Hogg and Todd 2007; Hird et al. 2017).

On the other hand for the restoration of wetland, one of the valuable and complex ecosystems, a number of factors need to be assessed either individually or in conjunction that increases the complexity of the analysis. For such complex analysis for the wetland restoration, an integrated approach can be applied that takes into account ecological patterns together with machine learning algorithms such as artificial neural network. In most scientific studies, artificial intelligence algorithms have been widely applied for wetland restoration (Maleki et al. 2019). Though machine learning algorithms rarely require spatial locations, however, for the mapping of the wetland ecosystem inputs like remote sensing data and geocoordinates are crucial not only for the assessment of the extent but also for analysing the inflow

[1] http://scstsenvis.nic.in/index3.aspx?sslid=3208&subsublinkid=2441&langid=1&mid=4

and outflow from the wetland water regime. Therefore geospatial data when integrated with machine learning (deep learning) algorithm like ANN can provide a cost-effective, replicable and accurate decision-making tool for the restoration of the wetland ecosystem and preparedness for the disaster mitigation. Though deep learning provides a powerful framework to improve classification from remote sensing data, but further research is needed to improve accuracy for detailed wetland mapping, which can further help in identifying potential vulnerability zones to initiate an early warning for possible GLOF events in future by the local authorities to take measures and for risk analysis of planned future activities downstream.

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Chapter 12
Promoting Nature-Based Solution (NbS) Through Restoration of Degraded Landscapes in the Indian Himalayan Region

I. D. Bhatt, Vikram S. Negi, and R. S. Rawal

Abstract Deforestation and forest degradation due to environmental change and anthropogenic pressure have resulted in significant reduction in the provision of valuable ecosystem goods and services. UNFCCC has emphasized forest conservation as a part of achieving sustainable development. These efforts have been reinforced through new global development agendas such as the Sustainable Development Goals (Goal 15) and the Aichi targets. A strong relationship between ecological restoration and the ecosystem services concept has been established, with the latter informing how ecological restoration may be planned and implemented. Deforestation and forest degradation in the Himalaya are a major concern. This region provides ecosystem goods and services to both upstream and downstream populations. International and national agencies and NGOs have been responding to the challenges of forest and environmental degradation through various planning activities and technologies. However, ecological restoration and rehabilitation of forests and degraded lands is the only viable strategy in the Himalaya to improve the environment, mitigate climate change impacts and support the livelihoods of natural resource dependent traditional communities. Large-scale failure of past efforts can be attributed by lack of a participatory strategy to determine the essential needs of the local population and gain their cooperation. GBP-NIHE has been active in the Indian Himalayan Region for over 25 years, significantly contributing to environmental conservation and sustainability, developing restoration models involving local people. This chapter describes ecological restoration undertaken by the Institute in the wasteland across the Indian Himalayan Region (IHR), to promote effective biodiversity conservation and sustainable development.

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12.1 Introduction

Land degradation is one of the most disturbing problems in the world. It refers to reduction or loss of the biological and/or economic productivity of land and the reduction of carbon storage in soil and vegetation. Degradation of forests, rangelands and agricultural lands are major barriers to sustainable development, biodiversity conservation and climate change mitigation (IUCN 2014). It is also a major contributor to habitat and subsequent species loss, leading to decline in ecosystem services. The results of the 1991 Global Assessment of Human-induced Soil Degradation (GLASOD) indicated that 15% of total land surface is degraded. A more recent estimate, the Global Assessment of Land Degradation and Improvement (GLADA), revealed that 24% of land is degrading, of which 20% is cultivated; 23% broadleaved forest, 19% coniferous forest and 20–25% rangeland (Bai et al. 2008). This assessment also pointed out that more than 2 billion people depend directly on these degrading areas for their livelihood and income (Bai et al. 2008). Analysis has revealed a decline in biomass productivity over 25 years of 25% for croplands and vegetation-crop mosaics, 29% for forest/shrub/grassland mosaics, 25% for scrub land, 33% for grasslands, as well as 23% of areas with sparse vegetation (Le et al. 2014). Drivers of land degradation include over-exploitation for agriculture and over-harvesting of plant biodiversity, particularly trees, driven by population growth and economic development (Geist and Lambin 2004; MEA 2005; Alexander et al. 2016).

Over the past two decades, the ecosystem services concept has increasingly been taken into consideration in decision-making processes and in international studies, treaties and conventions (Alexander et al. 2011). International conventions (e.g. CBD 2012), intergovernmental platforms (e.g. IPBES 2013) and policy calls for action (e.g. IUCN 2014) have recognized that ecological restoration is now one of the global priorities for biodiversity conservation, combating desertification, land degradation and limiting the impacts of anthropogenic climate change (Aronson and Alexander 2013). While notable successes for reafforestation have been seen globally with extensive monoculture plantation, the potential for planting large areas with diverse, multipurpose, species has yet to be achieved (FAO/RECOFTC 2016). Efforts to restore forests and barren lands are continuously being undertaken, particularly in the developing countries, but the results are not always successful.

Ecological restoration differs from other approaches as it tries to restore the original biodiversity and ecosystem processes that existed before the degradation or disturbance (SER 2004; Alexander et al. 2016). A global policy for reducing emissions from deforestation, forest degradation and other forest management activities (REDD+) is designed to mitigate climate change and achieve sustainable development through forestry activities. These contribute directly to human well-being and are increasingly being quantified, monitored and evaluated at various spatial and temporal scales. The Rio Earth Summit in 1992 recognized the crucial role played by mountain ecosystems highlighting that the livelihood of about 10% of the world's population depend directly on them for example for resources such as water, timber and non-timber forest products, agricultural production and minerals and a further estimated 40% live in adjacent medium and lower watershed areas. The vulnerability of these mountain areas to environmental degradation was also highlighted, with Agenda 21 drawing attention to ecological degradation in the Himalayan region driven by population growth and consequent cultivation of marginal lands.

The Indian Himalayan Region (IHR) spreads over 11 States and 2 Union Territories, covering 18% of the geographical area and including 6% of India's population. More than 41.5% of the region is forested, representing one-third of the total forest cover of India (FSI 2017). It constitutes a large proportion of the Himalayan Biodiversity Hotspot, with a rich variety of all components, genetic, species and ecosystems (Palni and Rawal 2013). However, this rich environmental heritage is under pressure from declining forest cover and loss of wildlife habitat (Semwal et al. 2013; Negi et al. 2018). The remoteness and often extreme living conditions in the Himalayan region mean that local people are highly dependent on natural resources. These are sensitive and highly vulnerable to anthropogenic disturbances; this is especially true of the natural forests which are suffering under the pressure to clear land for cash crops, shifting cultivation, fires, livestock grazing and fuel wood collection.

Restoration of degraded land has been an important activity on the agenda of Government since the early 1980s, when India launched the Social Forestry Programme (SFP), followed by the more participatory Joint Forest Management (JFM) Programme. The effect of land degradation in the uplands is felt locally as shortage of food and fodder, and also in the distant Indo-Gangetic lowlands in the form of flood damage to agricultural productivity, property and human life. This has led to the adoption of rehabilitation strategies linked to community-based forest management and ecological restoration in the IHR to ensure the steady flow of ecosystem goods and services to both upstream and downstream populations.

Though numerous land rehabilitation projects have been implemented in the Himalaya, the impact has been poor because of inappropriate technologies, policies and implementation mechanisms and this has resulted an increase in the area of wasteland. In this context, GBP-NIHE has undertaken restoration programmes across these wastelands to promote biodiversity conservation while at the same time enhancing the livelihood opportunities for the communities living there. The approach taken was to use Nature-based Solution (NbS) for Ecological Restoration (ER). This has been achieved through implementing Ecological Engineering (EE) and Forest Landscape restoration (FLR) techniques in an integrated manner and informed by community engagement to ensure appropriateness to site-specific natural and cultural settings.

12.2 Framework for Ecological Restoration

Ecosystem functioning is the outcome of complex interactions among biotic communities and their abiotic environment, and this determines the quantity and quality of ecosystem services available for human societies (Mace et al. 2012). In socio-ecological systems, this is also related to the actions of local people and all these factors combined comprise the 'natural capital' of an area (Alexander et al. 2016). Poor communities in rural areas are highly dependent on this for their basic needs and survival (World Bank 2010) and are therefore vulnerable to degradation and deforestation (Dhyani and Dhyani 2020). Ecological restoration and rehabilitation of degraded wasteland is a potential option for sustaining agriculture, livestock and livelihoods particularly in the Himalayan region (Maikhuri and Dhyani 2013). Conceptual approaches to implement this have been suggested by many workers in the Himalaya, but practical examples of putting these into practice are limited (Semwal et al. 2013; Maikhuri and Dhyani 2013; Negi et al. 2015).

In order to implement restoration and rehabilitation programmes in the IHR and monitor their effectiveness, a practical framework was developed (Fig. 12.1) based on earlier studies (Negi et al. 2015). This includes (a) analysis of the sites before restoration, (b) selection of plant species based on the perception and traditional knowledge of local stakeholders combined with a scientific evaluation of the eco-physiological attributes of each species, (c) bio-engineering measures for soil and water conservation, (d) ensuring long-term benefits in terms of fuel, fodder, timber and ecological safeguards to the community, (e) involvement of local people in all stages of implementation and ensuring both short- and long-term livelihood opportunities and (f) inclusion of medicinal plants within the silvi-cultural (medi-silvi-pastoral) system to maximize income generating potential. Appreciation of traditional knowledge and involvement of villagers in decision-making is well established to be an effective method to mobilize their active participation (Maikhuri et al. 1997, 2000; Kothyari and Bhuchar 2010; Semwal et al. 2013).

12.3 Mechanism and Process of Ecological Restoration

The process of restoration has two stages; the first is to understand the problem that has caused the degradation and secondly devise and implement an appropriate intervention to enable it to return to its original state or at least to move nearer to this. The process attempts to identify the opportunities and constraints involved from biological, physical, social and economic perspectives. Understanding the extent and historical factors that have led to degradation and loss of ecological function can be done through collecting baseline information, such as species richness, composition and soil status combined with local knowledge. When the conditions are fully understood then the most appropriate species for restoration need to be selected and this should be based on the requirements of villagers, and local use as well as

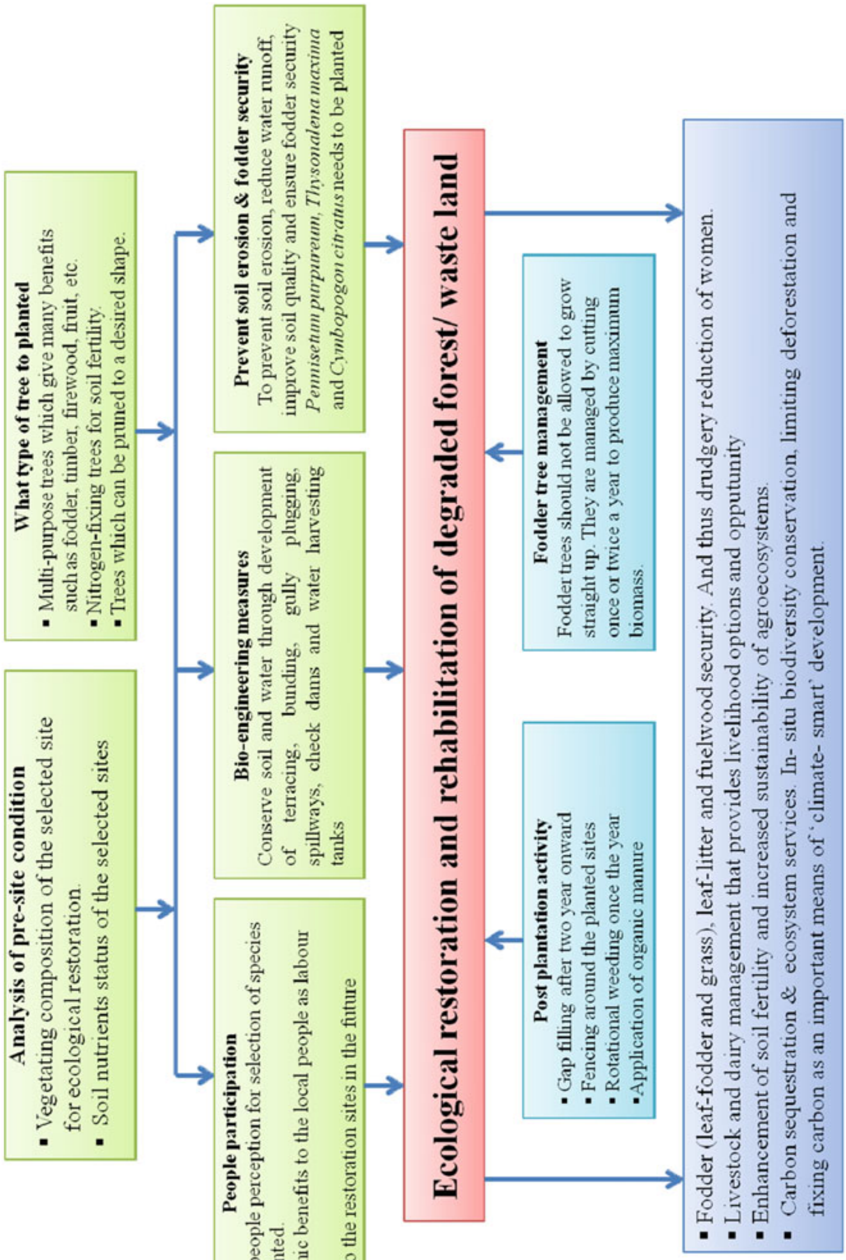

Fig. 12.1 Framework for rehabilitation of waste/degraded community land in the IHR

Fig. 12.2 Steps in ecological restoration at Gumod village cluster, Champawat, Uttarakhand

ecological importance. Pre-plantation activity involves preparation of pits and application of 2–3 kg of farmyard manure in each before the monsoon. Low-cost polyethylene-lined water harvesting ponds need to be constructed at suitable locations to facilitate irrigation as water is in short supply in the mountains. This should be followed by simple technologies such as terracing, bunding, gully plugging, staggering contours and check dams (Fig. 12.2) as required by the site topography to halt soil erosion and to maintain soil moisture at the planted sites (Negi et al. 2015). Fodder grass, such as *Pennisetum purpureum*, and medicinal grass, *Cymbopogon citratus,* may be used to stabilize slopes, prevent soil erosion, reduce runoff, improve percolation and enhance fodder production. Gap fillings should be carried out from the second year onwards to replace any plants that have died.

Demonstration of planting techniques and management methods and sharing of knowledge are important components of ecological restoration, particularly in the IHR. Local people in this mountain region are well aware that livestock are major source of income generation, providing a wide range of products as well as contributing to the agriculture system as a whole. They also acknowledge that successful restoration programmes will produce quality fodder, fuel wood and leaf-litter and an improved environment and their involvement in the restoration programme empowers them providing an opportunity to actively contribute to the conservation and management of their own natural resources.

12.4 GBP-NIHE: Experience of Promoting NbS through Land Restoration

GBP-NIHE has been working in the Indian Himalayan Region for over 25 years and has significantly contributed to environmental conservation and sustainability through Research and Developmental (R&D) work. The Institute has ecological restoration at the core of its research agenda and has developed various methods and models for ecological restoration and rehabilitation to minimize deforestation and land degradation in the Himalayan region (Fig. 12.3); some examples are given in the following sections.

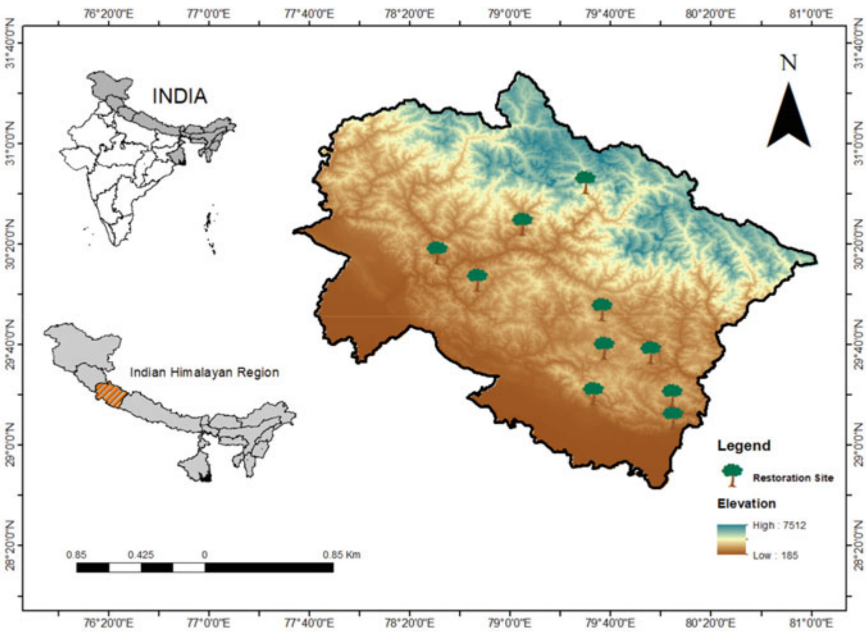

Fig. 12.3 Sites of the various restoration projects in the Uttarakhand

12.4.1 Sloping Watershed Environment Engineering Technology (SWEET)

SWEET was developed by GBP-NIHE (Anonymous 1994) and is an R&D based package with two goals: (a) ecological restoration of degraded lands and (b) livelihoods enhancement for stakeholders. This is based on integration of simple technologies such as water harvesting, soil conservation, selection of suitable species for wasteland plantation, nursery raising, bio-fencing and aftercare of plantations with people's participation. This includes, for example, constructing polythene lined ponds to store rainfall-runoff to supplement irrigation water, and bio-composting of weeds and agriculture waste to supplement farmyard manure (FYM). This technology has been used in a number of locations in the IHR, promoted through the Integrated Eco-development Research Programme (IERP) of the GBP-NIHE.

12.4.2 Integrating Science with Religion for Wasteland Rehabilitation

12.4.2.1 Badrivan Restoration Programme (BRP) at Badrinath

This case study is focused on Badrinath (3133 m asl), the major Hindu shrine in India, which lies in a remote valley of Garhwal, Uttarakhand. Learning from the past experience, the institute used the religious authority of the chief priest to involve pilgrims, local inhabitants and army personnel in a reforestation programme—the 'Badrivan Restoration Programme'—in 1993 (Dhyani 2004). Through systematic scientific selection of species, a large number of tree saplings blessed by the chief priest as 'Briksha Prasada' were planted and their survival and growth was monitored. This model, combining science and religion, has proved successful.

12.4.2.2 Eco-Restoration at Kolidhaik

This programme was undertaken in 2004 to create a Sacred Forest for eco-restoration and biodiversity conservation at Kolidhaik village, Lohaghat, Uttarakhand with the participation of local communities (Dhyani et al. 2011a, b). This village is inhabited by Hindus and Muslims and had a large barren, degraded, area of common land. About 8000 well-established tree saplings, blessed by both religious authorities, were planted by villagers on 5.6 ha of the site. Monitoring of the eco-physiological health of the planted trees (*Alnus nepalensis*, *Quercus leucotrichophora*, *Quercus glauca*, *Grewia optiva* and *Celtis australis*) confirmed their suitability for reforestation/afforestation in this region. This sacred forest development model demonstrates harmony with Muslims joining hands with Hindus working together to a common goal.

These examples demonstrate the importance of blending science and religion for environmental protection and biodiversity conservation.

12.4.3 Agroforestry for Rehabilitation of Cultivable Wastelands

12.4.3.1 Development of an Agroforestry Model

The development of an agroforestry model for degraded community land was carried out on 14 ha in Bansbara village, Rudraprayag District (Uttarakhand) for a land restoration programme (Negi and Joshi 2001). Ten locally valued, multipurpose, tree species were established as a mixed plantation on former forest land and annual food crops were grown along with the planted trees on an area of abandoned agricultural land. Tree species were selected based on an assessment of local requirements for fuel wood, fodder and other products. *Boehmeria rugulosa, Grewia optiva* and *Ficus glomerata* were considered best for fodder, *Albizia lebbeck*, *Celtis australis* and *Dalbergia sissoo* produced the best quality timber, and *Pyrus pashia* and *Sapium sebiferum* the best fuelwoods. Restoration was supported by establishment of water harvesting tanks, organic management of soil, agroforestry (native multipurpose trees traditional crops) and the participation of the whole community in decision-making. As a result, 6 of the 14 ha were transformed using this agroforestry model.

12.4.3.2 Participatory Afforestation of Community Wasteland

Community wasteland (open grazing land) at Arah village (Bageshwar District, Uttarakhand) belonging to 68 households was restored in 1992 by GBP-NIHE (Kothyari et al. 1996). A participatory approach was developed with the Van Panchayat (Forest Council), which defined the role and contribution of villagers, specifically the benefit sharing mechanism, access to resources, and post project management. Activities included planting multipurpose trees, setting up protected cultivation, water harvesting in poly-ponds, small scale fish farming, cultivation of high yielding crop varieties and nutritious fodder grasses, and nursery development, to provide short-term benefits and to encourage participation of the villagers.

12.4.4 Wasteland Restoration through Silvi-Pasture Development

12.4.4.1 Silvi-Pasture Development in Uttarakhand

Under this programme, a 40 hectare of community wasteland was developed into silvi-pasture in Uttarakhand (20 ha in Dobh-Srikot and 5 ha in Bhimli village, in Pauri-Garhwal; 15 ha in Katarmal village, Almora district) after detailed consultations with the village communities (Negi and Joshi 2001). With their support these sites were cleared of weeds and bushes, gullies were plugged, land levelled, and terraces were repaired. Fodder trees, shrubs and grasses were planted at these three sites.

12.4.5 Participatory Rehabilitation of Bhimtal Lake Catchment

GBP-NIHE implemented a project entitled 'Participatory Management of Bhimtal Lake Catchment' in Bhimtal to afforest degraded land and involving local communities with respect to livelihood enhancement. Vegetative and engineering measures were employed on about 55 ha of degraded community land using four land use models (viz., multipurpose tree species, silvi-pasture development, aromatic plants cultivation and agri-horticulture). In the first example 38,322 saplings of more than 20 multipurpose species were planted on the barren hill slopes.

12.4.6 Contour Hedgerow Farming System Technology for NE Region

Shifting cultivation in North-East India is one of the major drivers of deforestation and forest degradation. With increasing population and shortening of the jhum cycle from 15 to 20 years to less than 5, crop yield has dropped drastically as soil fertility is greatly reduced due to the increase in soil erosion. Addressing these two issues were the major challenges of this initiative and the North-East Unit of GBP-NIHE responded by devising Contour Hedgerow Farming System Technology (CHFST). This involves planting two rows of nitrogen-fixing native hedge species (such as *Crotalaria tetragona, Desmodium rensonii, Flemingia macrophylla, Indigofera anil, Leucaena leucocephala* and *Tephrosia candida*) along the contour lines 1.5–2.0 m apart, depending on the slope (Sundriyal and Jamir 2005). Soil fertility was increased by mulching and the crop yield of cauliflower, lady's finger, chillies, tomato and ginger increased from 20 to 100%. This technology resulted in control of soil erosion, reducing the average annual soil loss by 50% compared to control plots over a period of 3 years.

12.4.7 Rehabilitation of Landslides Using Bio-Engineering Measures in Sikkim

Bio-engineering technology was developed by GBP-NIHE in Sikkim to reduce soil erosion and control landslides (Krisna et al. 1998). This uses vegetation, either alone or in conjunction with civil engineering structures, to reduce instability and erosion on slopes. Measures such as modification of slope geometry, rip-rap drainage, filling of cracks and retaining structures and internal slope reinforcement using locally available plant material were applied over a long time period. Four basic interventions were used: (a) reducing the load at the top of the slope, (b) modifying ground and surface water flow, (c) reinforcing the bottom of the slope, and (d) shifting the position of the area with potential to fail. Three approaches were used to reduce the lubrication effect of seepage water: (a) preventing water entering the through cracks, (b) reducing water pressure in the vicinity of potential breakage points by introducing shallow and medium depth drainage, and (c) introducing drainage to reduce water pressure in the immediate vicinity of the hillside.

12.4.8 Rehabilitation of Degraded Community Land

Twelve ecologically adapted and socially valued tree species with economic potential were planted at two different degraded sites one, totaling 14.6 ha, in Dharaunj, along with 6.5 ha of degraded abandoned agricultural land at Gumod in Champawat district, Uttarakhand. Capacity building and active participation of local people were key aspects of this rehabilitation programme. Within 5 years this model improved availability of fodder, fuelwood and leaf-litter benefiting the livelihood options for local inhabitants.

12.5 The Contribution and Impacts of Restoration Programmes

Rural populations in the Himalayan region are highly dependent on forest resources (i.e. fodder, fuelwood, leaf-litter, grazing and non-timber forest products) for household and livelihood needs (Dhyani et al. 2011a, b; Semwal et al. 2013; Negi and Maikhuri 2016; Negi et al. 2018). Biomass extraction is the most widespread pressure on forests generally and particularly in the Himalayan region. Studies have revealed that removal of forest resources has increased resource extraction conflicts, malnutrition of women and their off-spring, lack of education for females, increased health risks and hazards to life including accidents due to landslides (Kothyari and Bhuchar 2010; Dhyani et al. 2011a, b; Rawal et al. 2012; Semwal et al. 2013; Negi et al. 2015, 2018; Dhyani and Dhyani 2020). The restoration models developed by GBP-NIHE in different parts of IHR have played an important role in meeting the need for forest resources such as fodder, fuelwood, leaf-litter, non-timber forest products, as well as improving local livelihoods and global environmental benefits. They have also reduced the drudgery of women in collecting fuel wood/fodder from distant forests. Multipurpose tree-crops combined with agroforestry models incorporating appropriate soil and water management technologies have become an effective way to mobilize local participation in the restoration programmes and increase their awareness of their environment, ensuring their contribution free of cost in long-term plantation management. With the initial success of restoration programme, people from neighbouring villages have also begun similar activities on both private and community lands.

The restoration models developed by the Institute have enhanced the livelihoods of the local inhabitants. For example, CHFST has enhanced yield of crops and vegetables by 40–50% at the model sites in the North-East region and addressed soil erosion reducing it by about 50%. The Banswara project enhanced yield of crops, herbs and spices while the restoration model at Champawat increased provision of fodder by a factor of four to five within 5 years. This generated 345–1280 t/ha (Rs. 10,483–52,964/season) on abandoned agricultural land and from 104 to 636 t/ha (Rs. 14,379–67,882/season) on the degraded community wasteland site. The increased grass production reduced the distance travelled for fodder collection as well as having financial benefits (Negi et al. 2015). These models serve as demonstration sites for institutions and government departments as well as for conducting research. They also have potential to reduce the pressure of extractive harvesting natural forests, contributing to in-situ conservation, limiting deforestation and fixing carbon in farmland and degraded lands.

12.6 Challenges and Lessons Learned

Despite the fact that the Institute has developed several successful restoration models in the IHR, various challenges were encountered. For instance, persuading communities to release land for restoration could be challenging. Multiple ownership and diverse attitudes of local people to restoration programmes can also limit success. Building trust is key to success in developing understanding about the long-term benefits of restoration and the Institute has followed this approach in every case. The cost of restoration was minimized by involving local people by offering them new sources of income to support their rural livelihoods. Traditional knowledge was supplemented with appropriate scientific innovations, and this was found to substantially reduce cost, speed up the process and mobilize local participation in inaccessible mountain areas (Maikhuri et al. 1997). The local people were made aware about the benefits of restoration programmes through regular interaction and meetings. Selection of species for plantation was done after assessing the needs of the villagers, particularly the women as they are primarily involved in collection of, for example, fuel wood, fodder and leaf-litter. Long-term management of the sites was also resolved by participatory approaches, and ecological, agro-ecological and socio-economic aspects were considered. Links have been developed between different institutions, villagers, practitioners and policy-planners with respect to wasteland restoration activities and this has led to the understanding that, although local people and scientists have different knowledge and skills, it is by working together that they can achieve better results than working in isolation.

12.7 Conclusion

Ecological restoration is an opportunity that provides a viable option to sustain the ecosystem goods and services in the context of adapting to climate change. An understanding of the mechanisms that have caused degradation on one hand and restoration techniques, such as planting multipurpose plant species on the other, is crucial for successful restoration strategies. Conversion of degraded land through mixed tree plantation rather than monocultures is favoured as this best meets the diverse product needs of local people as well as improving the environment. The research activities of GBP-NIHE have made a considerable impact on the attitude of local inhabitants with a positive change in their perception of conservation and natural resource management. This has helped reduce forest degradation, the drudgery for women and simultaneously met national and global targets for restoration in the Himalayan region. Most of the models and methods developed by GBP-NIHE are transferable and can be used in different locations in the IHR and incorporated into various government programmes, such as the Mahatma Gandhi National Rural Employment Guarantee programme (MGNREGS) and Integrated Watershed Management Plan (IWMP), which requires at least 40% of funding to target soil/water conservation and wasteland restoration.

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Chapter 13
Temporal Changes in Livelihood and Land Usage Patterns: Case Study of a Primitive Tribe, Van Raji, from Uttarakhand, India

Pankaj Tewari, Ripu Daman Singh, Pratap Nagarkoti, and Surabhi Gumber

Abstract Livelihood diversification may be of several types and it is believed that land usage patterns change with time, due to the changing livelihood patterns of mountain communities driven by multiple factors. This study was conducted to present the development of the Van Rajis with the developmental paradigm and to understand the changes in livelihood and land usage patterns in context of various factors, brought by several interventions made by Central Himalayan Environment Association (CHEA). Forest Landscape Restoration approach was adopted by CHEA as a Nature-based Solution to combat the problems faced by the tribes. The study is based on both quantitative and qualitative data collated from households and key-informants from community. The findings revealed that with temporal change in livelihood practices and land-use pattern, tribes were forced to look for alternative livelihood strategies, irrespective of various barriers such as no/poor education, small land holdings, etc. Such strategies would enable them to combat with the problem of income instability, food and nutritional insecurity. It is evident from the study that, livelihoods in tribal areas are vulnerable to factors such as climate change, unemployment, poor infrastructures, etc. Hence, tribal people experience various pressures and opportunities (livestock or land productivity) which are adopted as livelihood and coping strategies. This coping intent ability has arisen due to temporal change in the land utilization pattern in the present challenging scenario. Nature-based Solutions (NbS) can be an effective framework for establishing an alignment between biodiversity conservation and the sustainable development of the tribal communities.

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13.1 Introduction

Globally, land and forest have always been an intertwined part of rural life, especially for mountain communities. Change in land-use pattern has important implications for sustainable livelihoods of local communities where traditional crop-livestock-based mixed farming is sustained with local inputs (Semwal et al. 2004; Dhyani et al. 2011). Livelihood diversification may take place in various forms like concurrent diversification (when several activities are taken up at the same time to spread risk or increase income), temporal diversification (when household members change from one activity to another) or spatial diversification (geographical spread of activities, involving spatially separated assets or migration of household members) (according to Bhattacharjee et al. 2016). Steadily increasing population pressure, government restrictions on encroachment of reserve forests, better institutional support, education level, size of land holding, and social participation are some of the reasons for livelihood diversification (Samanta 2005; Saha 2006). These factors are also responsible for forcing rural people to move towards more remunerative and environmentally compatible land-use systems like horticulture, agro-forestry and timber plantations integrated with cereal crops (DFID 1999; Abdulai and CroleRees 2001).

In India, even after 72 years of independence, there are tribal communities that are still vulnerable, and in deplorable condition e.g. the Raing from Tripura, the Kuraga and Jenu Kuruba from Karnataka. Some of the major problems which tribal communities faces are poverty, health issues and social factors i.e. lack of education, however, it is more pertinent to look at each categories into greater details by carefully taking into account the nuances of a problem. This is despite the implementation of various schemes, plans and strategies by the Government of India, State administration, Non-Government Organizations and social workers, working for the wellbeing of these communities. These communities lag woefully behind others in terms of development and continue to be among the weakest and most exploited section of society. The Van Raji, one of the smallest tribes in India is among the five tribes (Raji, Bhotia, Tharu, Jaunsari and Buxa) of Uttarakhand state, in India. Despite been given the Primitive Vulnerable Tribal Group (PVTG) status by the Government of India, this community, residing in Central Himalayan region of Pithoragarh and Champawat districts in Uttarakhand is still educationally and economically backward. This tribal group constitutes around 811 individuals (~0.29% of the total tribal population of Uttarakhand) in ten villages occupying various mountainous elevations in both the districts. According to a survey conducted by CHEA in 2011, 688 individuals of this tribal population are from the nine villages of Pithoragarh and 123 in a single village in Champawat (Pandey and Sharma 2015). Until a few decades ago they lived a life typical of the Neolithic age, as cave dwellers and food gatherers, subsisting on hunting, fishing and Non-Timber Forest Products for their survival. At present, they are in a transitional stage between hunter-gatherer and preagricultural economy. However, being the natural owners of forests and its adjoining lands they are being deprived of their rights to own them.

There is the dearth of information about this small tribal community with respect to their socioeconomic status. This can be attributed to the close community structure that prevents interaction with other communities as well as their remote geographic location. In this context a case study was undertaken to understand how changes in land use over time has altered and influenced the process of transforming the livelihoods of this indigenous tribal community in the Central Himalayas.

13.2 Materials and Methods

The broad objective of the present study is to present mainstreaming of Van Raji community with the developmental paradigm as well as to understand the changing pattern of livelihood and land usage among the selected tribal population in the context of the changes brought about by various development interventions by the Central Himalayan Environment Association (CHEA). The study was also conducted to examine and understand the modes of diversification in livelihood generating activities that have gradually taken place amongst this indigenous population as a result of the changes that have occurred to traditional practices, such as encroachment into Reserve Forests and the ban on green felling above 1000 m, to promote settled agriculture and stability in livelihood practices. The study was conducted in nine villages in the Didihat, Kanalichina and Dharchula blocks of Pithoragarh District, of Uttarakhand.

To better understand how diversification of livelihood and patterns of land use have changed over time, 688 respondents were interviewed. Various methods were used for collecting precise quantitative data on income generation and livelihood resources i.e. questionnaires, Focus Group Discussions (FGDs), general observation, individual interviews, meetings and discussions with the community members. Before the household surveys a structured questionnaire was developed to gather the baseline information, and this was administered to 173 Van Raji households in Pithoragarh district, representing a statistically valid sample of all the age groups. The method was based on a participatory management approach, with direct involvement of the tribal communities with adequate representation of the women. A participatory, top-down approach was followed for the efficient implementation of the project activities (Fig. 13.1) and a mechanism was developed for promoting sustainable interventions to benefit livelihoods (Fig. 13.2). The collected data were analyzed and interpreted by measuring frequency distribution and percentage.

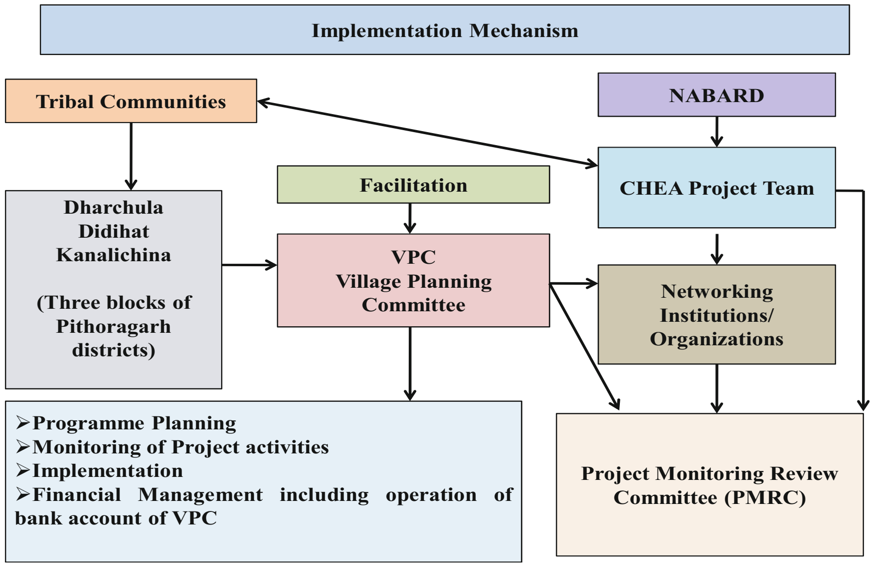

Fig. 13.1 Implementation mechanism following participatory approach

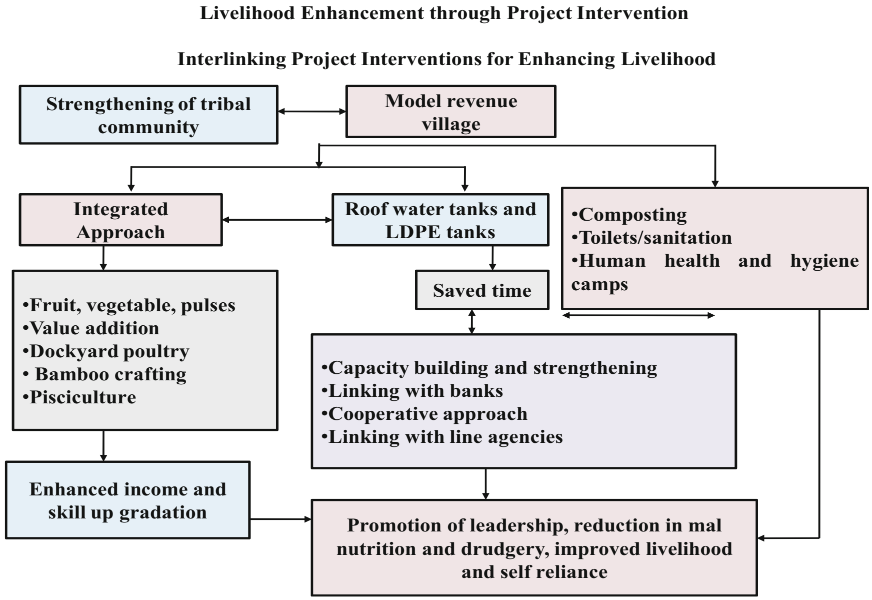

Fig. 13.2 Schematic framework of project interventions for livelihood enhancement

13.3 Results

13.3.1 Demographic Profile

The lifestyle and traditions of Van Raji is unique and related to the natural resource utilization as they live in close proximity with the biodiversity-rich landscape at high altitudes. According to the census of 1991 the population of Rajis was 1279 (Census 1991) but the present situation is different. The population is now 688 individuals, of which 333 are female and 355 male (Table 13.1). Six hundred and eighty eight live in nine villages of Pithoragarh District (Survey under the project study 2012) and 123 in one village of Champawat district (Kundu and Pal 2018). From the information gathered during the study period, it was evident that three villages, viz. Kimkhola, Kuta Chaurani and Jamtari, have a sizeable Raji population whereas Jamtari, Gainagaon, Madanpuri, Kulekh and Bhagtirwa villages have moderate numbers and the remaining two villages, viz. Aultari and Chifaltara, have a very small population. Population growth rate increased from 2.78% to 3.35% between 2011 and 2017 (Census 2011; Kundu and Pal 2018). The Raji have a low literacy rate of just 35.8% (7 years and above), comprising 47.2% of male and 22.5% of female literates (Anonymous 2001). Interest in education and literacy rates are growing but they have no technological facilities.

13.3.2 Cultural and Ethnic Diversity

At present traditional practices, such as hunting and gathering, are rarely observed. Agricultural labour, fishery and working with wood are the major sources of livelihood for the individuals of this community. They work as daily wage labours at constructions sites, receiving wages of Rs. 150–200 per day. They also work as

Table 13.1 Demographic profile of the study villages

Village	Development block	Households (No.)	Total population (No.)	Male (No.)	Female (No.)
Aultari	Kanalichina	8 (8[a])	38 (38[a])	24 (24[a])	14 (14[a])
Kulekh		8 (8[a])	54 (35[a])	19 (19[a])	35 (16[a])
Jamtari		22 (22[a])	94 (95[a])	44 (44[a])	50 (51[a])
Madanpuri	Didihat	15 (15[a])	60 (60[a])	32 (28[a])	28 (32[a])
KutaChaurani		27 (27[a])	103 (113[a])	53 (58[a])	50 (55[a])
Gainagaon	Dharchula	20 (20[a])	74 (71[a])	39 (39[a])	35 (36[a])
Chifaltara		12 (12[a])	36 (36[a])	19 (19[a])	17 (17[a])
Bhagtriwa		16 (16[a])	54 (54[a])	31 (35[a])	23 (19[a])
Kimkhola		45 (46[a])	175 (176[a])	94 (93[a])	81 (83[a])

Source: Survey under the project study (2012)
[a]Kundu and Pal (2018)

unskilled labour under Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGS) schemes, successfully introduced to support livelihoods by the Central Himalayan Environment Association (CHEA) which is active in this region. The Van Rajis are skilled carpenters and are associated with logging activities. Traditionally, they carved beautiful vessels from wooden logs but this practice is being lost. Large chir pine trees were felled with the help of indigenously made tools like the two man saw and then converted for construction was another traditional skill, a practice known as '*chiran*'. They also used to work as porters, lifting sand from riverbeds for construction purposes (known as '*bijri ka kaam*' in their local language). Out of 173 households of the Raji tribal community, 14 households were engaged in 'Chiran'; 28 households were agricultural labourers; 18 households were involved in making and selling wooden implements to sustain their livelihoods; 17 in both Chiran and agricultural activities; 66 households in miscellaneous works such as Chiran, hunting, and agricultural labour followed by 18 households in agriculture, ten in rock and mud loading and one each in private and government services, respectively.

In the past the Van Rajis were nomads and therefore did not possess any land or property. However, the effort of the CHEA and some other NGOs have enabled allocations of land, with named owners of fields, resulting a change in their status—now 128 households have received land rights from the government. The Van Rajis have a close relationship with the forest and have been living intimately with it for centuries. Non-Timber Forest Product (NTFP) collection was reported by almost all households as fulfilling daily requirements, with collection of a large number of edible fruits like mango, papaya, banana, hisalu, kaphal, and tarud, for example, as well as regional medicinal plants such as *Urtica dioca*, *Berberis chitria*, and resin collection from *Pinus roxburghii* (Table 13.2). A significant erosion of traditional knowledge, particularly in the youth of the Van Raji community was reported, relating to the forests and lifestyle changes.

A lot of the traditional culture has been lost. Deities like Kaiyu and Masan—'The Forest Gods'—are no longer worshipped and the traditional usage of plant roots, stem, leaves, bark and other parts against various diseases has been lost. No basic health facilities have contributed to deterioration of their health. To our dismay, it was also found that traditional skills in making wooden vessels and other wooden articles are also deteriorating. Poverty is the basic reason for quitting art and working as labourers to earn their daily bread. Though this community is trying to merge with civilized society lack of legal possessions and extreme poverty means they continue to be disadvantaged. They have shifted from traditional life as carpenters to rearing of livestock like goats and cows and practicing agriculture (wheat cultivation) on a small scale using homemade tools. However, Participatory Rural Appraisal (PRA) and household surveys indicate that on average 4–5 goats and 1–2 cow (along with one or two calves) are owned by a Van Raji household. As they are dependent on the monsoon for irrigation, they face poor crop productivity and insufficient crops to meet their food requirements.

Table 13.2 A comprehensive details of the various plants used for vivid purposes by Van Rajis

Species (common name)	Local habitat	Uses
Quercus leucotrichophora (Banj)	Madanpuri	Wood Sawing (Chiran), fuelwood, fodder
Cupressus torulosa (Surai)	Madanpuri	Wood Sawing (Chiran), leaves used for flavouring indigenous liquor
Cedrus deodara (Deodar, cedar)	Madanpuri	Wood Sawing (Chiran), fuelwood
Pinus roxburghii (Chir)	Aultadi, Jamtadi	Wood Sawing (Chiran), fuelwood, resin (lisa) for selling as well as for medicinal properties
Emblica officinalis (Amla)	Aultadi, Jamtadi	Edible fruits
Mangifera indica (Aam, mango)	Aultadi, Jamtadi	Edible fruits, fodder
Carica papaya (Papaya)	Aultadi, Jamtadi	Edible fruits
Musa paradisiaca (Kela, banana)	Aultadi, Jamtadi	Edible fruits, stem used as vegetable
Juglans regia (Akhrot, walnut)	Aultadi, Jamtadi, Madanpuri	Edible fruits, fuelwood
Myrica esculenta (Kaphal)	Aultadi, Jamtadi	Edible fruits
Citrus reticulata (Narangi, orange)	Aultadi, Jamtadi	Edible fruits
Citrus aurantifolia (Neembu, lemon)	Aultadi, Jamtadi	Edible fruits
Citrus sinensis (Mosambi, sweet lemon)	Aultadi, Jamtadi	Edible fruits
Diploknema butyracea (Cheura, Indian Butter Tree)	Aultadi, Jamtadi	Seeds oil yielding, medicinal value, fat extracted from the seeds named as Cheura Ghee
Urtica dioca (Bichooghaas)	Aultadi, Jamtadi	Medicinal value, used for soothing of burns, leaves used as vegetables, cloth made from leaf and stem hairs
Rumex dentatus (Janglipalak)	Aultadi, Jamtadi, Madanpuri	Soothing of burns, chutney
Berberis aristata (Kilmoda)	Madanpuri	Bark, root and seeds have medicinal value
Rubus ellipticus (Hisalu)	Madanpuri	Edible fruits
Dioscorea sativa (Tarud)	Madanpuri	Roots used as vegetable
Aillium (Doan)	Aultadi, Jamtadi, Madanpuri,	Roots and leaves mixed with wheat flour for making chapattis, good for stomach, roots for cooking
Sapindus mukorossi (Ritha)	Madanpuri	Soap, cosmetics, medicinal value

(continued)

Table 13.2 (continued)

Species (common name)	Local habitat	Uses
Rhododendron arboretum (Buransh)	Madanpuri	Flowers collected and sold in the market, medicinal value
Arundinaria falcata (Ringal)	Madanpuri	Baskets and other woven handicrafts
Acer oblongum (Putli)	Madanpuri	Fodder, enhances milk production
Ipomea batatas (Salgham, sweet potato)	Aultadi, Jamtadi, Madanpuri	Root edible
Bombax ceiba (Semal)	Madanpuri	Bark as medicine, mixed with flour, fodder
Terminalia chebula (Harad)	Madanpuri	For cough, medicinal value
Tagetes patula (Gendaphool)	Madanpuri	Leaves extract applied for soothing burns, antiseptic
Quercus glauca (Falyat)	Madanpuri	Fodder
Bauhinia purpurea (Koyral)	Aultadi, Jamtadi	Fodder
Ficus carica (Timla)	Aultadi, Jamtadi	Fodder
Terminalia bellirica (Behera)	Madanpuri	Edible fruits, medicinal value
Syzygium cumini (Jamun)	Aultadi, Jamtadi	Edible fruits
Psidium guajava (Amrud)	Aultadi, Jamtadi	Edible fruits
Litsea umbrosai (Dudhila)	Madanpuri	Fodder

13.3.3 Interventions for Livelihood Diversification

Tribal communities and their development are closely associated with the availability of natural resources, exploitative technologies and management. Over exploitation of natural resources due to population explosion resulted in depletion and deterioration of forest environment and it have much reflections on the livelihood of tribes. Protection, regeneration and optimum utilization with appropriate management of natural resources are the best solutions to achieve the sustainable environment. Stable and sustainable forest environment definitely provide ample scope for the sustainable livelihoods of tribals in the study region.

Nevertheless, with the constant efforts of CHEA under a project entitled, '*Livelihood Improvement of Tribal Community through promotion of Appropriate Technologies in Rural Hills of Pithoragarh District*' through the Integrated Tribal Development Programme, funded by National Bank for Agriculture and Rural Development (NABARD) between 2011 and 2017 and the Kailash Sacred Landscape-Conservation and Development Initiative, a transboundary project supported by ICIMOD, Nepal between 2013 and 2017, the Van Rajis have now adopted permanent settlements and the Hindi language. Traditional knowledge and their cultural practices are taken into consideration in order to chalk out a development programme and its implementation. Forest Landscape Restoration approach was adopted by CHEA as a Nature-based Solution to strengthen the livelihoods of the tribals which includes, protecting plant genetic resources through wadi establishment (Agri-horti-silvi), managing wild species (especially fish), and providing drinking and irrigation water. Following the results of rapid field surveys and review of secondary data, additional interventions have been promoted.

Though women contribute more to their family incomes, hence women empowerment of tribals through Self Help Group (SHG) formation was another initiative of CHEA which helps to elevate their status and participate in decision making process in all spheres. The tribal women have indigenous knowledge in collection of NTFP (Non-Timber Forest Products) items without damaging such yielding plant species in forest environment. Their participation in all the development activities is definitely helpful for the overall development of tribal communities. The households were organized into 16 Self Help Groups (SHGs) and Participatory Groups (PGs) leading to a collective approach involving 165 community members of which 153 are women and 12 male.

During the recent years the inhabitants, in spite of the difficult nature of terrain have, with hard work and surprising ingenuity, succeeded in eking out livelihoods from the fields, but not enough is produced to sustain the entire population. Land Restoration and distribution of additional land to the needy families with the help of state administration were the immediate interventions to solve the problem of food security. The livelihood interventions implemented in the study area were off-season vegetable cultivation (OSV) and cash crop cultivation (adopted by 175 households), wadi establishment (120 households), kidney bean cultivation (145 households), vermi-composting (120 households), rainwater harvesting tanks (141 households), bamboo crafts (14 households), protected cultivation under polytunnels (13 households), apiculture (bee keeping five households), integrated pisciculture (two households) (For more information, see Fig. 13.3). A total of 50 training sessions, each lasting 5–7 days, were delivered to support this along with 15 awareness raising camps on topics such as sanitation and child education were organized in selected villages. These events were organized for community members to develop social capital and raise awareness of simple rural technologies and this resulted in 102 master trainers/Rural Resource Persons (RRPs) across diverse topics and there are now a number of households which have adopted these technologies.

Tailoring workshops were organized for 20 Van Raji families with a financial aid from NABARD and followed up with the provision of sewing machines enabling repair of clothes and also making simple dresses for other community members for payment. CHEA has initiated the wadi system among the youth of the tribal communities. Demonstration plots of 0.1 ha (05 *nali*) were set up for different crops such as tomato, capsicum, cauliflower, brinjal, cabbage, chilly, pea, French bean, etc. 13 polytunnels for protected cultivation were established in Van Raji villages. In all, 22 ha of land was converted to cash crop production benefiting

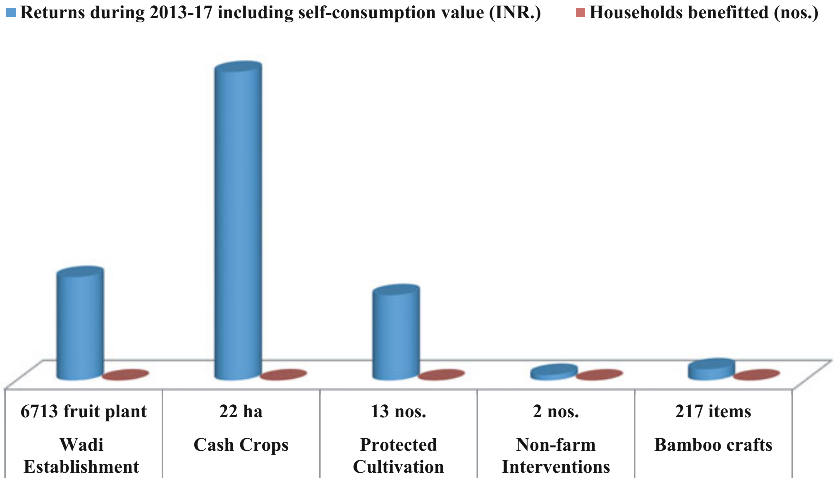

Fig. 13.3 Graph showing the income generated by different livelihood intervention and the households benefitted

175 households and the production was estimated to be 2735 quintals (Fig. 13.3). The financial gains are not very high but good enough for this tribal forest dweller community. They used the produce for self-consumption, with an average annual saving of Rs. 4500; the surplus was sold in the market. 145 households were supported in cultivation of kidney beans as an under crops in wadi or in agricultural land. About 3 ha area is being cultivated for kidney bean every year with approximate production of 1200 kg/year and income of around Rs. 55,000 is generated every year after self-consumption. None of the elderly respondents were resorting to pisciculture reflecting the propensity of this ground to continue their land and crop-based activities inherited from their ancestors.

All of the respondents expressed satisfaction with the experience of working with the CHEA initiatives. One, Mrs. Kalawati from Kuta Chaurani village, shared that, '*before the inception of the project we were dependent on the local market for fulfilling our daily requirements of fruits and vegetables, but after initiation of the project high yielding vegetable seeds were provided to us, along with technical support on cultivation practices and nursery preparation for reaping the benefits*'. In addition, the higher wage rates in private constructions, agricultural fields and other sources are additional income supporting the livelihood status of the family. Though males of this community were engaged in fisheries the major problem as expressed by respondents regarding this livelihood option was the lack of available ponds and lakes in the villages that were a common property resource. Two fish ponds were created in Van Rajis villages, with the help of ICAR Cold Fisheries Institute Bhimtal and Fisheries Department, Pithoragarh, as demonstration projects. The land reforms laws of the State government under the Forest Rights Act has given land rights to the tribes for plantation crops and orchards within the forest, depending on soil structure, but prohibits them from additional encroachment. The younger tribal generation was found to be proactive in utilizing such opportunities for economic gain.

Scarcity of water has always been a big challenge and a key issue in mountains and for the Van Raji it is further accentuated due to remoteness and the dry zone of the upper ridges. In order to deal with conservation and management of water and reducing associated labour for tribal families, 141 water harvesting tanks were constructed in nine Van Raji villages during the project period; 91 were stone masonry tanks, and 50 were LDPE. Formerly long distances were travelled to reach natural water bodies to collect drinking water. These are being used for fulfilling water needs ensuring water availability of 2,115,000 L (thrice in a year) and saving 1650 h annually for each household.

Bee keeping, is another livelihood intervention initiated by CHEA. After project completion there were around five beneficiaries with sufficient experience to train others. Honey production averaged 4–5 kg honey annually, fetching around Rs. 350–400 per kg in local markets.

Due to non-existence of the government or private services in this community, low education status, coupled with restricted land use and productivity individuals have been forced to choose non-farm-based livelihood options in many instances for survival. Previously, large scale exploitation by the non-tribal moneylenders and traders was taking place in the study region with Van Rajis, due to their innocence, ignorance and illiteracy. Education programmes were implemented properly in the study region to combat this problem. In this context reintroduction of adult education programme in the study villages of tribal communities had improved the literacy rate of Van Rajis. The Van Rajis speak a Tibeto-Burman language called 'Rawat' (Grierson 1909). The language is coded according to international standards as ISO 639-3: jnl and is an amalgamation of 'Raute' (ISO 639-3: rau) and 'Raji' (ISO 639-3: rji) {'Ethnologue, languages of the world.' ethnologue.com}. As these people did not understand any other language, but after interacting with the other communities and the outer world and the initiatives of CHEA, they have understood the value of education. From a position of little interest in education, they have begun to send their children to school enthusiastically. Some Raji individuals have got contractual jobs in the Raji tribal school, at Kimkhola. Two female students from Kulekh (Ms. Janki Kumari and Ms. Kumari Devki) and one from Jamtadi (Ms. Kumari Manju) had passed intermediate exams in 2015, inspiring the rest of the community. In Kimkhola village, one woman was found to be working as a maid in a block office and another reportedly working as maid in a tribal school.

Another initiative of CHEA is the conversion of Van Rajis village's Open Defecation Free (ODF) into 107 permanent and temporary toilets established by contribution, in six villages. These are now used by around 60% of the total tribal population in the region. Mrs. Dhana Devi, told us that '*initially we thought that why to invest but after receiving the guidance and benefit we not only constructed the toilet but also extended the infrastructure to have bathroom. Now we are using the infrastructure well which have reduced the mental stress and fear of moving out in* *open and forests. All families are happy and in comfort from such creation*'. She is now acting as a leader educating Van Raji families to contribute and adopt this intervention on contribution basis as an appropriate development.

13.4 Discussion

Rajis, residing in remote and inaccessible areas have a long history forest dwellers and hunters. They are deprived of almost all basic necessities like education, sanitation, health assistance and pure drinking water, due to their habitat in remote and inaccessible areas (Fig. 13.4). The Raji tribes have lived a very isolated existence. Traditional settlement, sociocultural life and environmental sustainability are challenges both for sustaining their current way of life and for responding to the need to provide for both the present and future generations. Sustainability is also necessary to create a balance between their demography, ecology, social and livelihood needs.

However, increasing population pressure and the consequent depletion of resources have made traditional livelihoods unsustainable, forcing their expansion into marginal areas, such as steep slopes, for diversification. Livelihood strategies in the farm sector are highly vulnerable to the uncertainties of nature. At high altitudes, such as the study area, the number of crops harvested in a year is limited. As a result, non-agricultural livelihood strategies are sought but hindered by lack of available markets and inadequate physical infrastructure.

Despite these barriers, coupled with no/low education and small land holdings, all the tribal families/beneficiaries targeted during the project period were forced to look for alternate livelihood strategies to enable them to combat the problem of income instability, food and nutritional insecurity of their respective families. Along with the adoption of new interventions and appropriate technologies and opening up to the outside world, they have become a major source of labour as well as wood sellers in the area. Agricultural and horticultural activities remain the mainstay of the tribal economy and continue to be the main source of livelihood for the majority of the population with new developments in the following areas:

1. Diversification in to cash crops like kidney beans, peas, cauliflower, tomato, etc. are being grown on a large scale which has resulted in increasing the financial status and livelihoods of the households (Fig. 13.5),
2. Planting of high yielding varieties of citrus fruits, etc. A pivotal role was played by the livelihood interventions implemented in Van Raji villages in generating cash, which has been scarce in the region in past. Kidney bean production along with vegetables was comparatively high under polyhouses and can continue all year round the year. Thus it can be treated as a useful adaptation.

Tribal people are now able to grow fruit and vegetables for their own consumption, and for sale at nearby markets. In non-farm sector most of the supplementary activities, such as skill-based industries are not long lasting. The economic activities

Fig. 13.4 The photographs depicting the livelihood status of Van Rajis. (Courtesy: Surabhi Gumber)

in this sector range from a simple increasing wage labour to trading and producing traditional skill-based commodities in individual households. In the study area, wage labour seems to have emerged as a viable non-farm economic activity. Van Rajis lead a simple life with meagre needs for day-to-day survival. After CHEA's initiatives, they had started learning from the outside world and understand the significance of education as well as modern ways of life (Fig. 13.5). In spite of some

Fig. 13.5 The photographs depicting the changes in livelihood status of Van Rajis (interacting and participating in Focus Group Discussions and meetings; involvement in on-farm activities and adoption of modern technologies). (Courtesy: CHEA Project Team)

non-farm activities, they remain closely connected with the forests and are still heavily depends on natural ecosystem goods and services. It is evident from the PRA conducted and the interest shown by the community towards new interventions that females of this community are more likely to invest in appropriate modern technologies and adopt ideas aiming at economic diversification.

In a nutshell, it may be concluded that the Van Rajis are likely to have more diversified livelihoods when they have better training and skills. The scope for livelihood diversification will also improve in line with better education facilities and awareness of government planning and schemes. It is clearly evident from this study that livelihoods in tribal areas are highly vulnerable to climate change, unemployment, poor infrastructure and inadequate traditional settlements and declining health status. Hence, a sustainable livelihood approach is required for Van Raji tribal communities, aiming to fully investigate livelihood options to design and implement an effective poverty reduction strategy.

13.5 Conclusion

Climate is changing rapidly, undermining the security of current and future generations. NbS are a fundamental part of action for climate and biodiversity; and also value harmony between people and nature, as well as ecological development and represent a holistic, people-centred response to climate change (Dhyani et al. 2018). Scaling-up NbS for mitigation, resilience and adaptation, ensuring people's livelihoods in the face of climate threats, including the conservation and restoration of forest, freshwater resources, and sustainable agriculture and food systems can play a major role in sustainable development of tribals as well as other communities in several ways. Many different combinations of occupations to support livelihoods have emerged in different contexts and in response to changes over time (Bhattacharjee et al. 2018). The result of the efforts made by CHEA for strengthening the livelihood status of this tribal community through NbS have revealed that no society remains completely static and a range of diversification options have been adopted by the Van Rajis, as an option, although income instability has compelled them to adopt, for example, restoration of land through wadi establishment and kidney bean cultivation etc. However, these solutions have their own merits and demerits and efforts are still required to support sustainable development and align this group with wider changes in society. Therefore, government policies, programs and schemes should involve such tribes in developing their sociocultural, economic and health conditions as promoting both welfare and development of the Van Rajis could lead to keeping their identity intact and preserving this small tribal population in India.

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Part III
Advanced Institutional Provisions and Policies for NbS

Chapter 14
Nature-Based Solutions for Restoration of Freshwater Ecosystems: Indian Experiences

Rooprekha Dalwani and Brij Gopal

Abstract In the wake of rapid environmental degradation including climate change, caused by various human activities, several concepts and approaches such as ecological restoration, ecological engineering, ecohydrology, ecosystem-based adaptation/mitigation, ecosystem-based disaster risk reduction, green infrastructure and ecosystem-based management, have been put forward during the past three decades for managing and restoring the natural and human-made ecosystems. More recently, the International Union for Conservation of Nature (IUCN) developed a new concept of Nature-based Solutions (NbS) which has been promptly promoted by the European Commission, World Bank and the UN-Water, among others. The NbS is projected to differ from the other concepts in its integrative, systemic approach to societal challenges and focus on human well-being and biodiversity benefits. The NbS approach is being applied to a wide range of issues—from agriculture and water resources to climate change as well as urban development. While the term 'NbS' has not yet been officially and formally used in India, many of the projects aimed at restoration and management, especially of freshwater ecosystems, have followed the elements of the NbS concept and approach, at least in some respects. This article briefly discusses the NbS approach in the context of freshwater ecosystems, and presents a few examples of its application to their restoration in India.

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14.1 Introduction

Water is one of the most important natural resources that determine the very existence of life on the planet Earth. It occurs in great abundance but about 97.5% of the total water on the Earth is saline or brackish and resides in the oceans (Shiklomanov 1993). Practically all of the fresh water is held in glaciers, polar ice caps, snow, and below the ground. Less than 0.3% of all freshwater on the Earth that is utilisable by humans for all their needs and is shared by numerous plants, animals and microbes dependent upon it, resides in rivers, lakes and wetlands which together occupy approximately 6% of the Earth's land surface. These freshwater ecosystems along with their enormous biodiversity provide immense valuable ecosystem services. However, various human activities, both on land and in water, severely impinge upon the water quantity, quality and the biodiversity, and in turn affect the ecosystem services of these freshwater ecosystems. It is now necessary to not only prevent further degradation but also to restore these ecosystems through various kinds on interventions. A variety of interventions, mostly based on engineering and grey infrastructure have been employed for the reduction and mitigation of the adverse impacts and as far as possible restoration of the ecosystems. It is in this context that the nature-based solutions are now proposed for meeting the objectives.

In this article, the emerging concept of Nature-based Solutions (NbS) are briefly examined together with its application to fresh water resources management and the state of degradation of freshwater ecosystems in India described. Then, the Indian experience with the restoration of rivers, lakes and wetlands using the principles and approaches relevant to NbS, discussed. It may be noted that the NbS is starting to appear in official or academic circles, but similar approaches developed in the past had been employed in India in many cases for mitigating environmental problems.

14.2 Nature-Based Solutions

During the past few years, various new concepts and approaches have been proposed that attempt to bring together several emerging ideas and extend them to a variety of natural and human-made ecosystems for their management. Some of them include ecological restoration, ecological engineering, ecohydrology, ecosystem-based adaptation/mitigation, ecosystem-based disaster risk reduction, green infrastructure and ecosystem-based management. These concepts and approaches emphasise upon the need to understand the structure and functioning of natural ecosystems, and how the human activities disrupt them with consequent impacts for humans themselves. They also stress upon the need for restoration activities that can lead to return to the earlier natural or near-natural state of the ecosystems.

The IUCN introduced the concept of Nature-based Solutions in its position paper to the United Nations Framework Convention on Climate Change (UNFCCC), (IUCN 2009), and promoted the concept by adopting it for its Programme for the period 2013–2016 that envisages ecosystem-based development and conservation using nature-based solutions for achieving the sustainable development goals (IUCN 2013). The IUCN defined it as, '*actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits*' (Cohen-Shacham et al. 2016). The concept soon found its way into policy and has been vigorously followed by the European Commission (2015) which states: '*Nature-based solutions aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes*' (see also, Maes and Jacobs 2015).

Although the concept of nature-based solution is still being debated and developed (Potschin et al. 2016), it has found wide support for application to a wide range of issues such as flood control, urban development and disaster risk management. As per Potschin et al., 'The term NbS first entered the mainstream scientific literature in early 2000s, in the context of solutions to agricultural problems-including Integrated Pest Management, Use of habitats to mitigate farm runoffs etc.' From mid 2000s, the concept also started appearing in works of industrial design and biomimicry and later from 2009, it was being related to methods for enhancing ecosystem resilience or adaptations. Eggermont et al. (2015) consider the nature-based solutions as the sustainable use of nature in solving societal challenges, Nesshöver et al. (2017) find in the NbS, an opportunity for: (a) transdisciplinary research into the design and implementation of solutions based on nature; and (b) overcoming a bias towards development alternatives with narrow perspectives that focus on short-term economic gains and effectiveness. Nesshöver et al. (2017) also state that the strength of the NbS concept lies in its integrative, systemic approach which prevents it from becoming just another 'green communication tool that provides justification for a classical model of natural resource exploitation and management measures'. Interestingly, a recent IIED Brief (2019; http://pubs.iied.org/17725IIED) on Nature based solutions to Climate Change adaptation, discusses only the Ecosystem-based adaptation (EbA), treating them as synonymous.

Very recently, Cohen-Shacham et al. (2019) have critically analyzed the strengths and weaknesses of the NbS comparing it with four other ecosystem-based approaches. They identified three distinguishing principles of NbS:

1. The NbS can be implemented alone or in an integrated manner with other solutions to societal challenges;
2. The NbS are applied at a landscape scale; and
3. NbS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

However, they also recognised that several concepts of other frameworks such as adaptive management/governance, effectiveness, uncertainty, multi-stakeholder participation, and temporal scale are not captured in the NbS principles. IUCN drafted global NbS standards and put on for global consultation in September, 2019 (https://www.iucn.org/news/ecosystem-management/201908/17th-september-have-your-say-iucn-global-standard-nature-based-solutions). The public consultation has now closed and IUCN plans to release these standards in it next World Conservation Congress (WCC) being held in Marseille, France in June, 2020.

14.2.1 NbS Typology

Eggermont et al. (2015) proposed a typology for the NbS, based on the nature and extent of interventions, and recognised three types as:

Type 1. None or minimal intervention in ecosystems. This type maintains/improves delivery of ecosystem services of preserved ecosystems. It incorporates areas where people live and work in a sustainable way including nature conservation and national parks.

Type 2. Partial interventions in ecosystems. This type develops sustainable and multi-functional ecosystems and landscapes that improve delivery of selected ecosystem services. It is strongly connected to benefitting from natural systems agriculture and conserving the agro-ecology.

Type 3. Inclusive intervention in ecosystems. This type manages ecosystems in intrusive ways and includes full restoration of degraded or polluted areas using grey infrastructures.

14.2.2 NbS and Water Resources Management

Haase (2015) observed that NbS can help to tackle three water-related problems: flood risk, water scarcity and water quality, for example through using or mimicking the natural processes of infiltration, evapotranspiration and phytoremediation. Recently, the UN World Water Assessment Programme has also lent its support to the nature-based solutions by stating that the '*NbS are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water. The defining feature of an NbS is, therefore, not whether an ecosystem used is "natural" but whether natural processes are being proactively managed to achieve a water-related objective*' (WWAP/UN Water 2018).

The World Water Development Report (WWAP/UN Water 2018) has discussed three areas of application of NbS in relation to water: (a) management of water availability, (b) management of water quality and (c) management of water-related risks. Natural ecosystems offer solutions for water storage along with other attendant ecosystem services (such as groundwater recharge). An important function of natural watersheds is to regulate the fate of precipitation by influencing its partitioning. Delayed and gradual runoff ensures prolonged availability downstream and prevents water-related hazards (flood and drought). The most significant of all functions of natural ecosystems is the maintenance/improvement or regulation of water quality in which the biota—from microbes to algae, plants and fish play a major role. Another important aspect related to NbS is the use of organisms in the assessment and monitoring of water quality. The Report also states that the 'NbS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. They can be applied at micro-or macro-scales'.

14.2.3 Advantages of Nature-Based Approach

With particular respect to water resources management, NbS offer several advantages that include (see Liquete et al. 2016, WWAP-UN Water 2018):

- Costs of implementation and maintenance are comparable or much lower than any engineering solution that involves elaborate construction and demands energy.
- Improved water quality can be assured at all times.
- There is better flexibility and adaptability to changing environmental pressures.
- These are more effective in tackling non-point sources of pollution.

Liquete et al. (2016) also concluded that green infrastructure performs equal or even better than the grey infrastructure alternative for water purification and flood protection, it has a similar cost, and it provides additional benefits (like wildlife support and recreation).

14.3 Degradation of Freshwater Ecosystems in India

Most of the freshwater ecosystems in India—rivers, streams, natural and man-made lakes and wetlands—are in different states of degradation. Deterioration of water quality due to organic pollution from disposal of domestic wastewater and other solid wastes is the most serious and widespread problem. Water quality deterioration is manifested in two forms: depletion of dissolved oxygen and enrichment with nutrients, high organic matter content (dissolved or particulate) in the wastewater causes turbidity and coloration of water, and its high biochemical oxygen demand (BOD) rapidly depletes the dissolved oxygen. Further chemical processes in the absence of oxygen result in the release and accumulation of harmful substances. Nutrients which enter the water bodies along with the runoff from the catchments, including urbanised catchments, cause eutrophication that leads to unsightly and often toxic algal growth, with consequent impacts on aquatic biota (Ryding and Rast 1989; Hutzinger et al. 2015).

Both mineral and organic matter are carried with the runoff from catchments where erosion occurs due to a variety of anthropogenic activities, making siltation a serious problem in all reservoirs and lakes. Himalayan rivers are known for their sediment load which contributed to the development of fertile floodplains and productive deltas but are now getting rapidly accumulated behind the dams, thereby affecting the reservoirs adversely. Whereas in rural areas, agriculture and overgrazing in the close vicinity of water bodies are important factors contributing to siltation, in the urban areas storm runoff carries with it all silt and solid wastes to the water bodies.

River ecosystems in India are degraded largely by the discharge of untreated or partly treated domestic sewage, industrial effluents and storm water from urban areas. However, they are getting increasingly impacted by the reduction in the extent of their floodplains (by embankments and urban encroachments) and agrochemical-based intensive cultivation on the remaining floodplains. The rivers are further degraded due to flow diversion and abstraction upstream that significantly lowers or eliminates their waste-assimilation capacity (Gopal and Vass 2013).

Invasive aquatic weeds, particularly exotic species such as water hyacinth, are among other drivers of rapid degradation, especially in lakes and reservoirs. They accelerate siltation as well as degradation of water quality. Amongst the other factors adversely affecting the freshwater ecosystems, mention must also be made of in-lake/in-stream activities such as washing, idol immersion, and disposal of religious offerings. Further, there is widespread shoreline modification through removal of natural vegetation, and disposal of solid wastes, usually followed by concretisation in name of lake beautification, river front development and recreational facilities, particularly in urban areas.

14.3.1 Impacts of Degradation

The degradation of aquatic bodies, especially lakes and wetlands, has both direct and indirect consequences for humans. The reduction or loss of various functions of lake ecosystems directly affects humans. For example, the reduction in area and depth by siltation affects the amount of water stored and the groundwater recharge. Recent flood events (September 2019) in and around Hyderabad were found to be the direct consequence of loss of natural water bodies in the drainage basin. Loss of riparian vegetation both along the river banks and lake shores not only causes loss of biodiversity but results in accelerated erosion and siltation, as well as unchecked entry of pollutants from the surrounding areas into the water body. Degradation of water quality affects drinking water supplies, human health and recreational use. The loss of fisheries and other biota due to eutrophication or toxic pollution have both direct and indirect social, cultural and economic impacts. Another impact of lake degradation is the decline in tourism which provides sustenance to numerous people (Gopal et al. 2010).

14.3.2 Restoration of Freshwater Ecosystems

During the middle of the past century, great concern for the rapid degradation of water quality, exemplified by the development of toxic algal blooms (eutrophication) emerged from a view point of recreational use of large lakes. In developing countries, the water quality concerns centred largely around domestic use of water. It is only during the past three decades that the multiple benefits or ecosystem services of the freshwater ecosystems are being realised along with the need for their restoration/rehabilitation. Initially, most of the efforts aimed at restoration of water bodies focussed largely upon engineering-oriented solutions that did not consider the water bodies as 'ecosystems'. More holistic, ecosystem-based approaches to restoration of degraded freshwater ecosystems however, emerged towards the end of the last century.

14.4 Indian Experiences

Long before the concept of NbS was formulated and promoted, its elements were well recognised and practised in India as also in many other countries (MOEF 2008). These elements of NbS also found support and acceptance in good measure by the policy makers. Recognising the threats that anthropogenic and non-anthropogenic drivers and pressures pose on aquatic ecosystems, the Govt. of India through the Ministry of Environment & Forests had been implementing 'Conservation Programs for Wetlands & Lakes', located in urban and semi-urban settings, since late 1980s and early 2000, respectively. The guidelines for implementation of the conservation projects for the lakes specifically provided the overarching policy framework with a clear emphasis on the non-engineering interventions and green infrastructure (NbS) for their restoration and addressing degradation due to pollution (Gopal et al. 2010). After the merger of the conservation plans for wetlands and lakes into the National Plan for Conservation of Aquatic Ecosystems (NPCA), the new Plan further reiterated the objective of halting and reversing the continued degradation of lakes and wetlands in the country through integrated management involving NbS as part of planning and implementation of the conservation projects. However, since the management of lakes & wetlands is based on diagnostic evaluation of not only the ecological and socioeconomic but also hydrological features, a mix of NbS with certain engineering solutions found place in the guidelines for NPCA to address the root causes of the degradation in order to maintain a network of healthy water bodies that can contribute through their diverse ecosystem services as well as sustain varieties of wetland dependent species (MOEFCC 2019).

Some of the initiatives are described briefly here. Two distinct areas of interventions can be recognised where nature-based solutions were recommended and implemented, at different scales, in case of all freshwater ecosystems—the rivers, lakes and wetlands.

14.4.1 Catchment Treatment

First of these areas relate to the catchments where anthropogenic activities cause depletion of vegetal cover with consequential soil erosion and high runoff. This results in hydrological changes, inflow of sediments and nutrients leading to rapid siltation and water quality degradation. Intensive agrochemical-based agriculture in the catchments also contributes to the same problems. Therefore, catchment treatment required extensive revegetation with minimal engineering support. Catchment treatment, focusing on revegetation around the lakes and wetlands has been undertaken extensively. Important examples of revegetating the catchment areas are those of Dal lake in Srinagar (Jammu & Kashmir), Loktak lake in Manipur, Lake Harike in Punjab, Lake Chilika in Odisha, and Upper Lake in Bhopal (Madhya Pradesh). During the past couple of years, extensive plantation exercise has been undertaken along a wide belt of floodplain on both sides of the river Ganga and River Narmada. Whereas in case of river Narmada, the State Government undertook plantation with the support of local communities (http://www.namamidevinarmade.mp.gov.in/horticulture.pdf), in the case of River Ganga, the National Mission for Clean Ganga formally supports this work through funds allocated to the forest departments of all riparian states (https://nmcg.nic.in/NamamiGanga.aspx#).

An action plan for 'Forestry Interventions in Ganga' were drawn out by the Forest Research Institute (FRI), Dehradun after a detailed study, which envisaged afforestation in 134,106 hectares along Ganga river in its riparian states. The project was approved for the period 2016–2021, at an estimated cost of Rs. 22,930.73 million and a MoU was signed with a Japanese firm in 2017. The plantation work was kick-started at Sambhal and Varanasi and is continuing.

14.4.2 Water Quality Improvement

Second area is that of improving water quality of rivers and lakes through two kinds of interventions: (a) prevention of inflow of pollutants by treating the wastewaters in a natural manner before they are released into the river or the lake, and (b) by in-lake treatment following NbS (see WWAP 2018).

14.4.3 Treatment of Inflowing Wastewaters

The conventional wastewater treatment by engineering-dominated methods involves huge civil construction and intensive use of energy for sewerage network and sewage/effluent treatment plants. Yet, a significant proportion of the wastewater effluents enter the freshwater systems through drains including storm water drains without treatment. One of the best-known nature-based solution to control, reduce and/or eliminate a wide range of pollutants from both the soil and water, and that is efficient, cost-effective, energy saving and resource-generating, is offered by bioremediation. Bioremediation is the process where pollutants are degraded or transformed to other less toxic forms under controlled conditions by the use of living organisms ranging from bacteria and fungi to plants (Dubchak and Bondar 2019). Prasad (2012) also considered bioremediation as 'interventions of biodiversity for mitigation (and wherever possible, complete elimination) of the noxious effects caused by environmental pollutants in a given site' and included phytoremediation and rhizo-remediation (often called as root zone treatment) within the term bioremediation. However, many people confine the use of the term bioremediation to only the use of microorganisms (Abatenh et al. 2017). Similarly, the term 'constructed wetlands' is used where aquatic and wetland plants are employed singly or in different combinations for the treatment of wastewaters from different sources (Vymazal 2008; Sundaravadivel and Vigneswaran 2001; Ghosh and Gopal 2010). In case of phytoremediation and constructed wetlands also, the microbes and the roots play a major role in the pollutant removal or degradation processes (see Shukla et al. 2011).

Whereas numerous studies have been undertaken in India on microbial bioremediation (Dafale et al. 2010; Kharayat 2012; Sharma and Malaviya 2016; Rana et al. 2017) and phytoremediation (including constructed wetlands) under laboratory and experimental conditions (see Prasad 2012; Juwarkar et al. 1995; Ghosh and Gopal 2010), there are relatively fewer examples of field scale applications with variable success. Microbial bioremediation has been attempted on some wastewater drains by dosing microbial consortia. Jain et al. (2013) used a microbial consortium developed by MSI Biotech, India, together with some co-enzymes at eight locations in the Khjarana drain in Indore (Madhya Pradesh). Data recorded seasonally over a 1-year period showed reductions in odour (more than 98%), BOD (75–80%) and COD (70%) as compared to that under natural conditions. Similar bioremediation has been implemented in drains in Kanpur (U.P.), Budha Nala, Ludhiana (Punjab), Morigate Nala, Allahabad (U.P.), City Drain, Farukhabad (U.P.) and Bakarganj Nala, Patna (Bihar) by the Central Pollution Control Board through different Implementing Agencies and with the funding from the Ministry of Environment & Forests, Govt of India, in 2012.

Constructed wetlands have been used on the field scale to treat domestic sewage and wastewater in drains before allowing the treated effluents to be discharged into streams or lakes (Billore et al. 1999, 2001). A large Phragmites-based constructed wetland was designed and implemented in Jaipur at Mansagar lake for meeting its water requirement. The wetland improved the quality of treated sewage effluents before their release into the lake. The National Lake Conservation Plan's guidelines specifically required the implementation of constructed wetland in lake restoration projects (Gopal et al. 2010).

Shristi Eco-Research Institute (SERI), Pune, developed a 'Green Bridge technology' which combines the components of both microbial bioremediation and phytoremediation, and involves filtration, biodegradation and biosorption mechanisms by microbes and plants. The technology patented by Dr. Sandeep Joshi, uses

Ecofert—the active microbial consortia, with biomats, sand, gravels and plants. The system is designed specifically depending upon the conditions and flow of the wastewater. It has been used satisfactorily for in-situ treatment in case of River Aharand Udaisagar lake in Udaipur (Kodarkar and Joshi n.d.; https://www.cseindia.org/green-bridge-technology-3788).

14.4.4 In-Situ Water Quality Improvement

Both bioremediation and phytoremediation have been implemented for in-situ improvement of water quality in the lakes. Microbial bioremediation was used for the first time in India in Lakes Ooty and Kodaikanal in Tamil Nadu, and lakes of Thane in Maharashtra (Box 14.1). Later, bioremediation was followed also in Lake Rankala of Kolhapur (Maharashtra). In the first phase of restoration of the Hauz Khas lake in Delhi also, in-situ bioremediation was initiated by INTACH to improve the quality treated effluent from a sewage treatment plant. However, its discontinuance created the problem of algal blooms in the lake (Bhatnagar 2018).

Box 14.1 NbS Experience at Thane, Maharashtra

Thane city is the first of the 18 Urban Centres on the periphery of Greater Mumbai. Topographically, Thane is separated from the mainland by the Ulhas estuary and the Thane creek, and is connected through reclaimed land with the island city of Mumbai. The city, surrounded by hills, has about 30 lakes within city limits. Most of the lakes were suffering from degradation of water quality to different extent.

Thane Municipal Corporation, responsible for addressing the environmental concerns, aims to conserve natural resources, protect the environment and improve standards of living on the concepts of Sustainable Development. In the year 2002, the Municipal Corporation initiated the Lakes Restoration Project under the National Lake Conservation Plan of the Ministry of Environment & Forests, to revive ten lakes in the first phase. In-situ bioremediation technology, using a consortium of microorganisms, was implemented for the first time in India. It also accompanied by the use of wetland vegetation around the lake periphery as well as the construction of filters and grease traps around the lakes (EMC 2010).

Around the same time, pollution levels along the creek were minimised by constructing lined soak pits, using bio-sanitiser enzymes, and planting about 0.1 million trees along the creek (EMC 2010).

Constructed wetlands in the form of small floating islands have been an age-old global practice for managing water bodies for various purposes (Van Duzer 2004). In India also, floating wetlands were traditionally constructed in Lake Loktak (Manipur), Dal lake (J&K), and Khajiar and Rewalsar lakes of Himachal Pradesh (Gopal et al. 2003). Although conflicting views have been expressed about them (Gopal et al. 2003), the floating masses of wetland plants have been demonstrated to help improve the water quality and have now been introduced in many lakes. In Hauz Khas lake (Delhi) itself, after the emergence of the problem of algal blooms, floating islands with wetland plants were introduced with encouraging results (https://www.indiawaterportal.org/articles/islands-float-delhi-lake).

In the Dal lake (Srinagar) while the age-old floating islands, which in fact got stranded and settled down reducing the lake area, were to be removed, new constructed floating wetlands were introduced as a part of the lake restoration program (Box 14.2). Recently, an NGO, Dhruvansh, introduced about 250 m^2 of floating islands in Lake Neknampur in Hyderabad (https://www.thebetterindia.com/129968/india-floating-island-hyderabad-lake/).

Box 14.2 NbS Experience in Dal Lake, Srinagar (J&K)

Under the component of Restoration and Development Works for Dal Lake Restoration Project in Srinagar (India), besides the activities like dredging of blocked channels, dredging and de-weeding within the lake, reed bed creation including creation of constructed wetlands was implemented effectively. The restoration of springs, shore line development, development of jetties and Ghats were other restoration activities undertaken.

Works on constructed wetlands were undertaken, mainly for further improvement in quality of treated effluents from the Sewage Treatment Plants and also to address the agricultural runoff from the lake catchment. Different plants species used for biological treatment in these wetlands were local species.

Another phytoremediation measure adopted in some places include the naturalisation of lake shore line with wetland plants in place of stone pitching or concrete lining, as implemented in Dal lake. Similar recommendations were made by a National Green Tribunal appointed expert committee for restoring the floodplain areas of River Yamuna in Delhi but the plan is yet to be implemented.

Among nature-based solutions, is also included the biological control of invasive aquatic weeds such as water hyacinth, *Salvinia molesta* and the alligator weed. Host-specific insects were introduced with good success against water hyacinth in Lake Manipur and lake Harike (Punjab). Since the insects had to be bred and introduced frequently, the control measures were discontinued.

Another oft-quoted and widely acclaimed example of NbS in India since late 1990s, are the East Kolkata Wetlands (EKW) which receive the untreated domestic sewage and storm water of the Kolkata metropolis. These are a series of natural and human-made freshwater ponds along an old estuary and have been turned into sewage-fed fisheries and vegetable fields on municipal solid wastes. The EKW is projected to have enormous waste-assimilation function and to support numerous livelihoods besides significant biodiversity. EKW were designated as Ramsar site in 2002. They are also projected to be a flood regulating structure for the metropolis but it is not readily realised that the original freshwater wetland system have turned into sewage lagoons and that out of the total sewage inflows, ‘more than 95% is siphoned off from the wetland to reduce water logging within the Kolkata city. Drastic reduction of freshwater flows and gradual dominance of marine flows has induced rapid siltation within the system’ (Kumar 2010). The system today suffers from several problems that raise a question mark on its being a NbS (for details see Kumar 2010).

Constructed wetlands, Dal Lake (Picture Courtesy: Dr. Rooprekha Dalwani)

Shore line naturalisation—in place of stone pitching/concrete lining.

Shore line development/plantation, Dal Lake (Picture Courtesy: Dr. Rooprekha Dalwani)

14.4.5 Sustainability of Conservation Measures Using NbS

The Nature-based Solutions need to be designed scientifically for achieving the desired results and require long-term monitoring and follow-up for providing standardised guidelines for implementing NbS. In this respect, the IUCN's planned release of Global NbS standards will go a long way to help streamline the use of the NbS. The sustainability of conservation measures using NbS is highly dependent on operation and maintenance resources to be provided by the local Government, having ownership of the responsible water management body or bodies (especially in case of the lakes and wetlands). One way of achieving this is by vesting the local bodies with specific statutory powers for generating resources through various means like, penalising the polluters, introducing sewage tax and collecting charges through the use of public facilities in the lake precinct etc., for making conservation efforts successful.

14.5 Conclusions

In its efforts to mitigate the problems of water pollution and to restore the freshwater ecosystems, India has already recognised the importance of interventions mimicking the natural ecosystem processes instead of grey infrastructure-based engineering interventions. Revegetation of catchments of water bodies, plantation along the margins of water bodies to check erosion and pollution, use of constructed wetlands for treatment of wastewaters entering the water bodies and even within the water bodies have been practised in recent years in many parts of the country at various scales. The restoration of these ecosystems for their biodiversity and ecosystem services has yet to go a long way and the NbS offer a viable, cost-effective and socially useful approach that needs to be adopted as a matter of policy (Dhyani et al. 2018; Dhyani and Thummarukudy 2016). However, adding a word of caution: the ecosystem structure and function if restored and/or managed can help, within certain limitations, solve the human-made problems only to a limited extent and at a certain rate. Some of the NbS also require to be standardised for their design parameters for effective implementation which is expected to be addressed to some extent by Global NbS standards of the IUCN. The nature and magnitude of the degradation of Indian freshwater ecosystems is more often so different and large as compared to some of the other countries that the NbS may have to be assisted or supported by some measure of engineering interventions.

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Chapter 15
Applicability of Nature-Based Solution Through Green Infrastructure Approach to Enhance Green Cover in Urban Transition Scenario

Shruti Lahoti, Ashish Lahoti, and Osamu Saito

Abstract Urban Green Spaces (UGSs) are relatively understudied in Indian context and needs immediate attention under severe pressure of destruction and degradation due to rapid urbanization. To protect and optimize the benefits received with increasing urbanization, it is utmost to understand potential role and current status of UGSs to achieve overall urban sustainability. Currently, UGS planning lacks holistic framework to create, maintain and enhance the UGSs, so the chapter explores possibility of applying NbS (Nature-based Solution) framework with a Green Infrastructure (GI) approach in emerging urban centres of India and the associated ground level challenges. The qualitative data was collected through 48 face to face key informant interviews (KII) in Nagpur city, to gain insights into affected greens in urban transition and the driver of change. Overall, 63% interviewee agreed with urban transition scenario, while water bodies, agriculture land and tree lined roads being the most effected UGSs. Amongst the key drivers, unplanned and haphazard development and overarching infrastructure demand are identified by KII. In terms of familiarity with NbS and GI concept, the awareness is poor, but overall discussion with informant indicated relevance of NbS concepts to enhance the UGSs of the city. This is further accentuated by review of different cases identifying the benefits of NbS to promote strategic planning through co-creation of knowledge with stakeholders and local citizens. Lastly, the applicability of NbS and GI concept is discussed as a potential way forward to guide UGS planning which looks at greens holistically with tailored approach for GI expansion.

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15.1 Introduction

The green areas (GAs) of the cities are key contributors towards maintaining the sustainability of cities by enhancing urban ecosystem and providing range of ecological and social benefits as evidenced in literature (Kabisch et al. 2015; Tzoulas et al. 2007). The extensive research on urban greens space (UGS) indicate the diverse and broad range of benefits they provide through various ecosystem service provisions (Kabisch et al. 2015; Tzoulas et al. 2007) along with cultural services which foster recreation activities, enhance the aesthetics, nurture human nature connection, knowledge sharing and preserve natural landscape features (Priego et al. 2008; Bowler et al. 2010; Lovell and Taylor 2013). This clearly identifies UGSs as crucial part of cities for wellbeing of urban dwellers. Thus, the key challenge for future urban planning is to prepare green spaces for an increasing urban occupant and create sustainable and liveable cities. However, in developing countries UGSs are under stress due to overuse and are threatened in transition process, while the vulnerability is further accelerated due to global environmental change (Bhaskar 2012).

Particularly, cities of developing countries witness special dynamics of urban transition with uneven demographic densities, changing landscape patterns, increasing traffic and congestion and other environmental challenges (Satterthwaite 2008). Indian cities are forerunner in urbanization with urban population rising up to 300 million by 2050 (UN-Habitat 2016). The urban transition scenario leads to conversion of significant proportions of agricultural land around urban areas and adversely effects the urban environment with substantial loss of green spaces (Govindarajulu 2014). The expansion of administrative boundaries while densities are low as the population growth rates lag behind the rate of the growth of built-up areas in all larger cities of India, posing several challenges like biodiversity loss, resource consumption and increased energy use for transport (IIHS 2011). The rapid transition is characterized by patterns and process of land use change (Schetke et al. 2016) which poses big challenge towards planning and expansion of urban centre while maintaining the UGS provisions within cities. The land use land cover (LULC) change analysis of emerging cities which are undergoing transition like Indore, Pune, Nagpur, Hyderabad, Vijayawada and many more clearly indicates impacts on urbanization on the urban environment (Bhaskar 2012; Gupta et al. 2014; Harika et al. 2012; Kar et al. 2018).

Particularly, in the emerging urban centres (more than one million populations) the urban planning efforts are disproportionate as compared to those in metropolitan cities, with less priority towards UGS provisions against other infrastructure demands like housing, water and sanitation, energy supply, which accelerates the challenges. In these emerging urban centres, which are undergoing urban transition, though the benefits of UGSs are recognized (Alberti et al. 2003), in general they are unrecognized, undervalued and are faced with either destruction or degradation in all major cities of India (Rao and Puntambekar 2014). The increasing urban sprawl, infrastructure development and land transformation with competing land use due to urban transition make the UGSs vulnerable (Anguluri and Narayanan 2017). Particularly, the arable land along the peripheries are engulfed by extending demands of cities grey infrastructure. As recorded in "McKinsey Global Institute" report, that through effective planning about 6 million hectares of arable land in India could be saved in coming 20 years (McKinsey 2010). In addition, several studies of LULC change have highlighted the impacts of urbanization on UGSs through increased built-up areas and decreased agriculture and waste land along the peripheries of the city (Bhaskar 2012; Harika et al. 2012; Kar et al. 2018). Some of the studies have highlighted the negative impacts of urbanization on reduced biodiversity of urban forest, degradation of wetlands and natural water courses within the cities (Dhyani et al. 2018a, b; Mundoli et al. 2017; Imam and Banerjee 2016; Surawar and Kotharkar 2012). The reserved greens like recreational greens are also faced with challenges due to over usage with increasing densities. The vegetation along the infrastructure corridor and the institutional greens are stressed and are declining with increasing pollution, concretization and under grey infrastructure expansion projects (Lahoti et al. 2019b). It is thus important to understand which greens are affected and what are the driving factors causing the decline of green cover.

Against this background of changing land use and lack of green space stewardship in urban areas which is resulting in fragmented and stressed UGSs (Dallimer et al. 2015), there is a need to revisit green space planning approach. In this situation the biggest challenge faced by authorities and urban planner is lack of capacity towards planning and implementing the change (ICLEI - South Asia 2015), unavailability of datasets and records of UGS provisions (TCPO 2014). This leads to disadvantaged situation. In order to revisit the standard planning approach and mediate the climate change related impacts, ecosystem-based approaches are gaining attention in urban planning and policy making to address water management, biodiversity conservation, urban biodiversity, human health and wellbeing related issue to attain sustainable solutions (Raymond et al. 2017). Though various strategies are introduced for developing and enhancing UGSs in developing countries the focus is more towards NbS (nature-based solution) concepts with an emphasis on GI (green infrastructure)-based approach to create sustainable cities as well as to address the "SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable" goal (Haase et al. 2017; Dhyani et al. 2018a, b; Dhyani and Thummarukudy 2016). NbS incorporate "the innovative application of knowledge about nature, inspired and supported by nature, to maintain and enhance natural capital" (EC 2015), that "address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits" (Cohen-Shacham et al. 2019). It is considered as alternative for grey infrastructure biased development and as an alternative approach for infrastructure update in cities (Fink 2016). NbS is also aligned with other sustainability concepts, with a subset of approaches like ecosystem-based adaptation, GI and ecosystem services which maximizes the benefits delivered and overall integration (Pauleit et al. 2017). NbS concept through GI approach mainly recognizes different contributions of green spaces to the urban environment.

In fact, in developing countries to overcome the pitfalls of standard planning approach new concepts are being explored to guide UGS planning at various spatial scales for protection, rejuvenation, revitalization, and creation of new UGSs in cities. Among these concepts, the ongoing research highlight the application of NbS related GI concept to provide place-based local solution with green spaces designed to generate co-benefits (Nesshöver et al. 2017; Raymond et al. 2017). The concepts are considered effective in restoring ecological flow in urban areas and strengthen sustainable urbanization with stimulated economic growth as well as improved environment (Frantzeskaki 2019; Lafortezza et al. 2018). The concept provides an attractive conceptual framework for viewing the mutual interdependence and interconnectivity of the ecosystems which exist within cities and which are mainly based in UGSs (Yusof 2012; Cohen-Shacham et al. 2019). As these concepts are not directly applied in green space planning in Indian cities the study reviewed some of the case studies from developed countries to identify the benefits of application of these approaches in UGS planning. For example, the many ongoing projects of Nature4Cities (N4C)[1] under "Horizon 2020" program of European union has clearly showcased the benefits of NbS to address challenges related to climate change, food security, disaster risk mitigation, water resource mitigation and biodiversity conservation (Balian et al. 2014). In green space planning, the benefits of NbS are recognized with increased provision and access to greens. The increased interaction with nature improves "quality of life, physical and mental health, recognized cultural identities, supporting a sense of belonging and place" (Keniger et al. 2013; Hartig et al. 2014). Under the N4C project many case studies have showcased various applications of NbS and the derived benefits. Like to mitigate the heat in urban areas (Kántor et al. 2017), health benefits for children and the elderly (Kabisch et al. 2017) and assessing the flooding and heat stress in Modena and developing the resilience plan (GoGreen Project website). These different cases clearly indicate the wider applicability of NbS concept not just to promote strategic planning but innovative ways of implementation through co-creation with stakeholder and local citizens. However, limited research and evidence-based frameworks with holistic perspective are still lacking (Haase et al. 2014; Frantzeskaki 2019). This hinders its mainstreaming in urban policy and planning (Frantzeskaki 2019). Particularly in India, application and integration of these concepts in planning practices are at nascent stage. Thus, the chapter intends to respond to this gap by understanding how far local stakeholders are familiar with these concepts through KII in the emerging city of Nagpur as case study area.

Nagpur is experiencing an unprecedented urban transition scenario with socioeconomic changes, population growth, land use changes, rapid infrastructure development and spatial expansion of city beyond the prescribed urban limits (Dhyani et al. 2018a, b). Additionally, the overarching focus on grey infrastructure under

[1]The N4C project aims to develop a scientific and technical database and operational tool for the effectiveness of Nature Based Solutions applied in a framework which considers a holistic approach and, which integrates multiple stakeholders (Ramusino et al., 2017).

smart city project and metro development project is putting an extra pressure on green spaces within the city limits. In addition, Lahoti et al. (2019a), identified a dire requirement to record the status of UGS and prepare spatial data to support planning, management and decision making to facilitate UGS governance in Nagpur. The identified deficit of recreational Gasby the Nagpur Municipal Corporation (NMC) development plan (MoUD 2015), further highlights the tremendous pressure on existing public UGSs to fulfill recreational functions as well as perform other ecosystem functions. Against this background, this paper reports the finding of the study on planning process and support transition process towards sustainable urbanization. The objectives of the study are: (a) to gain insights into the most effected green spaces in urban transition and key drivers of change; (b) to capture interviewees understanding about the standard planning approach and their familiarity with the key concepts of NbS and GI for green space planning and (c) explore the applicability of NbS concept through GI approach in addressing the challenges faced by Indian cities.

15.2 Materials and Methods

15.2.1 Study Area

Nagpur is thirteenth biggest urban agglomeration in India and third biggest city in state of Maharashtra (Fig. 15.1). Spatially, the city covers an area of 217.7 km^2 with

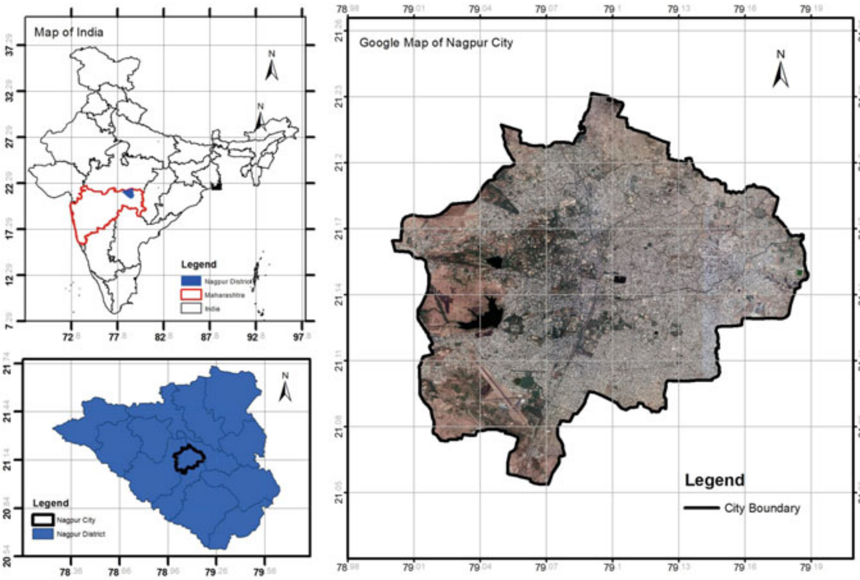

Fig. 15.1 Introduction to the study city Nagpur, Maharashtra, India

population 2.4 million (Census of India 2011). The city has tropical savannah climate (Aw in Köppen climate classification) with typical hot, dry and tropical weather with an average annual rainfall of 1162 mm, where summer temperature escalates to 48 °C and the winter temperature dips to 10–12 °C. The greenery in the city is mainly present in an around natural and artificial lakes, drainage basins of Nag and Pili River, vacant lands in fringes, urban forests, institutional greens, linear greens along the road, playgrounds, parks and gardens. The city is facing rapid and haphazard urbanization. In the urban transition scenario, the greens prevalent in the city are under tremendous pressure. Despite of the regulation and by laws of conservation the maintenance and management of urban green space poses a big challenge leading to their decline and deterioration.

15.2.2 Key Informant Interview

Key informant interviews (KII) were conducted with open and close-ended questions. In total 48 face-to-face interviews were administered during the period of March 25th to April 2nd, 2018 in Nagpur. For interview "semi-structured" format was selected against other methods of structured interview as the information to be sought was clear through literature review before conducting the interviews. The semi structured interview was designed to explore very specific questions related to urban transition and its impact on green spaces of the city. The method allowed to capture qualitative insights (McCracken 1988) with flexibility given to interviewer in terms of how objectives are to be achieved. Prior permission from municipal office was taken before conducting the interview along with letter of intent presented to the interviewee before commencing the interview. The participation was completely voluntary, and the interviewee can withdraw anytime, was mentioned to the Key informant (KI) before starting the interview. Each interview session took approximately 1 h to 1 h 30 min. The interviews were conducted up to saturation point, when the information became repetitive in nature the exercise was concluded.

In all, 38 pre-identified questions were prepared and divided in six sections. The set of questions used mixture of "open-ended", "closed" and "Likert scale" questions. The closed question allowed respondent to choose between specified categories which helped to complete the interviewee in stipulated time with increased rate of response and more sample size. However, to avoid biases due care was taken to balance between closed and open-ended questions. The last section was an open-ended discussion to get additional information which the interviewee feels relevant to the topic. Out of the six sections of the questionnaire, in this chapter the results of only sections 1, 3 and 4 are discussed. Section 1 captured the interviewee's professional background, qualification, experience, organization or workplace and general information. In section 3, impacts of urban transition, the key drivers of change and how it can be addressed to enhance natural environment of the city are gathered. While the following section recorded interviewee's opinion towards urban and landscape planning concepts widely used in other parts of the worlds, cities future vision and opinion on the strategies identified by smart city project (SCP) to increase green cover of the city.

15.3 Results and Discussion

15.3.1 Socio Demographic

Among the 48 interviewees 71% were male and 29% were female. The interviewee represented range of professionals like planners, engineers, environmentalist, ecologist and few from social science background (Fig. 15.2a). In terms of academic qualification most of the interviewee were highly qualified with doctorate and master's degree as shown in Fig. 15.2b.

The employment background reflects that majority of informant were working in Government sector and were involved in public UGS-related decision-making (Fig. 15.3a). The insights from private practitioner and social activist were also captured followed by opinions from academia. The professional and the educational background justify that interviewees had sound knowledge and expertise related to the research area. Their involvement and association with public UGSs also represented good coverage (Fig. 15.3b).

Additionally, more than 65% interviewee had worked and lived in the city for more than 10 years, which gives weightage to their opinions as they were associated with the city not just through their work but also as citizens of the city. The socio-demographic data validate that the interviewees were representatives working on different aspect of public UGSs who can associate well with the questions raised during interview.

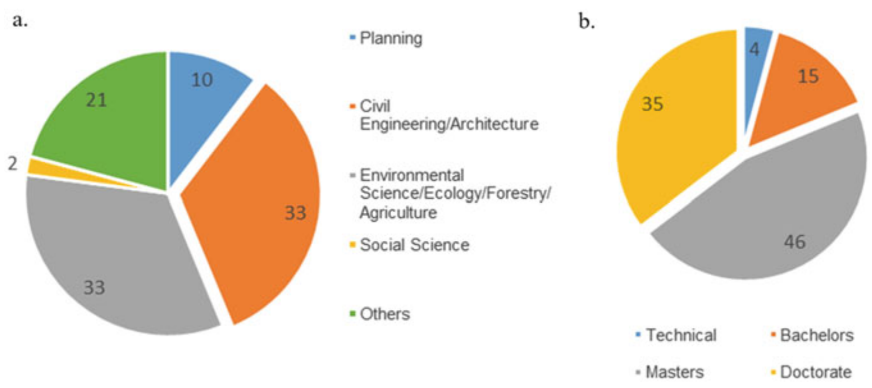

Fig. 15.2 (**a**) Professional background of interviewee in % (**b**) Academic qualification of interviewee in %

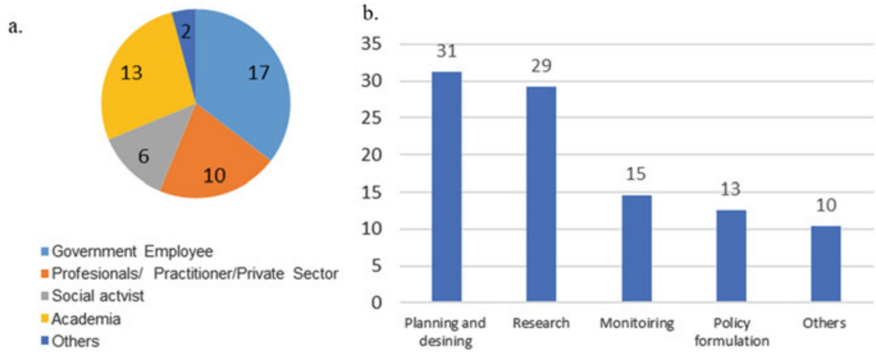

Fig. 15.3 (**a**) Employment background of interviewee in % (**b**) Involvement of interviewee with public UGS in %

15.3.2 Urban Transition and Key Drivers of Change

As Nagpur city is sprawling, the land use changes has posed many environmental issues to the urban dwellers like increasing air and water pollution, shrinking green spaces, increased flash floods due to increased build-up areas, and emergence of urban heat islands (Dhyani et al. 2018a, b). Nagpur's image as "Green city" and the presence of many "Tiger Reserves" in the vicinity is effected in urban transition scenario with substantial loss and degradation of natural greens (Surawar and Kotharkar 2012, 2017; Lanjewar and Kelkar 2007; Verma et al. 2011). The spatial mapping of urban growth of the city using geospatial technique for 1998 and 2010 indicate increase in built-up land by 15.47% and decline in vegetation and barren land (Kumar and Tripathi 2014). Another recent LULC study with 2016 land use data further emphasized on increasing sprawl with impacts on biodiversity and ecosystem services of the city (Dhyani et al. 2018a, b).

In addition to the research, the city development plan also indicates that city is undergoing expansion by merging surrounding villages into city's administrative boundary to accommodate the increasing population. However, the key informants helped in determining the typology of GAs as well as the key drivers of change. Overall, 63% interviewee agreed that the city has undergone considerable change in last decade, followed by 35% indicating slight change and 2% little change (Fig. 15.4a). This clearly represents everyone's agreement towards urban transition. The typology of greens mainly affected in urban transition scenario in last 10 years were mainly water bodies, agriculture land and tree lined roads as shown in Fig. 15.4b.

For determining the key drivers of change, the board categories of drivers were derived from the literature review carried out in general and specific to study area. The interviewees were asked to select top three drivers from broader category of five options and an open-ended category. Most interviewee chose unplanned and hap-hazard development as key driver followed by overarching infrastructure demand

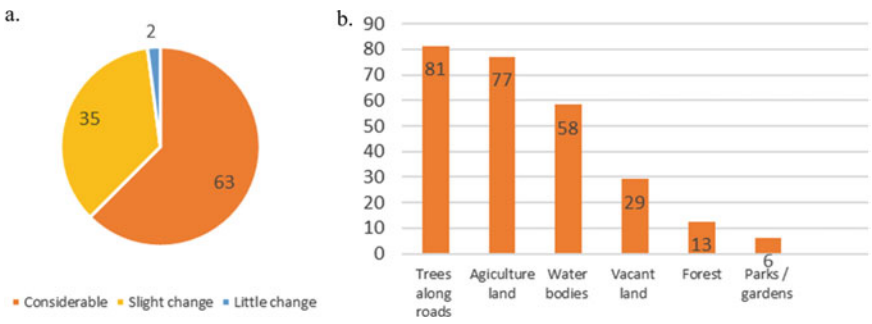

Fig. 15.4 (**a**) Interviewee's opinion on green cover change in last decade in % (**b**) Interviewee's reflection on UGS typology affected in urban transition in last decade in %

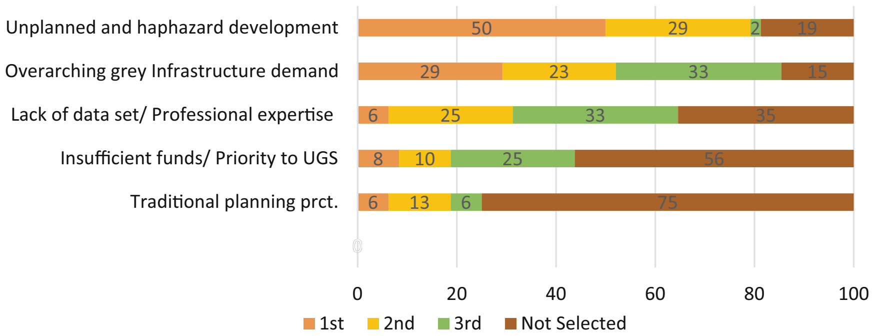

Fig. 15.5 Interviewee's opinion on key drivers leading to green cover change in city in %

and lack of data set or professional expertise as the main reasons of decline of green cover of the city (Fig. 15.5). However, it should be noted that planning practices is not considered as important driver. Though funding is highlighted by some respondents it's not identified as major driver effecting UGSs of the city.

15.3.3 Assessment of UGS Provisions

The cities have lower share of UGSs, and the standard provisioning approach is not effective as for many Indian cities the basic per capita open space availability is far below WHO norms of minimum 9 m^2 (McKinsey 2010). Thus, informant's satisfaction with city's greenery in terms of quantity and quality of UGSs is captured (Fig. 15.6). In terms of quantity and quality aspect responses favour towards dissatisfaction (44% and 54% respectively) than satisfaction (33% and 25% respectively), as the per capita recreational green space is only 3.65 m^2 per person (Lahoti et al. 2019b). Even for spatial distribution majority of interviewee (88%) agree that the distribution is uneven, as identified by Lahoti et al. (2019b).

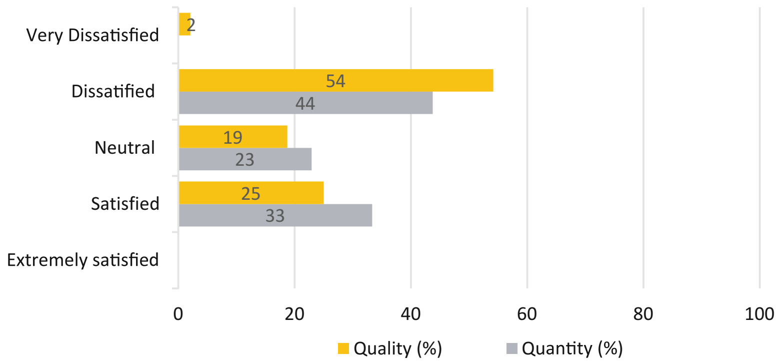

Fig. 15.6 Interviewee's rating about UGS quantity and quality in %

Regarding assessment criteria for UGS provisions, 75% interviewee agreed that quantitative data is necessary, but 90% interviewee strongly emphasized the need of more qualitative studies, to capture the landscape characteristics and functions of greens for more integrated planning to address uneven distribution and more inclusive planning approach. Also, as the quantitative assessment approach using landscape metrics (Kong and Nakagoshi 2006) are ineffective to understand the overall characteristics and structure of city landscape (Badiu et al. 2016), there is a dire necessity of revisiting planning approach as an effective way forward to operate urban areas, to achieve sustainable urbanization and save potential arable lands (McKinsey 2010).

15.3.4 Familiarity of Stakeholders with NbS and GI and Identified Benefits to Support Holistic Planning

In scientific discourse many recent researches revolve around the concept of NbS and GI approach and its application to enhance the co-benefits of UGSs and enhance the networks of green in city, however many gaps exist in term of its application in developing countries. Thus, the key informants where questioned to know about their familiarity about these concepts. In terms of existing level of incorporation of multifunctionality, the interviewee responded negatively (Fig. 15.7a), as 52% respondents suggest that the greens are not multifunctional. Although some of the greens were recognized as are multifunctional, the provisions are unintentional. When asked about familiarity with NbS and GI concepts, 38% interviewees were not at all familiar and 27% are slightly familiar (Fig. 15.7b). Only 25% interviewee had understating about these concepts and among them 70% recognize relevance of these concepts to maintain existing green, grey and blue infrastructures in the city (Fig. 15.7b). These stakeholders realize the role of UGSs to balance trade-offs while

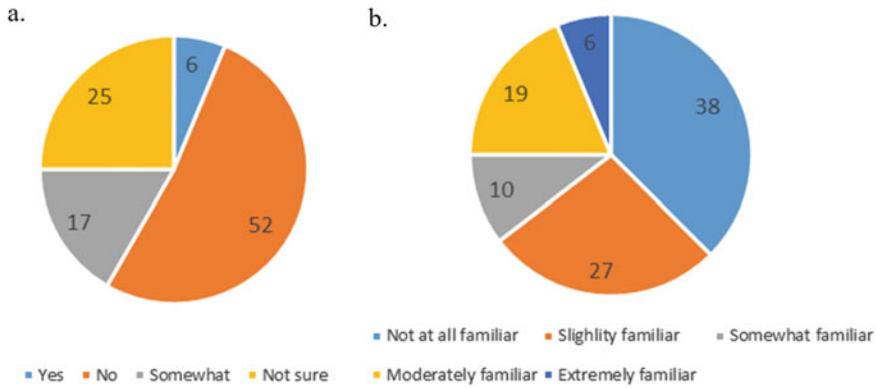

Fig. 15.7 (**a**) Interviewee's opinion on existing level of incorporation of multifunction in green spaces of the city (**b**) Interviewee's familiarity with planning concepts related to green space planning which are widely used in other countries to enhance the green cover of the city

the city is expanding and an emergent need of delivering multiple benefits though greens for overall sustainability of the city.

15.3.5 Applicability of Nature-Based Solution (NbS) Through Green Infrastructure (GI) Approach

Although during the interviews, most of the interviewee said that they were not much aware of the formal concepts of the NbS and GI approach, however during their interviews they discussed and shared several points, opinions and experiences which gave a clear indication that unknowingly they were aware of similar concepts and practices that can be somehow linked with the NbS concepts. In this section we have made an initial attempt to compile these outcomes of the interviews to check the applicability of the NbS concept for UGSs of the city.

NbS is an emerging concept which diverges from the conventional "grey infrastructure" approach (Davies and Lafortezza 2019) and incorporates measures that copy nature (EC 2015). NbS are defined as "actions which are inspired by, supported by or copied from nature". As included in the term, the focus of NbS is towards providing solutions to overcome societal challenges, like urbanization (Lafortezza and Sanesi 2019). In urban areas, as a new infrastructure, NbS are considered effective in restoring ecological flow to enhance the resilience of a city (Frantzeskaki 2019). The strength of NbS concept is its integrated perspective to address societal challenges, with focus on "multiple co-benefits for the environment, economy and society in urban landscapes" (Lafortezza et al. 2018; Dhyani et al. 2018a, b; Dhyani and Thummarukudy 2016). The solution-oriented approach responds to environmental change with a focus to provide co-benefit to individuals and their environment (Lafortezza et al. 2018). From city management perspective, NbS emphasizes on multidimensional benefits and as a transdisciplinary umbrella concept considering green infrastructure, ecosystem services and landscape functions in environmental planning as base concepts (Alberti et al. 2003). GI is particularly considered as keystone for sustainability of urban areas (James et al. 2009). The key features of GI are "strategically planned network of high quality natural and seminatural areas with other environmental features, which are designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings." (EC 2013). The concept is not new and has been widely used in landscape field (Wright 2011) and is considered as an innovative planning approach for conservation and protection of nature and green space planning (Mell 2009). In GI approach, UGS are designed to enhance green space systems with network of multifunctional greens (EC 2012). The definitions of GI as perceived by practitioners and researchers depends on the context (Benedict and McMahon 2006), the core idea is "connected network of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes" (Kambites and Owen 2006). Thus, key features are "connectivity, multifunctionality, and greens" (Wright 2011).

The different types of greens like avenue plantation, private and public greens, water courses, drainage channels, agriculture lands are all over the urban areas, and they perform multifunction with several benefits (Landscape Institute 2009) however are not regarded in an integrated manner as GI (Schäffler and Swilling 2013). Hence, the multifunctional greens need immediate protection against upcoming urban challenges as well as an evaluated placement in long-term planning and management (Davies et al. 2008). Thus, the key role of GI is that it considers existing natural assets as its key infrastructure components which performs multiple functions for urban sustainability (Landscape Institute 2009) and encourages planning of these physical components to be seen as connected whole rather than isolated individual areas (Benedict and McMahon 2002). Like planning of grey infrastructure, GI also supports the idea of integrated planning of all-natural greens of the cities (Wolf 2004). The holistic nature of GI approach is effective in handling complexities associated with designed landscapes or socio-ecological system (Kambites and Owen 2006), however as pointed by Mell (2009), applying an approach does not mean imitation of solutions from a random area. It needs tailoring the concept to suit the site-specific context to meet local needs.

The NbS framework can be effective in providing innovative solutions and eliminate sectoral thinking to safeguard and enhance UGSs in urban transition scenario (Fig. 15.8). They can help in recognizing the multiple benefits provided by UGS and their incorporation in totality at various spatial scales for conservation/protection, rejuvenation, revitalization and for creation of new UGSs. Like, sustainable water management is possible through NbS approach, where in co-benefits can be produced by managing storm water flooding while dealing with water scarcity (Lafortezza and Sanesi 2019). The urban trees can absorb carbon dioxide and provide cooler air temperature to ameliorate heat island effect (Mariani et al. 2016). Particularly for emerging urban centres like Nagpur, which are growing at three levels viz. congestion of the existing inner-city core, densification of the

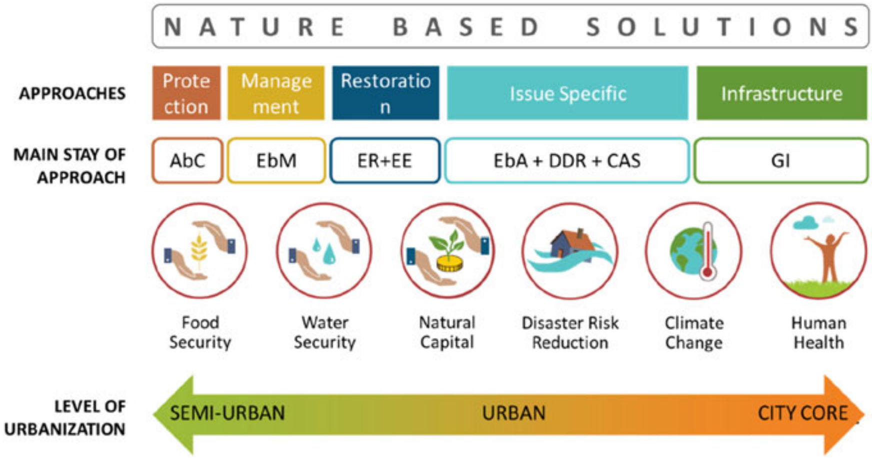

Fig. 15.8 Conceptual representation of application of the NbS umbrella for five categories of ecosystem-based approaches (adapted from Cohen-Shacham et al. 2019) to the emerging urban centre of Nagpur city keeping in mind the place specific natural contexts as well as needs (*AbC* area-based conservation, *EbM* ecosystem-based management, *ER* ecological restoration, *EE* ecological engineering, *EbA* ecosystem-based adaptation, *CAS* climate adaptation services, *Eco-DRR* ecosystem-based disaster risk reduction, *GI* green infrastructure)

existing peripheral urban areas within the officially administered areas and sprawling of the semiurban areas beyond the official administered urban boundaries. The above-discussed concepts have potential to guide UGS planning through a framework which looks at greens holistically with tailored approach for green in the urban core, peripheral urban areas and semiurban areas. However, at present in absence of a defined framework and approach the UGSs in all these three regions are being looked in singular manner and are being developed in isolation with a prefabricated standard development blueprint pattern there by undermining the true development potential of the UGSs as GI.

The current planning approach further reinforces the action of monotonous development of UGSs without integrating the multifunctionality which severely impacts the diversity and makes them more vulnerable against other immediate needs of the city. However, like the grey infrastructure planning process which transcends the various administrative boundaries to create a holistic network, NbS-based GI approach can be used to create a framework as well as a visible networking through all the three growing regions of the Nagpur city (Fig. 15.9). This would not just reduce the degradation and diminishing of the existing UGSs but also provides an integrated framework for future UGS development. Some of the probable interventions and guidelines for Nagpur are indicated in Table 15.1. Further at smaller scale under the NbS, the GI approach can create new greens (Frantzeskaki 2019) where in "place-specific" approach of using the existing natural assets would bring diversity in the typology of the green as a whole and be further augmented with multifunctionality and sense of ownership and through community participation (Frantzeskaki 2019).

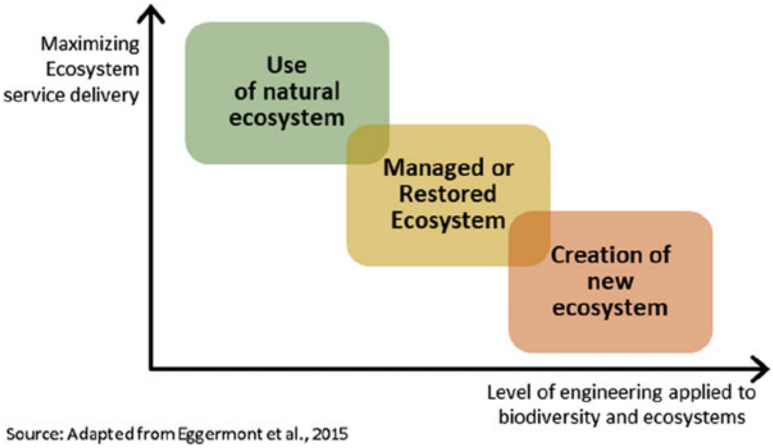

Fig. 15.9 A typology of NbS showing three main categories of solution based on natural, restored and new ecosystems. (Adapted from Eggermont et al. 2015)

Table 15.1 Conceptual representation of the probable NbS that can be implemented alone or in an integrated manner with other solutions to societal challenges

Solution	Intervention guideline	Probable intervention areas
Type 1	Solutions that involve making better use of existing natural or protected ecosystems	Mainly sprawl semiurban areas where a large part of the existing natural ecosystem is still intact like: lake catchment areas the hill areas some agricultural areas
Type 2	Solutions based on developing sustainable management protocols and procedures for managed or restored ecosystems	Mainly peripheral urban areas within the administrative limits where some part of the existing natural ecosystem can still be partly restored and managed; lake edges certain parts of Nag river the greens of hill the large-scale city level greens large roadside greens
Type 3	Solutions that involve creating new ecosystems	Mainly congested city core where the over urbanized areas need to create a new ecosystem mainly based on a large-scale engineering intervention Nag River edges community level open spaces Green roof and Green walls for new community buildings

15.4 Conclusion

Indian cities represents a case of in-situ urbanization, where cities are sprawling and expanding often devoid of systematic and scientific planning beyond formal administrative boundaries with drop in built-up densities (IIHS 2011). Moreover cities face urban grid lock with lack of basic quality of urban life, declining living standards, vulnerable infrastructure facilities and services (McKinsey 2010). In this fast pace urban transition scenario, the local authorities are faced with a challenge of providing basic facilities on the face of changing climate and weather variability, whereas the recent policy reforms have given more weightage to provision of immediate grey infrastructure facilities. And in the process consideration given towards protection and provision of green space services is negligible. Moreover, "inadequate environmental management measures have contributed to a significant degradation of existing valuable natural infrastructures, which is adversely affecting the quality of life of urban dwellers" (ICLEI - South Asia 2015, p. 16). In such urban transition scenario, the case of Nagpur city the study to understand the impact of urbanization on UGS and applicability of NbS concept through GI approach to guide UGS planning in totality at various spatial scales for protection, rejuvenation, revitalization and creation of new UGS in cities can provide a good way forward to the city planners.

However, many gaps exist in term of understanding the concept of NbS in a holistic manner as well as empirical evidence, particularly in developing countries. As evident from the KII, the understanding of NbS concept needs to reach at the grassroot level where the actual work takes place. Similarly, in the existing urban planning practices though these concepts are viewed as potential approach evidence-based frameworks which inculcate the holistic perspective to mainstream GI is lacking (Haase et al. 2014). Particularly in India, many barrier exit like spatial data availability, lacking interdisciplinary cooperation among different planning departments (Kambites and Owen 2006). Thus, for implementation of GI, a tailored approach as per the local planning task depending on spatial scale or thematic issue is recommended (Hansen and Pauleit 2014). Furthermore, explicit mention of the contribution of UGS as multifunctional landscape needs to be spelt out more clearly to prioritize them against other planning requirements. Hence, an integrated planning approach and framework of NbS and GI for planning and management of UGS with an empirical study is a priority area of research. A case study to showcase application of GI approach to enhance the network of greens as well as communicate various benefits in an integrated manner at city scale is needed to set a practical model which can be followed by other Indian cities as urban transition is recurring phenomenon in India.

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Chapter 16
Climate Adaptive Agricultural Interventions for Food, Nutritional, Health and Livelihood Security

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Abstract Managing agroecosystem via innovative agricultural practices and climate adaptive strategies is indeed a much-needed intervention to maximize the food production for feeding an ever-increasing human population. Also, such practises are essential for overcoming macro/micro nutrients deficiencies, hidden hunger and malnutrition. In this backdrop, the present chapter exemplifies various adaptive agricultural interventions that are vital in changing climatic conditions to maximize the food production for global sustainability. For an instance, adaptive practices to enhance major cereal productivity, improve soil quality, efficient use of water in agriculture, sustainable utilization of land, conserving lesser utilized pseudo cereals, green leaf's, vegetables, fruits and tubers, etc. are specifically conferred in this chapter. These interventions are imperative for agricultural sustainability and also to enhance the income and livelihood of smallest- to medium-scale farmers in many developing nations. Overall, large-scale adoption of listed climate adaptive measures herein, would also significantly contribute in meeting various national and global sustainable development goals and their targets set for year 2030.

16.1 Introduction

Agroecosystem is under constant rising threat principally due to overgrowing human population and changing climatic conditions (IPCC 2014). The progressive pace of human natality speculates world population to rise up to ten billion by the end of this century (IPCC 2014). Decline in per capita availability of agricultural land results into expanded pressure on land resource, land degradation and thereby food shortage in many parts of world (Edrisi et al. 2019). 1.5 billion people (expected to reach 3.9 billion by mid of century) are still living under the grind of food poverty in most

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developing nations of south Asia and sub-Saharan Africa (Wheeler and von Braun 2013). Nutritional insecurity, hidden hunger, malnutrition, obesity, premature death of children's, affected physical health, well-being and livelihoods of millions of resource poor farmers are threats too, that remain aligned with agriculture sector (Arora 2014). These are the holistic panniers for global biodiversity, amidst of which the agrobiodiversity and soil biodiversity largely faces radical penalties (Singh et al. 2019). Satisfying food and nutritional security is mandate for good physical and mental health, well-being, and quality of life (Dubey et al. 2016, 2019a). In this backdrop, managing agroecosystem under changing climate for food, nutritional, health and livelihood security for one and all, is therefore a prime concern of twenty-first century, both for farming and scientific communities as well as for national and global agencies (Dubey and Singh 2017). This chapter therefore exemplifies adaptive agricultural interventions such as climate resilient/smart agricultural practices; key resource (soil and water) conservation in agriculture; and sustainable utilization of neglected and underutilized crop species (NUC/NUS) for maximizing food production, offering nutritional and health benefits and decent livelihood for one and all. Agricultural interventions conferred in this chapter merits for their scoping and upscaling, if substantial number of United Nation Sustainable Development Goals (UN-SDGs) and their targets set for year 2030 and also post-2030 transformational change (craving to be imperative for agricultural sustainability) has to be achieved (Abhilash et al. 2016; Dubey et al. 2019a, b, 2020).

16.2 Sustainability Challenges in Agriculture Under Changing Environment

Explicitly, changing climate negatively impacts the agriculture sector through various biotic and abiotic stresses on daily basis. Major biotic stress affecting crop plants are: emerging newer pests and disease incidences; herbivory; weed infestations, etc. Abiotic stresses are direct climatic influences or erratic weather events affecting larger agricultural landscape viz. drought, heat shock/waves, flood, chilling stress, salinity, UV radiations, ozone pollution, storms, heavy rains, cloud bursts, etc. (Dubey et al. 2019a). In addition, depleted critical natural resources due to anthropogenic influences further bud these biotic and abiotic stresses (Fig. 16.1).

UN backed study reveals that farmers and industrial agriculture altogether have largely been able to increase food production up to threefold in past two decades as also evident for worlds major cereals discussed in ensuing section (https://news.un.org; Fig. 16.2). However, this has been possible at expense of intensive and unsustainable agronomic practices (such as heavy tilling, overuse of agrochemicals, pesticides, fertilizers, water for irrigation, multiple harvests, etc.) which extensively degrades/depletes the environment (farmlands, soil, water, groundwater and air). For one example, intensive agriculture has globally degraded ~33% of land resources

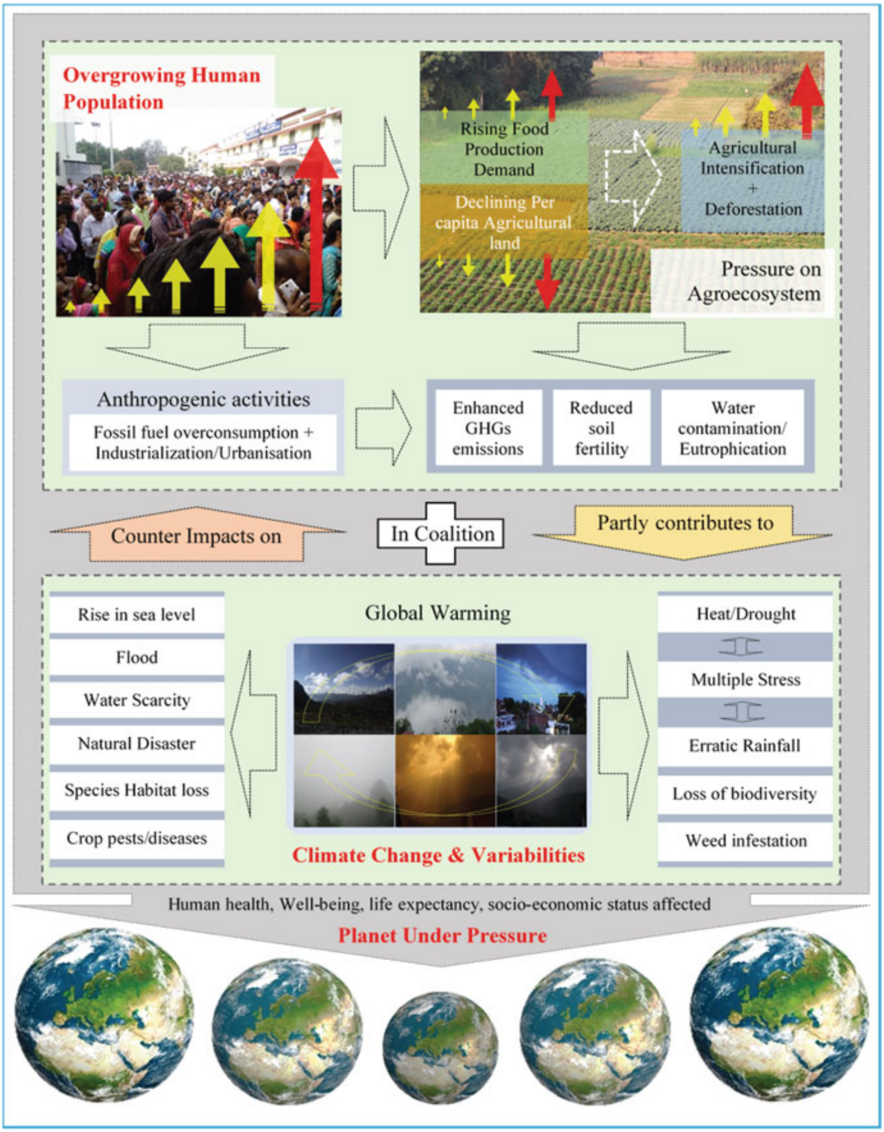

Fig. 16.1 Outline of combined impact of changing climate and overgrowing human population on agricultural system negatively affecting the planet healthy food production (Singh and Abhilash 2018a, b, 2019; Dubey et al. 2020). 'Yellow' and 'red' coloured upright/downward arrows are schematic representation of 'past to present trend' and 'future projections', respectively

and is turning soil infertile at the rate of 2 billion t year^{-1} (Wall and Six 2015). Unsustainable ways of agricultural intensification have already reduced the soil nutrient status (especially organic carbon content) and biodiversity, caused desertification, pollution, etc. Nutritionally deficient soil eventually results in nutrient

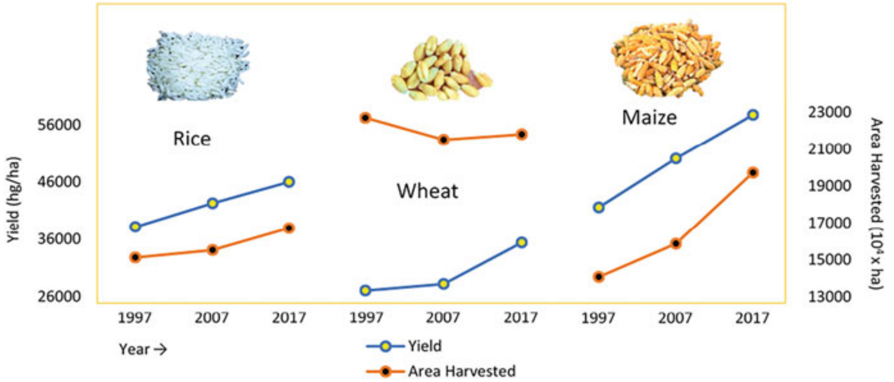

Fig. 16.2 Rise in yield of major cereals (maize, rice and wheat) over past two decades, attained through various adaptive interventions viz. increase/decline in total harvested land area for these crops. This showcase the agricultural adaptability under changing climate, overgrowing human population, land degradation and other factors arising due to climate change. (*Source: FAOSTAT*)

deficiency in humans also (Bhaduri and Purakayastha 2014; Dubey et al. 2019a, b). By middle of the century, ~50% to 70% more production demand of food, fibre, fuel, pharmaceuticals etc. is predicted, which inevitably is forcing for agricultural extensification (requires >60% additional land and ~2.7 to 4.9 M ha year^{-1} arable land by 2050) amid of expanding industrialization and urbanization (Alexandratos and Bruinsma 2012; Abhilash et al. 2016). Agriculture, at such crossroad in second half of the century will face enormous harsh impacts, if no immediate climate adaptive measures are taken in remaining three decades of first half of the century (Challinor et al. 2014).

16.3 Climate Resilient Agronomic Practices for Agricultural Sustainability

Farmers themselves are highly adaptive in nature and keep experimenting new ways at local level to improve their farm productivity (Dubey et al. 2019a; Dhyani and Dhyani 2015). Crop/species/breed/field/farm level emerging agronomic practices are employed by almost all range of farmers (small, medium and large landholding) to bring climate resilience in agriculture either by conserving resources viz. water or building resilience in agricultural soil. However, large-scale utilization of such climate resilient agronomic practice needs industrial and/or government support (Hartoyo et al. 2016). Climate resilient/smart agricultural practices potentially sustain food production in harsh environment thereby ensuring maximum farm generated income, profitability, nutritional and health benefits, reduced GHGs emission and agricultural pollution (Rao et al. 2016).

16.3.1 Climate Resilience Through Water Resource Conservation

Climate resilient agriculture includes shifting the dates of sowing, irrigation, harvesting and also changing planting densities, volume of irrigation water and mode of irrigation viz. drip irrigation or flood irrigation, fertilization rate, and monitoring of straw biomass to be returned into the field etc. (Rao et al. 2016; Dubey et al. 2019a). Water resource conservation is equally crucial for agricultural sustainability and enhanced profitability for all range of farmers. Water harvesting and storage can be done in various ways such as from roads, by small water harvesting pond/fish pond, tube recharge, subsurface dams, sand dams, check dam, valley dam, valley tank, demi-lunes, terraces, grass strips, mulching, agroforestry, etc. (Salman et al. 2016). Countries lying in east (Uganda) and west (Burkina Faso) parts of Africa are employing such methods of surface or ground water storage and soil moisture conservation. These adaptations are beneficial for farmers and local people as it supplements irrigation, and helpful for vegetable production in regions having rainfed agriculture regime. Grass strips on contour lines with gentle slope of 2% having band width of 1 m with grass species such as *Vetiveria nigritana*, *Cymbopogon Schoenateus* and *Andropogon Gayanus* conserve soil moisture significantly. Overall, mode of water conservation and storage could offer scope of irrigation during dry seasons or during dry spells in wet season. Conservation agriculture (CA) has quite substantial scientific evidence to be one of the promising climate adaptive strategy been practiced not just in tropical nations like India and Africa but also in North African (Morocco) and South American (Brazil, Paraguay) countries which are relatively less vulnerable to warming climate (Dubey et al. 2019a). Agronomic practices under CA majorly include crop rotation, crop residue retention, cover crop cultivation, and organic manuring. In Indo-Gangetic Plain region of Asia, CA minimizes nearly one-fourth of production cost, reduces GHG emission to some extent, increases irrigation water productivity by >65%, and reduces canopy temperature by 2.5 °C that allows crop to withstand under warming climate (Sapkota et al. 2015). Example from north African nation (Morocco) could also be cited as ‘crop rotation and crop residue retention’, increase the crop yield in range of 10–150% over conventional tillage practices (Salman et al. 2016).

16.3.2 Climatic Adaptation by Building Resilience in Soil

Soil resilience in crude sense means soil enriched with organic carbon and microbial diversity. Crop diversification strategies such as intercropping, perenniation, crop rotation, double, mixed and companion cropping are means to increase net system productivity, above and below ground interspecific interactions, soil microbial diversity, and soil health and fertility (Rakshit et al. 2017; Misra et al. 2008a, b, c). Mixed plant canopies offered by crop diversification helps in absorbing more heat and light and tends to increase the uptake of soil macro and micro nutrients by crop plants, thereby enhancing nutritional value in plants edibles parts. Plant growth-promoting microbes/bacteria/rhizobacteria (PGPM/PGPB/PGPR) does multitrophic participation in between plant, soil and microbial communities which offers climate resilience for plant growth and development under stressful environmental conditions (Rana et al. 2012). Alteration in soil microbial community by PGPR agent such as arbuscular mycorrhizal fungi (AMF) has potential to increase soil aggregation and carbon sequestration (Dubey et al. 2017). Beside single inoculation, application in form of consortia may improve both soil C and N storage depending on synthesis of glomalin or glomalin-related proteins (Walley et al. 2014). Under elevated CO_2 condition it has been reported that inoculating *Pseudomonas fluorescens* is able to enhance crop productivity by enhancing C:N ratio in plants (Nie et al. 2015). PGPR also has potential to sequester carbon, reclaim degraded land, promote yield, and improve nutritional make up in plants. For instance, pot study of inoculating consortia (*Pseudomonas aeruginosa* BHUJY16 + *P. putida* BHUJY13 + *P. aeruginosa* BHUJY20 + *P. putida* BHUJY23 + *P. fluorescens* BHUJY29 + *Azospirillum brasilense* + *Azotobacter chroococcum* + 30 kg ha^{-1} P_2O_5) in rice showed significant increase in grain yield by ~9 g pot^{-1} (Yadav et al. 2014). Likewise, in wheat crop inoculation of '*Providencia* sp. PW5 + $N_{60}P_{60}K_{60}$' significantly increases Mn, Cu and Fe content by >36%, 150% and >105%, respectively, while co-inoculation of '*Providencia* sp. PW5 + *Anabaena* sp. + $N_{60}P_{60}K_{60}$' showed rise in yield and grain protein content in range of 11–18% as compared to only $N_{60}P_{60}K_{60}$ application (Rana et al. 2012). Furthermore, enhancement in terms of grain yield, soil quality and economic returns in cereal based cropping is discussed in ensuing section.

16.4 Adaptive Agriculture for World's Three Major Cereals: Maize, Rice and Wheat

Maize, rice and wheat are world's topmost produced cereals with average production of 817, 685, 600 million t during year 2009, 2008 and 2007 respectively (http://www.fao.org/faostat/en/#data). As a result of adoption of climate adaptive strategies and practices by farming communities worldwide, yield of these cereals remained increasing in general and over preceding two decades in particular despite of multiple sustainability challenges in agriculture (Fig. 16.2). Existing scenario urge replication (based on similarity in agroclimatic/agroecological conditions) of resilient agronomic practices at larger agriscape for attaining global food, nutritional, health and livelihood securities (Dubey and Singh 2017). For illustration, some examples of promising practices for cereal cultivation from different regions/nations are discussed herein subsections.

16.4.1 Climate Adaptive Agronomic Practices in Rice-Wheat System

Decision-making for adoption of climate and site-specific agronomic practices are being done through simulation-based studies via climate and crop models (Dubey et al. 2019a). For one example, CERES model for rice and wheat crops and DSSAT cropping models estimated 'alternate wet and dry irrigation practices + dry seeded rice with deep placing of urea in soil + crop residue retention' for drylands of central Asia to be far more beneficial and resource conserving as compared to 'water seeded rice with flood irrigation and no crop residue utilization for soil health recuperations'. Adoption of such climate smart agronomic practices can save ~60% irrigation water and increase crop yield nearly by 0.5 t ha^{-1} (Devkota et al. 2015a). Simulations studies revealed rice yield increases 13 years after adoption of practice, while wheat yield increased since inception of the practice (Devkota et al. 2015a). Likewise, various adaptation in agronomic practices is employed time and again by farmers for more farm-derived benefits such as enhanced yield, resource conservation and improved soil quality etc. For example, 'dry seeded rice + surface seeded wheat + crop residue retention' saves >65% volume of irrigation water in comparison to conventional (dry tillage + flooded irrigation in rice + surface seeded wheat) farming practice as witnessed in North-West Uzbekistan (Devkota et al. 2015b). This practice can overcome excessive salinity loss at deeper soil depth (which otherwise may have long-term disadvantages in cereal cultivation), and when done in established bed field 15% more volume of irrigation water could be saved. Study done in Faisalabad, Pakistan revealed 'zero tillage in wheat + aerobic rice culture' over 'deep tillage + flooded irrigation/alternate wet and dry irrigation' conserve relatively more resources and has higher monetary benefit: cost ratio (Farooq and Nawaz 2014). Although, zero tillage in wheat leads in occurrence of narrow leave weeds such as little seed canary grass but mentioned agronomic practice minimizes the emergence of other major weeds such as toothed dock (Rumex dentatus L.). For Indo-Gangetic plain (IGP) region, in addition to zero tillage practice, timely sowing of wheat after rice harvest offers multitude of advantages. For example, it can conserve water, control weed (Phalaris minor), increase yield (by 5–7%) and save input cost (by and US$ 52 ha^{-1}) (Erenstein and Laxmi 2008). For improving soil health and system productivity using cover crops, wheat crop residue retention in field prior to rice cultivation, direct seeded rice, zero/reduced tillage in wheat and green manure viz. *Sesbania* cultivation during fallow periods are promising practices for tropical climate as in IGP plains (Rao et al. 2016). Bhattacharyya et al. (2015) also investigated in Indian tropics Shift from rice-wheat to rice-wheat-green gram cropping system following dry seeded rice cultivation as well as no tillage (for rice and mung bean) and residue retention (40% of rice residue and entire mung bean residue) increases above ground biomass by 2.9 Mg ha^{-1} $year^{-1}$, grain yield by 10–15%, soil organic carbon by 150 kg C ha^{-1} $year^{-1}$ in 5–15 cm top soil layer. Labile carbon pool increases by ~25% subsequently projecting 125% increase in soil carbon content in next 3 years. This will reduce soil bulk density, increase surface soil nutrient holding capacity thereby enhancing overall system productivity.

16.4.2 Encouraging Maize Cropping as an Emerging Adaptation

Owing to relatively high system yield and less water intensive, maize cultivation in rotation with rice or wheat crop is gaining more attention and is replacing the existing typical rice-rice or rice-wheat cropping pattern that predominated in many south Asian nations (Gathala et al. 2015; Singh et al. 2016). Farmers adopting maize-based cropping are getting additional income benefits, as maize production provides feedstocks for poultry and fish industries which are expanding their brim owing to overgrowing global food and dietary demands. Therefore, global rise in 'area harvested' and 'yield' of maize is relatively higher than rice and wheat in past two decades as shown in Fig. 16.2. In eastern gangetic plains of Bangladesh and in West Bengal, India where three seasons (boro/rabi; aus/premonsoon kharif; aman/monsoon kharif) of intensively irrigated/rainfed rice cultivation with wet tillage leaving rice stubble of 5–10 cm in the field, was once (decades ago) largely practiced, has now shifted to just two seasons rice cropping (Boro and Aman) due to declining critical natural resources in agriculture. In compensation to system yield losses caused by such transformation and restore/enhance system productivity, Alam et al. (2015) in Bangladesh validated two adaptive strategies. One is integration of maize/mung bean during fallow period (aus season) and second is replacement of Boro rice cultivation by potato-relay maize-mung bean cultivation. Both practices showed significant rise in yield, water and energy use efficiency and net economic benefit in range of two- to threefold. In addition to this, intervention of resilient agronomic practices specifically for maize cropping is need of an hour for better water resource conservation and many associated farm benefits. For an instance, rice-maize cultivation with conventional tillage and puddled rice transplantation degrades the soil structure, hamper yield potential due to delay in maize plantation, require intense cost, energy and labour inputs (Gathala et al. 2015; Singh et al. 2016). However, interestingly practices such as zero/strip/reduce tillage on established raised bed, dry seeded rice cultivation and crop residue retention can potentially increase grain and system yield and be a cost-effective strategy for resource poor farmers (Bhattacharyya et al. 2015). 'Flat-bed crop establishment mode replaced with raised bed + zero tillage' practices in maize-wheat-green gram cropping system along with residue retention of wheat and maize crops in the field can increase system energy use efficiency by 9% over conventional farming practices as observed in North-West IGP in India. Despite relatively more energy is invested in mentioned adaptive practice during the process of land preparation, seed sowing and irrigation, but residue retention on other hand significantly increases the energy output by 17% (Saad et al. 2016). Intensively irrigated maize systems in North India majorly includes maize–wheat–mung bean, maize–mustard–mung bean, maize–maize–Sesbania and maize chickpea–Sesbania (green manure) etc. Parihar et al. (2016) enumerated how 'permanent bed preparation + zero-tillage' agronomic practices can be beneficial over 'conventional tillage' practices in these maize based cropping systems in terms of maize and glucose equivalent yield, water use efficiency and net economic gain over period of 6 years. Rise in maize and glucose equivalent yield ranges between 1.3 and 1.9 Mg ha^{-1} and 0.5–1.0 Mg ha^{-1} respectively, while irrigation water volume required decreased by 50–81 ha mm. System water productivity and net profit raised by 20% as the cost input for zero tillage minimizes at rate greater than 70$ ha^{-1} (Parihar et al. 2016).

16.4.3 Balanced Fertilizer Application for Reduced Environmental Externalities

Optimum fertilizer dosage and limiting the leaching of soil nutrients in cereal based cropping, is mandate to limit agriculture based GHGs emissions and thereby global warming. For example, shallow flooding with suitable nitrogen management in rice can reduce N loss in soil by 2.8%, limit GHG emissions by $>$34% and increase rice yield by 1.7% (Chen et al. 2016). In summer maize cropping, optimum dosage of N fertilizer could reduce N losses by 44–65 kg N ha^{-1} and increases N efficiency and partial factor productivity by 16% and 36 kg kg^{-1} respectively (Cui et al. 2008). Guo et al. (2015) in parts of China where average rice grain yield is 7.67-t ha^{-1}, advised 200–250 kg N ha^{-1} to be optimum field nitrogen fertilizer dosage for appropriate plant nutrient uptake, nitrogen use efficiency and grain yield. Cao et al. (2014) proposed increment in fertilization frequency and decrement in rate of N fertilizer field input with dense planting of seedlings in rice-wheat cropping system. This practice enhances rice grain yield by ~7%, reduces nitrogen leaching by 21% (in particular reduction in nitrate leaching by 14%). Study done in Haryana, India for rice-wheat cropping system convince 'no tillage + split nitrogen fertilizer application with site specificity (amount and time of fertilizer broadcasted is based on nutrient expert, Green Seeker TM)' to be much more climate adaptive and resilient over 'conventional tillage + fertilizer inputs as per state recommendation'. Significant decline in global warming potential of wheat production was noticed with 3% and 5% rise in plant biomass and yield (Sapkota et al. 2014). Specifically, basal N fertilization as per nutrient expert optical sensor for wheat cultivation can limit N_2O emission to a large extent. Moreover, suitable NPK nutrient management strategy (depending on yield targets, crop nutrient demand and field nutrient application) for wheat cultivation at landscape level in IGP region of India have showed rise in grain yield by 1.55-t ha^{-1} and provides remarkable net economic return of US$ 585 ha^{-1} (Singh et al. 2014).

16.5 Neglected and Underutilized Crops (NUC) for Nutritional and Health Security

Food and agriculture organization of united nations (UN-FAO) have recently projected Neglected and underutilized crops/species (NUC/NUS) and its wild varieties to be future climate smart crops (www.unfao.org). Such wild crops are genetic resource and a treasure trove of special climate resilient traits for breeding and future crop improvement program (Dubey et al. 2016; Nair 2019). These crops can be grown anywhere (marginal/degraded land, rail/road ways), demands minimal agronomic care, are stress (drought, heat shocks, salinity etc.) tolerant, less resource intensive, and are nutritionally and medicinally enriched (Nair 2019; Singh et al. 2018a, b, 2019; Fig. 16.3). NUC have tendency to eradicate poverty, hunger, hidden hunger by generating local markets of locally grown wild edibles and providing balanced diet through dietary diversification. It can profoundly help in meeting various UN-SDGs (No poverty, zero hunger, good health and wellbeing) by providing healthy and nutritive food to one and all (Singh et al. 2018a,b; Singh and Abhilash 2019; Dubey et al. 2019a).

Wild crops such as Indian spinach, wild amaranth, pseudo cereal, pearl millet, winged bean, word bean, ground cherry, etc. are rich in Vitamins, Calcium, Iron,

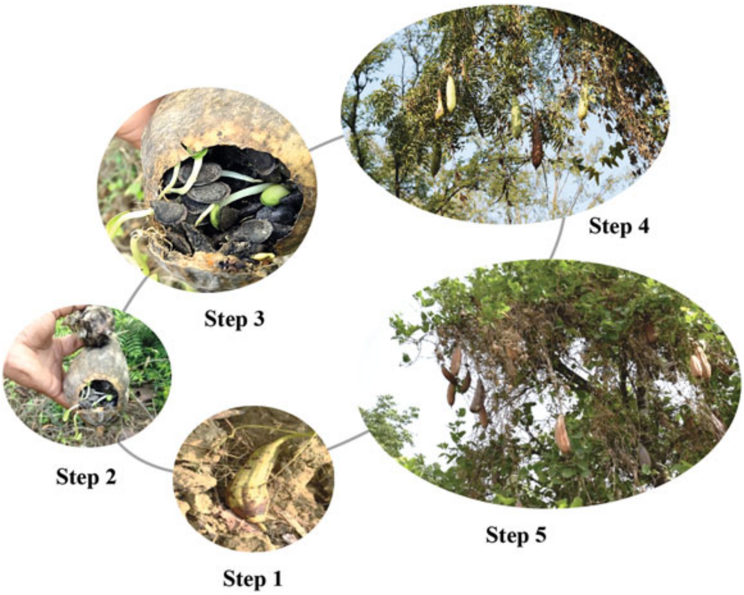

Fig. 16.3 The cycle (steps 1–5) shows minimal/no care required for NUS and wild crops, as they are highly drought, salinity, temperature and pest tolerant. Step 1: Ripened fruit fall on its own on ground at maturity; Step 2: In rainy season seed germination starts by available soil moisture; Step 3: Germinated seed emerge out; Step 4: Plant connected to surrounding shrubs or tree start luxurious growth; Step 5: Ripened fruit again falls on ground and cycle continues likewise

Magnesium, Phosphorus, Potassium, Zinc, and other essential amino acids (Singh et al. 2018a). Many NUC crops in general have vitamins and other nutrients in relatively much higher proportion in comparison with many modern crops (Dhyani et al. 2010; Misra et al. 2008a, b, c). For one example, the protein content in winged bean is 5 and 10 times more than in yam/taro and cassava/sweet potato respectively (Karikari 1978). Similarly, Vitamin A, Vitamin C, Ca, K, Fe and protein content in Moringa is 10, 7, 17, 15, 25 and 9 times more as compared to carrot, orange, milk, banana, spinach, yoghurt, respectively (Rockwood et al. 2013). Reports states Amaranthus contains Vitamin C, Ca, Niacin 3 times more than spinach; and Vitamin A, Vitamin C, Ca, Fe more than 18, 13, 20, 7 times as compared to Lettuce (Guillet 2004). Interestingly, the habit and habitat of Amaranthus or Indian Spinach (Basella Sp.) lies at areas where human influences are extremely common (Fig. 16.4).

Arora (2014) reported total 992 NUC species of world, region wise distribution of which across globe is shown in Fig. 16.5. Few examples of highly nutritive, neglected and underutilized millets species suitable for Indian climatic conditions are listed and displayed in Table 16.1 and Fig. 16.6. Moreover, validation of suitable agronomic practices for growing different NUC crop species in any agroclimatic conditions is also highly imperative. In addition, recently four steps have been proposed for sustainable utilization of such wild, neglected and underutilized crops as: (1) exploring the unexplored; (2) refining the unrefined traits; (3) cultivating the uncultivated; (4) popularizing the unpopular (Singh et al. 2019). For attaining food and nutritional security in different geographies of the world different set of agronomic practices those are validated for different NUC species are listed in Table 16.2 for illustration.

16.6 Integrated Farming Practices for Enhancing Farmers Livelihoods

16.6.1 Organic Farming Practices

Integration of animals viz. cow, buffalo, sheep, goat, poultry, fish, etc. in farmlands, use of green manure, biofertilizers, bioinoculants, replacement of chemical fertilizers and pesticides with organic agroinputs, etc. are all one or other form of organic farming been practiced by farmers (Misra et al. 2008a, b, c; Rao et al. 2016; Dubey et al. 2019a). Organic farming can be best coupled with mixed crop-livestock farming practices as crop residues (straw) generated can be used for feeding domestic animals, while animal waste/cattle dung generated is used as source of organic agroinputs for optimum soil and crop nutrient management (Abhilash et al. 2016; Rakshit et al. 2017). Small to large farmlands in African region viz. Murehwa, Ruaca, and Gorongosa generates 0.2–2.2 t ha^{-1} of crop residue which is less in quantity (<30%) for utilizing it as cover crop, however since it serves as straw for

Fig. 16.4 Two NUS i.e. *Amaranthus viridis* (A–F) and *Basella alba* (1–6) shows ubiquitous distribution: backyard garden (A, 4); kitchen garden (2); agricultural field/boundaries (3, 5); on boundary walls (B, C); vegetables field (D); road side (E, 1); railway track (F); Boundary walls (6)

cattle feeding therefore it can sustain livestock population as well as soil fertility by addition of dung and urine excreted by livestock (Rusinamhodzi et al. 2016). In rice-wheat cropping system addition of farm yard manure + domestic sewage sludge can compensate 25% requirement of N fertilizers, impart soil fertility, and results in less water intensive rice cultivation (Bhaduri and Purakayastha 2014). Green manure is more beneficial than cattle manure in terms of reducing risk of nitrogen loss (as nitrate in soil and as NH_3, N_2O, N_2 in atmosphere), replacing amount of chemical fertilizer and high crop yield (Ti et al. 2012). For instance, green manure input in maize field reduces requirement for chemical fertilizer input by 30% (Shun et al. 2015). Use of biofertilizers is also a unique alternative as an organic agroinputs as it

Fig. 16.5 Worldwide distribution of Neglected and Underutilized Species (NUS) Arora (2014)

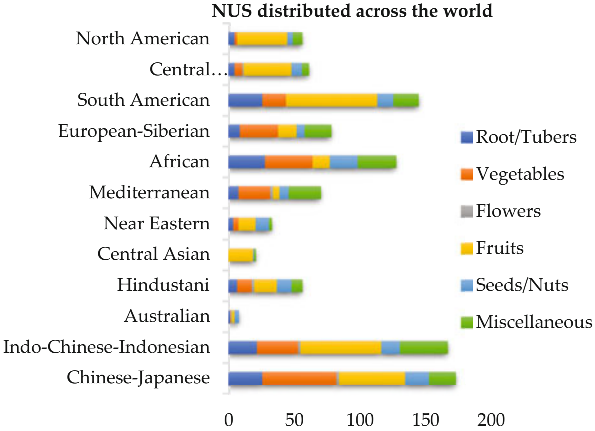

Table 16.1 Neglected and underutilized millets of India with per 100 g nutritional content (Gopalan et al. 1989)

Nutrients	Pearl millet	Sorghum	Finger millet	Foxtail millet	Proso millet	Barnyard millet	Kodo millet
Energy (kcal)	361	349	328	331	341	397	309
Protein (g)	11.6	10.4	7.3	12.3	7.7	6.2	8.3
Fat (g)	5.0	1.9	1.3	4.3	4.7	2.2	1.4
Calcium (mg)	42.0	25.0	344	31.0	17.0	20.0	27.0
Iron (mg)	8.0	4.1	3.9	2.8	9.3	5.0	0.5
Zink (mg)	3.1	1.6	2.3	2.4	3.7	3.0	0.7
Thiamine (mg)	0.33	0.37	0.42	0.59	0.21	0.33	0.33
Riboflavin (mg)	0.25	0.13	0.19	0.11	0.01	0.10	0.09
Folic acid (mg)	45.5	20	18.3	15.0	9.0	–	23.1
Fibre (g)	1.2	1.6	3.6	8.0	7.6	9.8	9.0

can significantly raise the phosphorous use efficiency and reduce the requisite for phosphatic fertilizer (costliest for small farmers) to large extent phosphate solubilizing micro-organisms (PSM) and vesicular arbuscular mycorrhizal (VAM) are commonly used biofertilizers. For soybean-wheat cropping system in inceptisol soil of Indo Gangetic Plains, use of these two biofertilizers can minimize P fertilizer application by half the amount as used in normal practice while increasing yield of both crops nearly by 4–5% (Mahanta et al. 2014). Biofertilizers specifically alters the root morphology and phosphorous inflow rate and enhance crop yield. Sustainable utilization of cattle integrated farming, green manure, biofertilizers at larger

Fig. 16.6 Neglected and underutilized millets of India (for popularizing the unpopular crops) having more Vitamin and mineral as compared to most of modern grains viz. rice, wheat, etc.

landscape can be significant, cost effective and upgrade the livelihood of millions of farmers.

16.6.2 Agroforestry

Tree-based farming is largely practiced by aware farmers today as it is high income giving, increases farm productivity and profitability and has many ecosystem benefits (Mbow et al. 2014). Integration of horticultural trees, crops, livestock, woody plants, bamboo, shrubs, etc. were cultural practices in many parts of world such as in East Kalimantan, Indonesia and its small cultivation areas like Simpung munaan, Lembo, Kampung merabu and kampung birang since long time back (Hartoyo et al. 2016). Similarly, bamboo-based agroforestry was traditionally practiced by local and indigenous people in Barak valley of North East India (Nath et al. 2015). These agroforestry practices were source of soil carbon sequestration and have been reported to sequester carbon at rate of 0.44 Mg C ha^{-1} $year^{-1}$ thereby gathering 30.5 Mg C ha^{-1}. Modern agroforestry practices are extension to such traditional practices in which new crop and tree species (rubber/cocoa etc.) are grown in same land and serves commercial purpose. Agroforestry practices done over from past 15 years have been seen to increase overall biomass and soil carbon sequestration by 70% and 30% respectively (Kim et al. 2016). Since it sequesters carbon at appreciating rate i.e. upto 10-t C ha^{-1} $year^{-1}$ therefore can potentially mitigate GHG (methane and N_2O) emission with rate of 13–41 t CO_2-eq ha^{-1} $year^{-1}$. Not just this promoting agroforestry practices in pasture land or land where monoculture cropping predominated could increase biodiversity and livelihood of local and indigenous people. For one example, by introducing coffee-based agroforestry in

Table 16.2 List of reported agronomic practices with neglected and underutilized crops and their output for enhancing food and nutrient security

Neglected and Underutilized crop species (NUC/NUS)	Nutritional and health benefits/source of income	Climate adaptability and agronomic remarks	Country (References)
Talinum fruticosum (L.) Juss	Young foliage leaves are the source of income for rural people	Planting with 3 × 5 cm with 10 t ha^{-1} poultry manure provide highest fresh and dry matter yields	Nigeria (Uko et al. 2013)
Basella alba L.	Leaves are rich in Vit A, B, C and minerals such as Fe and Ca	Combined application of poultry manure at 3 t ha^{-1} and weekly harvesting can positively increase the crop growth, yield and fresh foliage (177.40 g plant^{-1})	Nigeria (Salami and babajide 2017)
Cleome gynandra L.	Rich source of protein, Vit A and C, minerals viz. Ca and Fe	Application of farm yard manure at 11.5 t ha^{-1} gives highest fresh yield up to 12.3 t ha^{-1}	Kenya (Ng'etich et al. 2012)
Amorphophallus paeoniifolius	Used for making culinary dishes, pickles and used in remedy for patients suffering from dysentery, piles, asthma and abdominal pain	Integrated application of N-P_2O_5-K_2O (100-60-100 kg ha^{-1}) + FYM at 10 t ha^{-1} under irrigated condition is recommended for increasing corn productivity	India (Sahoo et al. 2015)
Corchorus olitorius L.	Rich in Fe and folate	Chicken manure input at 20 t ha^{-1} substantially increases the growth under semi-arid environment.	Sudan (Naim et al. 2015)
Trigonella foenum-graecum L.	Rich in Fe, Ca, vitamins and essential amino acids (e.g. lysine, leucine and phenylanaline)	Application of vermicompost at 4 t ha^{-1} and Sulphur at 40 kg ha^{-1} is recommended for higher growth attributes, root nodules, leghaemoglobin content, seeds and straw yields	India (Verma et al. 2014)
Crotalaria juncea L.	Important source of natural fibre and highly useful green manure that can grow robustly in entire India	Showing sunnhemp at spacing 30 × 10 cm coupled with topping at 30 days after sowing is effective in increasing the seed yield of sunnhemp.	India (Tripathi et al. 2013)
Colocosia esculentus L.	High energy food enriched with protein, vitamins and minerals. Small farmer cultivates as cash crop	Poultry manure at 10 t ha^{-1} and NPK at 150 kg ha^{-1} increases cocoyam plant height, number of leaves per plant and yield.	Nigeria (Hamma et al. 2014)

(continued)

Table 16.2 (continued)

Neglected and Underutilized crop species (NUC/NUS)	Nutritional and health benefits/source of income	Climate adaptability and agronomic remarks	Country (References)
Physalis peruviana L.	High income giving crop with significant medicinal applications	Application of vermicompost at 5 t ha^{-1}, Azotobacter at 10 kg ha^{-1}, and PSB at 10 kg ha^{-1} produces maximum number of fruits per plant, fruit weight, fruit volume, fruit yield per plant.	India (Nagar 2018)
Ipomoea batatas (L.) Lam. (Sweet potato)	Cash crop with high tolerance for abiotic stress. Rich in protein, carbohydrate, Fe, vitamins A, C and fibre.	Planting on ridges and harvesting vines after 65% growth completed (105 days after planting) produces herbage for fodder in sufficient amount without compensating yield (in form of tuberous roots)	Ethiopia (Ahmed et al. 2012)

Chiapas, Mexico the Inga tree species diversity which was 34% of all tree species raised to 45% (Valencia et al. 2014). Rubber-based agroforestry was also seen to reduce soil erosion by 50–70% in comparison to when no rubber plantation or rubber monoculture was established (Liu et al. 2016). Cocoa–coconut-based agroforestry in Indonesia was found to increase microbial (Pseudomonas and Trichoderma) population in soil, soil organic carbon and yield of both plants (Utomo et al. 2016). This agroforestry practices are good for environmental sustainability also as producing 1 t of cocoa pod requires only 2.25 E−05 kg PO_4-eq, 3.67 E+01 kg CO_2-eq and 4.31 E−02 kg SO_2-eq which are known causes for eutrophication, global warming and acidification, respectively. Besides this, agroforestry practices with integration of livestock can be even more income giving and sustainable practice. For an instance, poultry + olive orchard system can enhance fertilization in olive orchards, reduce weed infestation, and reduce harmful land use impact by 18% and 12% that was caused due to chickens and olive production respectively (Paolotti et al. 2016). Overall, agroforestry practices are promising source for enhancing livelihoods of millions of poor peoples by alleviating poverty (Mbow et al. 2014).

16.7 Concluding Remarks and Way Forward

Small- to medium-scale farmers (owing less than a hectare of agricultural land) in particular of tropical nations such as Africa and India are sturdily predicted to be hit hardest by the climate change and its harsh impacts (Abhilash et al. 2016; Dubey et al. 2019a). Hundreds of millions of such farmers are responsibly feeding and nourishing the world by the quantitative and qualitative food they produce (Arora

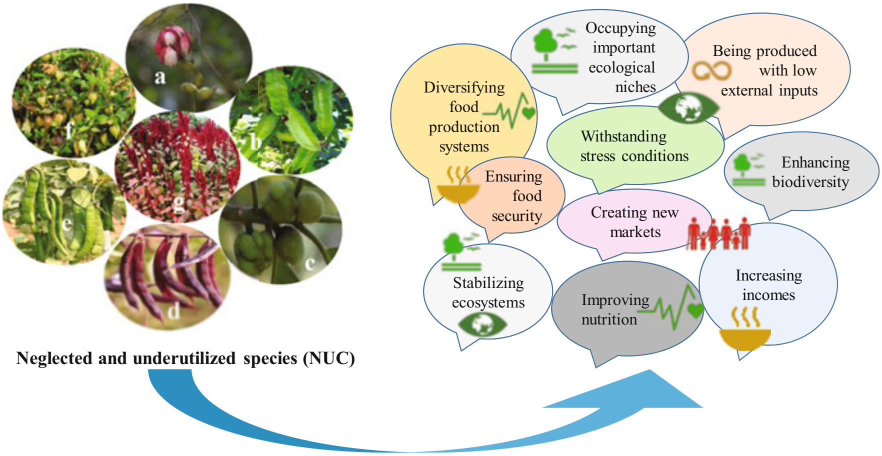

Fig. 16.7 Interrelation between NUS and some of UN-SDGs (represented with symbols) such as goal 1 (No Poverty), goal 2 (zero hunger), goal 3 (good health and well-being), goal 12 (responsible consumption and production), goal 13 (climate action), goal 15 (life on land). NUS shown here are: (**a**) Madras Thorn (*Pithecellobium dulce* (Roxb.) Benth.), (**b**) Winged bean (*Psophocarpus tetragonolobus* (L.) DC.) (**c**) Cluster fig (*Ficus racemosa* L.) (**d**) Lablab (*Lablab purpureus* (L.) Sweet) (**e**) Sword Bean (*Canavalia gladiata* (Jacq.) DC.) (**f**) gooseberry (*Physalis angulata* L.) (**g**) red amaranth (*Amaranthus cruentus* L.)

2014; Singh et al. 2019). However, unfortunately possibly tens of millions among these farmers themselves are barely nourished and are unable to afford three meals a day for their families and themselves. Many such small-scale farmers are devoid of direct access to extension services provided by government due to unawareness and also lack of access to markets as well as affordability in purchasing expensive external agroinputs from the markets (Challinor et al. 2014). This conclusively push farmers to either lease out their agricultural land for industrial/urbanization interests or make them shift from their traditional trade of farming to searching job opportunities and employment in urban sector (Dubey et al. 2019a). This will essentially end up in largely creating climate refugees and thereby economic disturbances in future. To avoid inevitable cusp that may arise on planet due to climate refugees and economic slowdown, the agriculture sector therefore needs urgent climate actions in form of large-scale adoption of sustainable, climate adaptive, resilient, resource conserving, innovative and profitable agronomic practices.

In conclusion, this chapter eloquently highlights certain promising farming practices (such as crop diversification, residue retention, agroforestry, balanced use of chemical fertilizers, organic farming, livestock mixed farming) along with suitable intervention of science (climate and crop models for climate smart agriculture, use of biofertilizers/bioinoculants, breeding technologies, precision agriculture) and innovations (integrated farming, conserving agrobiodiversity, utilizing neglected and underutilized crops). Overall, adoption of these climate adaptive measures in large agriscape, would significantly contribute in meeting various global and national SDGs and their targets set for year 2030 (Fig. 16.7). Explicitly UN-SDGs goal

1 (No poverty), goal 2 (Zero Hunger), goal 3 (Good health and well-being), goal 12 (responsible consumption and production), goal 13 (climate action), and goal 15 (life on land) are directly linked to enhanced farm productivity and agricultural sustainability.

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Chapter 17
Agroforestry as a Nature-Based Solution for Reducing Community Dependence on Forests to Safeguard Forests in Rainfed Areas of India

Manoj Kumar and Hukum Singh

Abstract The communities living in the areas that are devoid of irrigation facilities usually categorized as "rainfed areas" cannot meet their subsistence need through conventional agriculture. People in these areas are often forced to adopt alternate livelihood option including extraction of resources from the nearby forests. Extraction in the form of food, fuel, fodder, timber, etc. is more in rainfed regions compared to the areas where agriculture can fulfill such demands. The ever-increasing population of the rainfed areas has resulted in rapid upsurge in the extent and magnitude of extraction. This poses a serious question on self-sustainability of the forests. Forests in such regions are at the various levels of threats in the form of overexploitation, degradation and loss of biodiversity. Situation and site-specific agroforestry models can act as one of the land management intervention to safeguard the forests. Agroforestry provides opportunity to use the same piece of land for multiple benefits such as enhanced crop yield, improved soil quality, supply of fuelwood, fodder and timber, improvement of biodiversity and carbon sequestration, etc. Agroforestry in such regions could serve as one of the options of nature-based solution (NbS) to reduce community dependence on forests. We discuss the various aspects of agroforestry in the context of rainfed areas of India to qualify agroforestry as one of the viable options of NbS. We also present some of the research initiatives in the country in recent years for evolving suitable agroforestry models that could be tested to qualify as NbS.

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17.1 Introduction

The ever-increasing population of the world has put up tremendous pressure on the natural resources for meeting subsistence need of the human. The gap between the demand and supply is increasing day by day which has resulted in ruthless exploitation of natural resources. The alarming situation has forced us to think for viable options to safeguard natural resources. There is a need to identify actions to protect, manage and restore these natural resources. Nature-based solution (NbS) is one of the approaches visualized by the planners to safeguard the natural ecosystems that benefit human well-being as well as biodiversity (Dhyani et al. 2018; Dhyani and Thummarukudy 2016). The International Union for Conservation of Nature (IUCN) defines NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2019, 2016).

Agroforestry, a system of managed land unit where woody trees are grown in combination with agriculture crops and/or animals, involves the interaction of both ecological and economic components. The ecological and economic interactions taking place in an agroforestry ecosystem could be fine-tuned in a way to extract positive benefits for ecological as well as economic components. This will definitely lead to include agroforestry as one of the NbS. Agroforestry serves to meet the increasing demand of food, fuel, fodder and timber which renewed the awareness of productive and protective value of trees and rejuvenated concept of agroforestry (Huxley 1983). Agroforestry encompasses variety of practices, including crop fallow rotations, simple and complex agro-forests, silvi-pastoral systems, and urban agroforestry (Leakey 2017; Nair 2011; Udawatta et al. 2019). The planting of perennial trees in combination with variety of agriculture crops in an agroforestry system helps to restore and manage soil fertility (Campanhola and Pandey 2018; Jose 2012; Nair 2011; Udawatta et al. 2019). The agroforestry system helps in controlling soil erosion and could be used for managing water logged areas (Dagar and Minhas 2016). It has also been found to effectively manage acidification and eutrophication of river streams (Leakey 2017; Michel et al. 2007; Schultz et al. 2009). It helps to improve local biodiversity (Huang et al. 2002; Jose 2012; Kalaba et al. 2010; Udawatta et al. 2019; Bucheli et al. 2017) at the same time appropriately developed and implemented agroforestry system can also assist in reducing the pressure on nearby natural forests from where communities extract fuel and fodder (Kumar et al. 2020; Savita et al. 2018). It could be used as one of the systems that could withstand the adverse impacts of climate change if the selection of species in the system is appropriate. These benefits provide enough reason to justify agroforestry as one of the NbS that could be effectively implemented at a landscape level for the redressal of societal challenges of meeting various demands. Keeping these facts in mind we discuss various facts of present day agroforestry practiced in India and put forward the facts to support agroforestry as a nature-based solution for reducing community dependence on forests to safeguard forests and protect biodiversity particularly in rainfed areas of India.

Application of agroforestry models as one of the NbS need to be tested in regions where community dependence for extraction of fuel, fodder and other livelihood resources is largely upon the forests. Rainfed areas are example of such regions where community dependence upon forests is increasing day by day. Rainfed areas have less irrigation facilities and agriculture is largely dependent upon the rains. This makes the lands less suitable for the conventional agriculture. In lack of sufficient knowledge for effectively using the lands to meet daily requirement, communities are forced to search for alternate livelihood options. Forests of the rainfed regions serve as one of the alternate livelihood options and they face acute pressure of ever increasing human and cattle population. Forests of the rainfed regions are at various levels of degradation in the form of canopy opening, decrease in tree density and biodiversity losses primarily because of livestock grazing, and extraction of fuel-wood, fodder, timber and non-wood forest produce. This necessitates a scientific investigation to evolve a system that can meet the demands of the communities with limited available natural resources. Agroforestry is thought to be one of the systems that could successfully be implemented in such situation. It will, however, require a deliberate selection of model after thorough investigation of the situation. Whether a selected agroforestry models is able to suffice the purpose is the main concern. With this perspective, we present (1) a brief account of prevailing situation in rainfed regions of India where agroforestry can serve as one of the NbS for reducing extraction pressure upon the forests together with improving the livelihood of the communities, (2) highlights of some of the research initiatives for evolving appropriate agroforestry models that could be tested for rainfed regions of the country, and (3) what should be the way forward for successfully evolving appropriate site and situation-specific agroforestry model that can serve as one of the NbS in general and for the rainfed regions of the country in particular.

17.1.1 Rainfed Areas of India: Present Status and Challenges

Agriculture areas of India has broadly been categorized into "rainfed" and "irrigated" on the basis of percentage of the net sown area depending on rains and the irrigation. Area having irrigation facility in less than or equal to 30% of its net sown area is termed as "rainfed" while rest of the areas having extent of irrigation exceeding 30% of the net sown area is classified as "irrigated" (NRAA 2012). Rainfed areas are referred to as the areas that have insufficient irrigation facilities and the agriculture is primarily rain dependent (FRI 2017; Kumar et al. 2020; Savita et al. 2018). The social and the ecological systems of rainfed regions are primarily dependent upon rains. The lack of sufficient irrigation facilities in these regions makes the agriculture-dependent communities suffer for meeting their basic needs. Thus, the communities of rainfed regions are forced to look for alternate sources of livelihood (Kumar et al. 2020). However, the agriculture of rainfed areas plays a vital role in India's economy. It is witnessed that most of the coarse cereals of India are grown in the rainfed regions. However, per unit area productivity of crops in these regions is quite low and people are forced to explore for alternative sources of livelihood other than the traditional agriculture practices. The communities of these regions often are forced to migrate for other sources of livelihood. If the region is supported by forests, the communities are often heavily dependent on these forests for meeting their subsistence need. This has resulted in the degradation of the forests together with loss of biodiversity that needs the attention of the planners and managers for the implementation of feasible solutions for safeguarding these forests together with supporting the daily needs of the forest dependent communities.

One of the major concerns for the policymakers in the rainfed area is to evolve effective tools that would improve the productivity with the available limited supply of water and irrigation facilities. To address the multitude of problems faced in these regions and for evolving effective management plans for developing rainfed regions of the country Government of India under the aegis of Ministry of Agriculture and Farmers Welfare constituted National Rainfed Area Authority (NRAA). The major focus of the authority is to prepare guidelines and management plans for effectively managing the rainfed areas. Soon after the creation of NRAA, it has successfully been guiding and implementing management plans in the rainfed regions that have helped to effectively manage the region for improving the environmental, social and economic status of the region. NRAA works in close association with various development agencies, research organization and individual domain experts for tackling the emerging issues of rainfed regions. Identification of the key issues to be addressed and implementation of site-specific plan to tackle the situation has successfully been done through NRAA, since its creation and it continues to do so. NRAA also works as the nodal hub for the generation and dissemination of information relevant for designing a specific work plan for the improvement of the rainfed regions. NRAA has been successful in improving the livelihood of the rainfed communities through various plans and action-oriented projects. Majority of the population in the rainfed regions are poor and marginalized farmers who have been benefitted through NRAA.

There is a need of focused approach to identify and prioritize emerging issues of the rainfed regions which require utmost attention. Once these issues are identified, site-specific management plans need to be developed in close consultation with the community of the region to address the issues. The rainfed regions could be divided into various groups based on different agro-climatic zones so that the plans are developed focusing the agro-climatic conditions of the region. State-wise assessment shows that states like Maharashtra, Madhya Pradesh, Rajasthan, Karnataka, Uttar Pradesh, Andhra Pradesh, Gujarat and West Bengal account for a larger portion of the total rainfed area. However, depending on the magnitude of rainfall the extent of the rainfed regions and its coverage may vary from year to year in each of the states. Rainfed regions of the country face a shortage of irrigation facilities to support conventional agriculture practices. As a result, communities are forced to rely on alternate sources of livelihood including heavy dependence upon the nearby forests of their dwelling places. Communities residing near the forests could be addressed as

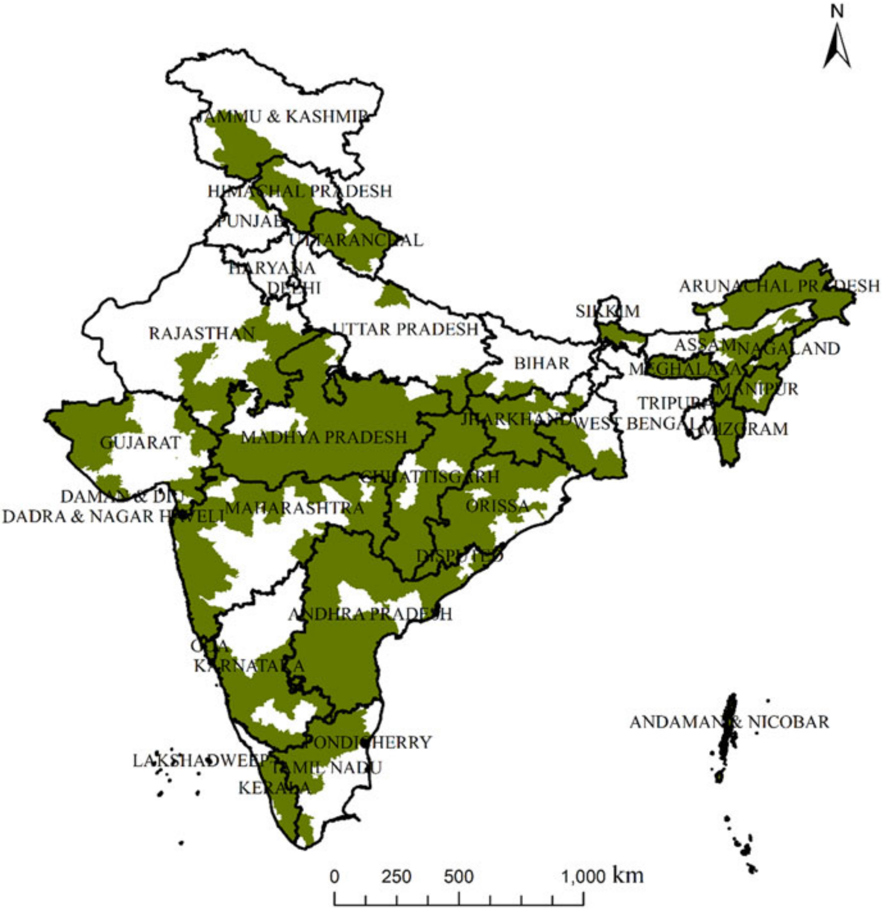

Fig. 17.1 Prioritized rainfed districts of India (shown in green colour) by Forest Research Institute for assessing Socio-ecological status (FRI 2017)

"forest fringe communities" or simply "fringe communities" as they live near to the forests and are largely dependent on forests for their source of livelihood in absence of an alternate source of income. A study implemented by Forest Research Institute (FRI) in association with NRAA identified 275 rainfed districts of India (Fig. 17.1) to investigate various socio-ecological parameters to evolve management priorities and interventions for the improvement of economic status of the community together with the improvement of the forests and agriculture production. Major components of the study included identification of forest fringe villages, fringe areas having open and/or dense forests, species composition of fringe forests, dominant species, regeneration status, land holding of individuals living near to forest (i.e. forest fringe), cropping pattern in forest fringe, household income, livestock population, extent of dependence on forests for fuelwood and fodder of forest fringe communities, etc.

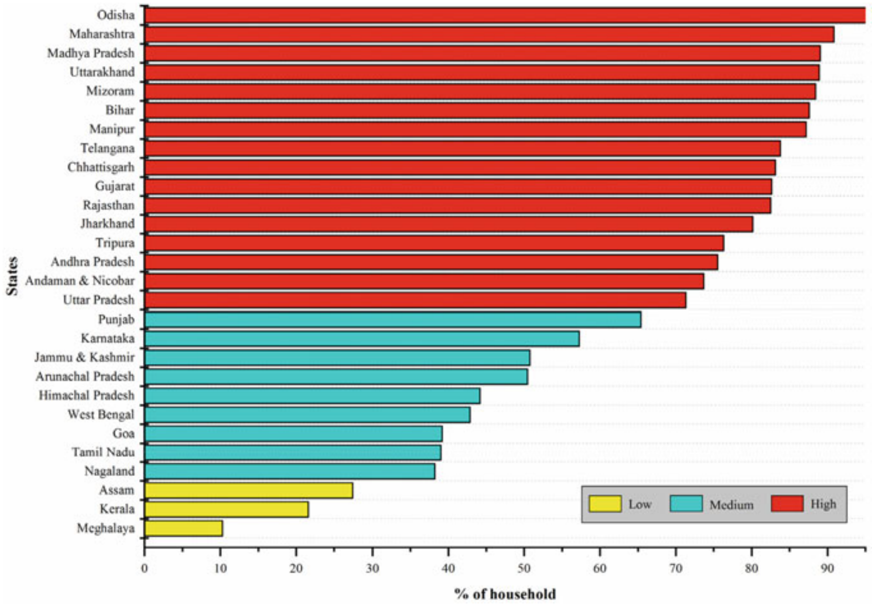

Fig. 17.2 Categorization of rainfed Indian states as low, medium and high classes of fuelwood extraction (Kumar et al. 2020)

The compiled information is one of the most extensive information that could be used by the planners for the identification and implementation of site-specific intervention to deal various socio-ecological problems. Various levels of ecological and sociological status could be inferred from this study for developing and implementing NbS.

Some of the priority issues of the rainfed regions include varying levels and extent of land degradation in the absence of sufficient water to support crops. The degradation of forests of these regions due to heavy extraction of forest-based resources to meet daily requirement of fuel and fodder is yet another key issue that needs to be addressed. A study by Kumar et al. (2020) has categorized different states into low, medium and high category of fuelwood extraction from the fringe forests in rainfed regions (Fig. 17.2). The findings could be used for prioritizing agroforestry models that supplement fuelwood demand in these regions. Fringe communities much often support their livelihood through cattle rearing which has resulted in the increased cattle population thus adding on to the pressure on forests for the extraction of fodder. This has resulted in the degradation of the forests and needs the attention of the planners. The communities of the region have various levels of education and engagement in terms of government and private job.

The economic status of the community in rainfed regions varies and there prevail various levels of hierarchical dependence on the forests to support livelihood. Agriculture landholding and varying levels of income of the community in these regions could be used as one of the criteria to prioritize and rank districts where NbS could be first implemented. If a well thought NbS is not implemented timely in these regions to arrest the ever increasing pressure of human and cattle population on forests of rainfed regions it would not just impact the fringe forests but very soon the pressure would reach to the core forest regions. This will diminish the supply of various ecosystem services derived from the forests. This is evident in most of the regions of the country and it is witnessed that forests are degrading and the supply of goods and services from forests is diminishing. Hence, there is a need to evolve site-specific NbS that supports the growth and supply of food, fuel, fodder, and other essential needs of the forest fringe communities to safeguard the forests. In the absence of such solution, the ultimate pressure would lead to degradation of the forests. One of the solutions visualized for this kind of prevailing situation is in the form of agroforestry. Agroforestry needs to be tested as one of the viable options of NbS in rainfed areas to support the livelihood of communities together with improving local environment and biodiversity. There is a need to develop and test appropriate agroforestry model which would address the prevailing issues of the rainfed region to improve the health of the forests, improve and manage lands, protect soil erosion, increasing income and economic status of the community, etc. to qualify selected agroforestry model as NbS in true sense.

17.1.2 Agroforestry for Rainfed Areas in India

In India, agroforestry is practiced to manage scattered trees on farm land, trees on farm bunds and vegetative live hedges for ecological, social and economic functions. However, “rainfed agroforestry” can specifically be referred to those selected agroforestry models that can effectively be implemented in the rainfed regions to address the prevailing issues. The rainfed agroforestry could successfully be used for managing various issues, such as livestock support, enhanced biomass production, improved productivity, improved regeneration and biodiversity, enhancing the income of the local communities, supply of fuel and fodder, supply of timber, supply of essential medicinal value products, etc. The development of non-forest and forested areas for their sustainable use would invite various planning options to tackle arising problems. It may invite just single or combination of approaches. Rainfed agroforestry seems to provide solution to various arising problems. It may support sustainable livelihood security through simultaneous production of food, timber, biomass, fodder, firewood, improved productivity and various other co-benefits (Fig. 17.3). Management of trees in combination with a variety of crops practiced through agroforestry models in rainfed regions would assist in protecting from various socio-environmental risks. The limited use of the land in the absence of agroforestry may or may not support the various needs of the communities; whereas, agroforestry can provide multiple benefits from a single piece of land.

Rainfed agroforestry for protecting livelihood and improving the socio-environmental status of a region seems to be an appropriate solution that is nature

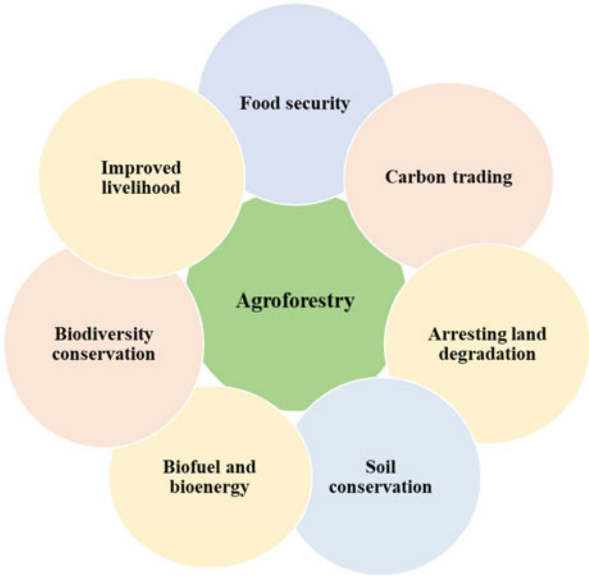

Fig. 17.3 Agroforestry and associated components serving various co-benefits

based. The concept of NbS might look new; however, agroforestry is not a new concept. This has been in practice in most of the countries including India. The Government of India launched National Agroforestry Policy in 2014 as one of its ambitious programme to manage trees grown on farms to extract more benefits. The policy intends to integrate various agroforestry-related activities of the ongoing projects being implemented through various schemes and by different agencies so that maximum benefit is extracted to have enhanced productivity and support to poor marginalized farmers. The policy aims to help in meeting the demand through agroforestry along with improvement of the environment, protection of forests and minimizing risks associated with extreme events. Looking at the various kinds of co-benefits derived from the agroforestry system, the broader categorization could be done into socioeconomic, ecology, agriculture and forestry that together integrate to qualify an agroforestry system (Fig. 17.4).

Agroforestry is not a new concept; however, rainfed agroforestry may require a detail elaboration especially for the selection and prioritization of the models that are most suited for the site-specific requirement. Taskforce on Greening India (Planning Commission 2001) identified potential of 10 million ha in irrigated and 18 million ha in rainfed areas that could be developed by appropriate models of agroforestry. The key questions which need to be addressed are:

- Which are the priority areas?
- Whether agroforestry could successfully be implemented?
- What kind of prevailing and potential agroforestry models?
- What kind of species combination?
- What are the targets to be achieved?
- What are the indicators for measuring the success?

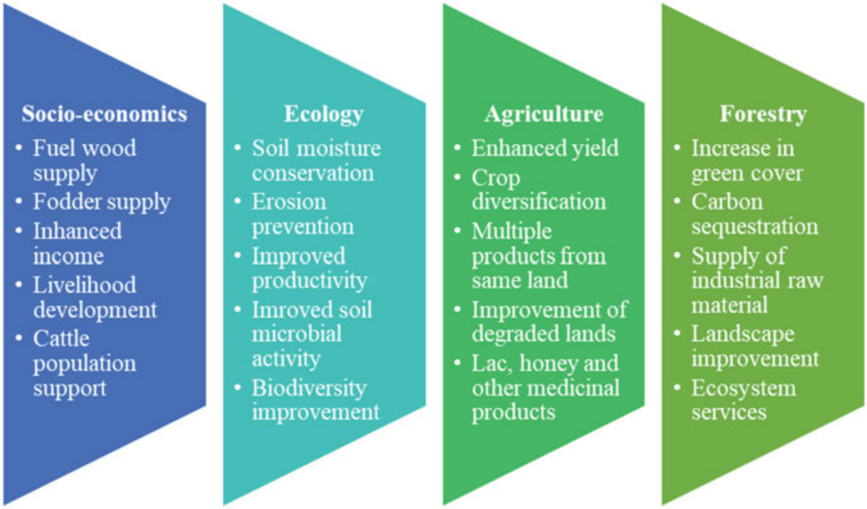

Fig. 17.4 The broader components of agroforestry categorized as socioeconomic, ecology, agriculture and forestry and associated derived co-benefits

The selection of agroforestry models should focus on site-specific requirements, need of the region where it's planned for implementation, cultural and socioeconomic-related issues for its wider acceptance by the community, combination of specific species based on pre-tested successful combinations, identification and implementation of innovative technologies that ensures better economic returns, etc. The basic principles of agroforestry must be substantiated such as selection of fast growing trees having deep rooting systems with minimum lateral spread, trees with narrow crown, good nitrogen fixers, trees must not transmit insect-pest and diseases to associated field crops, there must be some economic return in the form of either fuel, fodder, fibres or some small timbers, the pruning operations must not disturb the photosynthesis rate of trees, trees must have the ability to maintain soil fertility, productivity and control of soil erosion, litter decomposition rate of the tree crop must be fast enough not to interfere the growth of field crop, market accessibility of the harnessed products, etc. Above all the social, economic and environmental acceptance to the community should be the top agenda while selection of the models. Some of the successful agri-silvi systems in India are presented in Table 17.1 (Pathak et al. 2006).

Prioritization of sites for the implementation of agroforestry must not be a random choice of site selection but should be selected on a scientific basis. Rainfed areas, which suffer because of scanty rainfall, are the obvious choice for prioritization, but again, which are the most priority areas and what kind of agroforestry model would suffice the purpose will need thorough investigation. The key areas that can benefit from suitably planned and managed agroforestry practices include increasing crop yield, improved soil quality, salinity and water table control, fulfilment of rural needs

Table 17.1 Zone wise some of the tested agri-silvi models of India (Pathak et al. 2006)

Zones	Trees	Crops	Years	Benefit:Cost ratio
E. Himalaya	*Anthocephalus kadampa*	Paddy	8	1.60
W. Himalaya	Peach	Maize, Soybean	15	1.21
Lower Gangetic	*Eucalyptus hybrid*	Paddy, wheat	10	2.33
Middle Gangetic	*Dalbergia sissoo*	Sesamum	20	1.15
Upper Gangetic	*Populus deltoides*	Paddy, wheat	7	3.31
Trans Gangetic	*Acacia nilotica*	Pearl Millet	20	2.61
Eastern plateau	*Harwickia binata*	Pennisetum	15	2.13
Central plateau	*Emblica officinalis*	Ground nut	8	1.01
Western plateau	*Albbizia amara*	Cenchrus	16	1.56
Southern plateau	*Tamarindus indica*	Chilli	10	2.03
West Coast and Ghat	*Casuarina*	Paddy	7	1.39
Gujarat plains	*D. sissoo*	caster	20	2.14
Western dry	*Prosopis cineraria*	Pearl millet	20	1.65
Island	Coconut	Paddy	6	1.17

of fuelwood and fodder, economic and social impact in the form of alternative livelihood like lac production, Kosa cocoon production, honey production, production of herbal drugs, increased green cover, reduction in incidences of crop failure, improvement of biodiversity and carbon sequestration, etc. Scientific information and precise information is required to be carefully communicated so that agroforestry practices can be sustained to make most of the benefits.

17.1.3 Initiatives of Research Institutes in India in Developing Agroforestry Models that Can Qualify as NbS

Research institutes involved in the development and testing of new agroforestry models have been pragmatic in approach and have successfully evolved agroforestry models that could qualify as NbS (Dhyani et al. 2013). Forest Research Institute (FRI), Dehradun has been developing and testing various agroforestry models for its successful implementation at the regional level which can be scaled up at national level. FRI has developed high yielding clones of Eucalyptus, Populus and Dalbergia to increase the economic value of the plantation per hectare. FRI also endeavours to promote region and site-specific non-timber forest products based models in its research programme to ensure higher productivity improved livelihoods and economic growth. The institute conducts regular training and capacity building programme, especially for marginal farmers, women and other sections in rural and tribal areas. Some of the initiatives of FRI are discussed ahead.

FRI has been implementing agroforestry-based research in different states of the country to demonstrate the successful transfer of technologies to the farmers. Socioeconomic survey of the selected villages of Uttar Pradesh indicated that trees viz., Populus, Teak, Eucalyptus, Sissoo and Bamboo were having wider acceptability. Farmers are motivated to participate in plantation on their farms and other available lands. Training programmes on nursery, plantation technology, bio-fertilizer application, seed technology and forest products are implemented regularly through training courses by the FRI. After training, quality planting material are also provided to farmers together with necessary guidance. Farmers are also motivated to start their own nursery for production of quality planting stock. Poplar (*Populus deltoides*), Bamboo (*Dendrocalamus strictus*, *D. membranaceus*), Teak (*Tectona grandis*), Eucalyptus and *D. sissoo* plants have been distributed to the farmers by FRI on various occasions. Demonstration cum experiment plantation in the form of block and bund plantations have been established on the fields of farmers. The following agroforestry models of Poplar of different clones viz. G-48, G-3, S7C15, L30-82, D121 etc., with different geometry have been tested by FRI:

- Boundary plantation having spacing of 3 m between the trees
- Row plantation spacing of 10 m between rows and 4 m between trees
- Silvi-horticulture system where Poplar trees are planted with various fruit trees
- Block plantation spacing of various sizes such as 5 m × 4 m and 5 m × 5 m.

The farmers were found to prefer block plantation of 5 m × 4 m with 6-year rotation for poplar-sugarcane agroforestry. In the first year, first week of January was identified as the appropriate time to plant sugarcane while the harvesting was suggested in December of the same year. From the leftover clumps of the first harvest, new culms of sugarcane grow that could be harvested in the November month of the second year. While other crops such as wheat, chari fodder, poplar could be grown in between these intermediate period. In December, wheat was sown which was harvested in April. This was followed by the sowing of chari fodder in May which was harvested during August–September. Poplar crop grown in the same system is harvested after every 6 years. The farmer's income was found to increase who were benefitted by these multiple crops derived from the same land.

Studies on agroforestry systems and development of suitable agroforestry models in Punjab, Haryana and Uttar Pradesh was conducted by FRI. Under this study, six viable agroforestry models namely Poplar-Sugarcane-Turmeric block plantation, Poplar-Sugarcane-Wheat-Chari block plantation, Poplar-Sugarcane-Wheat-Chari-Potato-Maize-Bajra block plantation, Poplar-Sugarcane-Potato-Barseem-Chari block plantation, Poplar-Paddy-Wheat boundary plantation and Poplar-Sugarcane-Wheat-Paddy boundary plantation were developed. A study was done by FRI to evaluate income enhancement of the communities adopting these models. The successful implementation and demonstration of success stories through such models in the district of Yamuna Nagar has attracted the farmers to adopt such agroforestry models. It could be witnessed that agroforestry is at a very advanced state of development in the Yamuna Nagar district of Haryana state. Quick and high financial returns have attracted farmers to adopt Poplar-based agroforestry. Agroforestry has not only uplifted socioeconomic status of the farmers but also has contributed towards the overall development of the region. Growth performance of different clones of *P. deltoides* was also studied and the performance of clones S7C15 and S7C20 was found significantly suitable for agroforestry system.

The study concludes that the essential ingredients for the success of the participatory approach essentially require:

- Willingness on the part of the villagers to bring change by adopting new agroforestry models developed and tested in the region
- An integrated approach with agricultural, horticultural, animal husbandry and forestry departments for holistic development of the villages
- Meeting the primary needs of water, food and shelter
- Dedicated and motivated staffs

Women and NTFP-based agroforestry systems in Uttarakhand and western Uttar Pradesh were assessed by FRI. Survey of NTFP-based agroforestry practices was taken up in three districts of Dehradun, Pauri Garhwal and Pithoragarh in Uttarakhand state and two districts of Ghaziabad and Meerut in Western Uttar Pradesh. Collected information on NTFP-based agroforestry including general information, biodiversity, the status of agriculture, the participation of women, marketing mechanisms of the end products was used to evaluate NTFP-based agroforestry. It was observed that if the Government provides adequate facilities, the villagers are willing and much keen to adopt such models under agroforestry. The women were found actively participating in all type of works related to agriculture and were willing to adopt suggested interventions of agroforestry. The study has shown that NTFP-based agroforestry is not being practiced on desired scale but is a potential option for the upliftment of socioeconomic status of the people including rural poor and women. If the models are developed scientifically, it can ensure availability of firewood and charcoal, fodder for the cattle, small timber for house construction and agricultural implements. Planting of suitable NTFP species under agroforestry can provide raw material or indirectly supporting rural cottage industries and crafts e.g. dairy, silk, basket and rope making, wood carving, toy making, collection and processing of medicinal plants, essential oil, honey, gums and resin, tans and dyes, pine needle board, fruit packing cases etc. It can also ensure increased availability of fruits and nuts for supplementing the rural diet. NTFP-based agroforestry has the potential for increasing income of landholding people and direct and indirect employment opportunities for the landless people.

Effect of Pine and Oak forests on agricultural crops were analysed by FRI. The forest of both Oak and Pine influence the nearby crops by their hydrology and ecology, though there is no remarkable difference in crop yield of downstream regions. However, the production is more in those regions where the crop is grown near the forest area of both Oak as well as Chir pine forests. It is a well-known fact that the oak forest is moisture retainer and increases the moisture contents under it and in nearby areas. The leaves of the Oak forests reach in nearby agriculture land where they decompose and enhance the nutrients content of the soil.

This has a positive impact on the productivity of nearby fallow land in the vicinity of the forested landscapes. Increasing moisture in the soil either by hydrological effects or by irrigation also enhance the litter decomposition rate and increase the crop production. In the case of Chir pine, rate of leaf decomposition is very slow due to dry land under the forest. Nearby lands of Chir pine forests has relatively low moisture content. Fire hazards are more frequent in Chir forests which cause more dryness to the land in these forests and destruction of leaf litter on the ground. Observations on the effect of Oak and Pine on agriculture crops viz., *Zea mays* and *Triticum aestivum* (wheat) were taken and it was revealed that there was more production of wheat and maize in Oak forest dominated areas. In areas dominated by Chir pine forests, the yield of both the crops was found to be less. It was presumed that the loss in yield is due to the burning of ground litter by frequent fire in the Chir pine forest. Overall the study needs to be done to visualize for any significant difference in crop yield for the different agro-ecological regions of the country to see the influence of the proximity of crop field to various dominant forest types.

Effect of *P. deltoides* on shade loving medicinal plants was analysed by FRI. The experiment on medicinal plants viz. Satavar (*Asparagus recemosus*), Chitark (*Plumbago zeylanica*), Tulsi (*Ocimum sanctum*), Ashwagandha (*Withania somnifera*) was conducted in farmer's field at Kuhedi village of Haridwarm district and in the demonstration plots of FRI near to Premnagar in Dehradun district of Uttarakhand state. Effect of shade on the medicinal plants was studied and it was observed that the Satavar and Chitark is a suitable combination with *P. deltoides* having a spacing of 4×5 m where Satavar and Chitrak are planted at 60×60 cm as under-storey crop. The understorey crop of these medicinal plants showed to have fewer bushes compared to cultivation done in open area. Cost-benefit analysis revealed that Satavar and Chitark are suitable medicinal crops to be grown as understory plantation with *P. deltoides*. Tulsi and Ashwagandha were not found as suitable combinations with poplar due to lower market prices.

Tree-crop interaction and effect of *Melia composita* on crops were studied by FRI. The study reveals that *M. composita* is a suitable species under agroforestry system in Punjab. It was observed that even in adverse conditions the growth of the species is adequate. It can gain height up to 14 m with an average girth of 65 cm in 4 years. The plants also produce a good quantity of fuelwood under a regular and proper canopy management. Under an agroforestry system the interaction of *M. composita* was found suitable when grown with wheat and maize. Soil fertility was found to improve up to some extent in the plantation of *M. composita*. In the plantation done at spacing 4×6 m, the light remains normal and under-storey crops get a proper light for its survival and growth. The study concludes that farmers would adopt suggested agroforestry models of *M. composita* to be implemented on their owned lands as this system didn't affect the growth of under storey crops. *M. composita* significantly showed a fast growth in different spacing done during the study. The species grow under scanty rainfall conditions. The species do not pose a remarkable adverse effect on the growth of under crop. However, only a marginal reduction in yield of under storey crops was noticed which was ultimately compensated by the growth of *M. composita*. The combination of *M. composita* with wheat and maize was found to be best with a spacing of the plantation at 4 × 6 m.

Due to overexploitation of water resources in the Punjab state, the water level is going down day by day. On the other hand, many exotic species like Eucalyptus and Poplar are infested by many insect pests. Sometimes there is a great loss to farmers due to attack of insect pests on these species. *M. composita* being a pest and pathogen-free species was found as one of the appropriate species in an agroforestry system for such situations. In the area where the Poplar and Eucalyptus are generally not grown, the *M. composita* can easily be grown as a substitute of these species.

Study on status of existing agroforestry systems in Punjab, Haryana, Uttarakhand and North-west Uttar Pradesh have been done by FRI to assess the status of existing agroforestry systems in Haryana, Punjab, Uttarakhand and N-W Uttar Pradesh. The study suggests tree species like *P. deltoides*, *Eucalyptus* spp., *Mangifera indica* and *D. sissoo*, were dominant species of a commercial agroforestry system. Composition of different species was mostly dominated by Poplar followed by Eucalyptus, Mango and others mainly in Haridwar and Yamunanagar districts. The conducted study reveals that the states under the survey are agroforestry-rich states where almost all types of agroforestry systems are prevalent. People of these states have adopted commercial agroforestry very well where various agroforestry models have been tested and implemented that includes models of agri-silviculture, agri-horticulture and agri-silvipasture systems. Dominant species from the commercial point of views are Poplar, Eucalyptus under agri-silviculture system and mango, litchi, citrus, guava and aonla, etc., dominating under agri-horticulture systems in these states.

FRI has successfully developed models of some important medicinal plants with *M. composite* and *E. officinalis* in degraded lands of Punjab and Uttarakhand. *M. composita* and *E. officinalis* are fast growing species and show a remarkable performance even in water stressed regions. *M. composita* and *E. officinalis*-based agri-silvi-medicinal agroforestry is one of the successful models that could be implemented even in degraded lands and adverse agro-climatic conditions. Such models require lesser nutrients and moisture for the growth of species while the overall maintenance cost of such models is low. The study suggests that an appropriate *M. composita* and *E. officinalis*-based agri-silvi-medicinal system established in a rainfed region and on degraded lands can enhance the productivity of the land along with supporting the improvement of soil fertility. This system also assists in converting alkalinity of the soil to make it neutral thereby making favourable condition conducive for available nutrients uptake by the plants.

17.1.4 Agroforestry in India as One of the NbS: The Way Forward

For effective and successful implementation of the agroforestry models as one of the NbS, there is a need to provide a forum for knowledge dissemination to various alike agencies. This may include communication of information related to the selection of appropriate sites based on parameters like environmental gradients of temperature and precipitation, severity of drought, forest extraction loads for fuel and fodder, ecological status of the forests in terms of its diversity richness, disturbance indices based on forest fragmentation and other alike attributes, topographic conditions guiding successful establishment of agroforestry models, etc. Categorically, the knowledge dissemination can be in the form of:

- Information related to the identified sites for agroforestry intervention in rainfed districts of India
- Identification and selection of site-specific agroforestry models
- Testing the applicability of selected models for its implementation
- Skill up gradation of stakeholders through capacity building/training programmes for the transfer of technologies to implement agroforestry models.

Some of the nodal institutes of the country dealing with agroforestry models such as FRI, Dehradun and the institutes of Indian Council of Forestry Research and Education (ICFRE) and Indian Council of Agriculture Research (ICAR) may plan for the activities that will serve the purpose of achieving the mandate of managing these rain stressed regions. Various steps involved would require focus on:

- Collection and dissemination of information related to natural resources and livelihood status
- Integration of information to prioritize site-specific actions in the rainfed areas of the country
- Development of thematic GIS layers of fuelwood extraction, fodder extraction, livestock population, etc. from the baseline information of recently completed projects
- Integration of thematic layers in GIS environment to develop classes of high, medium and low priority sites at state level
- Dissemination of information for the identification of potential species of agroforestry
- Reconnaissance survey and selection of sites for the testing of identified actions with special emphasis to agroforestry models
- Testing of the agroforestry model at selected sites
- Development of training modules specific to agro-climatic zones
- Compilation and synthesis of reports and manuals for its communication to implementing agencies, communities, government and private institutions and all other associated stakeholders.

Identification of suitable sites and appropriate rainfed agroforestry models should receive high priority in areas identified through its collected wealth of baseline information of previously completed projects. Designated authorities may come forward to provide support for the successful implementation of agroforestry as one of the NbS. There is a need to provide support in the form of innovation of technology, financial support in the form of capital or credits, infrastructure support, training of the users, forward and backward linkages with the user and other agencies, etc. Selection of appropriate intervention that suits the demand of specific region is the need of the hour while practical approach for wider acceptability is needed to explore agroforestry models that would qualify as one of the viable options of NbS. This will demand continued effort to test various existing agroforestry models to establish them as NbS.

17.2 Conclusion and Future Recommendations

There is a need to be more logical in approach while adopting agroforestry as one of the options of NbS. Identification of the issues and its prioritization for effectively adopting suggested solutions through any agroforestry system considered as NbS will require further testing. There is a need to test and establish different site-specific agroforestry models in all agro-ecological regions of the country. Majority of the area of the country that is water stressed are the poorest ones and these could be the top priority area where immediate intervention is needed to uplift the socioeconomic conditions of the community. At the same time, the overall environment of these regions including the health of the forests needs to be revived on priority by adopting appropriate NbS. Areas receiving lesser rains and having inadequate irrigation facilities need a different solution where the core issue relates to providing solutions that demand lesser water. Such areas need to be identified in the rainfed regions where the dependence of the community on nearby forests is relatively much higher. There is need to identify areas where conventional agriculture practices are not successful, especially to fulfill the need of the dependent communities, while they may have potential for better economic return. For such regions, identification of crops is desirable which could thrive in the absence of sufficient rains. All agroforestry models may not be a successful model for such regions and there is a need to identify models for such harsh conditions. Areas where the communities are largely dependent on forests for the extraction of fuel and fodder, we may aim for models that can provide these two major products. In almost all of the rainfed areas of the country, fuel and fodder have been identified as the two primary requirements that are extracted extensively from the forest by the fringe communities (Kumar et al. 2020). Thus, the focus should be oriented to develop models that support an adequate and continuous supply of fuel and fodder. Fringe communities need to be motivated to adopt alternative options of livelihood that reduces the pressure on forests.

Some of the identified priority issues of the rainfed regions are degradation of lands in absence of adequate irrigation and unplanned activities, overexploitation of forest resources, degradation of forests, diminishing biodiversity, poor air and water quality, low income of the community, lack of professional trainings for alternate livelihood, rapid increase of human as well as cattle population, small landholding of the farmers, less employment opportunities, etc. All of these identified issues may be used for ranking and prioritization of the districts where intervention is desirable for safeguarding natural resources for further degradation. Factors influencing the sustainability of the natural resources need to be identified so that appropriate management intervention is planned and implemented. Forests and the fringe communities of the country have been living since long past in close association with each other in harmony. However, the recent pace of human and cattle population growth has resulted in an imbalance between the two and forests are at various stages of degradation. The goods and services derived from these forests are diminishing and there is a need to effectively evolve solutions that make these services sustainable. There is an urgent need to develop an integrated system from where maximum benefit is extracted for meeting various needs of the society such as the agroforestry system.

Agroforestry can serve to safeguard the pressure of the fringe communities upon forests. This is expected to support the sustainability of the forests which in turn would ensure a continued flow of goods and services. Agroforestry will not only reduce the pressure upon forests but at the same time, it will also augment the livelihood of the fringe communities by providing an additional source of income. Agroforestry could be considered as one of the NbS for improving the rainfed regions. However, this will require a comprehensive analysis of the collected baseline data to suggest site-specific interventions. Although, there can be multiple strategies for improving the ecological status and socioeconomic conditions of the region thus multiple NbS would exist, however, agroforestry is visualized as one of the potential solutions.

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Chapter 18
Trees, Shrubs and Herbs for Slope Stabilization in Landslide Prone Areas of Eastern Himalaya

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Abstract The Himalayan region is prone to natural calamities such as flash flood, glacial lake outburst, landslide and avalanche. The region falls within high risk seismic zone 'V' and witnesses unpredictable weather conditions like cloud-bursts and incessant rainfall. Developmental activities undertaken in these areas compounds the risk considerably. Of all, landslides are the most commonly occurring natural disasters in the Eastern Himalayan Region. Technologies for mitigating the landslide hazard focus mostly on building civil engineering structures such as retainer walls and boulder sausages. As part of the long-term solution, and to ensure the provisioning of ecological services, native plant species having slope stabilizing traits must be planted along with the engineering structures. Trees having a deep tap root system keeps boulders from sliding while herbs and shrubs with their fibrous root system prevent soil run-off. We surveyed the landslide prone areas of the Tawang river basin in Arunachal Pradesh and identified species with potential to stabilize the landslide affected/vulnerable slopes. The species were selected based on their relatively broad niche preferences, efficacy and usefulness in soil characteristics improvement, r-selection life history strategy, contribution to the ecosystem services and local economy, and extent of occurrence, in addition to their root architecture. In most circumstances, the growth of such species escalates after the landslide event, and they form the pioneer species in the secondary succession of the destabilized slope.

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18.1 Introduction

The Indian Himalayan Region (IHR) comprises of four sub-provinces i.e. the *Himadri* (Great Himalaya), the *Himachal* (Lesser Himalaya), the Siwalik, and the Tethys Himalaya, which are physiographically as well as lithostructurally distinctive (Valdiya 2016). Slope instability owing to variability in the mass of sedimentary rocks viz., shale and sandstone, recurring seismic activity, variable geoclimatic condition, erratic rainfall pattern, and declining vegetation cover makes the IHR highly susceptible to landslides (Gerrard 1994; Bhandari 2004). Landslides/landslips are a mass movement of rocks, debris and soil down a slope, and occur when such debris are loosely bound in unstable terrain. Torrential rains create a flow that disintegrates the loosely bound debris. Earthquake creates a fault line in the underlying structure, and the tremors cause the loosening and disintegration. Anthropogenic and developmental activities viz., road cutting, tunnelling and construction activities add to the hazard and vulnerability in the landslide prone areas.

Slope stabilization is an effective way to mitigate landslide hazards in such areas (Dhyani and Dhyani 2016). Generally, slope stabilization in a mountainous region is done through civil engineering activities such as the construction of concrete retaining structures (Abramson et al. 2001). However, the influence of local climate, ground water, and anthropogenic factors often lead to weathering of such structures, making them less stable in due course of time (Hack 2012; DeMulder et al. 2012). As an alternative technology, bioengineering of the unstable slopes using plant species has gained popularity in recent years (Perez et al. 2017; Dhyani et al. 2018; Dhyani and Thummarukudy 2016). Here, vegetation cover controls substrate erosion and enhances slope stability as their root system augments the shear strength of root-reinforced soil apart from the positive influence of root tensile strength on the shear strength of soil (Ali 2010; Boldrin et al. 2017). Also, it positively enhances the potential of such sites in providing miscellaneous ecological services and improves the overall aesthetics of the region. However, the selection of suitable plant species for bioengineering is crucial in the eco-restoration of landslide prone/affected areas. Therefore, the challenge lies in the identification and selection of the species having potential in slope stabilization and restoration. The selected plant species must have (1) high soil reinforcing capacity, (2) positive impact on the local flora, fauna and the ecosystem, and (3) complements the socioeconomic interests of the local community.

In the present study, we follow a multi-criteria approach to identify suitable plant species from within the regional floral resource for stabilization of landslide prone/affected area in the Tawang river basin of Eastern Himalayas.

18.2 Materials and Method

18.2.1 Study Area and Sampling Sites

The present study was undertaken in Tawang district (27°25′ and 27°45′ N latitude and 91°42′ and 92°39′ E longitude; area: 2172 km^2) located in the extreme western corner of the state of Arunachal Pradesh in India. The district shares the boundary with West Kameng district of the state on the east, Tibet on the north, and Bhutan on west and south. Six landslide affected sites under three major types namely of (1) recent occurrence (~2 to 3 years), (2) recovering (~5 to 10 years), and (3) stabilized (>15 years), were identified for vegetation sampling (Fig. 18.1).

18.2.2 Geomorphology and Topography

Geomorphology of the district is divided into two major units, viz., (1) Denudo–structural hills mainly comprised of metamorphites and some igneous intrusions with high cliffs and steep slopes between 2100 and 6800 m altitude. This unit occupies about 90% of the total geographical area of the district and acts as the runoff zone; (2) Valley fills within the hill ranges, which are covered by recent alluvium. This unit acts as a recharge zone for the rivers. Major part of the region has a mountainous topography with elevation ranging from ~1000 to 6500 m along. About two-thirds of the area of the district falls in the higher Himalayan zone and is covered by hard rock terrain (Barik et al. 2015). Most of the geographical area in the state has moderate to high slopes (31–44°), while in the more upper reaches, the slope often approaches 90°.

18.2.3 Climate

The climate of the region is monsoonal with distinct warm-wet and cold-dry seasons. The monsoon season starts at the end of May and lasts till September or early October. Winter begins in October with occasional rainfall or snowfall. January and February are the driest and coldest months when the temperature drops below freezing point. The monthly maximum temperature varies between 9 and 25 °C, and the mean monthly minimum from 1 to 12 °C. The relative humidity is high throughout the year. The nature of its terrain strongly influences the climate of the district. The mountain peaks are covered with perpetual snow. By and large, the area exhibits a mosaic of climatic zones varying from place to place mainly due to its geographical location, i.e. elevation and varied topography, i.e. slope and aspect.

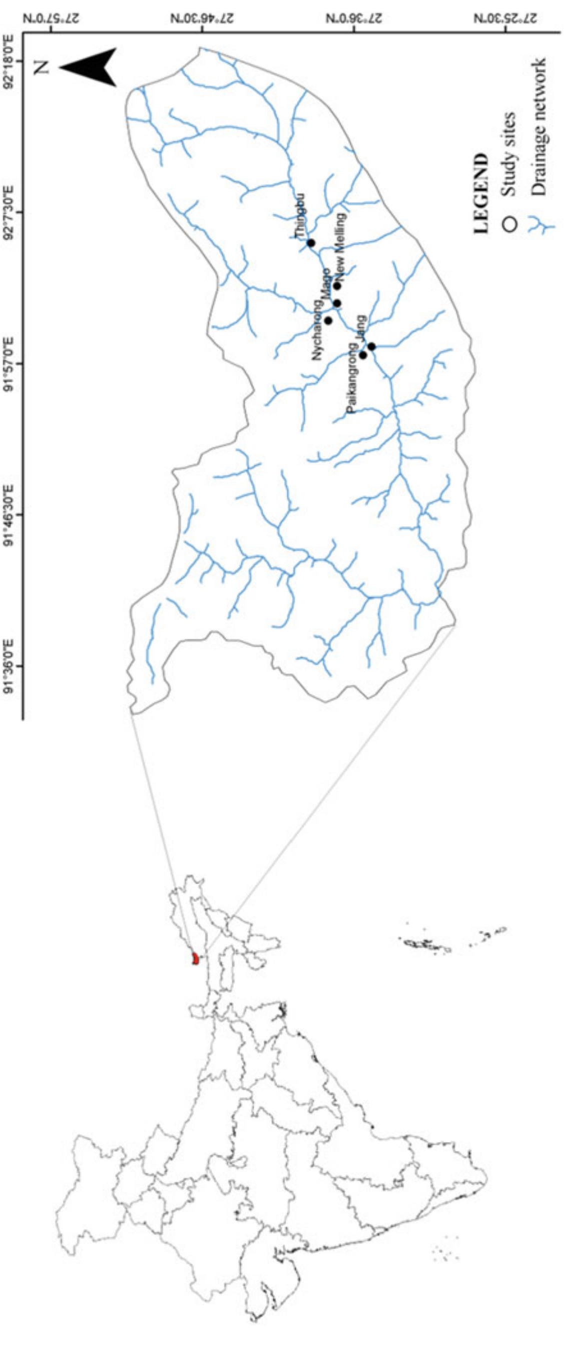

Fig. 18.1 Location of the study sites in the Tawang district of Arunachal Pradesh in the Indian Eastern Himalaya

18.2.4 Soil

The soil in most parts of the district, is red, sandy and skeletal in nature. The soil in the forested region has a relatively high humus content than on mountain slopes owing to decomposition of leaf and litter. Soil on the mountain slopes are relatively poor in organic material due to frequent runoff of top soil with rain and its depth ranges between 30 and 100 cm (Harmonized World Soil Database, Nachtergaele et al. 2012). The slopes are characterized by nutrient poor reddish acidic soil, while the soil in the foothills is alluvial, loamy, or sandy loam mixed with gravel and pebble brought down by rainwaters from high altitudes. Mostly, the soil in the valley is clayey alluvium and is rich in organic matter content (Barik et al. 2015).

18.2.5 Vegetation Sampling

Quantitative assessment of vegetation attributes such as species diversity and dominance is essential as it helps in understanding plant community response to perturbations (Walker et al. 1999). Notably, the dominance of a given species or a group of species in the community indicates their efficiency to exploit the available resources such as sunlight and soil nutrients (Holt et al. 1994). Dominance may thus be an essential criterion for the screening of species with potential for restoration purposes such as slope stabilization.

Considering the above, vegetation sampling was undertaken in the identified sites during the pre-monsoon season (April–June 2014). We enumerated the plant species composition and studied the diversity and dominance patterns following standard vegetation sampling methods (Kent 2011). In each site, we laid 100 × 10 m belt transects to enumerate tree species. Within the belt transect, ten nested random quadrats of 5 × 5 m were used to identify shrubs and climbers, while ten random quadrats of 1 × 1 m were laid for enumeration of herbaceous species.

Species identity was ascertained using regional flora (Hooker 1872–1897; Kanjilal et al. 1934–1940; Hajra et al. 1996), Flora of China (http://www.efloras.org/), and the herbarium of Botanical Survey of India, Shillong. Community characteristics viz., frequency, density, and basal area were determined (Misra 1968). The importance value index (IVI) of tree species was computed based on relative frequency, relative density, and relative basal area values. IVI for herbs, shrubs, and climbers was computed based on the relative frequency and relative density. Shannon's diversity index, Simpson's dominance index, and Buzas and Gibson's evenness index were calculated based on density values in PAST 3.26 software (Hammer et al. 2001).

18.2.6 Selection of Potential Species for Slope Stabilization

Likely species for slope stabilization were selected following a multi-criteria approach. First, we screened the dominant species based on IVI from the list of plant species enumerated following vegetation sampling. Subsequently, from the screened dominant species, the potential candidate species were identified based on (1) their efficacy to improve soil characteristics, (2) rate of biomass accumulation indicating rapid growth, (3) economic importance/utility/ecosystem services, geographical range and (4) root architecture. The presence of the desired traits was ascertained based on field observations as well as published literature.

18.3 Results and Discussion

18.3.1 Family and Species Composition

We enumerated 102 species belonging to 53 families from the six landslide affected areas of Tawang district, which comprised of 22 trees, 23 shrubs, 42 herb, and 15 climbers (Annexure). Asteraceae was the dominant family consisting of 12 species followed by Rosaceae (6), and Pinaceae and Urticaceae (five species each). Polygonaceae and Ericaceae were represented by four species each, while three species each represented Poaceae, Ranunculaceae and Fabaceae. Thirteen families were represented by two species each, while one species each represented 31 families. Members of Asteraceae and Rosaceae mostly dominate in areas with a recent disturbance history as they have better competitive abilities and can exploit the available resources more effectively compared to members of other families (DeFerrari and Naiman 1994; Lloyd et al. 2002; Gaur et al. 2005). Single species representation in ~58% of the families indicates a higher degree of niche specialization/habitat requirement for such species/families.

18.3.2 Species Richness, Diversity and Dominance Patterns

The number of species of tree, shrub, and herb did not show a clear-cut spatial or temporal trend (Table 18.1). A plausible explanation for this may be that all the study sites are embedded in a mosaic of disturbed and less disturbed vegetation, and therefore have a high probability of being occupied by species from nearby areas. Nevertheless, the number of climber species in 10- and 15-year-old landslide affected sites was nearly two times higher than that of 2-year-old sites. This might be attributable to climbers such as *Hedera nepalensis*, *Aristolochia griffithii*, *Herpetospermun pedunculatum*, *Stephania glandulifera*, etc. in the area, these

Table 18.1 Diversity attributes of tree, shrub, herb and climbers in the landslide affected areas in Tawang district. The years represent the recovery stage after the landslide event

	2-year-old sites			10-year-old sites			>15-year-old sites		
Life-forms and diversity attributes	Jang	Paikangrong	Total	New Melling	Thingbu	Total	Nycharong	Mago	Total
Tree									
Number of species	9	7	9	9	8	11	9	10	13
Simpson's dominance index	0.15	0.16	0.15	0.17	0.22	0.18	0.15	0.13	0.11
Shannon diversity index	2.03	1.89	2.00	1.94	1.77	1.98	2.02	2.17	2.32
Buzas and Gibson's evenness index	0.85	0.95	0.82	0.77	0.73	0.65	0.84	0.87	0.78
Shrub									
Number of species	10	9	11	13	13	17	11	11	14
Simpson's dominance index	0.12	0.14	0.12	0.12	0.14	0.12	0.14	0.13	0.12
Shannon diversity index	2.18	2.08	2.20	2.32	2.24	2.37	2.16	2.19	2.29
Buzas and Gibson's evenness index	0.89	0.89	0.82	0.78	0.72	0.63	0.79	0.81	0.70
Herb									
Number of species	14	10	18	12	13	18	13	15	20
Simpson's dominance index	0.09	0.12	0.08	0.12	0.09	0.06	0.13	0.12	0.10
Shannon diversity index	2.49	2.21	2.63	2.29	2.51	2.76	2.24	2.35	2.58
Buzas and Gibson's evenness index	0.86	0.91	0.77	0.83	0.95	0.88	0.72	0.70	0.66
Climber									
Number of species	6	5	7	9	7	9	12	11	13
Simpson's dominance index	0.20	0.24	0.19	0.12	0.17	0.12	0.10	0.10	0.09
Shannon diversity index	1.68	1.51	1.76	2.15	1.84	2.12	2.42	2.35	2.47
Buzas and Gibson's evenness index	0.89	0.90	0.83	0.95	0.90	0.93	0.94	0.95	0.91

species are woody and more associated with a stable substrate such as rocks and big trees.

18.3.3 Species for Slope Stabilization

A total of 32 species comprising of trees (6), shrubs (6), herbs (11), and climbers (9) with potential for slope stabilization were identified (Table 18.2, Fig. 18.2). The tree species comprised of *Acer campbellii*, *Alnus nepalensis*, *Pinus wallichiana*, *Rhododendron arboreum* and *Tsuga dumosa*. The shrubs included *Artemisia nilagirica*, *Arundinaria maling*, *Coriaria nepalensis*, *Daphne papyracea*, *Euphorbia sikkimensis* and *Pipthanthus nepalensis*. The herbaceous species comprised of *Ageratum conyzoides*, *Oplismenus compositus*, *Persicaria capitata*, *Pilea umbrosa*, *Plantago erosa*, *Polygonum hydropiper*, *Polygonum molle*, *Primula bracteosa*, *Primula denticulata*, *Rumex nepalensis* and *Urtica dioica*. The climber species comprised of *Celastrus paniculatus*, *Dioscorea bulbifera*, *Hedera nepalensis*, *Holboellia latifolia*, *Periploca callophylla*, *Philadelphus tomentosus*, *Rubia cordifolia*, *Stephania glandulifera* and *Thladiantha cordifolia*.

Slope stabilization using plant species has garnered much traction within past few decades owing to its cost efficiency, negligible or complete absence of adverse ecological impacts, pleasant aesthetics and high success rate in reducing landslide occurrence (Ghestem et al. 2014; Nilaweera and Nutalaya 1999; Reubens et al. 2007; Normaniza et al. 2008). Root abundance in the soil is one of the most important functional traits (Ghestem et al. 2014) in determining efficiency for stabilizing slopes. In nature, the plants which are dominant flora of a region are most successful in resource partitioning and thus have the highest root abundance (Schimper 1903). Within root type, tap roots anchor the substratum with parent bedrock, and fibrous roots hold the fine soil thereby preventing runoff and erosion. Therefore, the best results are expected when the species depicting either of both the functional traits are working in tandem.

Among the species identified with having a potential for slope stabilization, distinguished species belonging to the genera such as *Alnus*, *Pinus* and *Rhododendron* were reported to be used in erosion/landslide control elsewhere in the world (Paudel et al. 2003; Reubens et al. 2007; Lee et al. 2008). However, we did not find any reports of similar uses for most other species reported in our study. Nevertheless, we opine that selecting native plant species in slope stabilization is always desirable, as these species are acclimatized to the local environment, and therefore are quickly established in the landslide affected areas. This character in combination with other discussed traits have considerable implications in a successful restoration of the landslide affected areas, apart from stabilizing landslide prone areas. Besides, considering their cultural and economic importance, they may also contribute to the socioeconomics of the region.

Table 18.2 Species identified for slope stabilization

Name of species	Root architecture	Habitat preferences	Geographical range	Economic importance/ utility
Tree species				
Acer campbellii	Tap root	Mixed forests at elevations between 1800 and 3700 m	China, Bhutan, N India, Myanmar, Nepal, Vietnam	Construction
Alnus nepalensis	Tap root	A pioneer deciduous species reaching a height of 30 m. Grows well in full light but also shade tolerant. Does not require high soil fertility and prefers permeable soils	China, Bangladesh, Bhutan, India (Sikkim), Myanmar, Nepal, N Thailand, N Vietnam	Fuelwood, construction, tanning, dye, medicine, nitrogen fixation, land reclamation, charcoal
Pinus wallichiana	Tap root	Grows in the Himalayas in the valleys and foothills, between elevations of 2700–3400 m a.s.l. Often forms pure stands or forests, in other places it appears as an important forest component mixed with broad-leaved trees such as *Quercus*, *Acer* and *Ilex*. In Western Himalayas, where conditions are drier, *P. wallichiana* forms mixed forests with *Cedrus deodara*. Other conifers with which it may be associated are *Pinus roxburghii*, *Abies spectabilis*, or *A. densa* and *Tsuga dumosa* in the wetter eastern part of its range	China, Afghanistan, Bhutan, India (Sikkim), Kashmir, Myanmar, Nepal, Pakistan	Construction, fuelwood, resin
Rhododendron arboreum	Tap root	Forests, thickets, slopes; 1500–3800 m	China, Bhutan, India (Sikkim), Kashmir, Nepal, Sri Lanka, N Thailand, N Vietnam	Edible, medicine
Rhododendron sp.	Tap root			Fuelwood
Tsuga dumosa	Tap root	Occurs in the Himalaya in a belt between 2600 and 3200 m a.s.l., in a wide range of habitats, usually on alpine lithosols. It is especially abundant on slopes with a northerly exposure, where it is the most shade-tolerant tree	China, Bhutan, N India, N Myanmar, Nepal, Sikkim, N Vietnam	Construction, religious use

(continued)

Table 18.2 (continued)

Name of species	Root architecture	Habitat preferences	Geographical range	Economic importance/ utility
Shrub				
Artemisia nilagirica	Tap root	Along forest margins on slopes	Slopes; middle elevations. SW Sichuan, SE Xizang, N India, N Myanmar, China	Medicine
Arundinaria maling	Fibrous root	Occurs in open areas at elevations between 2500 and 3000 m	India, Nepal and Bhutan	Construction, food, religious purposes
Coriaria nepalensis	Tap root	Growing in thickets, mountain slopes; 200–3200 m	China, Bhutan, India (Kashmir), Myanmar, Nepal, Pakistan	Ornamental, medicine, food
Daphne papyracea	Tap root	Forests, shrubby and herbaceous slopes; 700–3100 m	China, India, Nepal	Handmade paper
Euphorbia sikkimensis	Tap root	Meadow steppes to alpine meadows, sparse forests, scrub; 600–4500 m	China, Bhutan, India (Sikkim), Myanmar, Nepal	Medicine
Pipthanthus nepalensis	Tap root	2000–3800 m	China, Bhutan, India (Kashmir), Nepal	Ornamental garden plant, natural fence
Herb				
Ageratum conyzoides	Fibrous root			Medicine
Opliomenus compositus	Fibrous root	Undergrowth in moist forests on hillsides, moist places in open forests, degraded deciduous forests and shady places	China, Japan, Philippines, Thailand, and elsewhere in tropical Asia extending westward through India to Africa; Australia, Pacific Islands (Polynesia)	Fodder, lawn grass
Persicaria capitata	Adventitious roots	Mountain slopes, shaded places in valleys; disturbed area, 600–3500 m	Pakistan, India (Himalayas) extending in east up to W. China through Xizang	Medicine, ornamental
Pilea umbrosa	Fibrous root	Shaded moist places in forests, near streams; 1500–2800 m	S-Tibet, China (NW-Yunnan), Nepal, Bhutan, India (Arunachal Pradesh, Sikkim, Jammu & Kashmir), Pakistan (Swat, Hazara, Murree), Vietnam	
Plantago erosa	Fibrous root	Open degraded area, Grasslands	India (Assam), Ceylon, Himalaya (Kumaun to Bhutan), Burma, S. E. Tibet, W. China.	Medicine

Polygonum hydropiper	Fibrous root	Occurs in seasonally inundated disturbed nutrient-rich soils, typically occurring in seasonally inundated arable, river, stream, lake and pond margins particularly where they are poached by cattle and on seasonally exposed silt and mud forming islands and bars in large lowland river systems.	China, Bangladesh, Bhutan, India (Sikkim), Indonesia, Japan, Kazakhstan, Korea, Kyrgyzstan, Malaysia, Mongolia, Myanmar, Nepal, Russia, Sri Lanka, Thailand, Uzbekistan; Australia, Europe, North America]	Food, medicine
Polygonum molle	Fibrous root	The plant is found in forest, scrub and damp ground, slopes and in valleys. The species is distributed at an elevation range from 1200–3500 m	China, Bhutan, India (Sikkim), Indonesia, N Myanmar, Nepal, Thailand	Food
Primula bracteosa	Fibrous root	In rock crevices of ravines; 2300–2700 m	China, Bhutan, NE India & Sikkim, Nepal	Ornamental
Primula denticulata	Fibrous root	Moist meadows, grassy slopes, among shrubs, open forests; 1500–4100 m	China, Afghanistan, Bhutan, India (Sikkim, Kashmir), N Myanmar, Nepal, Pakistan	Food
Rumex nepalensis	Tap root	Grassy slopes, moist valleys, along ditches; 1000–4300 m	China, Afghanistan, Bhutan, India (Sikkim), Indonesia, Japan (introduced), Myanmar, Nepal, Pakistan, Tajikistan, Vietnam; SW Asia	Food, medicine
Urtica dioica	Fibrous root	The species grows in anthropogenic (man-made or disturbed habitats), river or stream floodplains, forest edges and shores of rivers or lakes (New England Wild Flower Society 2011–2015).	China, Afghanistan, C Himalayas; N Africa, Europe, North America	Food, medicine, compost
Climber				
Celastrus paniculatus	Tap root	Moist deciduous and semi evergreen forests, Forest slopes	China, Bhutan, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand, Vietnam; Australia, Pacific islands (New Caledonia)	Medicine
Dioscorea bulbifera	Tuberous roots	Moist deciduous forests, also in the plains, common in the moist regions of shaded valleys and disturbed forests	China, Bhutan, Cambodia, India, Japan, Korea, Myanmar, Thailand, Vietnam; Africa, Oceania	Medicine
Hedera nepalensis	Adventitious roots	Moist stones and tree stems at elevations of 1600–3000 m, In moist forests, 1900–2600 m	W. Asia, Japan, Afghanistan and the Himalayas	Medicine

(continued)

Table 18.2 (continued)

Name of species	Root architecture	Habitat preferences	Geographical range	Economic importance/ utility
Holboellia latifolia	Tap root	Forest margins, especially cool broad-leaved forests	China, Bhutan, NE India & Sikkim, Nepal	Food
Periploca callophylla	Tap root	Warm broad-leaved forests, 900–2000 m	China, Bhutan, India (Sikkim), Kashmir, Nepal, Vietnam	Medicine
Philadelphus tomentosus	Tap root	Forests, thickets; 2500–4400 m	China, Bhutan, India (Sikkim, Kashmir), Nepal	Ornamental
Rubia cordifolia	Tuberous roots	Occurs in shaded and moist forest banks. The plant is common throughout India, ascending up to an altitude of 3750 m	Sparse forests, forest margins, grasslands; 300–2800 m. China, Japan, Korea, Mongolia, Russia (Far East); S and SE Asia to Sri Lanka and Java, through the Himalaya to Afghanistan; (sub)tropical Africa]	Medicine
Stephania glandulifera	Tuberous roots	Occurs in warm forests, at altitudes of 1000–2000 m	Himalaya (Nepal to NEFA), Assam.	Medicine
Thladiantha cordifolia	Tuberous roots	Forest margins at high elevation	E. Himalaya (Nepal, Sikkim), India (Assam), Burma, Thailand, Indo-China, China, Malaysia.	Medicine

Fig. 18.2 Important species potentially useful in slope stabilization

18.4 Conclusion

Landslides cause substantial damage to infrastructure and also result in habitat and biodiversity loss. Nature based solutions to this problem can be cost effective, durable, ecologically sustainable, and add to the aesthetics. In the present study, we identified species that are adapted to the local environment, have slope stabilizing traits, and therefore can establish fast in the landslide sites. Using these native species will potentially help in mitigating landslides and improve stability of the slopes.

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18.5 Annexure

Density and importance value index of species with their respective families in various landslide affected areas of Tawang district in Arunachal Pradesh. Density is expressed as number of individuals in 0.1 hectare. The years represent the recovery stage in years after the landslide event.

Name of species	Family	2-year-old sites				10-year-old sites				>15-year-old sites			
		Jang		Paikangrong		New Melling		Thingbu		Nycharong		Mago	
		Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI
Tree													
Abies densa	Pinaceae	–	–	–	–	–	–	3.0	19.9	–	–	–	–
Acer campbellii	Sapindaceae	–	–	–	–	–	–	–	–	11.0	56.3	17.0	52.8
Acer sikkimense	Sapindaceae	–	–	–	–	7.0	28.7	–	–	–	–	–	–
Alangium alpinum	Cornaceae	3.0	20.0	–	–	–	–	–	–	12.0	43.5	–	–
Alnus nepalensis	Betulaceae	11.0	75.0	10.0	77.2	15.0	67.5	8.0	46.4	16.0	70.1	15.0	57.0
Betula alnoides	Betulaceae	–	–	–	–	2.0	14.9	2.0	10.0	2.0	7.7	4.0	18.6
Brassaiopsis glomerulata	Araliaceae	–	–	–	–	–	–	–	–	5.0	20.5	6.0	24.8
Larix griffithii	Pinaceae	–	–	–	–	3.0	17.1	2.0	12.7	–	–	–	–
Leucosceptrum canum	Lamiaceae	1.0	7.6	–	–	2.0	11.1	–	–	4.0	17.4	5.0	17.0
Persea odoratissima	Lauraceae	–	–	–	–	–	–	–	–	3.0	14.2	–	–
Picea spinulosa	Pinaceae	–	–	–	–	–	–	3.0	16.1	–	–	–	–
Pinus wallichiana	Pinaceae	9.0	54.2	7.0	45.4	5.0	27.7	7.0	33.8	–	–	9.0	41.6
Populus ciliata	Salicaceae	–	–	–	–	4.0	19.2	–	–	–	–	3.0	13.2
Quercus griffithii	Fagaceae	4.0	24.5	3.0	22.0	–	–	–	–	–	–	–	–
Quercus serrata	Fagaceae	3.0	23.0	5.0	33.8	–	–	–	–	–	–	–	–
Rhododendron arboreum	Ericaceae	7.0	39.6	7.0	55.7	–	–	–	–	12.0	44.2	7.0	26.3
Rhododendron campanulatum	Ericaceae	–	–	–	–	–	–	–	–	7.0	26.1	–	–
Rhododendron nerifolium	Ericaceae	–	–	–	–	–	–	–	–	–	–	7.0	21.2
Rhododendron sp.	Ericaceae	–	–	–	–	7.0	31.8	9.0	52.6	–	–	–	–
Rhus javanica	Anacardiaceae	4.0	25.0	5.0	30.9	–	–	–	–	–	–	–	–
Schima wallichii	Theaceae	5.0	31.3	6.0	35.2	–	–	–	–	–	–	–	–
Tsuga dumosa	Pinaceae	–	–	–	–	17.0	82.1	21.0	108.5	–	–	7.0	27.6
Shrub													
Artemisia nilagirica	Asteraceae	84.0	32.5	84.0	40.1	115.2	30.1	148.0	43.4	136.0	44.5	108.0	33.9
Yushania maling	Poaceae	–	–	–	–	56.0	22.4	64.0	19.8	56.0	19.9	92.0	24.8

(continued)

		2-year-old sites				10-year-old sites				>15-year-old sites			
		Jang		Paikangrong		New Melling		Thingbu		Nycharong		Mago	
Name of species	Family	Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI
Berberis aristrata	Berberidaceae	–	–	–	–	40.0	15.1	36.0	18.6	28.0	10.6	16.0	13.5
Boenninghausenia albiflora	Rutaceae	–	–	–	–	11.2	6.4	–	–	–	–	–	–
Budlejia asiatica	Scrophulariaceae	25.6	16.1	24.0	18.4	–	–	–	–	–	–	–	–
Cannabis sativus	Cannabaceae	48.0	23.9	44.0	19.0	–	–	–	–	–	–	–	–
Coriaria nepalensis	Coriariaceae	56.0	24.6	48.0	24.6	64.0	18.4	60.0	22.2	6–8.0	22.2	36.0	18.1
Daphne papyracea	Thymelaeaceae	–	–	–	–	108.0	30.6	56.0	25.7	56.0	19.9	96.0	33.4
Elaeagnus parvifolia	Elaeagnaceae	–	–	–	–	–	–	12.0	6.6	20.0	15.2	–	–
Euphorbia sikkimensis	Euphorbiaceae	68.0	31.2	68.0	32.9	–	–	–	–	–	–	68.0	16.8
Girardinia grandiflora	Urticaceae	24.0	17.0	–	–	30.4	13.4	32.0	15.7	32.0	15.1	36.0	12.8
Heracleum nepalense	Apiaceae	–	–	–	–	–	–	8.0	3.7	–	–	–	–
Hypericum choisianum	Hypericaceae	–	–	–	–	–	–	8.0	3.7	–	–	20.0	14.3
Neillia thyrsiflora	Rosaceae	–	–	28.8	21.1	20.8	8.1	–	–	16.0	8.2	–	–
Pipthanthus nepalensis	Fabaceae	–	–	–	–	20.0	11.6	24.0	13.1	36.0	20.9	24.0	15.9
Plectranthus sp.	Lamiaceae	–	–	–	–	11.2	5.5	–	–	–	–	–	–
Rubus ellipticus	Rosaceae	40.0	18.3	40.0	19.5	–	–	20.0	8.1	48.0	17.0	36.0	10.1
Rubus nivies	Rosaceae	32.0	17.6	36.0	17.0	28.0	14.8	28.0	9.6	–	–	–	–
Rubus rugosus	Rosaceae	28.0	9.2	–	–	36.0	11.7	–	–	–	–	–	–
Seigesbeckia orientalis	Asteraceae	–	–	–	–	27.2	11.9	24.0	9.9	–	–	–	–
Triumfetta rhomboidea	Malvaceae	14.4	9.7	11.2	7.5	–	–	–	–	–	–	–	–
Viburnum foetidum	Adoxaceae	–	–	–	–	–	–	–	–	8.0	6.6	–	–
Zanthoxylum armatum	Rutaceae	–	–	–	–	–	–	–	–	–	–	16.0	6.5
Herb													
Ageratum conyzoides	Asteraceae	2500.0	21.8	1100.0	18.8	–	–	–	–	–	–	–	–
Ainsliaea latifolia	Asteraceae	–	–	–	–	–	–	–	–	–	–	200.0	4.1
Dipsacus asper	Asteraceae	–	–	–	–	500.0	9.0	–	–	–	–	–	–
Anaphalis margaritacea	Asteraceae	–	–	–	–	900.0	18.7	700.0	11.0	–	–	–	–

Anemone rivularis	Ranunculaceae	400.0	9.1	–	–	–	–	–	–	–	–	–	–
Arisaema erubescens	Araceae	–	–	–	–	–	–	–	–	–	–	700.0	10.0
Aster trinervius	Asteraceae	–	–	–	–	–	–	–	–	–	–	600.0	6.4
Bidens pilosa	Asteraceae	800.0	10.6	1500.0	22.0	–	–	–	–	–	–	–	–
Centella asiatica	Apiaceae	1100.0	12.2	–	–	–	–	–	–	–	–	–	–
Crassocephalum crepidioides	Asteraceae	–	–	400.0	8.2	–	–	–	–	–	–	–	–
Cyathula capitata	Amaranthaceae	–	–	–	–	700.0	13.5	1200.0	17.6	700.0	12.1	–	–
Cymbopogon citratus	Poaceae	500.0	7.5	–	–	–	–	–	–	–	–	–	–
Cynoglossum sp.	Boraginaceae	300.0	10.6	–	–	–	–	–	–	–	–	–	–
Drymaria cordata	Caryophyllaceae	900.0	11.1	–	–	–	–	–	–	–	–	–	–
Elatostemma sessile	Urticaceae	–	–	–	–	1300.0	15.9	1000.0	13.2	900.0	13.5	1400.0	13.9
Eupatorium adenophorum	Asteraceae	–	–	1200.0	17.1	–	–	–	–	–	–	–	–
Fragaria nubicola	Rosaceae	–	–	–	–	–	–	–	–	–	–	1100.0	15.2
Galinsoga parviflora	Asteraceae	900.0	10.4	700.0	13.1	–	–	–	–	–	–	–	–
Geranium pratense	Geraniaceae	–	–	–	–	700.0	12.0	700.0	13.9	300.0	6.6	–	–
Halenia elliptica	Gentianaceae	–	–	–	–	–	–	1200.0	14.6	–	–	–	–
Hemiphragma heterophyllum	Plantaginaceae	–	–	1100.0	18.8	–	–	–	–	–	–	–	–
Houttuynia cordata	Saururaceae	900.0	11.1	–	–	–	–	–	–	–	–	–	–
Lecanthus penduncularis	Urticaceae	–	–	–	–	–	–	700.0	8.0	–	–	–	–
Ophiopogon intermedius	Asparagaceae	–	–	–	–	500.0	12.7	700.0	13.9	400.0	8.2	300.0	7.7
Oplismenus compositus	Poaceae	–	–	–	–	–	–	1300.0	12.4	2100.0	20.9	1400.0	13.9
Oxalis corniculata	Oxalidaceae	1100.0	11.5	–	–	–	–	–	–	–	–	–	–
Parochetus communis	Fabaceae	–	–	–	–	700.0	10.5	900.0	12.4	–	–	–	–
Persicaria capitata	Polygonaceae	2300.0	17.2	900.0	14.7	–	–	–	–	–	–	–	–
Pilea umbrosa	Urticaceae	–	–	–	–	1800.0	22.7	1300.0	18.3	1700.0	19.1	1300.0	13.3
Plantago erosa	Plantaginaceae	1500.0	15.0	2300.0	33.4	–	–	1900.0	28.6	2400.0	31.2	–	–
Polygonum hydropiper	Polygonaceae	–	–	–	–	–	–	–	–	–	–	2500.0	26.1
Polygonum molle	Polygonaceae	–	–	–	–	–	–	–	–	–	–	2100.0	20.8
Potentilla cuneata	Rosaceae	–	–	–	–	800.0	15.0	–	–	300.0	8.4	100.0	3.6

(continued)

Name of species	Family	2-year-old sites				10-year-old sites				>15-year-old sites			
		Jang		Paikangrong		New Melling		Thingbu		Nycharong		Mago	
		Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI	Density	IVI
Primula bracteosa	Primulaceae	–	–	–	–	2300.0	29.5	–	–	–	–	–	–
Primula denticulata	Primulaceae	–	–	–	–	–	–	1500.0	22.7	–	–	–	–
Ranunculus diffusus	Ranunculaceae	–	–	–	–	–	–	–	–	–	–	–	–
Rumex nepalensis	Polygonaceae	1800.0	18.0	1900.0	30.2	2500.0	33.9	–	–	2900.0	38.3	4400.0	39.7
Sambucus adnata	Adoxaceae	–	–	–	–	–	–	–	–	–	–	200.0	4.1
Senecio cappa	Asteraceae	–	–	–	–	300.0	6.7	–	–	200.0	5.0	–	–
Trifolium repens	Fabaceae	–	–	–	–	–	–	–	–	1800.0	18.0	–	–
Urtica dioica	Urticaceae	–	–	1400.0	23.7	–	–	700.0	13.9	400.0	10.1	1000.0	11.6
Viola sikkimensis	Violaceae	900.0	11.1	–	–	–	–	–	–	300.0	8.4	600.0	9.4
Climber													
Aristolochia griffithii	Aristolochiaceae	–	–	–	–	12.0	17.2	–	–	8.0	8.1	12.0	14.1
Celastrus paniculatus	Celastraceae	–	–	–	–	20.0	22.3	20.0	38.8	12.0	14.0	–	–
Cissampelos pareira	Menispermaceae	–	–	12.0	27.3	–	–	–	–	–	–	12.0	14.1
Clematis buchananiana	Ranunculaceae	4.0	10.7	8.0	15.8	–	–	–	–	–	–	–	–
Cuscuta reflexa	Convolvulaceae	12.0	25.3	–	–	–	–	–	–	–	–	–	–
Dioscorea bulbifera	Dioscoreaceae	20.0	40.0	–	–	–	–	–	–	8.0	15.3	16.0	16.2
Hedera nepalensis	Araliaceae	–	–	–	–	20.0	27.1	12.0	24.5	20.0	18.5	20.0	22.2
Herpetospermum pedunculosum	Cucurbitaceae	–	–	–	–	16.0	19.8	–	–	12.0	14.0	16.0	16.2
Holboellia latifolia	Berberidaceae	16.0	29.3	28.0	59.0	12.0	17.2	24.0	49.0	16.0	16.2	20.0	18.3
Periploca callophylla	Apocynaceae	28.0	54.7	28.0	59.0	–	–	–	–	28.0	30.2	28.0	30.3
Philadelphus tomentosus	Hydrangeaceae	–	–	–	–	28.0	32.2	16.0	28.5	16.0	19.8	24.0	24.3
Rubia cordifolia	Rubiaceae	20.0	40.0	16.0	38.8	–	–	–	–	12.0	14.0	16.0	20.0
Smilax sp.	Smilacaceae	–	–	–	–	12.0	17.2	8.0	14.3	12.0	14.0	8.0	8.1
Stephania glandulifera	Menispermaceae	–	–	–	–	12.0	17.2	16.0	34.8	12.0	14.0	16.0	16.2
Thladiantha cordifolia	Cucurbitaceae	–	–	–	–	24.0	29.7	4.0	10.3	20.0	22.1	–	–

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Part IV
Insights to Research Innovations in NbS

Chapter 19
Permeable Pavements as Sustainable Nature-Based Solutions for the Management of Urban Lake Ecosystems

Harini Santhanam and Rudrodip Majumdar

Abstract Permeable pavement systems (PPS) are becoming integral parts of the urban green infrastructure (UGI) planning approaches for the implementation of nature-based solutions (NbS) especially in rapidly developing regions. Global research has demonstrated that UGI is quite essential to regulate and establish the hydrological and ecological functions of urban aquatic ecosystems such as lakes. At a micro-scale level, design of storm water management systems requires detailed planning, as urban flooding has the potential to affect a huge population dwelling in the cities often without any warning. Such events cause drastic changes in the hydrological statuses of urban lakes, by gradually decreasing their natural resilience over a period. An associated risk with the degradation of urban lake systems pertains to their immense contributions in maintaining the ambient temperature profiles. The loss of the urban lake systems will directly lead to a substantial rise in the ambient air temperature and enhanced heat island effect. PPS can offer successful NbS to improve the resilience of the lake systems. PPS would also prove to be instrumental in mitigating the urban heat island effects by intercepting the excessive run-offs, increasing green water collection and storage, as well as by maintaining close-to-natural flow regimes in the case of urban lakes. Such micro-scale NbS offered by the design and implementation of PPS can offer huge environmental, social, and economic benefits in the long run. PPS can also offer direct benefits towards regulating the lake services and can assist in addressing the sustainable development goals for the lake ecosystems in the urban set-up, which are under stress due to various anthropogenic detrimental activities.

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19.1 Introduction

In the present era of unprecedented floods occurring in the areas of dense human habitations, the urban infrastructure has been under the spotlight for several reasons. First, several incidents of flash floods, especially under the influence of monsoons, have echoed the criticality of sound urban planning of public sewerage and sewer systems around the world (e.g. Thorne et al. 2018). This becomes even more crucial for the Indian scenario (Nagendra 2010), where ambitious city development projects are currently underway. Second, the perspective of how to make sustainable urban drainage systems (SUDS) has been approached from the perspective of providing nature-based solutions (NbS), with the inherent need to adhere realistically to the sustainable development goals (SDG). The third perspective pertains to challenges in preserving the unique urban hydrological cycle, by reinforcing the urban green infrastructure (UGI) using pragmatic NbS for providing effective land management solutions (Keesstra et al. 2018) as well as options for storm water drainage. Woven around these ideas, the unique environmental settings of urban lakes offer the broad scope for utilizing NbS protocols for planning blue-green sustainable infrastructure.

Starting with the classical Forbes' concept of lakes as '*microcosms*' (Forbes 1887), the scientific perspectives of urban ecological values of lakes as environmental, socio-economic, and cultural hotspots have been important to understand their roles in promoting urban resilience. Campanella (2006) also adds to the understanding of urban resilience with an anthropological perspective of voluntary citizen participation as reinforcements for achieving the urban '*stable state*'. The central idea propounded by the studies on urban sustainability stress on the unique capabilities of NbS to provide a 'scientific niche', 'conceptual flexibility' (Nesshöver et al. 2017) or a '*thought space*' towards the conservation of urban lakes, which are threatened by the accelerated pace of urban sprawl. Under the lens of the careful lake management plans, the attention now needs to be drawn to the twofold goals of ensuring water balance as well as the water quality of the urban lakes, which are necessary for the waterbodies for extending the ecological and anthropological services as drivers of UGI. Recognition of the barriers for successful implementation and strengthening of UGI (Fig. 19.1) is increasingly being realized as core to the city development (O'Donnell et al. 2017).

Of the several barriers, the problem of increasing imperviousness around these lakes push the limits to realizing the SDGs unique to the urban planning (Thorne et al. 2018). Under the circumstances, it is important to address the unique opportunities provided by permeable pavement networks (PPS) as ideal NbS options for strengthening the UGI.

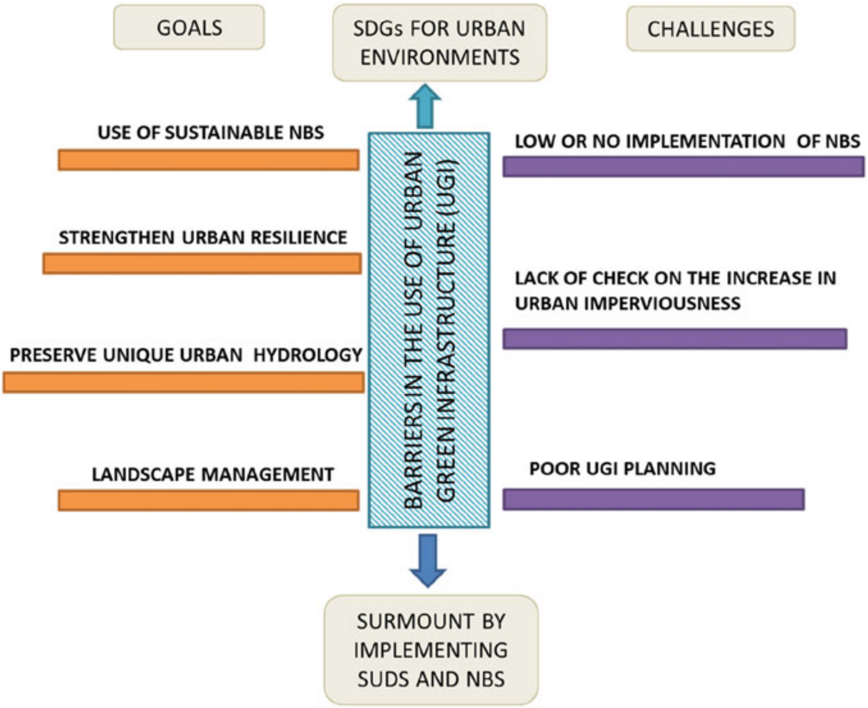

Fig. 19.1 Barriers for implementing UGI for preserving the unique hydrological setting of urban lakes (*SUDS* sustainable urban drainage systems, *NbS* nature-based solutions, *UGI* urban green infrastructure)

19.2 Permeable Pavement Systems (PPS)

Pavements are an intrinsic and integral part of the urban lives. However, the quality of their construction, as well as, the management are usually given much less attention than required (Online Resources: Hun-Dorris 2009). For the urban developers, industrial facilities, and municipal bodies addressing storm water and associated water-quality guidelines and regulations, paved urban sidewalks are of foremost importance in the context of healthy urban planning (Tennis et al. 2004; Rowe et al. 2010; Saadeh et al. 2019). According to Professor Bruce Ferguson, one of the pioneers of the porous pavement research field and the Director of the School of Environmental Design at the University of Georgia in Athens, 'Pavements are the most ubiquitous structures built by man. They occupy twice the area of buildings. Two-thirds of all the rain that falls on potentially impervious surfaces in urban watersheds is falling on pavement'. Therefore, with a view to facilitating better management of the rainwater, design, and implementation of durable permeable pavement systems (PPS) is of pivotal importance. It is noteworthy that permeable pavement is one of the recommended technologies for the low-impact development

(LID) in the United States of America (USA) (Zahmatkesh et al. 2014; Vogel et al. 2015; Weiss et al. 2019), as well as for the water-sensitive urban design (WSUD) in Australia (Pezzaniti et al. 2009; Beecham et al. 2010).

Permeable pavement or the pervious concrete is a specific kind of pavement that allows rainwater to pass through it into the underground aquifers, owing to its high porosity. The pervious concrete is capable of reasonably mimicking the natural process that occurs on the ground's surface and reduces run-off considerably by returning water into the ground below, thereby recharging the groundwater table (Online Resources: Green Building Alliance (Permeable Pavement) (n.d.); Pavement Interactive (Permeable Pavements) (n.d.)). Pervious pavements can hold the storm water in multiple air voids or cells, and thus can help to curb the pollution of the groundwater table by retaining suspended solids and pollutants present in the runoff stream within the structure (Hun-Dorris 2005; Online Resources: Pavement Interactive (Permeable Pavements) (n.d.)). Such pavements also facilitate degradation of captured hydrocarbons into carbon dioxide and water (Online Resources: Pavement Interactive (Permeable Pavements) (n.d.)).

In an urban environment, with proper arrangements and judicious implementation, porous pavements can facilitate biodegradation of the oils spilled from cars and trucks, help rainwater in infiltrating through the soil, decrease urban heating by reducing the absorption of solar radiation and urban heat storage potential (Sonebia et al. 2016), replenish groundwater, allow the tree roots to extend their roots and breathe and reduce the total run-off, as well as, the frequency of flash flooding by reducing the peak water flow through the drainage channels (Ferguson 2005). Particularly, in the water scarce and water-stressed regions, water reuse becomes essential. This prompts the porous pavements, with their significant and unique potential, to revolutionize storm water management; and emerge as an important futuristic technology option. Pervious pavement technology also facilitates efficient use of land by eliminating the need for retention ponds, swales, and necessary storm water management devices, leading to much reduced overall project costs on a first-cost basis (Tennis et al. 2004; ACI report 2010). Currently, porous pavements constitute only a small fraction of all pavement installations. However, the technology is steadily gaining popularity as the most rapidly developing way of restoring large parts of the urban environment (Ferguson 2006), and they have been installed in all regions of the United States (Chopra et al. 2011; Online Resources: Cahill et al. 2018).

A large fraction of the existing permeable pavement systems has been installed at the parking lots, as well as at the commercial areas that are prone to frequent light traffic loads moving at low speeds (Weiss et al. 2019). However, past two decades have seen a substantial progress in the application-oriented research and development of permeable pavements, which includes mix design, hydrologic design, assessment of hydrologic performance and maintenance requirements. However, this is an emerging field, and there are still many important aspects that need to be addressed before permeable pavements can be fully integrated into urban highways that experience heavy loads and high traffic (Weiss et al. 2019; Saadeh et al. 2019).

Ferguson identified nine categories of the porous pavement, viz. decks, open-celled paving grids, open-graded aggregate, open-jointed paving blocks, plastic geocells, porous asphalt, pervious concrete, porous turf and soft paving (Ferguson 2005). Some of the most commonly used permeable pavement surfaces include pervious concrete, porous asphalt and permeable interlocking concrete pavers (MPCA report 2008). Porous asphalt is used on highways to remove excess water, whereas permeable interlocking concrete pavers (PICP) are popular in public areas due to its architectural appeal. PICP can be laid out in an interlocking grid pattern, with in-between spaces commonly filled with grass or small stones (Online Resources: Green Building Alliance (Permeable Pavement) (n.d.)). Pervious concrete, which is also known by the names like no-fines and gap-graded concrete, is essentially a mixture of gravel or granite stone, cement, water and little or no sand (fine aggregate) with or without admixtures (Obla 2007). Typically, 15–35% of the pervious concrete volume consists of interconnected void network (Tennis et al. 2004; Obla 2007; Kia et al. 2017), and it allows for the passage of a water flow rate of 3–5 gpm (0.014–0.023 m^3/min) through the open cells for each square foot (0.0929 m^2) of the surface area, which far exceeds most of the rain occurrences (Tennis et al. 2004). Pervious concrete is primarily used in residential roads, alleys, driveways, low volume sidewalks and low water crossings. It can be used as the sub-base for the conventional concrete pavements, as well as for the slope stabilization.

Other alternatives include plastic and concrete grids, as well as the amended soils where artificial media is added to soil to maintain soil structure and prevent compaction (MPCA report 2008; Fig. 19.2). Plastic grids allow for a 100% porous system, and they distribute the weight of traffic and prevent compression of the

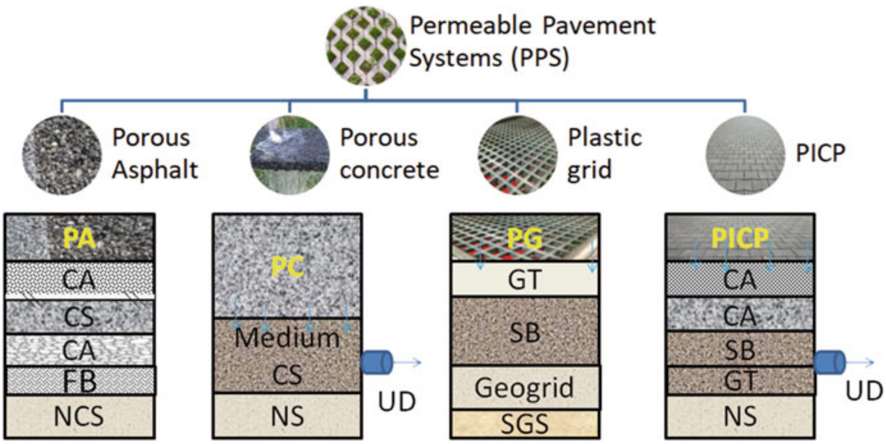

Fig. 19.2 Types of predominant PPS as providers of NbS for the implementation in UGI (*PA* porous asphalt, *PC* porous concrete, *PG* plastic grid, *PICP* permeable interlocking concrete pavers, *CA* coarse aggregates, *CS* coarse stone, *FB* filter blanket, *GT* geotextile, *NCS* non-compacted soil, *NS* native soil, *SB* sub-base, *SGS* sub-grade soil, *UD* under drain)

underlying soil (Online Resources: Plastic Grid Pavers (n.d.)). These grids help in reinforcing the gravel driveways, the parking lots and the fire lanes and are gaining popularity in the Leadership in Energy and Environmental Design (LEED) projects, mainly due to their light weight, ease of installation and durability (Online Resources: Green Building Alliance (Permeable Pavement) (n.d.); Plastic Grid Pavers (n.d.)). Plastic grid pavers are constructed primarily from recycled plastic materials and can be found in the form of interlocking blocks or in rolls. The honeycomb shape of the plastic grids allows grass to grow through the holes, thereby adding to temporary soil stabilization, as well as the urban architectural aesthetics (Online Resources: Plastic Grid Pavers (n.d.)).

From the foregoing discussion, it follows that although several types of permeable pavements and surfaces are available, each of them presents us with unique set of pros and cons. Therefore, the choice of a pervious pavement material revolves around the nature of the application and the project-specific requirements. Some of the key attributes that help an end user in deciding upon a pervious pavement material are cost-effectiveness, durability, the ability to provide safe drainage and effectiveness in flood protection. Furthermore, the larger perspective includes effective land utilization, protection of the landscape and long-term sustainability of the installed permeable paver network (Online Resources: The Complete Guide to Permeable Paving Systems (n.d.)). Maintenance requirements of the permeable pavements invite a lot of attention, as well as detailed planning. The porous media of PPS is prone to clogging by sediment. The extent of clogging depends on several factors such as the rainfall characteristics, characteristics of the catchment soil, air quality and temperature, attributes of the contributing drainage area and the type and volume of the flowing traffic (Razzaghmanesh and Beecham 2018).

A few reported works have analysed and discussed the effectiveness of the techniques such as power blowing, pressure washing and vacuuming, as well as a combination of these methods for restoring infiltration rate on small area pervious concrete pavements. It was found that pressure washing and vacuuming are equally effective as the initial cleaning techniques, both increasing surface infiltration rate by over 90%. Further, it was found that combining vacuuming and pressure washing resulted in more efficient clog removal over either method alone (Hein et al. 2013). Other pivotal concerns include the limited validity of the laboratory permeability test results that usually tend to deviate greatly from the design infiltration rate values of the in-place pervious concrete, as well as the quality control of the in-place pervious concrete (Tong 2011).

Design of a typical permeable pavement system consists of a top permeable concrete layer with sub-base coarse aggregate layer and subgrade soil beneath it. Based on the practical needs, viz. retention of storm water runoff until it infiltrates into the existing soil or the controlled drainage of the run-off traffic following adequate filtration; the number of sub-layers, as well as, the thickness and composition of each layer can vary substantially (Kia et al. 2017). Permeable pavement system designs can be customized to facilitate partial or zero exfiltration for sites with poorly draining soils, contaminated soils or in groundwater sensitive areas by providing sub-drains or an impermeable liner to prevent water reaching the underlying soil.

Pervious concrete typically contains single-sized coarse aggregates, narrowly graded between 3/4 and 3/8 in. (19 and 9.5 mm). Aggregates used in pervious concrete are made to meet the ASTM D488 requirements: 'Specification for Crushed Stone, Crushed Slag and Gravel for Waterbound Base and Surface and Surface Courses of Pavements'; as well as, ASTM C33: 'Standard Specification for Concrete Aggregates'. The coarser aggregates in the mixture enhances skid resistance, void ratio and permeability, whereas the smaller aggregates result in reduced permeability, although the mechanical strength is found to improve. Angular aggregates result in comparatively lower density, accompanied by higher extent of void and permeability. However, pavement structures with angular aggregates tend to offer lower strength compared to rounded aggregates. Sizing of the aggregates is done such that a suitable application-oriented trade-off between the permeability and mechanical strength is ensured (Kevern 2006).

It is worth reiterating that apart from the primary goal reducing the storm water run-off and recharging groundwater table, another important function of PPS is the effective removal of the various pollutants, such as bio-degradable organic matter, nutrients (phosphorus and nitrogen), heavy metals (lead, copper, cadmium and zinc), oils and suspended solids emanating from construction activities, so that the pollutant load reaching the receiving waterbodies (e.g. urban lakes) is minimized (Scholz 2013). Especially, in order to enhance filtration and separation properties in the permeable pavement system, non-woven geotextiles have been manufactured and tried. Non-woven geotextiles are made by putting together small fibres of polyester, polypropylene or a mixture of polyester and polypropylene in the form of a sheet or web, and then binding is facilitated either by needle punching or by the application of chemical and/or heat (Holtz 2009). It is noteworthy that polyesters and polypropylene are highly resistant to chemical and biological degradation and hence can serve as a durable reinforcement material for the sub-surface permeable paving layers of PPS. However, polyester has been found to degrade over time, especially under alkaline conditions. As the urban run-offs are usually acidic in nature, the durability of the geotextile layer remains by and large unfazed by the characteristics of the flow traffic (Boving et al. 2008; Scholz 2010).

The hydrocarbons generated from incomplete combustion in vehicle engines end up in the urban run-offs following unwanted leakages and would prove to be detrimental for the ecological health of the urban waterbodies during the instances of excessive rainfall. Hence, effective decomposition of the hydrocarbons and other greasy pollutants is very important. Recently researchers have identified the geotextiles as a suitable environment for the development of biofilms comprising of the consortium of microorganisms, capable of reducing the presence of hydrocarbons in the storm water (Bayon et al. 2015). Such a controlled microorganism-based solution would prove to be a nature-based solution as additional contributions from the air and other natural sources are likely to favour the establishment of an adequate microbial community within the chosen layers of the pervious pavement network.

19.3 Nature-Based Solutions for Urban Planning

One of the key motives behind the formulation of the guidelines for nature-based solutions (NbSs) is to render sustainable strategies for mainstream land management (Keesstra et al. 2018). The aggressive urban sprawl of the modern era necessitates the development of cost-effective long-term solutions towards mitigating the hydrological risks, as well as the persistent problems related to urban land degradation. Land management-oriented solutions can be divided into two main categories, viz. soil-related solutions and landscape-related solutions. Soil-related solutions are aimed at enhancing the soil health and soil functions for restoring local eco-system services, whereas the landscape solutions mainly focus on making the landscape less connected, facilitating less rainfall to be transformed into the runoffs, thereby reducing the risk of the urban flash floods (Keesstra et al. 2018). Evidently, pervious pavement systems have great potential to meet the primary goal of nature-based landscape-related solutions. Permeable pavement networks are gradually emerging as a popular technology for the sustainable urban drainage systems (SUDS) for storm water management and mitigation of the water pollution in the urban waterbodies (Elizondo-Martínez et al. 2020). Additionally, the PPS system can facilitate other benefits, such as the mitigation of the Urban Heat Island (UHI) effect through the reflection of solar radiation (Fini et al. 2017), sound reduction by absorbing the frictional noise generated owing to the interaction between the vehicle tyres and the pavement (Chu et al. 2017). It can also offer betterment in road safety, which is attributed to the enhanced skid resistance emanating from the high void content within the PPS network (Nicholls 1997).

The use of NbS provides a strong framework to understand and manage lake environments in urban centres. From the perspective of successful implementation and preservation of UGI, the urban lakes themselves are perceived to be providers of NbS (van den Bosch and Sang 2017). The presence of urban waterbodies as reservoirs of water and catchment drainages adds value to the ecological services offered by these ecosystems in the form of providing nesting habitats for several species of flora and fauna, as well as improving groundwater recharge, apart from providing significant socio-cultural spaces for human interactions. However, anthropocentricity of these ecosystems has altered the normal urban biogeochemistry to a vast extent (Kaushal et al. 2014). Nevertheless, quantitative and qualitative studies illustrate the inherent benefits of adopting UGI in the form of NbS (such as the lakes themselves) in mitigating the effects of UHI (Demuzere et al. 2014).

Some successful examples of NbS adopted in relation to sustainable land management, SUDS as well as UGI include creation of green spaces around lakes, such as vegetated trenches, open percolation ditches, artificially created wetlands, filtering fields and biofiltration systems (Dondajewska et al. 2018) and for diversion, as well as retention of flows from the roofs, surfaces of roads, shelters, garages and buildings in order to minimize the risks of overland floods. Creation of UGI also enhances the scope for the NbS to emerge as market instruments towards facilitating the blue-green infrastructure planning (e.g. Sörensen and Emilsson 2019).

19.4 PPS Implementation for Urban Lakes Environments

A major component of the hydrology that influences the role of the urban reservoirs as the NbS pertains to the flow from storm water run-off into the urban waterbodies (Dickie et al. 2010). It brings the challenges of preserving the overall environmental quality, managing the influence of waste assimilation on the aquatic ecology, as well as maintaining the base flows despite the changes in the hydrological flow regimes. In this perspective, while the basic support of UGI is relevant, the use of NbS assumes greater importance as it provides the potential to augment natural flow and feedback mechanisms for urban lakes and water bodies. The anthropological element of UGI, which is often overlooked, becomes crucial in preserving the unique urban biogeochemistry is a driver for preserving urban aquatic ecosystems (Kaye et al. 2006). One major factor pertains to the use of PPS for improving the base flows, as well as for maintaining the water balance by supplementing the losses due to evaporation and human consumption. The use of PPS around the urban aquatic systems can contribute to achieving specific urban SDGs (URDPFI, Ministry of Urban Development 2014) in multiple ways:

1. Sustained release of storm water can prevent the excess floodwater from entering the lakes and water bodies.
2. The occurrences of urban flooding episodes due to excess outflows to the shores can be prevented or minimized.
3. Adequate filtration of excess solids at the transition zone between the lake and land will be possible, before entry of storm water discharges into the urban water bodies, which would help communities to manage and preserve water quality for longer periods of time.
4. Percolation through permeable surfaces and subsurface storage of floodwaters would improve the groundwater recharging.

Concepts and frameworks such as Water Sensitive Urban Design and Planning (WSUDP; Australia), Low Impact Development (LID; USA), Sound Water Cycle on National Planning (Japan), Decentralized Storm Water Management (Germany) and SUDS (UK) provide important insights which can support the designs for PPS as NbS especially for the Indian scenario (Rohilla et al. 2017) and consider the use of PPS as significant contributors to integrated urban water management apart from the use of other NbS protocols, such as rainwater harvesting, water conservation through artificial wetlands, natural wastewater recycling and reuse, as well as bio-retention systems. Some of these approaches are highlighted in Table 19.1.

Among the options listed in Table 19.1, PPS can be well-integrated with the SUDS and WSUDP concepts as shown in Fig. 19.3. Apart from these, the use of reusable materials for NbS in PPS systems is also being explored in detail. For example, Yilmaz et al. (2018) suggested the vast scope of using structural soils in combination with waste materials for urban greening as an innovative NbS for dense urban areas with the goal of resource recycling and reuse.

Table 19.1 NbS solutions for water-centric design and planning in the urban context

NbS for urban water ecosystems	Mode of operation	Ecological services as NbS	Temporal type	Advantages	Disadvantages
Vegetated swales, buffered strips	Natural filtration and recharge	Increase surface area of capture and detention of rainwater and storm water	Long term	Flood minimization, excess salt retention, groundwater recharge	Can be under intense developmental pressures and construction activities and can disappear in short term due to land grabbing without public participatory approaches
Adopting transitional boundaries around the ecosystems	Design and construction of PPS through engineered intervention	Filtration of storm water entering aquatic bodies, preserve ambient concentrations of total dissolved solids and nutrients such as nitrogen	Medium to long-term (based on implementation)	Regulation of baseflows, capture and detention of storm water and enhanced percolation for subsurface storage	Without adequate exposure to their unique advantages, PPS can be adversely managed or not properly maintained without a nexus of administrators and citizens; PPS can also be severely impacted by the growth of urban traffic
Artificial wetlands	Construction of wetland zones as a part of urban landscape design	Increased sequestrations of nutrients and provide urban niches for a variety of flora and fauna	Long term	Provide plenty of habitats and nesting grounds for a variety of flora and fauna; help in natural wastewater recycling	Largely disappear due to construction activities and urban sprawl. Without the social and environmental memories of their existence, it is difficult to recover these systems
Rainwater harvesting systems	Engineered storages	Reservoirs for storage of excess rainwater and divert to aquifers	Medium to long term	Can provide excellent water conservation and reuse at micro- and macro-scales	Implementation requires careful design and maintenance, involving financial investments
Decentralized wastewater treatment system with a natural flow approach, filtering fields and biofiltration systems	Engineered structures including primary, secondary and/or tertiary treatment units	Water recycling and reuse	Long term	Can provide excellent opportunity for natural wastewater treatment and pollution control	Provides a common public amenity for managing waste streams and reduce pollution

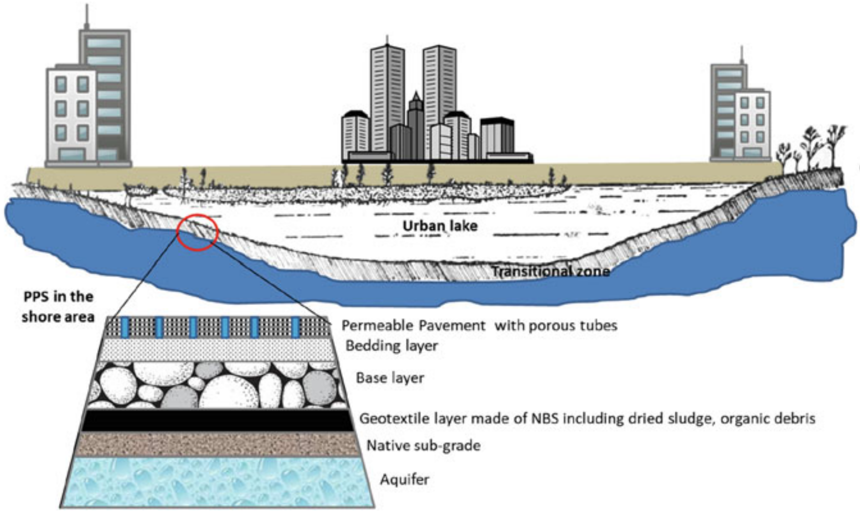

Fig. 19.3 Implementation of PPS in an urban lake environment. Inset of the PPS shows different layers into which NbS options can be examined for sustainable use of resources

The PPS as NbS options can be advantageous due to several reasons. The use of specific types of PPS such as porous asphalt or concrete, as part of the shore area development projects for lake environments will allow a large flow of the storm water to directly flow back into the lake and hence would help in maintaining the water tables even under the excess evaporation induced by densely constructed surfaces in urban centres. Thus, PPS would offer direct support for mitigating the UHI and would serve as a major component of NbS along with the urban lakes for sustainable UGI. The combined effect of the geotextile layers in PPS along with NbS materials such as the dried sludge from the urban wastewater treatment plants, as well as the organic debris are also being investigated (Lin et al. 2006).

Along with the innovation of NbS-oriented PPS, it is also of importance to have an estimate of cost of installation of the pervious pavement along the shorelines of the urban lakes, which would enable us in assessing its economic viability as compared to the impervious conventional concrete. For an example, we can consider Sankey tank (Perimeter = ~1.7 km) in Bengaluru to study the feasibility of paving the lake shore with PPS. A pervious pavement installation of 3 m width has been considered on the bank of the lake (Fig. 19.4). Also, in order to ensure safe discharge of filtered water into the tank, additional 2 m paving is considered along the bathymetric depth from the edge of the tank.

Therefore, the coverage area of the proposed PPS for this chosen waterbody is about 8500 m^2. The usual thickness of the PPS for urban environment is approximately 150 mm (Lucke and Dierkes 2015). Literature suggests that the approximate cost for paving surfaces with pervious concrete is Rs. 558/m^3, whereas that in case of conventional concrete is about Rs. 587/m^3 (Shah et al. 2013). Evidently, the use of pervious concrete saves Rs. 29/m^3. For paving the shoreline of the Sankey tank using

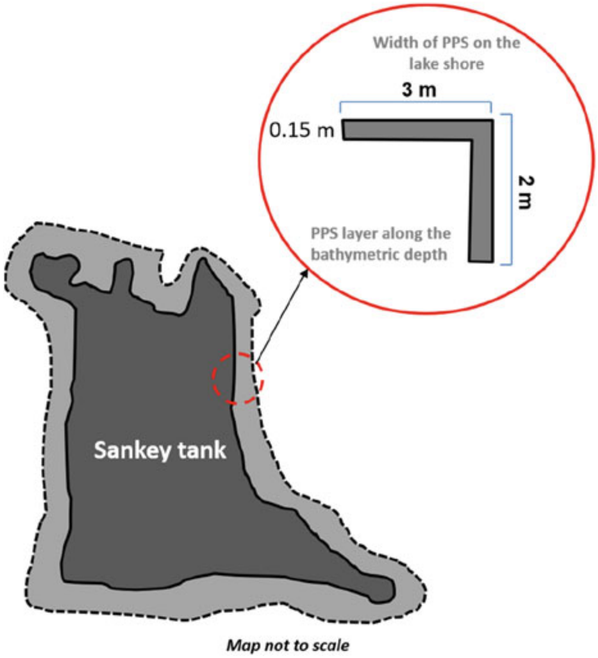

Fig. 19.4 Schematic representation of PPS implementation for a lake system in India (Sankey Tank, North Bengaluru)

pervious concrete, as per the plan discussed above, the total estimated expense will be about Rs. 711,450, and the amount saved by using PPS will be around Rs. 36,975.

19.5 Implementation of PPS for the Indian Scenario

NbS, on a very broad scale, brings together several different aspects such as the biodiversity and ecosystems, natural resource management, sustainable urban development and climate change responses. However, the core idea of NbS revolves around improving the quality the interaction between the people and the existing fragments of nature within the cities, as well as minimizing the severity of the impacts of rapid urbanization. NbS for the urban set-up includes strategies pertinent to the restoration of the wetlands and preservation of urban forestry; greenfield afforestation and retention of the health of brownfields; the greening of grey surfaces such as rooftops and walls; and implementation of efficient flood control techniques (Online Resources: Gajjar 2016a). In the context of sustainable urbanization, it is important to mention that the Ministry of Urban Development, Government of India launched the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) in 2015, with a national priority of providing basic services and civic amenities to the city dwellers, as well as reducing pollution in cities. Some of the key aspects that the AMRUT mission is expected to cater to include supply of clean drinking water, hygienic management of sewerage and septage and effective drainage of storm water (AMRUT, Ministry of Housing and Urban Affairs, Government of India (n.d.)). Cities like Bangalore, Surat and Gorakhpur are looking towards the nature-based solutions for addressing the problems of shortage in water supply. Particularly in Gorakhpur, farmers switched from mono-cropping to rotating multiple crops in order to improve soil health and drainage. They have also adopted several organic practices, which resulted in a reduced level of harmful agricultural run-off to the nearby rivers, and at the same time, the crops also ensured a competitive edge for the farmers at the local markets (Online Resources: Du 2019). Protection of the water bodies and drainage channels has led to a reduced extent of street flooding and stagnant water. Bruhat Bengaluru Mahanagara Palike (BBMP) recently allocated about Rs. 800 crores for constructing new storm water drains and remodelling of the existing ones, where blocks of indigenous pervious concrete with customized proportion of water, cement and other aggregates will be used (Online Resources: Joshi 2017). The colour of this concrete being light grey would result in a considerably reduced level of solar heat absorption when implemented in various urban constructions, as compared to the black bituminous pavement concrete, thereby leading to lesser extent of UHI effect (Online Resources: Rasheeda and Rizvi 2009).

Some of the water-constrained cities of India, such as Jaipur, Bikaner, Bharatpur and Ajmer, have been facing water scarcity with the expansion of the urban population size. Additionally, these cities have recently seen an upsurge in the urban floods with the city's growing built-up footprint. Recharging of the groundwater table and minimization of the flash floods are of pivotal importance for these cities in order to ensure water security and quality of life. Permeable pavement system can serve such cities in the semi-arid regions greatly, as it comes with the ability to remove pollutants from the storm water and to curb the run-offs from flowing into urban waterbodies. PPS can also be employed for the retention of groundwater in the wetlands and harvesting of rainwater through the built environment (Online Resources: Du 2019). Looking at the bigger canvas, it can be seen that the PPS, as a technological tool, offers the promise to reduce the frequency of severe droughts in the semi-arid parts of India, if the installations are made by taking into account the dynamic nature of the land usage in the developing urban environments. Furthermore, the lakes and wooded groves in the periphery of the growing cities need to be protected from being absorbed into the sprawl of real estate development. Conservation and access to the nature should be planned in such a way that these urban natural resources can continue to be harvested harmoniously for a substantial period into the future (Online Resources: Gajjar 2016b).

19.6 Conclusions

Although NbS offers options for long-term sustainable urban development, the implementation poses several challenges as the urban environment comprises of several different components that interact in a complex and dynamic fashion.

Additionally, the customization of NbS is not straightforward as a suitable trade-off between design aspects and cost needs to be drawn. Considering the importance of mitigating urban flash floods as well as preventing the entry of pollutants into the waterbodies, the use of PPS has emerged as a promising NbS for the protection of urban ecology and harmonious usage of fragmented natural resources by the city dwellers. The NbS needs to be implemented such that the UGI does not get compromised in the face of accelerated urban sprawl. This is especially true for several developing cities in India. Preliminary calculations indicate that about 5–10% savings in capital costs can be achieved while opting for the PPS in the urban context as compared to the conventional paving techniques.

While implementing the NbS for long-term sustainable development, structured adaptive management strategies need to be developed as well, so that ecological responses to the implemented solutions can be obtained and assessed to enable prediction of further challenges, as well as the costs of the NbSs. Continued effort and sustained financial support are required to foster research and innovations related to various nature-based solutions, and a global market for the most feasible technologies need to be created to ensure viability of the beneficial technological solution. Policy interventions would also prove to be instrumental at the different levels, once the mettle of such solutions is proven for large-scale installations.

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Chapter 20
Habitat Suitability Modelling and Nature-Based Solutions: An Efficient Combination to Realise the Targets of Bonn Challenge and SDGs in South Asia

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Abstract South Asia supports exceptional biodiversity elements despite facing land degradation, as it includes some of the worst-affected countries with huge economic losses annually. Increasing urbanisation, mining, industrialisation, ground water dependent agriculture, natural disasters and climate change are leading to land degradation in the region. Land degradation has contributed to enhanced food insecurity and poverty that will further worsen in future due to climate change. Realising the targets of global policy initiative of Bonn Challenge will support UN decade on Ecosystem Restoration (2021–2030) for restoration of 150 M ha of degraded lands by 2020 and 350 M ha by 2030. Restored landscapes under Bonn Challenge are biodiverse, productive, carbon-rich and climate-resilient regions fulfilling SDGs 1, 2, 6, 13, 14 and 15 and support Intended Nationally Determined Targets (INDCs) under Paris COP, 2015. For increasing cooperation in South Asia for increasing landscape restoration, this chapter proposes an effective approach that helps address restoration challenges in diverse agro-climatic zones of South Asia. The approach endorses a habitat suitability modelling tool for mapping suitable niches and selecting important species, following the natural course of succession for reducing the planning time for landscape restoration. Situation and target-based applications of appropriate nature-based solutions (NbS) that support livelihood for the local community can help in poverty alleviation and skill development while overcoming restoration challenges.

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20.1 Deforestation Challenges: A Huge Cause of Concern for South Asia

Deforestation and degradation across the world have led to reduction in flow of ecosystem services due to immense loss of biodiversity (Gourevitch et al. 2016). Land degradation across the world has negatively affected more than 3.2 billion people and has accounted for more than 10% of the annual global gross product (GGP) by massive loss of biodiversity and ecosystem services (Global Assessment Report on Biodiversity and Ecosystem Services, IPBES 2019a; Global Assessment Summary for Policymakers, IPBES 2019b). Simultaneous environmental changes have challenged persistence of biodiversity and the flow of ecosystem services. Alterations of landscapes due to deforestation and degradation of landscapes have affected humanity with impacts on both the local and global scales (Schulz and Schroder 2017).

South Asia, with seven countries at the forefront of global population and economic growth, is considered as a world within the world. It hosts approximately 1.5 billion people (with more than 500 million poor of the world), which is about one-fourth of the world's total population dwelling in less than about 5% of the land area of the world (Hughes 2017). Comprising Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, as important countries, the human population of the region has more than tripled during the last six decades (1950–2009), from 473 million to 1.6 billion. It has been projected to grow by 41% by the end of 2050 (Clark et al. 2013).

The region has been historically vulnerable to several natural hazards (floods, droughts, earthquakes, cyclones, landslides, Tsunami, tidal surges, etc.). South Asia, with its multiple and varied hydrogeological characters, contributes to the ecosystems and hence regulates flow of ecosystem services (ES). Though the region is a global biodiversity hotspot, it has been witnessing fast degradation of key biodiversity areas (KBA). Ecosystems of the region are threatened by diverse direct and indirect drivers of biodiversity loss that potentially increases the probability for extinction of species (Ahmad et al. 2015). In the IUCN programme 2017–2020, South Asia has been considered as a region that requires greatest conservation need among IUCN's eight Statutory Regions (South Asia IUCN 2019). Deforestation rates for South Asia have been reported to be among the highest globally (Ahmad et al. 2015). Monoculture plantations and deforestation are one of the most prominent threats to the ecosystems of the region, and countries such as India, Nepal and Pakistan have lost a significant portion of their forest cover. The IUCN projects more than 98% loss for many countries in Asia by 2050 (Hughes 2017). Degradation of habitat has been a common phenomenon in the region, mostly because of ground water and chemical-intensive agriculture and using previously fallow land for farming (Clark et al. 2013) (Table 20.1). Anthropogenic soil degradation remains a serious problem in entire South Asia. About 43% of the region's total agricultural land has undergone one or another form of degradation, or sometimes it is even more. Nearly 31 M ha of land is intensely degraded, and 63 M ha remains

Table 20.1 Crucial threats to ecosystems in South Asia

Ecosystems	Threats	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Coastal (mangroves, mudflats, estuaries)	Inundation, salination, storm, species loss		■		■	■			■
Coral reefs	Bleaching, acidification, loss of ecological and protective services, reduction in species diversity				■	■			■
Inland wetlands	Desiccation, drainage and diversion degradation and service loss	■			■			■	■
Forests	Loss of forest cover and species, altered composition and structure, enhanced evapotranspiration			■	■		■		■
Mountain (sub-temperate, temperate)	Altitudinal shift in vegetation disrupting species types			■			■		
Mountain (sub-alpine, alpine)	Loss of vegetation cover	■		■	■		■	■	
Glaciers	Loss of coverage	■		■	■		■	■	
Desert	Expansion	■			■			■	
Rangeland and grasslands	Regime shift, degradation due to overgrazing and increased incidence of fire	■			■			■	
Freshwater (rivers, lakes)	Desiccation, increased salinity at coast, degradation due to increased demand	■	■		■	■	■	■	
Species diversity (flora and fauna)	Loss of diversity and habitat, changes in species composition and food web		■		■		■		■

Key ■
Locations particularly vulnerable to impacts of climate change
Source: South Asia IUCN Report (2019), World Bank (2009)

moderately degraded. The worst-affected country is Bangladesh (75%), followed by Pakistan (61%), Sri Lanka (44%), Afghanistan (33%), Nepal (26%), India (25%) and Bhutan (10%) (Khor 2019). The land area has been degraded by water erosion (55 M ha), wind erosion (24 M ha), desertification (80 M ha), salinisation (17 M ha), water-logging (12 M ha) and nutrient depletion (11 M ha). Moreover, a large area is lost by ground water depletion due to excessive dependency on ground water for flood irrigation purposes (Hughes 2017). It has been well observed and reported that land degradation in the region has resulted in increasing food insecurity and poverty, which is only going to worsen in coming years on account of climate-led variability and vulnerability (www.ipbes.net). The crucial challenge in front of the South Asian countries is to reverse and halt biodiversity loss and loss of ecosystems that was well highlighted and projected in IPBES Asia Pacific Assessment (2018) and IPBES Assessment on Land Degradation (IPBES 2019c).

Decision makers at global, regional and national level are appreciating the need to protect the remaining forests and restore the forest cover of deforested and degraded landscapes. Considering the scale of restoration of degraded landscapes, the opportunity to re-vegetate is enormous. It has been observed at all levels that a much-sophisticated understanding of contemporary trends will be required with a multidisciplinary approach to address and reverse the rapid pace of deforestation and degradation in the region. Forest landscape restoration is an offer as well an opportunity to mitigate the losses and manage and reduce biodiversity losses that can help to improve NCPs (Gourevitch et al. 2016). However, forest landscape degradation, so far, has been viewed as an issue, and restoration remains a potential solution. Thus, restoration in the present context needs to address and achieve many national, regional and global targets. Countries need to realign their efforts to address deforestation by increasing transboundary cooperation in restoration of forest and non-forest landscapes. Many South Asian countries being active partners to realise the Aichi Targets, Bonn Challenge, Paris COP, 2015, promises through INDCs and also in localising and realising SDGs 1, 2, 6, 13, 14 and 15. Natural forest restoration is clearly the most effective approach for storing carbon and reducing disaster risks through ecosystem-based approaches for disaster risk reduction (Eco DRR) and ecosystem-based approaches for climate adaptations (EbA) (Lewis et al. 2019). Restoration of degraded forest and non-forested landscapes is a dynamic, long-term process to achieve ecological integrity, INDCs and NCPs (Chazdon and Guariguata 2018). For increasing cooperation in landscape restoration, this chapter proposes an effective approach that helps in realising the restoration targets proposed in the Delhi Declaration during UNCCD COP 2019 (Khor 2019). Conservation and climate restoration of degraded landscapes need to include participatory planning, which results in ensuring livelihood and economic benefits to communities. Considering the background of the pertinent issue of degradation, this chapter attempts to address the issue to achieve the Bonn Challenge and SDG 15 by using the well-tested and successful approaches of habitat suitability modelling tools (known as niche modelling or species distribution modelling) and nature-based solutions (NbS) for South Asia.

20.2 Bonn Challenge to Realise Forest Landscape Restoration (FLR) and Achieve Multiple Ecosystem Benefits for South Asia

The global movement of restoration has gained momentum in the last one decade. Decision makers and policy planners at global, regional as well as national level have demonstrated inspiring political will and determination to achieve ambitious global targets through restoration process, viz. the Aichi targets, Bonn Challenge and Paris COP, 2015 promises to name a few (Chazdon and Guariguata 2018; Chazdon et al. 2017; Chazdon and Uriarte 2016). Initially, the ecological restoration approach was conceptualised. The same was planned to be implemented using predominantly a natural science lens. In the present context, ecological restoration is a much evolved discipline and has integration of diverse disciplines, which includes key social concepts and other disciplines of science without being limited to ecology (IPBES 2018). The science and practice of restoration ecology, in collaboration with other disciplines, can contribute to overcoming these challenges (IPBES 2019a) Realising and localising the global policy targets through initiative of Bonn Challenge is going to be an important platform to support UN decade on Ecosystem Restoration (2021–2030) for restoration of 150 M ha of degraded lands by 2020 and 350 M ha by 2030. FLR, under the Bonn Challenge, is a key long-term initiative for maintaining or restoring biodiversity to help degraded landscapes regain ecological functionality for improving human well-being.

Ecological restoration has been viewed and endorsed globally as a primary tool that can help conservation and management of biodiversity inside and outside protected areas (PAs), for improving ecosystem services and NCPs. Globally more than 3 trillion dollars is invested annually in restoration to halt loss of ecosystems. With increasing investment in forest restoration, stakeholders responsible for implementation have shared the need of more scientific guidance. The guidance sought needs to include strategically planning and prioritising restoration activities that result in increased survivability of endemic tree species (Devkota et al. 2019). Conservation, management and restoration of biodiversity are a constant and clear precursor to achieve long-term social and economic prosperity while achieving targets of the Bonn Challenge, Aichi targets, sustainable development goals (SDGs), Paris COP promises and other international, regional and national initiatives (Beatty et al. 2018). Restoration approaches to meet the present and future landscape challenges urgently require novel and scientific approaches that include both habitat suitability modelling (SDM) and NbS (Beatty et al. 2018). There has been growing concern to include flexible restoration approaches, along with protection for long-term protection of biodiversity and ecosystem services (Perino et al. 2019). India and Pakistan have been the key implementing countries for Bonn Challenge in South Asia, and every year, both of these countries have taken the cause very seriously. In Parties (COP) 2015 Paris, India got involved in voluntary Bonn Challenge pledge by aiming to restore 13 M ha of degraded land by 2020 and an addition of 8 M ha by 2030. Although Pakistan's effort of implementing plantation under plantation tsunami has gained it much international appreciation, there has been not much discussion on post-plantation care or how sites were chosen, etc. to enhance the success rates. Similarly, in many states/provinces of India, there have been massive plantation exercises during monsoon, and the survivability rates have never been shared. This shows that though the intention of policy makers is sound, the result might not be satisfactory due to the lack of efficient scientific tools.

To reduce the monetary loss and loss of government machinery, it is important that scientifically sound research and development and academic organisations should participate in the entire programme right from the initial planning. One of the core challenges for non-forest restoration has always been identifying areas within the landscape, where multiple functions operating on different scales can be enhanced by understanding the suitability of landscape for plantation (Schulz and Schroder 2017). The Bonn Challenge as a global effort was launched in 2011 to restore 350 M ha of degraded forest landscapes by 2030, and countries have promised to restore more than 60 M ha under the challenge (Verdone and Seidl 2017). The challenge is planned to realise the goals of SDG 15 and Paris COP promises, while achieving and proving many socio-economic benefits (Dave et al. 2019). The concept of FLR was introduced in 2000 with participation of 30 countries and was defined as '*a planned process that targets to restore ecological integrity and improve human wellbeing in degraded and deforested landscapes*' (Cohen-Shacham et al. 2016).

FLR has its own framework to implement restoration that collectively targets and addresses the key environmental challenges, viz. land degradation, loss of biodiversity, water shortage, dearth of rural livelihoods and mitigation and adaptation of climate change. There is an urgent need to involve more inclusive approaches applicable for different ecosystem types and incorporate an integrated-scientific support system for large-scale restoration. Stepping back and up requires assessments that answer *where* to restore and *which* species, keeping in mind that in different landscapes, there are diverse habitat types that are required to be restored (Temperton et al. 2019). In the scope of FLR, identification of suitable sites that can be restored on priority still remains a major grey area (Cuong et al. 2019). Most of the studies that were undertaken using habitat suitability modelling tools or SDM were used to apply the outputs in assessment of biodiversity, and forecasting the impacts of climate change on biodiversity suggesting potential areas to set up protected areas, restoration of habitat and/or also in species translocation (Araujo et al. 2019).

20.3 Integrating the NbS Approach as a Participatory Approach in Maximising the Social Benefits of Restoration in South Asia

Key challenges in restoration approaches include setting up realistic targets that are socially acceptable, withstand the ongoing climate changes and actions need to be prioritised for increasingly space-competitive world by using NbS (Perring et al. 2015; Cohen-Shacham et al. 2016, 2019). NbS remains one of the most cost-effective climate solutions. So far South Asia does not have any quick mechanical solutions to resolve the climate crisis or to reduce and address over-exploitation of bio-resources. It still has some very rich ecosystems and key biodiversity areas (KBA), and they can help the region to address climate emergency by its immense restorative capacities (Martin 2017). Approaches that use NbS for reducing disaster risks and adapting to emerging climate risks and vulnerability are increasingly getting popular across global and national policy arenas (Fig. 20.1). This has been clearly observed in UNFCCC COP 14 in Poznan, later it came full-fledged in 2015 in all the international agreements and COPs ranging from CBD COP, UNFCCC COP, RAMSAR COP, Sendai Framework for Disaster Risk Reduction, etc. The Executive Secretary of UNCCD during the recently concluded IPCC COP 25 called for allocating around 30% of climate financing for land-based solutions that involves

Fig. 20.1 Ecosystem restoration as an NbS for climate action and for localising the benefits of SDGs. (Adapted from FAO 2019)

NbS (Mead 2019). NbS has presently been mainstreamed in most of the international and regional policies and has certainly well-established concept in South Asia, right from restoring degraded slopes in Nepal to landslide stabilisation (IUCN Report 2018) and restoration of wastelands in India (Dhyani and Dhyani 2016) and many more such examples (Keesstra et al. 2018). The Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) of the Government of India, also considered one of the biggest payment of ecosystem services (PES), uses NbS (World Employment and Social Outlook 2018) and works through more than 200 direct and indirect activities including restoration that support biodiversity conservation and restoration on landscape level. It supports livelihood of the rural poor. Restoration, as an important NbS, can help to improve the ability of ecosystems to sequester more carbon and enhance more fertile croplands by improving soil quality and, therefore, can help to reduce carbon emissions from deforestation due to extension of agriculture (FAO 2019). NbS does not aim to achieve any single objective and, hence, brings multiple co-benefits. These are designed to provide many opportunities for improving human well-being. Some of these benefits are reducing costs, more livelihood and alternative livelihood opportunities that develop into green economy, etc.

In the present scenario, when the vulnerability is increasing, enhancing resilience and addressing uncertainties using NbS is no more choice but a necessary requirement for South Asian countries. Though there is a growing support for NbS internationally, in reality they are yet to be mainstreamed as a vital and fundamental measure to address a lot of diverse issues on restoration, green infrastructure, conservation and protection of biodiversity (Dhyani and Thummarukuddy 2016; Kumar 2019). With speedy evolution in theories, protocols and implementation strategies, NbS is feasible, and it is perfect time to utilise the existing available knowledge and apply the same in FLR for restoration of non-forested areas (Dhyani and Dhyani 2016; Potschin et al. 2015; Lal 2007). NbS is a fairly new concept and can be well defined as an umbrella term that covers diverse environmental protection and management approaches introduced by IUCN (Cohen-Shacham et al. 2016, 2019) (Fig. 20.1).

It was initially proposed by IUCN to respond and help achieving promises of climate change negotiations '*as a way to mitigate and adapt to climate change, secure water, food and energy supplies, reduce poverty and drive economic growth*' (Cohen-Shacham et al. 2016). During the late 2000s, the World Bank introduced the nature-based solution approach (Nesshover et al. 2017) for promoting nature as a vital solution to address risks and disasters linked with climate variability and vulnerability. NbS, in the present context, has been helping to readdress policy debates on conserving biological diversity, mitigation and adaptation to climate change and judicious use of natural resources, etc. (Cohen-Shacham et al. 2016, 2019). IUCN and presently all ongoing international policy discussions have recognised the vital requirement to link NbS in global policy and related implementation approaches on ground (Eggermont et al. 2015). It is no more restricted to dialogues and discussions on ecosystem services and natural capital build-up, and presently NbS has been regularly used in soft engineering practices that increase

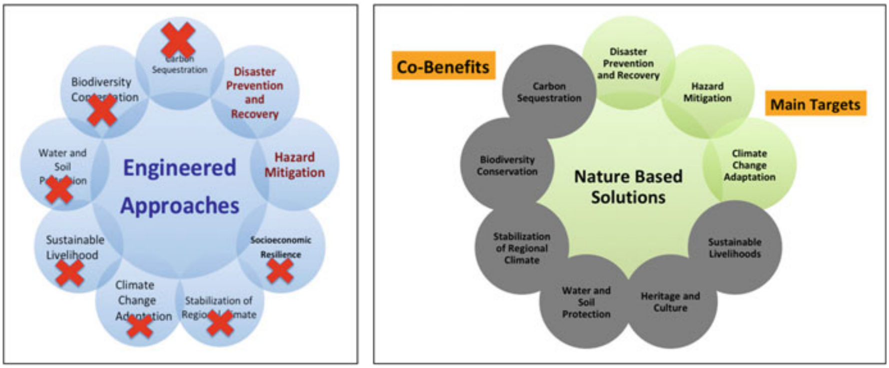

Fig. 20.2 Comparing conventional engineering approaches with NbS that provide co-benefits along with addressing societal challenges and long-term biodiversity benefits that ensure human well-being. (Source: Cohen-Shacham et al. 2016)

resilience from extreme events and climate change (Cohen-Shacham et al. 2016; Kumar 2019; Stanturf et al. 2017; NbS 2015). The European Commission has included NbS as an important area in its Horizon 2020 research programme (Nbs 2015, 2019) with its explicit focus on urban sprawls and developing green infrastructure and natural infrastructure. The scope of NbS as presented in Fig. 20.2 is very broad and not limited to green infrastructure, management of ecosystems, protection of biodiversity and issue-specific planning. The core idea of NbS application is to enhance the resilience of landscapes as well as communities by building back the natural stock against the traditional engineered approaches (Eggermont et al. 2015; Maes and Jacobs 2017; Squires 2014). It has been well-defined as engagements stimulated by or sustained by impersonating nature to support people in ecological, societal and financial tasks in sustainable ways (Ruwanza 2019).

Eggermont et al. have deliberated three significant characteristics of NbS (no or nominal external interferences in ecosystems, interferences in managed ecosystems that involve sustainability and multi-functionality, and establishment or expansion of ecosystems to foster green or blue set-ups) to recover the flow of variety of ecosystem services (Eggermont et al. 2015). These methods should be well materialised from a range of domains (some from the scientific investigation fields, others from customary or policy frameworks), allocate a mutual focus on ecosystem services and target to tackle social challenges. For example catchment area treatment by plantation and restoration to improve water infiltration for replenishing ground water sources and aquifers is cheaper and more sustainable than constructing a new water supply system. Similarly, using sloping watershed environmental engineering technology (SWEET) to stabilise slopes in mountain areas by catchment area treatment is effective and provides multiple benefits. It would be pertinent to integrate NbS in planning from the very initial stage to realise and localise the targets of the United Nations Decade of Ecosystem Restoration 2021–2030 in South Asia.

20.4 Habitat Suitability Modelling to Improve Success Rates

To realise the targets of Bonn Challenge, IUCN initiated a global exploration for the large opportunity for restoration, along with World Resources Institute (WRI) and the University of Maryland. The effort shaped the World of Opportunity map, which identified approximately 2 billion ha of degraded land across the world with prospects for restoration. At large, there are real limitations in real-time conditions that a global map cannot fulfil especially for national and location-specific analysis. National-level planning for restoration will require micro-level understanding related to degraded sites, potential species as per agro-climatic zone and their habitat suitability. South Asia, being a highly biologically diverse region, will require specific provincial or national-level approaches for understanding the habitat suitability for restoration of forested and non-forested landscapes using species that are native or endemic to the region. This will help in enhancing the rates of performance of species and securing post-plantation success in survivability. Hence, the large analysis used with the datasets that are consistent globally with 1 km spatial resolution is not efficient to guide the countries on where to carry out restoration and what interventions will be suitable for specific locations. However, the global map is helpful in identifying areas where a more refined analysis could help in creating large opportunities.

The refined analysis should be carried out using SDM, also known as habitat suitability modelling or niche modelling, for different suitable species to be used for restoration. This global analysis needs to be well supported by national or sub-national assessments that incorporate higher-resolution data and consider local bioclimatic conditions by engaging local experts and stakeholders. This approach has been used by IUCN and the WRI to develop a Restoration Opportunities Assessment Methodology (ROAM) being used in around a dozen countries of the world (Bonn Challenge 2019). ROAM has six main parts and includes stakeholder engagement, geospatial mapping, economic analysis, carbon analysis, enabling conditions and financial analysis for developing country-specific restoration strategies (Bonn Challenge and Forest Landscape Restoration 2019). Inclusion of SDM for understanding the habitat suitability of selected species in present and furture restorations can be an extended support to ROAM.

Restoration ecology, with a multidisciplinary and transdisciplinary approach, can help to address a lot of challenges that are critical to success of restoration. There are over 6000 published works on SDMs, applied for predicting the habitat suitability of various kinds of plant species for better conservation planning in the light of impending climatic variability. Traditionally, climatic variables (temperature and precipitation) are often considered for statistically relating the trends in species occurrence, but least efforts were made to integrate any biotic factors such as competition, symbiosis and prey-predation. However, the predictability of SDMs can be significantly improved by modelling the keystone or dominant species' spatial distribution over a region (Crase et al. 2015). Some authors argue that the

SDMs inherently lack the deterministic ability in accounting the landscape-level inhibits in localising the probable habitats of the species (Dutra Silva et al. 2019; Hijmans et al. 2005). Several abiotic factors such as soil suitability, physical connectivity and land use and land cover significantly influence the spread of habitats. Despite lacunae with SDMs, they are widely applied mainly due to easier applicability and requirement of limited field data. Further, the bioclimatic data for SDMs and future trends of climate data are readily made available for wider usage (Phillips et al. 2005). Several computational tools based on entropy maximisation theory (Maxent) (R Core Team 2017) and machine learning algorithms (Support Vector Machine and Random Forest) were developed by the ecological community and are made available for easy implementation in open-source platforms, mainly through (Kumar et al. 2016) Geographical Information Systems (GIS). Availability of these software packages and data made the ecologists and conservation planners better equipped for scientific decision-making.

The success of restoration projects at large depends on appropriately identifying potential sites or locations for restoration. Using machine learning approach of SDM provides novel tools for mapping areas of interest for restoration projects in changing climate conditions (Zellmer et al. 2019; Allen et al. 2015). Model-based approaches to consider and understand complex socio-ecological systems are able to allow generalisations for evidence-based interventions for successful initiatives (Mead 2019). The scale of climate variability demands adoption of a landscape approach in the restoration exercise (Perring et al. 2015; Eggermont et al. 2015; Allison and Murphy 2017).

Though restoration focuses on ecosystems and species, it is basically a human effort to address and localise range of motivations and goals, and hence, there is increasing consideration to the cost aspect that is an essential ingredient for successfully designing and executing restoration projects (McConnachie et al. 2013; Aronson et al. 2010). Having NbS and SDM included as key tools for successful restoration planning can help to secure important socio-economic and ecological benefits that are now important to be integrated into assessments for restoration success (Nielsen-Pincus and Moseley 2010, 2013; Wortley et al. 2018; Jonson 2010) in the long run (Fig. 20.3). There has always been need to identify cost-effective, practical and successful tools to address broad-scale restoration challenges (Torrubia et al. 2014). Technological improvements, if coupled with the simulation models to address restoration priorities as per habitat characteristics, will improve the identification of land parcels as per habitat and species requirements (Mace et al. 2005). SDM tools will be a necessity in future, along with site-specific NbS (Mace et al. 2012; Balvanera et al. 2014; Hulvey et al. 2017) for restoration (Fig. 20.3). Simulation modelling helps to provide an advanced-level fundamental understanding to help ecological restoration. Restoration islands need to have concentrated plantings in strategic locations, to efficiently use the resources and achieving restoration goals (Jacobs et al. 2015). To assist designing resistant and resilient ecosystems that can withstand emerging challenges, an adaptive NbS approach along with SDM can help to achieve win-win situation in terms of high costs involved in restoration (Possingham et al. 2015; Foley et al. 2005). Stacked SDMs (SDMs for single species

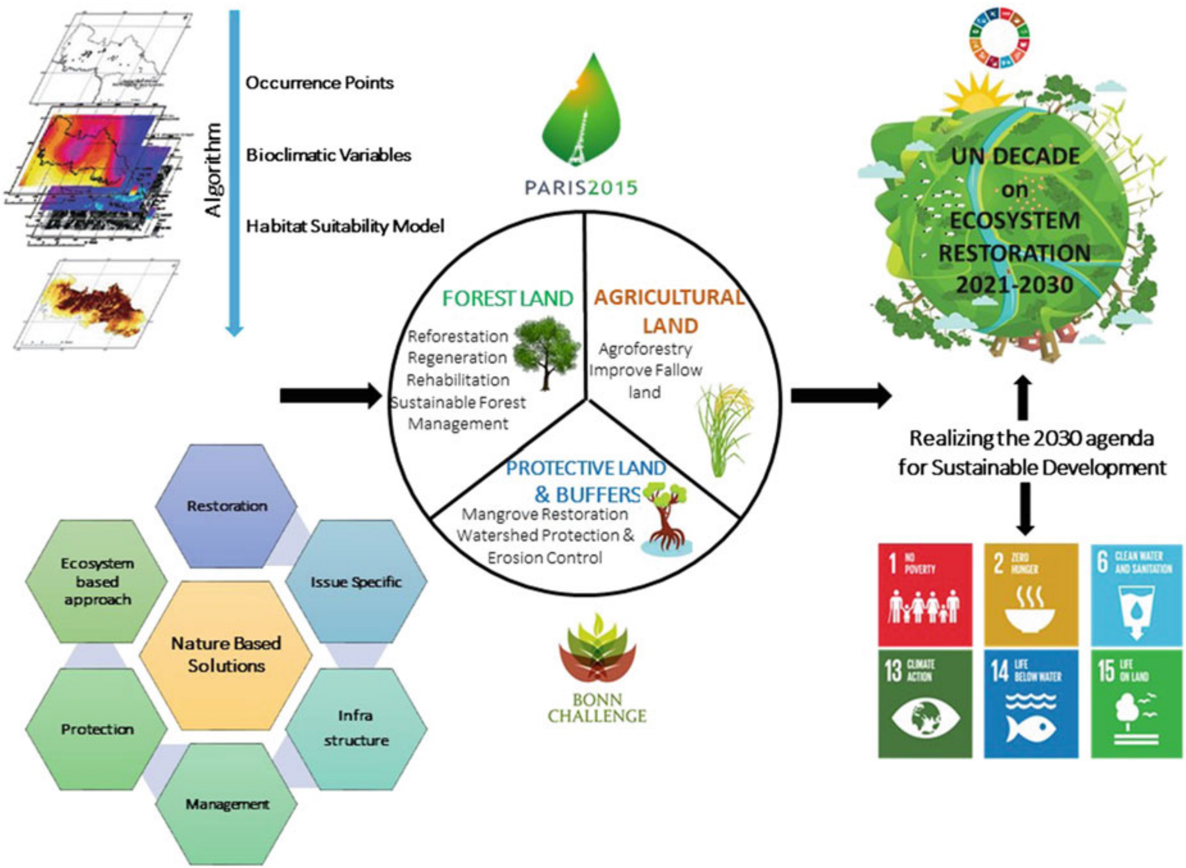

Fig. 20.3 Incorporating NbS and SDM in planning successful restoration efforts to localise SDGs and targets of Bonn Challenge and UN Decade on Ecosystem Restoration (2021–2030). (Images from Sequeira et al. 2018; Cohen-Shacham et al. 2016)

later stacked for different species) serve an important opportunity to find suitable habitat for multiple species that are to be used in restoration. Stacked SDMs have already been used for understanding spatial patterns of environmental suitability for diverse taxa (Foley et al. 2005). Increasing habitat loss and degradation worldwide could be better addressed (Bender et al. 1998), resulting in declining population (Lowe et al. 2005), loss of genetic diversity (Barnosky et al. 2011) and even species extinctions (Chazdon et al. 2017). Habitat restoration is an important tool for managing degraded ecosystems (Volis 2019), in an effort to restore and prevent species loss (Hulvey et al. 2017). Yet, habitat restoration initiatives are not always successful (Martin 2017). One key factor that influences the success of habitat restoration projects is the quality of sites chosen for management (Bottin et al. 2007; Pearce and Lindenmayer 1998). For example, man-made habitat structures can fail when placed in areas with non-ideal environmental conditions. To prevent such failures, it is crucial that we develop and test methods for identifying candidate sites for habitat restoration. SDM has been proposed as an important tool for identifying habitat suitability of sites for restoration, and in the coming years, its integration in restoration planning will be very crucial (Beatty et al. 2018). Using presence, absence or occurrence data, along with the spatially gridded bioclimatic or environmental data, SDM helps to identify environmental predictors for species occurrence and creates model that can be well projected across the landscape to identify suitable habitats (Elith et al. 2011; Porfirio et al. 2014). SDM has already been used to predict suitable sites for restoration for an array of species, including plants (Riordan et al. 2018). For many degraded landscapes or habitats, restoration is required for the entire communities (Xiao et al. 2019). To identify and source required plant material for restoration in the diverse landscape is a crucial task that is further threatened due to ongoing climate change. SDM has been thought as an important tool that integrates climate scenarios into ecological restoration decision-making. There are examples where past and future baselines were integrated to model climate conditions for more than 40 important plant taxa in five future climate scenarios. So, this multitaxon suitability stacking resulted in patterns for different vegetation groups that were less clear and available for individual taxon-modelled maps. Hence, caveats regarding SDMs suggest that it can be part of the integrated toolset for successful application in restoration planning (Riordan et al. 2018; Xiao et al. 2019).

20.5 Integrating SDM and NbS in Restoration for Localising SDGs

Land degradation neutrality has been considered a key to address climate vulnerabilities and localise SDGs and Bonn Challenge targets. In order to localise and realise the SDGs, it will be vital to reduce the increasing pressure on land and reduce and reverse land use change. Awareness generation at all stakeholder levels is warranted to change stakeholders' outlook and improve opportunities for economic benefits (Chazdon et al. 2017). To realise and localise the SDGs that are linked to food, water, health and climate, there is going to be enhanced pressure on land and land-based resources. To promote restoration and reverse land degradation, it is necessary to promote multifunctional uses of land resources within the boundaries of soil and water systems. This needs promotion of NbS and SDM in restoration planning. The SDGs 1, 2, 6, 13 and 14 specifically addresses to curtail land degradation due to climate and anthropogenic drivers. It is imperative to understand the patterns of vegetation change and realise the need of conservation measures, by suitable selection of species, which can cope up with the degraded scenario of land and climate. Particularly the dry land species are more sensitive towards the temperature and precipitation variations (Xiao et al. 2019). Against this backdrop, predictive models based on species habitat suitability plays an important role in bridging the gap between the land degradation and habitat suitability of certain keystone or dominant species.

20.6 Challenges and Way Forward

One of the key limitations of mainstreaming and scaling up NbS is still the lack of interest for choosing NbS/ecosystem-based measures over engineering approaches for reducing disaster risks. Constraints lie with engineering community from further replicating and implementing such measures as one size does not fit all problems and geographical locations. NbS needs to be customised as per area, local/regional issues of disaster intensity and frequency. Engineering approaches can provide short-term solutions for DRR, while NbS with civil engineering approaches are long-term solutions for DRR. A lot of local and indigenous knowledge support can help in scaling NbS as communities have been practicing so many NbS for climate adaptations, if not mitigations. Introducing different capacity-building approaches for NbS and increasing the reach of the existing courses by involving universities and private sector remain crucial. There is need to facilitate dialogue and networking on increasing awareness through standalone courses, online courses and linking up with ongoing efforts, along with dialogue on increasing co-operation for NbS by discussing the need of the key policy stimulus, potential partners' availability of international support and partnerships and using national missions on DRR and climate change for maximising NbS.

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Chapter 21
Role of Tropical Floodplain Wetlands in Carbon Sequestration: A Case Study from Barak River Basin of Assam, Northeast India

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Abstract Wetlands store an enormous amount of carbon in its different biophysical components, namely vegetation, soil, and sediment, thus playing an important role in mitigating climate change. Floodplain wetlands cover substantial area in northeast India. They are seasonally inundated by nutrient-rich floodwater that facilitates luxuriant growth of shrubs, herbs, and pteridophytes. High productivity and rapid turnover of such plants may play an important role in carbon-stocking and sequestration in such wetlands. We tested this proposition in Chatla, a seasonal floodplain wetland in Assam, Northeast India by estimating the carbon stock and sequestration of vegetation and soil. The estimated total carbon stock was 21.75 Mg C ha^{-1}. Of this, the vegetation component contributed 3.18 Mg C ha^{-1} (14.62%), saturated soil contributed 8.53 Mg C ha^{-1} (39.22%), and unsaturated soil contributed 10.04 Mg C ha^{-1} (46.16%). The carbon sequestration potential of Chatla was estimated to be 6.36 Mg C ha^{-1} $year^{-1}$, of which the contribution of vegetation was the highest (4.14 Mg C ha^{-1} $year^{-1}$), followed by saturated soil (1.76 Mg C ha^{-1} $year^{-1}$), and unsaturated soil (0.46 Mg C ha^{-1} $year^{-1}$). Thus, it is evident that tropical floodplain wetlands sequester large amount of carbon annually through its biophysical components, i.e., vegetation especially the lower angiosperms like shrubs and herbs, and soil. Therefore, management strategies should focus on maintaining vegetation cover comprising the lower angiosperms in the wetland.

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21.1 Introduction

Wetlands cover 5–8% of the earth's surface (Mitsch et al. 2012; Junk et al. 2013) and provide a range of ecological services which include provision of food and fiber, drinking water, hydrological regulation, climate regulation, and recreational services (Costanza et al. 1997, 2014; Mitsch and Gosselink 2000; de Groot et al. 2012; McInnes 2013). Wetland ecosystems are one of the largest storehouses of the terrestrial carbon pool (20–30%) (Dixon and Krankina 1995; Lal 2008). They play a significant role in balancing the global carbon cycles (Sahagian et al. 1997; Chmura et al. 2003; Mitra et al. 2005; Bernal and Mitsch 2008) and mitigate climate change (Saintilan et al. 2013; Gao et al. 2014; Liu et al. 2014).

Generally, the role of higher plants in carbon stocking and sequestration process in the terrestrial ecosystems including floodplain wetlands is well-studied (Megonigal et al. 1997; Robertson et al. 1999; Piedade et al. 2001; Burrows et al. 2002; Nowak and Crane 2002; Dieter and Elsasser 2002; Pietsch et al. 2003; Silver et al. 2004; Kumar 2006; Wauters et al. 2008; Guyette et al. 2008; Baishya et al. 2009; Sharma et al. 2010; Schöngart and Wittmann 2010; Rizvi et al. 2011; Pan et al. 2011; Murthy et al. 2013; Bora et al. 2013; Mohanraj et al. 2011; Mensah et al. 2016a; Nath et al. 2017). Policy measures pertaining to carbon trading are therefore deemed to be more inclined toward conservation and management of higher vascular plants, i.e., trees (Návar 2009; Rodríguez-Loinaz et al. 2013; Mbow et al. 2014; Mensah et al. 2016a).

Emphasizing on tree species for stocking carbon may be more appropriate in a long-term perspective (Dieter and Elsasser 2002; Silver et al. 2004; Kumar 2006; Sharma et al. 2010; Murthy et al. 2013; Mensah et al. 2016b). However, such plant groups might not be a viable option for stocking and sequestration of carbon in wetland ecosystems considering their low turnover rate (Cronk and Fennessy 2016). Here, it is important to mention that higher carbon stock in wetlands compared to terrestrial ecosystems has been primarily attributed to higher accumulation and slower decomposition rates of organic matter owing to the anaerobic environment created by water-logged conditions (Gorham 1991; Hobbie et al. 2000; Mcleod et al. 2011; Mitsch and Gosselink 2015).

Through a survey of literature as cited above, we could observe that a lot of studies related to carbon sequestration by trees in terrestrial systems and wetlands have been done in different parts of the world including India. However, there are relatively less information on this aspect in case of lower plant groups in tropical flood plain wetlands. Therefore, based on the gap in information, the lower angiosperm group was taken into consideration. The lower groups of plants, e.g., the herbs and shrubs may have significant role in carbon-stock and sequestration owing to their rapid turnover, which needs to be studied.

In India, climatic and topographic variations support diverse wetland habitats ranging from high-altitude Himalayan lakes to the floodplains in river basins (Prasad et al. 2002; Sarkar and Das 2016). Of the total 1 million ha area covered by floodplain wetlands in India (Sarkar and Borah 2017), the state of Assam in

Northeast India has about 1392 wetlands spreading over an area of 0.1 million ha (http://aquafind.com/articles/Floodplain_Wetlands_Of_India.php). Among these, about 322 wetlands are located in the Barak river basin covering an area of ~8000 ha (Sugunan and Bhattacharya 2000). These wetlands are subjected to periodic flooding and seasonal inundation by nutrient-rich flood water (Nandan 2012). The unique hydrologic and geological regimes of these wetlands support luxuriant growth of lower angiosperm plants with a rapid turnover rate (Robertson et al. 2001). We hypothesize that lower angiosperm plants play a significant role in carbon stocking and sequestration in the floodplain wetlands owing to their faster growth and turnover. To test this hypothesis, we estimated the carbon stock and sequestration potential of the major biophysical components of the wetland, namely soil (saturated and unsaturated) and vegetation (lower angiosperm plants) of a floodplain wetland located in the Barak Valley region of Assam in Northeast India.

21.2 Materials and Methods

21.2.1 Study Area

Chatla is a seasonal floodplain wetland located in the Cachar district of state Assam in Northeast India (24°8′ N and 25°8′ N latitude and 92°15′ E and 93°15′ E longitude) (Fig. 21.1). Chatla covers an area of ~1600 ha or 16 km^2 (Kar et al. 2008) and is surrounded by 52 riparian villages (Rao and Purkayastha 2003). The local inhabitants of the riparian villages are dependent on this wetland for its various natural resources like fish, paddy, soil, surface water, and NTFPs (thatch grass, fuelwood, fodder, and cane and common donax), the availability of which varies from the wet and dry phases of the wetland. Besides, grazing by livestock and cattle was also observed in the wetland. However, recently it has become a fast-degraded landscape due to unsustainable extraction of natural resources and conversion of the wetland for human settlement and agriculture, and setting up brick kiln industry (Sarkar et al. 2019a). The wetland retains water during pre-monsoon to post-monsoon period (April to October) and experiences a dry phase from winter to the beginning of pre-monsoon period (November to March). The total rainfall during the study period varied from 2121 to 2228 mm while the total rainfall during the flooding phase (April to October) varied from 2093 to 2190 mm. Its catchment includes a small portion of an Inner Line Reserve Forest. The common tree species in this floodplain wetland are *Barringtonia acutangula* (L.) Gaertn, *Lagerstroemia speciosa* (L.) Pers., *Vitex negundo* L., and *Vitex pinnata* L. Besides, the wetland is dominated by grasses such as *Chrysopogon zizanioides* (L.) Roberty and *Saccharum ravennae* (L.) L.

Chatla has numerous inlets and one outlet, and therefore, the fluvial pattern of the wetland changes with a change in seasonal rainfall. In wetlands, water-level dynamics results in shifting the mosaics of vegetation types (Keddy 2010) and affects the decomposition rates by disturbing the redox conditions in the wetland soil and

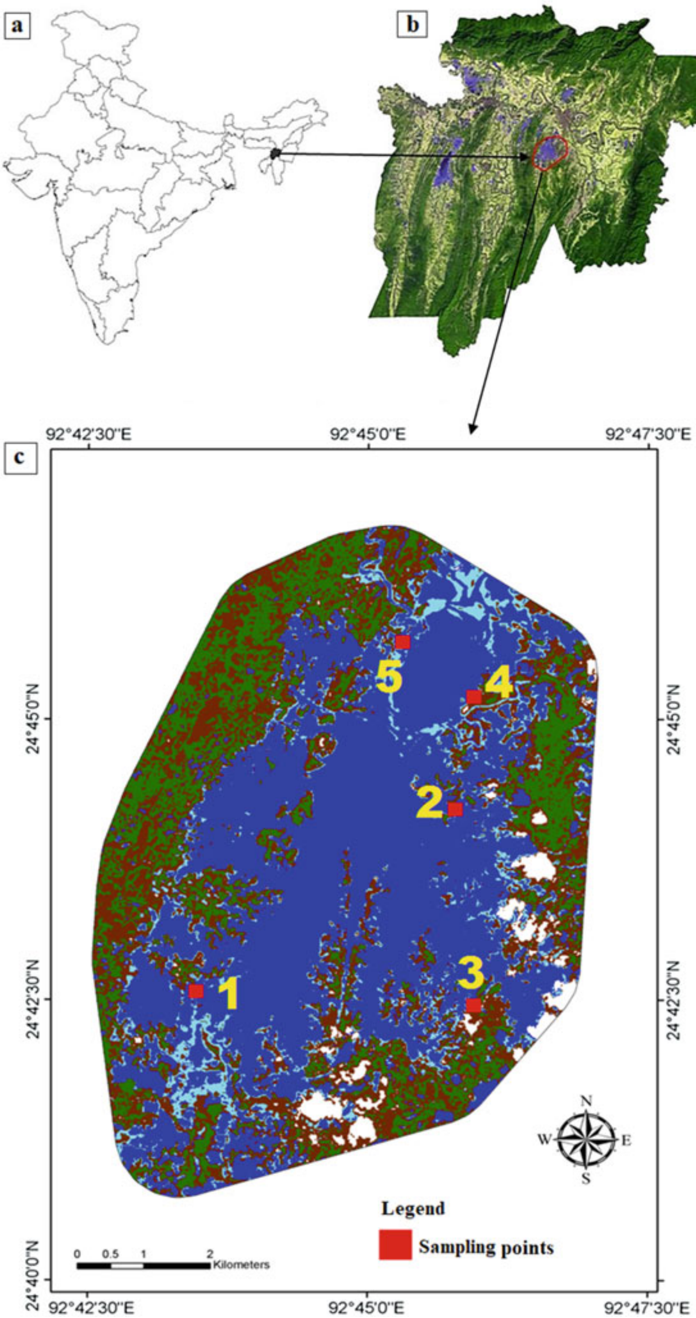

Fig. 21.1 Map of India (**a**); Southern Assam, Northeast India (**b**); location of the sampling points within Chatla wetland (**c**) (Sampling point 1, inlet point 1; Sampling point 2, middle point 1; Sampling point 3, inlet point 2; Sampling point 4, middle point 2; and Sampling point 5, outlet point)

ultimately interferes with carbon stocks (Zdruli et al. 1995). Considering the hydrological features of Chatla, a total of five sampling locations representing all the heterogeneity within the wetland were strategically selected. The sampling locations comprised of (1) *the major inlets* (sampling points 1 and 3, where the water discharge rate within the wetland varied from 1.96 to 6.41 $m^3\ s^{-1}$ for sampling point 1 and 1.31 to 7.90 $m^3\ s^{-1}$ for sampling point 3), (2) *middle points* (sampling points 2 and 4, where the water discharge rate within the wetland was below detectable level, and these sampling locations acted like a lentic system), and (3) *the outlet point* (sampling point 5, where the water discharge rate within the wetland varied from 0.81 to 3.92 $m^3\ s^{-1}$) along the wetland (Fig. 21.1). We did the sampling during the different phases of flooding (i.e., early flood, mid-flood, and late-flood phases) when the wetland remained inundated and turned into a continuous system. However, there was variation in the water level due to varied rainfall pattern which also lead to variation in the extant of the riparian zone (buffer zone) of the wetland which ranged from 5 to 10 m in width. So, it was not possible to demarcate the exact area of each sampling point which varied from one flood phase to the other. Besides, we needed to collect simultaneous samples of riparian vegetation and unsaturated soil from the riparian zone and saturated soil from the adjacent shore line of each of the selected sampling points. Therefore, based on the fluctuation of water level of the wetland due to variations in intensity of rainfall during the different flood phases and requirement of simultaneous sampling of riparian vegetation, unsaturated soil, and saturated soil from/near each of the sampling points, quadrats ($1 \times 1\ m^2$) were laid strategically along the riparian zone of the wetland (of 5–10 m width). During each sampling for analyzing the riparian vegetation, a total of ten quadrats were laid perpendicular to a 200–250 m long line transact along the riparian zone of each of the selected sampling points across the wetland. Simultaneous samples of unsaturated and saturated soil were also collected from the riparian zone and the adjacent shoreline of the selected sampling locations. In this process, we covered a total area of 10,000–12,500 m^2 (1–1.25 km^2) along the riparian zone and the adjacent shoreline for all the five sampling points within the wetland (Fig. 21.1) which represented 6.25–7.81% of the total area of the wetland. We followed a stratified random sampling design based on the fluvial dynamics of the wetland during different flood phases. Sampling of wetland soil (both saturated and unsaturated) and vegetation (lower angiosperm plants) were done at bimonthly intervals during the three flood phases such as early flood phase (May to June), mid-flood phase (July to August), and late-flood phase (September to October) during the years 2014 and 2015.

21.2.2 Analysis of Wetland Vegetation

21.2.2.1 Species Composition and Community Structure

Species composition and community structure of lower angiosperm plants, i.e., herbs, shrubs, grasses, and aquatic macrophytes, were studied by laying ten random quadrats of 1 × 1 m^2 along the riparian zone (within 2 m from the shoreline) in each sampling point. A total of 300 quadrats were studied during the entire study period. Species were identified by consulting regional floras (Kanjilal et al. 1934, 1936, 1938, 1940; Deb 1981, 1983; Hooker 1875) and the online database, http://www.theplantlist.org. Doubtful specimens were identified with the help of the herbarium of the Botanical Survey of India, Shillong, Meghalaya, India.

Frequency, density, and the basal cover of all the species within each quadrat were determined following standard methods (Kent 2011). Frequency was calculated by dividing the number of quadrats of occurrence of a species by the total number of quadrats studied multiplied by 100. Density was expressed as the number of individuals of a species present per unit area. Basal area (cover) was estimated by measuring the basal diameter of ten individuals of each species using a Vernier Caliper, where each tiller in the grass and any unit of other plants having functional roots were considered as one individual. Species-wise importance value index (IVI) was calculated by summing their relative density, relative frequency, and relative dominance (basal cover) values (Mueller-Dombois and Ellenberg 1974).

21.2.2.2 Estimation of Biomass, Carbon Stock, and Sequestration Potential

Above- and below-ground biomass of the riparian vegetation in each sampling point was estimated following the harvest method (Mishra 1968; Gibbs et al. 2007). During the study period, plants were harvested from a total of 90 random quadrats of 1 × 1 m^2 laid along the riparian zones (within 2 m from the shoreline). For minimal loss of below-ground plant parts in each quadrat, soil monoliths were excavated while uprooting the vegetation samples. Plant samples were then brought to the laboratory, rinsed and segregated species-wise, labeled, and kept for oven drying at 70 °C for 48 h. Oven-dried weight of individual plant species was recorded using an electronic balance (make: Shimadzu; model: BL-2200H) as their respective biomass during each sampling.

For estimation of the total carbon content of an individual plant species, the respective biomass value was multiplied with a conversion factor of 0.45 (Woomer 1999). The carbon content (g m^{-2}) of each species was multiplied by a factor of 0.01 to convert into Megagram per hectare (Mg ha^{-1}).

Carbon sequestration potential (%) of individual plant species was determined by using the following formula:

$$\text{Carbon sequestration potential of individual plant species } (\%) = \frac{\text{Carbon sequestered by an individual plant species}}{\text{Total carbon sequestered by all the available plant species}} \times 100$$

While, carbon sequestration (Mg ha^{-1} year^{-1}) of each species was estimated by deducting the value of its carbon stock during the preceding year from that of the succeeding year.

21.2.3 Analysis of Wetland Soil

Like any seasonal wetland, soil in Chatla experiences simultaneous saturated and unsaturated conditions with water level fluctuation due to the seasonal rainfall. Considering this, we have categorized wetland soil into two types such as saturated and unsaturated soil. Here, saturated soil represents soil from the low-lying region which was inundated during the flood, whereas unsaturated soil represented the soil from the riparian zone that experienced intermittent wet and dry phases based on the intensity of rainfall.

21.2.3.1 Physicochemical Properties of Wetland Soil

The temperature of wetland soil was measured in situ using a mercury bulb thermometer. For analyses of the other physicochemical properties, triplicate soil samples were collected from 0 to 15 cm soil layer from both saturated and unsaturated regions separately in each sampling point. Composite samples were prepared by mixing the triplicate soil samples separately for both saturated and unsaturated regions. Representative wetland soils were then brought to the laboratory in polythene bags, air-dried, homogenized, sieved (using 2 mm mesh size), and stored in airtight polythene packets for further analysis. Soil pH was measured in 1:2.5 soil-water (w/v) suspensions with a digital pH meter (make: Systronics; model: 103621) using potentiometric method (Tandon 1995). Soil color was determined using the Munsell soil color charts (Munsell 1994). Soil texture was determined using the Bouyoucos soil hydrometer method (Bouyoucos 1962). The water-holding capacity of the soil was determined following Keen-Raczkowski Box method (Piper 1966). Analysis of organic carbon content of the soil samples was done following Walkley and Black's rapid titration method (Walkley and Black 1934). Soil organic matter (SOM) was determined by multiplying the value of soil organic carbon content (%) by a factor of 1.724 upon the assumption that SOM contains 58% carbon (Allen et al. 1974). Bulk density of wetland soil was determined following the Corer technique (Brady and Weil 2008) for which separate soil samples were collected in triplicates from 0 to 15 cm soil layer from both the regions in each sampling point.

21.2.3.2 Carbon Stock and Carbon Sequestration of Wetland Soil

Carbon stock in wetland soil was estimated by multiplying the carbon content of wetland soil with its corresponding depth and bulk density (Pearson et al. 2007). Whereas, carbon sequestered in wetland soil was computed by deducting the values of its carbon stock of the preceding year from that of the succeeding year.

21.2.4 Contribution of Selected Biophysical Components to Carbon Stock and Sequestration

Contribution of the selected biophysical components in carbon stocking potential of the wetland was estimated using the following formula:

$$\text{Contribution of selected bio-physical components in carbon stocking }(\%) = \frac{\text{Cabon stocked by a selected bio-physical component}}{\text{Total carbon stocked by all the bio-physical components}} \times 100$$

Contribution of the selected biophysical components in carbon sequestration potential of the wetland was estimated using the following formula:

$$\text{Contribution of selected bio-physical components in carbon sequestration }(\%) = \frac{\text{Carbon sequestered by a selected bio-physical component}}{\text{Total carbon sequestered by all the bio-physical components}} \times 100$$

Total carbon stocked by Chatla was calculated by summing up the values of the individual carbon stocks of the biophysical components, namely the vegetation (shrubs, herbs, grasses, and aquatic macrophytes) and soil (unsaturated and saturated). Similarly, the total carbon sequestered by Chatla was calculated by summing up the respective values of the carbon sequestered by the individual biophysical components.

21.2.5 Statistical Analysis

One-way analysis of variance (ANOVA) was performed (1) to test the statistical significance of the variation in various physicochemical parameters, namely temperature, pH, organic carbon, and organic matter between the saturated and unsaturated soils, and (2) to test the statistical significance of the variations in the carbon stocked by different biophysical components of the wetland. Tukey post hoc analysis was performed for multiple comparisons of carbon stocked by different biophysical components of the wetland. All statistical analyses were done using Microsoft Office Excel 2007 and SPSS 20.0 software (Nie et al. 2011).

21.3 Results and Discussion

21.3.1 Wetland Vegetation

A total of 36 species of wetland plants belonging to the lower angiosperm group were recorded during the study. Those species with irregular encounter during the study period were grouped under the "miscellaneous" category (Table 21.1). *Cynodon dactylon* had the highest mean density followed by *Chrysopogon zizanioides* (Table 21.1). The higher density of *Cynodon dactylon* can be attributed to its potential to spread rapidly (Horowitz and Friedman 1971) plausibly due to grazing by cattle (White 1973; Belsky 1992). The dominance of the species such as *Chrysopogon zizanioides* may be due to its adaptability in a wide habitat range characterized by better reproduction and survival strategies through rhizome (Lytle and Poff 2004).

A species having higher IVI is best adapted to the existing environmental conditions in a habitat and has a high tolerance against anthropogenic activities such as burning, cutting, trampling and grazing by the domestic animals (Wood et al. 1994). Moreover, high IVI of any individual species indicates its higher resource utilization capacity as compared to its competitors and associates (Dwivedi et al. 2013), consequently facilitating its dominance, ecological success, and regeneration capacity. The present study revealed the highest IVI for *Chrysopogon zizanioides*, followed by *Cynodon dactylon* (Table 21.1). Highest IVI of *Chrysopogon zizanioides* indicates its dominance within the wetland plausibly due to its ability to resist the effects of grazing. Unlike most grasses, *Chrysopogon zizanioides* does not form a horizontal mat of roots; rather, the roots grow deep downwards to prevent disturbances (Dwivedi et al. 2013). Moreover, the species has high adaptability to a wide range of environmental conditions due to its unique morphological, physiological, and ecological characteristics (Mickovski et al. 2005; Truong 1999). On the other hand, the greater IVI of *Cynodon dactylon* might be attributed to its reproductive potential through extensively creeping stolons and rhizomes (Horowitz 1972).

21.3.1.1 Biomass, Carbon Stock, and Sequestration Potential of Wetland Vegetation

Among the 36 recorded taxa of wetland plants, *Chrysopogon zizanioides* had the highest biomass values followed by *Ipomoea carnea* and *Saccharum ravennae* (Table 21.2). The higher biomass of *Chrysopogon zizanioides* can be attributed to its abundant, complex, and an extensive lacework of the root system (Chomchalow 2000) that grows deep downwards (Hengchaovanich 1998; Lavania 2003),

Table 21.1 Variations in density and importance value index (IVI) of the wetland vegetation of Chatla during the study period

S. No.	Taxa	Density (no of individuals per hectare)	IVI
1	*Axonopus fissifolius* (Raddi) Kuhlm.	22,500 ± 50,311.53	1.49 ± 3.33
2	*Calamus tenuis* Roxb.	466.70 ± 1043.57	0.271 ± 0.61
3	*Centella asiatica* (L.) Urb.	37,666.70 ± 68,022.03	3.72 ± 2.11
4	*Chrysopogon aciculatus* (Retz.) Trin	61,866.6 ± 92,691.14	4.11 ± 4.62
5	*Chrysopogon zizanioides* (L.) Roberty	7,128,266.50 ± 14,128,642	95.07 ± 18.68
6	*Cyperus compressus* L.	1700 ± 3801.32	0.93 ± 2.08
7	*Cynodon dactylon* (L.) Pers.	16,038,066.60 ± 29,750,094	57.95 ± 22.04
8	*Eichhornia crassipes* (Mart.) Solms	2466.60 ± 2807.19	7.28 ± 6.23
9	*Eleocharis acicularis* (L.) Roem. & Schult.	491,000 ± 1,097,909	6.58 ± 14.72
10	*Fimbristylis bisumbellata* (Forssk.) Bubani	239,466.60 ± 322,807.70	29.51 ± 38.65
11	*Ipomoea carnea* Jacq.	179,333.30 ± 367,243.2	29.00 ± 27.85
12	*Melastoma malabathricum* L.	466.70 ± 1043.57	0.70 ± 1.57
13	*Paspalum scrobiculatum* L.	7366.60 ± 16,472.22	2.39 ± 5.35
14	*Persicaria hydropiper* (L.) Delarbre	19,900.10 ± 35,140.78	7.27 ± 11.25
15	*Pseudoraphis spinescens* (R.Br.) Vickery	45,466.70 ± 67,350.51	3.22 ± 5.29
16	*Saccharum ravennae* (L.) L.	721,833.30 ± 1,318,636	5.59 ± 5.95
17	*Schumannianthus dichotomus* (Roxb.) Gagnep.	4500 ± 10,062.31	1.22 ± 2.72
Miscellaneous sp.			
18	*Alternanthera paronychioides*A. St.-Hil.	313,666.60 ± 541,990.10	5.13 ± 7.83
19	*Alternanthera sessilis* (L.) R. Br. ex DC.	1,279,266.60 ± 2,803,575	5.31 ± 5.56
20	*Brachiaria ramose* (L.) Stapf.	26,033.40 ± 42,128.25	2.01 ± 3.88
21	*Centipeda minima* (L.) A. Braun & Asch.	1166.6 ± 2608.59	0.75 ± 1.69
22	*Ceratophyllum demersum* L.	12,500 ± 27,950.85	0.82 ± 1.82
23	*Colocasia esculenta (L.) Schott*	3833.30 ± 8571.52	2.81 ± 6.28
24	*Croton eluteria* (L.) W. Wright	500 ± 1118.03	1.53 ± 3.43
25	*Cyperus haspan* L.	101,200 ± 222,951.10	0.85 ± 1.17
26	*Cyperus javanicus* Houtt.	1333.30 ± 2981.35	2.42 ± 5.41
27	*Digitaria ciliaris* (Retz.) Koeler	3333.30 ± 7453.49	0.76 ± 1.69
28	*Eclipta prostrata* (L.) L.	3333.30 ± 7453.49	0.84 ± 1.57
29	*Eleusine indica* (L.) Gaertn.	14,166.70 ± 31,677.70	0.61 ± 1.36
30	*Eragrostis unioloides* (Retz.) Nees ex Steud.	29,766.70 ± 66,560.36	1.45 ± 3.24
31	*Fimbristylis littoralis* Gaudich.	1833.30 ± 4099.38	0.72 ± 1.60
32	*Oldenlandia diffusa* (Willd.) Roxb.	35,499.90 ± 73,349.58	1.62 ± 1.28

(continued)

Table 21.1 (continued)

S. No.	Taxa	Density (no of individuals per hectare)	IVI
33	*Hemarthria compressa* (L.f.) R.Br.	22,333.30 ± 49,938.78	0.75 ± 1.67
34	*Ludwigia hyssopifolia* (G.Don) Exell	100,000 ± 223,606.80	0.35 ± 0.77
35	*Paspalum notatum* Flüggé	466.70 ± 1043.57	1.56 ± 2.15
36	*Sacciolepis interrupta* (Willd.) Stapf	733.30 ± 1639.71	0.45 ± 1.01
Miscellaneous total		1,950,966.30 ± 4,120,697	30.72 ± 53.43

Mean ± SD
$n = 30$
Total quadrats studied = 300

supporting its survival by resisting disturbances and other environmental constraints (Wood et al. 1994; Dwivedi et al. 2013; Darajeh et al. 2014). On the other hand, the rapid growth and spreading capacity of *Ipomoea carnea* along with its adaptability from xeric to aquatic habitats might be the reason for this species to have a high biomass (Table 21.2; Mohanty and Mishra 1963; Eid and Sewelam 2010). *Ipomoea carnea* grows vigorously during the pre-flood period. However, the growth of the species slows down during flood putatively decreasing its overall biomass (Haase 1999). Besides, high biomass of *Saccharum ravennae* (Table 21.2) can be attributed to its highly efficient physiology which enables the species to increase the rate of photosynthesis by activating the phosphoenolpyruvate carboxylase even under lower stomatal conductance (Hattori et al. 2010).

The average vegetation carbon stock of Chatla was estimated to be 3.18 Mg C ha^{-1} (Table 21.5). In terms of species-wise contribution toward carbon stocking, *Chrysopogon zizanioides* followed by *Ipomoea carnea* and *Saccharum ravennae* had greater carbon stocking potential compared to other species (Table 21.3). This can be attributed to their ability for higher biomass production through diverse survival strategies as discussed above. The one-way ANOVA revealed significant differences in carbon stocks of wetland vegetation with respect to year during the study period (Table 21.7) which might be due to the year-wise variation in hydrological pulses in Chatla that facilitated the vegetation communities to be more productive in the second year (Table 21.5), and thus stocking more carbon in their biomass (Odum 1969; Odum et al. 1995).

On the other hand, carbon sequestered by wetland vegetation was 4.14 Mg C ha^{-1} year^{-1} (Table 21.6). In terms of species-wise contribution of wetland vegetation in carbon sequestration, *Saccharum ravennae* sequestered highest (1.236 Mg C ha^{-1} year^{-1}) followed by *Ipomoea carnea* (1.041 Mg C ha^{-1} year^{-1}), and *Chrysopogon zizanioides* (0.660 Mg C ha^{-1} year^{-1}) (Table 21.3). Although the biomass and carbon stock of *Saccharum ravennae* was lower than *Chrysopogon zizanioides* and *Ipomoea carnea* (Tables 21.2 and 21.3), it

Table 21.2 Variations in biomass of wetland vegetation in Chatla during the study period

S. No.	Taxa	Vegetation biomass (g m^{-2})		
		First year	Second year	Mean
1	*Axonopus fissifolius* (Raddi) Kuhlm.	0.15 ± 0.34	1.72 ± 3.86	0.94 ± 1.11
2	*Calamus tenuis* Roxb.	1.78 ± 4.44	20.50 ± 36.48	11.14 ± 13.24
3	*Centella asiatica* (L.) Urb.	0.33 ± 0.73	0.70 ± 1.08	0.51 ± 0.26
4	*Chrysopogon aciculatus* (Retz.) Trin	0.40 ± 0.89	9.12 ± 10.21	4.76 ± 6.17
5	*Chrysopogon zizanioides* (L.) Roberty	420.46 ± 201.69	284.79 ± 138.49	352.63 ± 95.94
6	*Cyperus compressus* L.	0.37 ± 0.82	1.37 ± 3.07	0.87 ± 0.71
7	*Cynodon dactylon* (L.) Pers.	10.99 ± 7.82	94.72 ± 35.38	52.85 ± 59.21
8	*Eichhornia crassipes* (Mart.) Solms	5.43 ± 7.15	27.54 ± 50.39	16.49 ± 15.64
9	*Eleocharis acicularis* (L.) Roem. & Schult.	3.46 ± 7.74	1.39 ± 3.10	2.43 ± 1.47
10	*Fimbristylis bisumbellata* (Forssk.) Bubani	40.94 ± 58.72	71.92 ± 101.65	56.43 ± 21.90
11	*Ipomoea carnea* Jacq.	138.91 ± 175.02	260.30 ± 282.80	199.61 ± 85.83
12	*Melastoma malabathricum* L.	0.44 ± 0.22	1.64 ± 3.68	1.04 ± 0.85
13	*Paspalum scrobiculatum* L.	2.59 ± 5.79	3.17 ± 4.56	2.88 ± 0.41
14	*Persicaria hydropiper* (L.) Delarbre	12.74 ± 28.48	16.09 ± 17.66	14.42 ± 2.38
15	*Pseudoraphis spinescens* (R.Br.) Vickery	0.61 ± 1.35	1.10 ± 1.67	0.85 ± 0.35
16	*Saccharum ravennae* (L.) L.	13.38 ± 29.91	279.22 ± 414.95	146.30 ± 187.98
17	*Schumannianthus dichotomus* (Roxb.) Gagnep.	0.67 ± 1.33	2.00 ± 4.44	1.34 ± 0.94
18	Miscellaneous sp.	67.59 ± 132.45	119.27 ± 263.41	93.43 ± 125.26

Mean ± SD
$n = 30$
Total quadrats studied = 90

had the highest carbon sequestration potential (Table 21.3). This indicates its fast growth rate (Mandal et al. 2016) during the flooding season and its significant role in carbon sequestration in floodplain wetland.

Table 21.3 Variations in carbon stock, carbon sequestration, and carbon sequestration potential of wetland vegetation in Chatla during the study period

S. No.	Taxa	Carbon stock (Mg C ha^{-1})			Carbon sequestration (Mg C ha^{-1} year^{-1})	Carbon sequestration potential (%)
		First year	Second year	Mean		
1	*Axonopus fissifolius* (Raddi) Kuhlm.	0.0002 ± 0.0005	0.008 ± 0.02	0.004 ± 0.006	0.008	0.19
2	*Calamus tenuis* Roxb.	0.008 ± 0.018	0.09 ± 0.16	0.05 ± 0.05	0.052	1.98
3	*Centella asiatica* (L.) Urb.	0.0005 ± 0.001	0.003 ± 0.004	0.002 ± 0.002	0.003	0.06
4	*Chrysopogon aciculatus* (Retz.) Trin	0.001 ± 0.001	0.04 ± 0.05	0.02 ± 0.03	0.043	1.02
5	*Chrysopogon zizanioides* (L.) Roberty	0.63 ± 0.30	1.29 ± 0.61	0.96 ± 0.47	0.660	15.98
6	*Cyperus compressus* L.	0.001 ± 0.001	0.006 ± 0.01	0.004 ± 0.004	0.006	0.12
7	*Cynodon dactylon* (L.) Pers.	0.05 ± 0.03	0.14 ± 0.05	0.10 ± 0.07	0.093	2.25
8	*Eichhornia crassipes* (Mart.) Solms	0.008 ± 0.01	0.14 ± 0.25	0.07 ± 0.09	0.127	3.09
9	*Eleocharis acicularis* (L.) Roem. & Schult.	0.005 ± 0.01	0.006 ± 0.01	0.006 ± 0.001	0.001	0.02
10	*Fimbristylis bisumbellata* (Forssk.) Bubani	0.06 ± 0.08	0.32 ± 0.45	0.19 ± 0.18	0.262	6.36
11	*Ipomoea carnea* Jacq.	0.20 ± 0.27	1.24 ± 1.38	0.72 ± 0.73	1.041	25.19
12	*Melastoma malabathricum* L.	0.002 ± 0.004	0.007 ± 0.01	0.005 ± 0.004	0.005	0.12
13	*Paspalum scrobiculatum* L.	0.004 ± 0.008	0.01 ± 0.02	0.009 ± 0.007	0.010	0.24
14	*Persicaria hydropiper* (L.) Delarbre	0.02 ± 0.04	0.08 ± 0.08	0.048 ± 0.041	0.058	1.40
15	*Pseudoraphis* sp.	0.001 ± 0.003	0.005 ± 0.007	0.003 ± 0.003	0.004	0.10
16	*Saccharum ravennae* (L.) L.	0.02 ± 0.04	1.26 ± 1.86	0.64 ± 0.87	1.236	29.88
17	*Schumannianthus dichotomus* (Roxb.) Gagnep.	0.003 ± 0.007	0.009 ± 0.02	0.006 ± 0.004	0.006	0.15
18	Miscellaneous sp.	0.10 ± 0.19	0.59 ± 1.30	0.35 ± 0.35	0.49	11.85

Mean ± SD
$n = 30$
Total quadrats studied = 90

21.3.2 *Wetland Soil*

21.3.2.1 Physicochemical Properties

The significantly lower temperature of saturated soil compared to the unsaturated soil (Table 21.4) can be attributed to its waterlogged condition that has created anaerobic conditions resulting in lower microbial respiration (Xu and Qi 2001; Han et al. 2014). Significantly lower bulk density of saturated soil (Table 21.4) as compared to its unsaturated counterpart can be attributed to its higher organic matter content responsible for an increase in soil pore space (Chen 2000; Han et al. 2010; Chaudhari et al. 2013). Besides, the formation of loose soil in the saturated zone of the wetland can also be attributed to filling up of the soil pore with the wetland water. Acidic soil condition of both the saturated and unsaturated soil of the wetland indicates the effect of decomposition of the built-up organic matter (Vymazal and Kröpfelová 2008) in both soil types (Table 21.4). Soil color comprehends the pedogenic processes and history of soil, where water and organic matters are the main colorings or pigmenting agents (Owens and Rutledge 2005). In the present study, the color of the saturated soil varied from light gray to light yellowish brown, whereas that of unsaturated wetland soil varied from light brownish gray to light yellowish brown. The high oxygen content of well-aerated unsaturated soils might have oxidized Fe^{2+} to Fe^{3+} resulting in the yellow or red color of the soil, whereas absence or reduction of Fe^{2+}, the non-color state might have resulted in gray colored soil (ASA 1973; Scharf 2009), implying that wetter the soil, greater the intensity of gray color in the soil (http://www.illinoissoils.org/Links_Files/Understanding%20Soils_Final2.pdf). All these indicate the formation of such soil color within the wetland due to its fluctuating water table underneath (Scharf 2009). Analyses of soil texture revealed lower amounts of silts and clay in both saturated and unsaturated regions of the wetland (Table 21.4). This can be attributed to the removal of these fine soil particles by water erosion (Hassan and Mazumder 1990) as a result of the annual flood event. The soil types in both saturated and unsaturated regions of the wetland were found to be loam-textured, where the saturated soil was sandy loam, and the unsaturated soil was loamy sand (Table 21.4). Loam-textured surface soils are known for supporting better plant growth as compared to other soil types (Young 1992). This is evident from the presence of a variety of vegetation growing in Chatla. However, in Chatla, dense vegetation growth was noticed in the unsaturated zone of the wetland, which can be attributed to the greater water-holding capacity of the unsaturated soil (Table 21.4), facilitating the growth of a variety of plant species (Sohi et al. 2009).

Both the organic carbon and organic matter contents were higher in the saturated soil though it did not vary significantly (Table 21.4). This can be attributed to the combined effects of higher allochthonous inputs in the saturated region of the wetland through floodwater and slow decomposition rate of the organic matter (Gorham 1991; Hobbie et al. 2000; Mcleod et al. 2011; Mitsch and Gosselink 2015).

Table 21.4 Variations in physicochemical parameters and the one-way analyses of variance (ANOVA) of wetland soil under saturated and unsaturated conditions in Chatla during the study period

	Saturated soil			Unsaturated soil			
Soil physicochemical parameters	First year	Second year	Mean	First year	Second year	Mean	F-ratio
Temperature (°C)[a]	28.13 ± 3.30	29.27 ± 1.25	28.70 ± 0.81	30.30 ± 3.56	30.36 ± 1.85	30.33 ± 0.04	5.392*
Bulk density ($Mg\ m^{-3}$)[b]	0.78 ± 0.29	0.98 ± 0.22	0.88 ± 0.14	1.12 ± 0.15	1.06 ± 0.23	1.09 ± 0.04	4.192*
Color[c]	Light gray (2.5Y 7/1) Light brownish gray (2.5Y 6/2)			Light brownish gray (2.5Y 6/2) Light yellowish brown (10YR 6/4, 2.5Y 6/4)			–
Texture[c]	Sandy loam (%Sand = 76.71, %Silt = 12.23, %Clay = 11.06)			Loamy sand (%Sand = 77.51, %Silt = 15.34, %Clay = 7.15)			–
Water holding capacity (%)[c]	29.96 ± 5.41			32.10 ± 7.25			–
pH[a]	5.50 ± 0.22	5.02 ± 0.20	5.26 ± 0.33	5.54 ± 0.45	4.96 ± 0.19	5.25 ± 0.41	0.000 (ns)
Organic carbon (%)[a]	0.69 ± 0.36	0.61 ± 0.20	0.65 ± 0.06	0.60 ± 0.32	0.64 ± 0.32	0.62 ± 0.03	0.147 (ns)
Organic matter (%)[a]	1.20 ± 0.61	1.06 ± 0.35	1.13 ± 0.10	1.06 ± 0.57	1.11 ± 0.56	1.09 ± 0.03	0.147 (ns)

For F-ratio, degrees of freedom $(n - 1) = 1$
Mean ± SD
$*p < 0.05$
[a] $n = 30$
[b] $n = 10$
[c] Represents that the data is based on one-time sampling

21.3.2.2 Carbon Stock and Carbon Sequestration by Wetland Soil

Wetland soils are considered as the important carbon sinks (Bernal and Mitsch 2012, 2013; Mitra et al. 2005). Our study showed that the carbon stock in saturated soil (8.53 Mg C ha^{-1}) was less than the unsaturated soil (10.04 Mg C ha^{-1}) (Table 21.5), which can be ascribed to the lower bulk density of the saturated soil. Howard et al. (1995) also suggested the significant role of bulk density in assessing the soil organic carbon content. Besides, lower carbon stock in the saturated soil might be due to the absence of lower angiosperm plants unlike the unsaturated region. The rapid turnover of the existing vegetation in the unsaturated region might have contributed to greater carbon stock (Limpens et al. 2008) in the unsaturated zone of the wetland. On the contrary, greater carbon sequestered in saturated soils (1.76 Mg C ha^{-1} $year^{-1}$) than the unsaturated soil (0.46 Mg C ha^{-1} $year^{-1}$) (Table 21.6) can be attributed to the slower decomposition rate of organic matter in the saturated region due to its anaerobic conditions (Bernal and Mitsch 2013; Kayranli et al. 2010).

21.3.3 Carbon Stock and Sequestration Potential of Chatla Wetland

Overall, carbon stock in Chatla was estimated as 21.75 Mg C ha^{-1}, in which contribution of unsaturated soil (10.04 Mg C ha^{-1}) was highest followed by saturated soil (8.53 Mg C ha^{-1}), and wetland vegetation (3.18 Mg C ha^{-1}) (Table 21.5). The OC stock in unsaturated soil contributed 46.16% of total OC content in Chatla, followed by the saturated soils (39.22%) and wetland vegetation (14.62%) (Fig. 21.2). Contribution of unsaturated soil toward higher carbon stock can be attributed to the presence of dense vegetation in the riparian zone of the wetland (Fig. 21.3), which in course of time died and decomposed in the riparian region itself, thereby increasing carbon content in unsaturated soil. This observation is also corroborated by Moreno-Casasola et al. (2017) who reported that in wetlands, vegetation acts as an important factor in controlling soil carbon stock. Further, one-way ANOVA for carbon stocked in different biophysical components revealed significant differences in the carbon stocks among the selected biophysical components of the wetland (Table 21.7). However, post hoc comparisons using the Tukey HSD test revealed no significant differences in carbon stock between saturated and unsaturated soils of the wetland (Table 21.8). This indicates the constant interaction between the unsaturated and saturated region of the wetland mainly due to flood pulse resulting in flushing down of organic matter from the unsaturated region and its subsequent deposition in the saturated region. Thus, the overall results (Fig. 21.2; Tables 21.5, 21.6, 21.7, and 21.8) highlight the interconnected nature of different biophysical components of the wetland ecosystem. This ensures flow of various ecosystem services including regulation of local and regional climate through carbon stocking and sequestration.

Table 21.5 Variation in carbon stock (Mg C ha^{-1}) of selected biophysical components of Chatla during the study period

Saturated soil			Unsaturated soil			Wetland vegetation			
First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean	Total carbon stock
7.65 ± 0.26	9.41 ± 1.71	8.53 ± 1.25	9.81 ± 1.83	10.27 ± 1.98	10.04 ± 0.32	1.11 ± 1.04	5.25 ± 6.35	3.18 ± 2.92	21.75

Mean ± SD
$n = 30$

Table 21.6 Variation in carbon sequestration (Mg C ha^{-1} $year^{-1}$) of selected biophysical components of Chatla during the study period

Saturated soil	Unsaturated soil	Wetland vegetation	Total carbon sequestered
1.76	0.46	4.14	6.36

Table 21.7 One-way analyses of variance (ANOVA) for spatial and temporal variations in carbon stocked by different biophysical components of the wetland and one-way ANOVA for carbon stocked among different biophysical components

	F-ratio			
Biophysical components	Sampling point-wise	Flood phase-wise	Year-wise	Biophysical components-wise
Unsaturated wetland soil	3.953*	1.333 (ns)	0.055 (ns)	20.042**
Saturated wetland soil	5.075*	0.519 (ns)	1.399 (ns)	
Wetland Vegetation	0.566 (ns)	1.172 (ns)	9.712*	

Degrees of freedom $(n - 1) = 4$ for sampling point; 2 for flood phase; 1 for years; 2 for biophysical components
ns nonsignificant
$*p < 0.01$
$**p < 0.05$

Overall, the total carbon sequestered by Chatla was estimated to be 6.36 Mg C ha^{-1} $year^{-1}$, of which contribution of wetland vegetation was highest (4.14 Mg C ha^{-1} $year^{-1}$, 65.09%), followed by saturated soil (1.76 Mg C ha^{-1} $year^{-1}$, 27.67%) and unsaturated soil (0.46 Mg C ha^{-1} $year^{-1}$, 7.23%) (Table 21.6, Fig. 21.2). The findings were comparable to similar studies elsewhere. For example, Walling et al. (2006), Mitsch et al. (2012,) and Adame et al. (2015) observed that carbon sequestration in saturated soil/sediments was 1.14 Mg C ha^{-1} $year^{-1}$ in floodplains, 1.29 Mg C ha^{-1} $year^{-1}$ in tropical wetlands, and 1.30 Mg C ha^{-1} $year^{-1}$ in tropical riverine wetlands, whereas Saunders et al. (2007) and Bernal and Mitsch (2012) observed that carbon sequestration of wetland vegetation in tropical wetlands and freshwater wetlands was 4.8 Mg C ha^{-1} $year^{-1}$ and 1.4–3.17 Mg C ha^{-1} $year^{-1}$, respectively. In the present study, the highest contribution of wetland vegetation to carbon sequestration can be attributed to its faster rate of biomass production than its decomposition rate (Mitsch and Gosselink 2007), whereas the corresponding turnover rate of soil organic matter takes decades (Kayranli et al. 2010). In terms of species-wise contribution, *Saccharum ravennae* had the highest carbon sequestration potential (29.88%), followed by *Ipomoea carnea* (25.19%), and *Chrysopogon zizanioides* (15.98%) (Table 21.3). Such variation in carbon stocking potential among different species has also been related to micro-topography and flow regime of the wetland (Sarkar et al. 2019b). On the other hand, greater carbon sequestration potential of saturated soil as compared to unsaturated soil can be attributed to the water-logged environment in the former soil type. The anaerobic condition thus

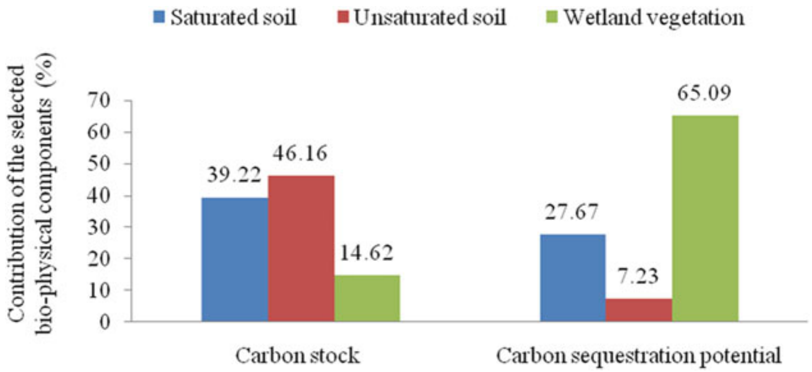

Fig. 21.2 Variations in contribution (%) toward carbon stock and carbon sequestration potentials of the selected biophysical components of Chatla wetland

Fig. 21.3 An overview of riparian vegetation in Chatla wetland

created might have slowed down the decomposition rates of organic matter contributing to its higher carbon sequestration potential (Gorham 1991; Mitra et al. 2005; Bernal and Mitsch 2012, 2013; Mitsch and Gosselink 2015). On the other hand, strong respiration pulses due to alternating drying and wetting of the unsaturated soil potentially decreased its carbon sequestration potential (Stevenson and Cole 1999; Jassal et al. 2005; Miller et al. 2005). Post hoc comparisons using the Tukey HSD test further revealed a significant difference in the variation of carbon stock in wetland vegetation with both the saturated and unsaturated soil of the wetland (Table 21.8). All these statistical results reveal that though the carbon stocked by wetland vegetation is significantly less as compared to both the unsaturated and saturated soil, its contribution toward carbon sequestration was higher (Fig. 21.2) primarily due to its fast turnover rate. Therefore, it may be inferred here that the

Table 21.8 Multiple comparisons for carbon stocked in different biophysical components of the wetland using Tukey post hoc analyses

Biophysical components (I)	Biophysical components (J)	Mean difference ($I - J$)
Unsaturated soil	Saturated soil	1.513 (ns)
	Wetland vegetation	6.925*
Saturated soil	Wetland vegetation	5.411*

Degrees of freedom $(n - 1) = 1$
ns nonsignificant
$*p < 0.05$

riparian vegetation comprising the lower angiosperms play a vital role in capturing atmospheric carbon dioxide, whereas wetland soil plays a significant role in storing the carbon sequestered by the riparian vegetation which also reveals the interconnected nature of different biophysical components of wetlands in carbon stocking and sequestration.

21.4 Conclusion

The present study revealed that the rapid turnover rate of wetland vegetation followed by a plausible low decomposition rate due to the anaerobic condition has resulted in the higher carbon stock of Chatla. The contribution of different biophysical components of Chatla toward carbon stock follows the order: unsaturated soil > saturated soil > wetland vegetation. However, the contribution of different biophysical components in terms of carbon sequestration follow the order: wetland vegetation > saturated soil > unsaturated soil. Thus, we highlight the significant role of riparian vegetation particularly the lower angiosperms in rapid sequestering of atmospheric carbon in tropical floodplain wetlands. The present study also revealed the interconnected nature of different biophysical components of the wetland ecosystem toward the regulation of its ecosystem services like carbon sequestration. Considering these, it can be concluded that maintaining the natural integrity of tropical floodplain wetlands is necessary for the continuous flow of the ecosystem services including carbon sequestration. The study also suggests that any change in wetland hydrology due to anthropogenic activities may potentially affect the wetland vegetation which in turn would affect the carbon stock disrupting the carbon sequestration potential of wetlands. Hence, proper strategies should be adopted for adequate protection, conservation, and management of various wetland biophysical components, particularly the lower angiosperms considering their significant role in carbon storage and its sequestration in tropical floodplain wetlands.

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Chapter 22
Ecosystem-Based Adaptation to Climate Change and Disaster Risk Reduction in Eastern Himalayan Forests of Arunachal Pradesh, Northeast India

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Abstract The present chapter focuses on climate change impacts and ecosystem-based adaptation in Eastern Himalayan forests of Arunachal Pradesh. High variations in altitudinal gradient, precipitation, and land surface temperature have resulted in high vegetation diversity and density. The varying relief zones implies all major types of climatic zones in the region. The sub-tropical zone (800–1800 m) occupies major geographical area (28.8%) followed by alpine (>2800 m; 27.3%), temperate (1800–2800 m; 23%), and tropical zone (<800 m; 20.9%). The study shows significant variations in the precipitation pattern and reduction in cumulative precipitation with varied intensity during 1998–2013. The Tropical Rainfall Measuring Mission (TRMM)-based standard anomaly of precipitation with reference to mean precipitation exhibits higher negative anomaly in recent years as compared to previous years, whereas the CRU TS4.00-based standard anomaly of long-term observations of precipitation pattern (1901–2015) exhibits episodic variability with increasing unevenness in recent years. The spatiotemporal annual land surface temperature (LST) patterns (2001–2016) indicates that northern periphery in latitudinal direction have low (5–10 °C) to very low (<5 °C) LST, whereas central to south parts have moderate (15–20 °C) to very high (>25 °C) LST. The climate change impacts on the Himalayan forest biomes are being further accelerated by

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various anthropogenic disturbances including illegal timber felling, forest fire, *jhum* cultivation, and hydroelectric projects. The present study discussed the ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction (EcoDRR) approaches to determine important ecosystems services, reduce community vulnerability, and increase resilience of people as well as the environment to climate change.

22.1 Introduction

Climate change is a global phenomenon affecting natural ecosystems as a consequence of physical and anthropogenic factors (Bujarbarua and Baruah 2009). The vulnerability of climate change is comparatively much higher in developing countries due to huge loss of biodiversity, ecosystem services, and resource as well as less affordability to mitigation and adaptation costs. Unusual climatic events may be a crucial factor causing spatiotemporal variation in seed production, seedling recruitment, and establishment, thereby causing extinction of many species. Rising concentration of atmospheric CO_2, accompanying increase in earth's surface temperature, and the changes in precipitation pattern have been the three most striking phenomena associated with global climate change (Kumar 2011). Changes in temperature and precipitation would affect changes in species' traits, vegetation structure, composition, and ecological and physiological processes across different vegetation types, land-uses, and regions (Niu 2001; Lindner et al. 2010; Gao et al. 2016). The effect of climate change on the natural system may be diverse, such as change in the timing of phenological events of plants, changes in species abundance and range, shifts in habitat in terms of latitude and altitude, and so on (Bharali and Khan 2011). The most basic and often observed response of climate change is upslope and poleward shifts in species' ranges (Hannah and Bird 2018). Marine taxa shift toward pole at higher rate (72 km per decade) as compared to terrestrial taxa (17 km per decade) (Pecl et al. 2017). On the other hand, lowland species are shifting upwards to higher elevations, highland species are constantly restructuring their community relationships (Woodward et al. 2010; Bhattarai 2017). It has a direct impact on biodiversity (Chapin et al. 2000), slowing evolutionary potential and disrupt ecological services (Dawson et al. 2011) leading to reduction in species richness as well diversity (Franco et al. 2006) which ultimately affects the livelihood security of the dependent community (Vitousek et al. 1997). It also lowers genetic diversity due to directional selection, genetic drift, as well as population migration (Rinawati et al. 2013). Climate change also results in increase of pest infestation, diseases, and plant invasion, which has a direct impact on crop productivity and food security (Negi et al. 2016). The possibility of appearance of some new insects and pathogens is also high under the future scenario of climate change in Northeast India. Protein and mineral contents of plant tissues are generally reduced under elevated CO_2 concentration; hence, it increases the possibility to damage the plants by insects, which will ultimately lead to increased crop loss and reduced productivity (Weigel 2014). The quantity and quality of soil organic matter gets deteriorated under the influence of rising atmospheric temperature, which in turn reduce the water- and nutrient-holding capacity as well as soil buffering capacity to change in pH (Kumar 2011).

Mountain ecosystems provide a wide range of goods and services to the people living in both the mountains and outside mountains (MA 2005, TEEB 2010; Dhyani and Dhyani 2016a, b). More than half of humankind depends on freshwater that is captured, stored, and purified in the mountain regions (Grêt-Regamey et al. 2012). The higher altitude ecosystems of the Himalayan region are considered as the most vulnerable geographic regions of the world to climate change (Cavaliere 2009; Xu et al. 2009). These regions are marked as pivotal zone of diverse flora and fauna regulating the vital ecosystem services. The state of Arunachal Pradesh occupies the major part of Eastern Himalayan ranges, with largest areas in the northeastern region of India. The state is predominantly hilly and mountainous and is one among the 200 globally important eco-regions (Olson and Dinerstein 1998). The state is characterized by diverse climate as well as temperature regimes ranging from near tropical to temperate and alpine due to varied physiological features and altitudinal differences. The potential impacts of climate change include abnormal floods, droughts, landslides (Barnett et al. 2005; Cruz et al. 2007; Dhyani and Dhyani 2016a, b), biodiversity loss, and food insecurity (Xu et al. 2009). Due to climate change, the patterns of snowfall and rainfall at higher altitude areas of Arunachal Pradesh are also changed. The forests in mountainous region have been subjected to combined effect of various natural hazards with varied intensity in different time and space namely forest fire, landslide, mud/debris flow, earthquakes, cloudburst, and flood. Biodiversity is critical for reducing poverty, creating sustainable livelihoods, and helping communities to adapt in the changing climatic conditions. Rapid melting of the Himalayan glaciers or decrease in snow cover will affect the overall availability of water for drinking, agriculture, hydropower, and other purposes in many places. Over 60% of the cultivated land is under rain-fed agriculture and located in areas highly vulnerable to climate variability and change. The northeastern regions of India are susceptible to climate change due to its ecological fragility, strategic geographical location, the Himalayan landscape, international borders, its trans-boundary river basins, and inherent socio-economic instabilities (Das et al. 2009). Mountainous regions are of global significance which are key destinations for tourists, recreational activities, and hotspots of biodiversity. It is sensitive to rapid global development (Korner 2000; Schröter et al. 2005), and the main pressures result from changes in land use practices, infrastructure development, unsustainable tourism, fragmentation of habitats, and climate change (EEA 2002). The human interference is comparatively less in Eastern Himalayan forests of Arunachal Pradesh due to its geo-climatic conditions, as well as less population density. The complex Himalayan ecosystems of Arunachal Pradesh is under grave threat due to big dams, deforestation, and indiscriminate mining and quarrying activities (Nibanupudi and Khadka 2015), which creates environmental imbalance in the region. The impact of climate change on the Himalayan biodiversity is further accelerated by anthropogenic disturbances like *Jhum* cultivation, habitat loss, deforestation, clear-felling, over exploitation of natural resources, and NTFP collections

(Saikia et al. 2016). Ecosystem services play a significant role as measures of disaster risk reduction (Krol et al. 2016), and its effectiveness increases manifold by integrating geographical dimensions. Earth-observing satellites effectively contribute in assessing and monitoring of biodiversity and climatic parameters. Moreover, it provides enormous possibilities to estimate climatic and anthropogenic impacts on biodiversity as well as to predict its temporal change through ecological modeling (Suzuki et al. 2010; Dhyani et al. 2018). The advancement in earth observations and geo-informatics contribute significantly in spatiotemporal analyses and modeling of various phases of disaster cycle, including pre-disaster hazard and risk estimation and decision support in risk reduction, risk-informed spatial planning, and disaster responses utilizing historical and concurrent datasets in geospatial environment (Teeuw et al. 2013; Krol et al. 2016).

The present chapter attempts to discuss the ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction (EcoDRR) approaches applied in the eastern Himalayan forest ecosystems of Arunachal Pradesh to understand community vulnerability to climate change and also to determine the important ecosystem services based on various datasets (FSI report as well as satellite based). Forest Survey of India (FSI) report is being used to analyze trend of forest cover change for the period 1989–2015. On the other hand, the Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model Version 2 (ASTER GDEM V2; 30 m acquired from www.earthexplorer.usgs.gov) elevation data has been used for evaluating forest cover change in various relief zones. The Sentinel 2A satellite image (https://scihub.copernicus.eu acquired on Nov. 2017) based Normalized Difference Vegetation Index ($NDVI = NIR - R/NIR + R$) has been used to estimate the vegetation cover of Arunachal Himalayan forests. Further for analyzing the impact of climate change, three different sources of data have been considered: (1) observational data (CRU-Climate Research Unit (2017) (http://data.ceda.ac.uk//badc/cru/data/cru_ts/cru_ts_4.00/data/pre/)), which is gridded from ground station data for period of 1901–2016, and (2) satellite-based Tropical Rainfall Measuring Mission (TRMM) datasets have been used for the duration 1998–2015 to determine standardized anomaly [(observed − mean)/standard deviation] on the basis of long-term cumulative mean, and (3) satellite based MODIS land surface temperature (LST) has been used for analyzing annual variation of land surface temperature.

22.1.1 Forest Vegetation of Arunachal Pradesh

The eastern Himalayan state of Arunachal Pradesh is a part of Himalaya biodiversity hotspot has the highest floral species richness among the eight Northeastern States (Chatterjee et al. 2006). It is the largest mountainous state of India and is one of the 200 globally important eco-regions. The diverse Himalayan forests of Arunachal Pradesh ranging from lowland tropical mixed and broadleaf evergreen forests to alpine meadow and scrub which are distributed along one of the largest elevation gradients in the world comprises over 5000 species of plants (Saikia et al. 2017).

Arunachal Pradesh ranks as second in terms of forested areas after Madhya Pradesh, and it ranks fourth in terms of percentage of forest cover (79.96%) (FSI 2017). The Arunachal Himalayan forests are highly diverse and rich in several endemic species (Tewari et al. 2017), and plants species richness and distribution patterns are largely regulated by altitude and other environmental factors (Saikia et al. 2017; Shooner et al. 2018). The temperate broad-leaved forest of Eastern Himalayas is one of the world's most species rich temperate forests, and it supports one of the world's richest alpine flora with high level of endemism (WWF and ICIMOD 2001). It is home to many botanically curious and rare plants including *Sapria himalayana*, the giant root parasites which is discovered from Arunachal Pradesh (Adhikari et al. 2003). Out of 825 species of orchids in Northeast India, 545 species are documented from Arunachal Pradesh of which 12 species are endangered, 16 are vulnerable, and 31 are threatened (Chowdhery 1998; Hegde 2000). About 98% *Rhododendrons* of India are restricted to Himalayan region (Singh et al. 2003), and Arunachal Pradesh has maximum number of endemic species (nine species and one subspecies) out of the total 12 species, two subspecies, and five varieties of endemic *Rhododendrons* of India (Mao et al. 2001). Besides, a total of 18 species of Rattans and canes are reported from Arunachal Pradesh, out of the total 60 species of Indian canes (Basu 1992; Renuka 1996; Thomas et al. 1998).

Indigenous knowledge system of the tribal displays many traditional practices vital for forest conservation and management and hence responsible for the protection of forest resources to some extent. Tribal people of Arunachal Pradesh use various forest resources and depend on their surrounding forests for their subsistence and livelihood. Various construction materials including wood, bamboo, and canes as well as hunting, fishing implements, agricultural tools, dress, ornaments, domestic utensils, and other implements of daily use are directly or indirectly collected from nearby forests. The National Forest Policy (1988) aims at maintaining two thirds of the area in hills under forest cover to prevent erosion and land degradation and to ensure the maintenance of ecological balance and environmental stability. The official report of Forests Survey of India (2017) indicates remarkable change in the total forest cover (80.93%) of the state in the last few decades largely due to pressures from farming, logging, and population growth (Table 22.1 and Fig. 22.1). Forests act as the huge reservoirs of atmospheric carbon, its degradation due to anthropogenic influences (influence of non-tribal communities) contribute largely (10–25%) in global carbon dioxide emissions (Houghton 2003). The declining trend of forest cover is attributed to climate change in the past few years in the ecological fragile state of Arunachal Pradesh. The *jhum* cultivation and other primary activities including hunting, fishing, food-gathering, and biotic interferences including insect herbivory, diseases, grazing, illegal timber felling, over harvesting of fuel woods, and other non-timber forest products (NTFPs) including medicinal herbs also affects the forest cover of the state. The destruction and fragmentation of natural forests are widely reported as the most significant drivers in the global decline in biodiversity (Strittholt and Steininger 2007). A positive change in forest cover in the state is evident during 1997–1999 due to the successful implementation of different plantation and community development schemes by Arunachal Pradesh State Forests

Table 22.1 Altitude-wise forest cover of Arunachal Pradesh during the last few years (area in km^2)

	Forest class	Very dense forests				Moderately dense forests				Open forests				Total forests			
	Year	2009	2011	2013	2015	2009	2011	2013	2015	2009	2011	2013	2015	2009	2011	2013	2015
Elevation Zone (m)	<500	1553	1487	1592	1593	3685	3705	3551	3492	2086	2203	2122	2165	7324	7395	7265	7250
	500–1000	2839	2771	2834	2828	4233	4214	4219	4178	3216	3302	3267	3281	10,288	10,287	10,320	10,287
	1000–2000	7812	7873	7766	7743	10,297	10,336	10,196	10,167	4508	4433	4620	4634	22,617	22,642	22,582	22,544
	2000–3000	6453	6473	6461	6465	9008	8911	9090	9102	1737	1786	1724	1730	17,198	171,710	17,275	17,297
	>3000	2201	2264	2175	2175	4333	4353	4358	4362	3392	3299	3346	3333	9926	9916	9879	9870
	Total	20,858	20,868	20,828	20,804	31,556	31,519	31,414	31,301	14,939	15,023	15,079	15,143	67,353	67,410	67,321	67,248

Source: Forest Survey of India (FSI) Report (2009, 2011, 2013, 2015)

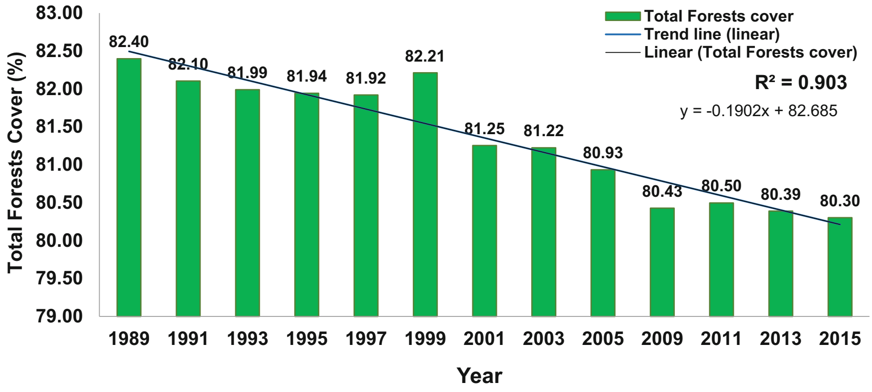

Fig. 22.1 Total Forests cover of Arunachal Pradesh over last decades. (*Source*: FSI reports)

Department (FSI 2017). The Sentinel 2A satellite image-based normalized difference vegetation index (NDVI) exhibits distribution of vegetation cover primarily governed by regional landscape (altitudinal variations) and precipitation patterns (Fig. 22.2b). The moderate (NDVI 0.3–0.6) to high (NDVI $>$ 0.6) vegetation cover is observed in central and southern parts primarily having temperate (elevation range: 1800–2800 m) to tropical (elevation $<$800 m) climatic zone (Fig. 22.2a). On the contrary, insignificant (NDVI $<$ 0.3) vegetation cover is observed in alpine ($>$2800 m) climatic zone in northern margins of Arunachal Pradesh, which is decreased gradually with the increase in elevation. The high altitudinal variations and significant variability in precipitation and land surface temperature patterns has been influencing the vegetation diversity and density over the decades.

22.2 Climate Change: Evidence from Eastern Himalayan Forests of Arunachal Pradesh

Climate change will not only impact the biodiversity but also affect the livelihood of local communities as most of the local people are entirely dependent on natural forests for their sustenance (Bharali and Khan 2011). The climate change directly causes early snowmelt, which in turn leads to the unexpected rainfall and frost in spring season. Many of the high altitude plant species are getting extinct due to the impact of climate change. Flowering of many *Primula* spp. is linked with season, and the frost may damage the flower buds, which in turn have adverse effect on its population and regeneration. Studies related to the effects of temperature on reproduction of five *Primula* spp. suggest that increase in global temperature adversely affects the quantity and quality of seed set in some species (Shimono and Washitan 2007). The increased tree mortality in natural forests has been attributed to shortened tree longevity associated with greater climate variability (Brienen et al. 2015) and to

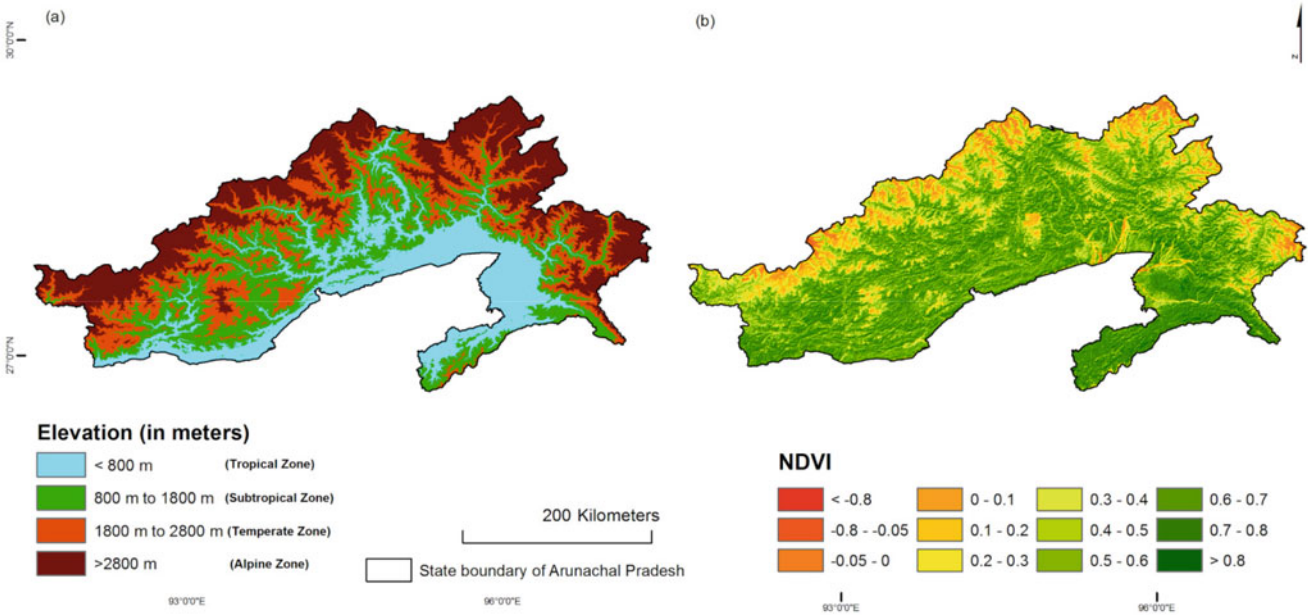

Fig. 22.2 (**a**) ASTER GDEM (V2) representing varied climatic zones based on relief, and (**b**) NDVI based on Sentinel 2A satellite images (acquired on Nov. 2017) representing vegetation chlorophyll concentration in Arunachal Pradesh

be the result of warming-induced increased demand for evapotranspiration exceeding water availability (McDowell et al. 2008). Analysis of temperature trends in the Himalayan region has shown that increase in temperature is greater at the higher altitudes than in the lowlands (Shrestha et al. 1999). The plant species inhabiting the mountains have already started migrating higher altitudes due to rising temperature (Padma and Chetti 2014), and some are on the verge of extinction even before they are recorded (Tewari et al. 2017). Researchers have established that some cold-adapted plant species in alpine environments have begun to gradually climb higher up mountain due to warming temperature (Saxena and Singh 1982). In this case, these plants migrate upward until there are no higher areas to inhabit, at which point they may face with extinction. Additionally, the upward migration of plant species can lead to increased competition for space and resources, causing further stress among alpine plant populations. The intense cloud bursts of unprecedented intensity in Western Arunachal Pradesh in 2004 produced devastating flash floods causing tremendous loss of crops, animals, infrastructure, economy, livelihoods, and death tolls in Sonitpur, the bordering district of Assam (Das et al. 2009). Bharali and Khan (2011) reported changes in snowfall patterns and intensity in Mechukha, and Bomdila, of West Siang, West Kameng districts, respectively. They also reported the changes in the phenology and taste of apple as well as distribution of *Abies* and *Rhododendron* over Arunachal Pradesh due to increase in temperature and population growth. Phenotypic plasticity including shifting of flowering time of *Rhododendron arboreum* and fruit ripening time of *Prunus cerasoides* as reported by people are some of the indicators of warming (Saxena and Rao 2009).

The remote sensing technology is an efficient tool for monitoring and mapping of spatiotemporal land surface changes as well as various atmospheric parameters, which contributes in understanding the perspectives of climate change. The Advanced Space-Borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) of Arunachal Pradesh exhibits high altitudinal variation of the Himalayas primarily in northern periphery in latitudinal directions, which has been longitudinally dissected by major rivers forming unique landscape of the region (Fig. 22.2a). Characteristics of all major types of climatic zone are visible due to high variation in the elevation of the state. The sub-tropical zone (elevation range: 800–1800 m) occupies major geographical area (28.8%; primarily in central and southern parts) followed by alpine (>2800 m; 27.3%) in the northern periphery in latitudinal direction, temperate (1800–2800 m; 23%) and tropical (<800 m; 20.9%) zone in central parts of Arunachal Pradesh. The Tropical Rainfall Measuring Mission (TRMM)-based observations indicate the significant changes in the precipitation patterns in Arunachal Pradesh during 1998–2013 periods (Fig. 22.3). The study indicates uneven patterns and reduction in cumulative precipitation with varied intensity during 1998–2013 periods in Arunachal Pradesh. The western and eastern parts of the state observed low cumulative rainfall (1000–2000 mm), whereas central parts observed moderate (2000–3000 mm) to high cumulative rainfall (3000–4000 mm). The standard anomaly of precipitation exhibits higher negative anomaly with reference to mean precipitation in recent years as compared to initial years during 1998–2013 periods (Fig. 22.4a). The standard

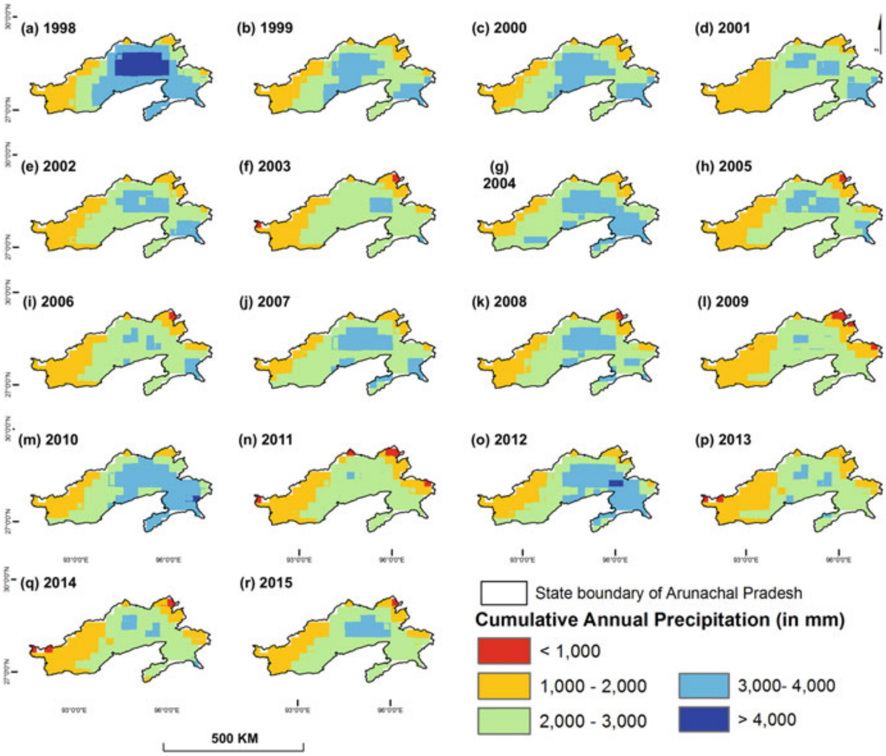

Fig. 22.3 Spatio-temporal variability of TRMM based cumulative annual precipitation patterns in state of Arunachal Pradesh during 1998–2015

anomaly of long-term observations of precipitation pattern (1901–2015) using CRU TS4.00 exhibits episodic variability in precipitation patterns with increasing unevenness in recent years (Fig. 22.4b). The land surface temperature in the state is primarily controlled by the high altitudinal variation of the Himalayas. The spatio-temporal mean annual land surface temperature (LST) patterns exhibit overall lower LST and insignificant variability in major parts in the state during 2001–2016 periods (Fig. 22.5). The northern periphery in latitudinal directions of the state is occupied by the Himalayan ranges, having low (5–10 °C) to very low (<5 °C) land surface temperature, whereas central to south parts are having moderate (15–20 °C) and very high (>25 °C) land surface temperature, respectively. The spatiotemporal study indicates minor variability in moderate to very high land surface temperature during the recent periods (2001–2016). In conformity with the present report, minor increase in annual temperature (0.01–0.04 °C year^{-1}) during 1970–2000 periods with (a) higher increase (0.04 °C year^{-1}) in higher elevation zones (>4000 m) as compared to lower elevation zones and (b) higher increase in temperature in winter

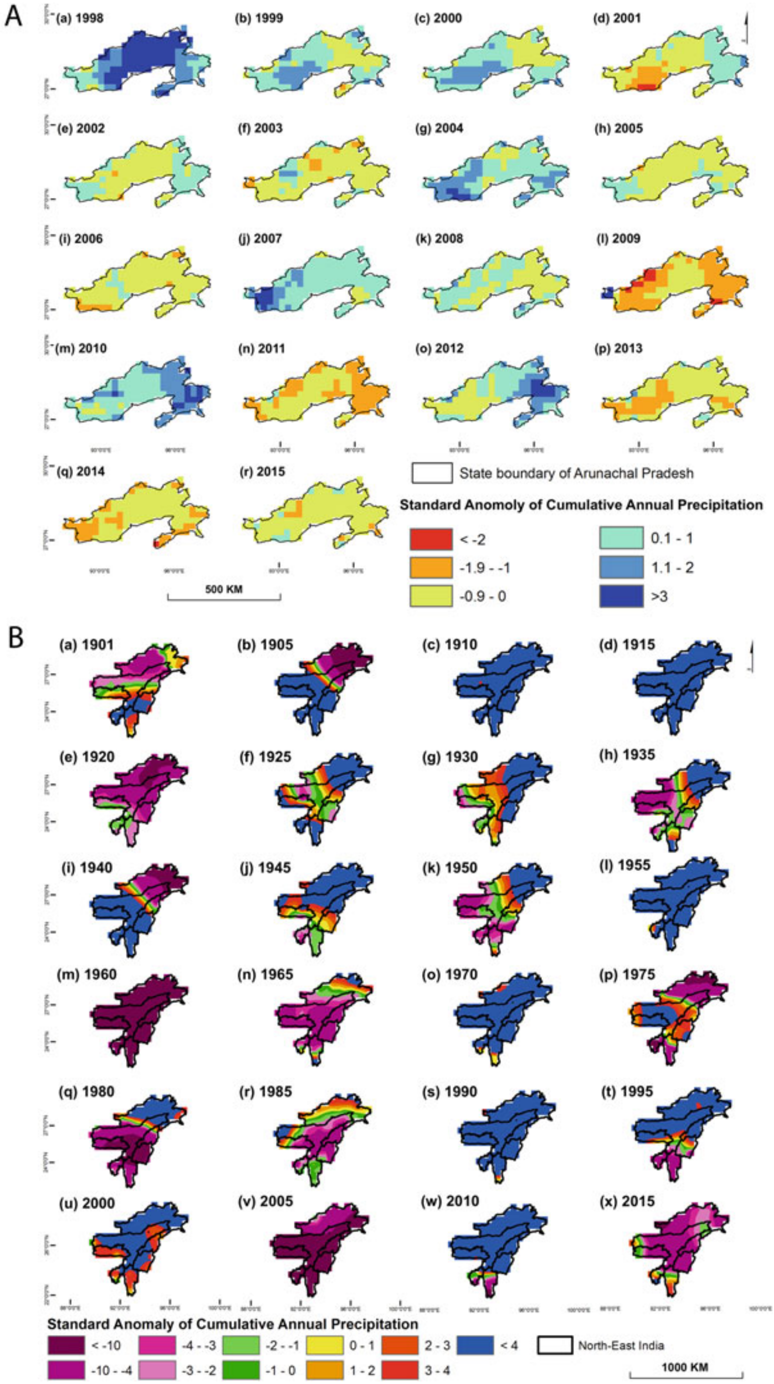

Fig. 22.4 (**a**) Standard anomaly of TRMM based cumulative annual precipitation patterns in state of Arunachal Pradesh during 1998–2015. (**b**) Climatic Research Unit (CRU) Time-Series (TS) version 4.00 based Standard anomaly of cumulative annual precipitation patterns in northeast India during 1901–2015

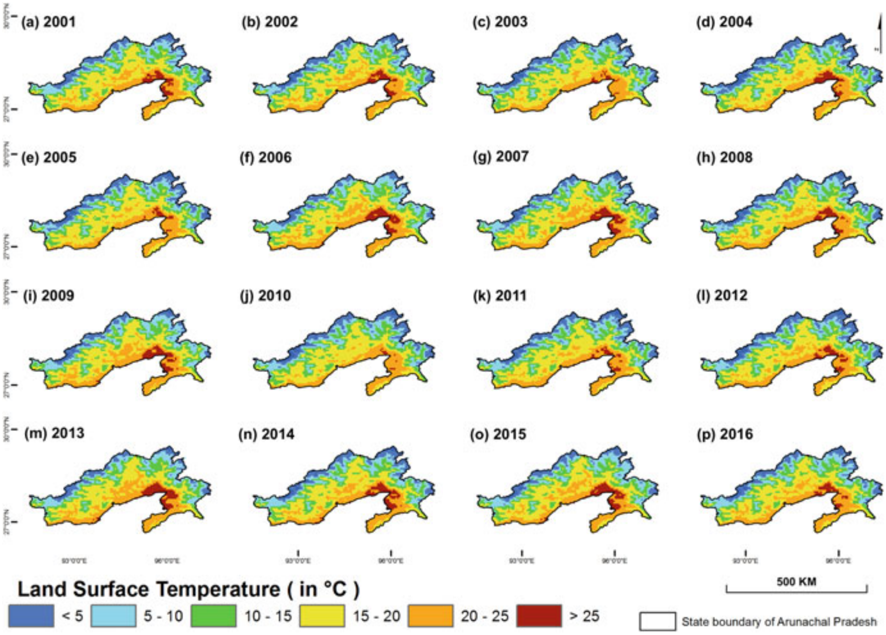

Fig. 22.5 Spatio-temporal variability of Land Surface Temperature patterns in state of Arunachal Pradesh during 2001–2016

(December, January, February) and spring (March, April, May) was also reported by Sharma et al. (2009).

22.3 Ecosystem-Based Adaptation (EbA) and Disaster Risk Reduction (DRR)

Ecosystem-based adaptations include a wide range of management activities to reduce the vulnerability of people and environment to climate change and increase their resilience. The local indigenous knowledge that is particular to the specific ecosystems and socioeconomic conditions of a particular area is also needed to cope up with climate change (Brace and Geoghegan 2011; Ford et al. 2011; Becker et al. 2012). The current unfavorable patterns of climatic change have anticipated the need to identify and understand the possible adaptation strategies. Farmers observed an increase in dominance of *Bauhinia vahlii* twining around *Pinus roxburghii* trees in Arunachal Pradesh and attributed this change to reduction in fire frequency arising from shortening of hot-dry period (Saxena and Rao). Conversion of rainfed to irrigated farming also reduces the risks of climatic uncertainty and improves productivity (Bhatnagar et al. 1996; Maikhuri et al. 1997). A better understanding is required to be developed in farmers toward climate change, and their ongoing adaptation measures is needed to expertise through development of policies and strategies for better crop production and yield (Bryan et al. 2009). The local communities practice tree/fodder plantations and livestock management in and around vulnerable areas to resist climate change. Trees may positively influence the interception of precipitation as well as the balance of evapotranspiration, which in turn can lead to an improved water balance of the soil (Frehner et al. 2005). Tree roots can prevent or at least reduce shallow landslides by mechanistic reinforcement of the soil (Coppin and Richards 1990; Hamilton 1992; Rickli et al. 2001; Schwarz 2011). In addition, they may increase water storage capacity, particularly in soils with limited permeability (Hegg et al. 2005) and can positively influence erosive and hydrological processes by reducing superficial erosion through permanent provision of litter (Hamilton 1992). Cattle are encouraged to graze on barren land to survive on dry fodder during drought period is another nature-based solution adopted by the tribal people of Arunachal Pradesh. People have used traditional stone walls to protect vulnerable areas from floods, while practicing watershed management in flood-affected areas. They also used to store foods in traditional containers made up of earthen and bamboo-based materials to make it last longer during the continuous rains to ensure survival. They used to build indigenous fuel-wood and feedstock storage to utilize during the times of crisis. The increasing trends of disasters, people affected, and economic losses are interlinked and induce higher risks due to rapid population growth, urbanization, and the concentration of populations and economic assets in specific geographical regions (IPCC 2012; UNISDR 2011). Ecosystem-based approaches to DRR offer a good alternative and/or complement because it is often part of livelihood and hazard mitigation strategies of local communities (Estrella and Saalismaa 2013). Ecosystem management provides important and readily accessible solutions to DRR by enhancing resilience through community participation or its ability to effect positive change (Manyena et al. 2011).

22.4 Conclusions

Climate change has adversely affected the global biodiversity, and there are ample evidences that confirms many species of flora and fauna have become extinct from their natural habitat. It poses hazardous and irreversible impacts on various ecosystems and their services and will ultimately affect the socioeconomic conditions of the residents. The eastern Himalayans, known for its diverse habitats and ecoregions, are subjected to a high level of risk and vulnerability due to changing climate and natural hazards. Hence, immediate sustainable forest management strategies are required to be adopted in Arunachal Pradesh to assess the trend of climate change and susceptibility to biodiversity. People's participation is a crucial factor in sustainable forest management, and therefore, innovative and traditional way of forest management including climate resilience cropping should be considered in policy making. The prohibition imposed by the honorable Supreme Court of India by means of various laws and Forests Protection and Management Acts in the last few decades effectively controlled exploitation of forest resources in major parts of the region. The widespread indigenous knowledge of local communities in the Himalayan region about climate change impacts is required to adopt with the expertise through the development of policies and strategies as they have been coping with these changes since millennia. It necessitates the development and promotion of effective mitigation and adaptation strategies for a climate-resilient agriculture production system in Arunachal Pradesh to ensure food security in changing climatic conditions. Traditional resource uses need to be scientifically evaluated, and conservation strategy should be built on the indigenous knowledge supplemented by scientific knowledge and institutional support.

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Chapter 23
Nature-Based Solution Entry Points Through Sectoral Policies, Strategic Instruments and Business Continuity

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Abstract Nature-based solutions emphasise on sustainable use and management of natural ecosystems by strategically conserving and restoring them and help in delivering multiple co-benefits. NbS has been widely recognised across the globe for providing a framework that can align development objectives with sustainability by offering socially and environmentally sensitive solutions to present-day developmental needs and challenges. There are multiple constraints that NbS faces in their implementation which majorly include technical barriers, knowledge gap, lack of financing options and integration into developmental planning and policies. These constraints have to be addressed for effective mainstreaming of NbS into developmental practices, for which an enabling policy environment needs to be created; constituting of the right mix of policy instruments across different strategic sectors. This chapter reflects on one such policy framework which focuses on regulatory, economic and information and education-based policy instruments for effective upscaling of NbS into developmental practices. Based on which, a case analysis for India is made for three of its key strategic sectors to identify potential NbS entry points across relevant existing sectoral policy instruments and tools. Further, the chapter discusses the need for addressing business continuity through NbS, which not just can help in risk-proofing businesses during a crisis but can also ensure the overall sustainability of the business operations.

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23.1 Nature-Based Solutions: The Potential Approach for Resilience Building

Nature-based solutions (NbS) have been significantly recognised across literatures as a viable sustainable solution to developmental challenges including climate change mitigation and adaption, disaster risk reduction and integrated management of natural resources. The term 'NbS' for the first time gained recognition in late 2000s through the work of the world bank (MacKinnon et al. 2008) which emphasised on biodiversity and climate change linkages. Another important work that established NbS in scientific literature is that of International Union for Conservation of Nature (IUCN 2009) which emphasised on harnessing the potential of well-managed and healthy ecosystem for reducing vulnerabilities and building resilience of communities towards climate change. Though, since early 2000s, the ideas governed by nature-based approaches have emerged significantly across literature and gained wide recognition under diverse themes; some of these include urban ecology (Barthel and Isendahl 2013), natural system agriculture (Jackson 2002; Welsh and Rivers 2011; Varghese 2018), green infrastructure (Canzonieri 2007; Gill et al. 2007) and green spaces for climate change adaption and mitigation (Kabisch et al. 2015, 2016).

NbS as a concept has been significantly shaped up by various practitioners in the field particularly in IUCN and European Commission. IUCN (2013), which advocated for the promotion of nature-based solutions for addressing global challenges, provided seven principles comprising the core of NbS. Thereafter, the concept was taken up as a policy by the European Commission (EU), wherein the concept has been integrated into a policy framework for innovation and research under EU's 'Horizon 2020' with the aim of maintaining and enhancing natural capitals (ecosystems and their services) for achieving environmental, societal and economic objectives; putting economic and social assets at core of NbS while maintaining environmental sustainability (European Commission 2015). Put forward a definitional framework for NbS which included different ecosystem-based approaches embraced under NbS umbrella and set of general principles for any NbS, in order to develop a common standards for different practitioners so as to facilitate easy adoption and successful implementation of NbS.

Also, over years, NbS have received lots of attention at international policy platforms. The role of nature-based solutions and its components like ecosystem-based approaches is well recognised across international policy frameworks for addressing global challenges including climate change, disaster risk management, natural resource management, etc. for ensuring sustainable development. One of the key international policy frameworks on disaster risk management, Sendai Framework for Disaster Risk Reduction (2015–2030), was adopted at the third United Nations World Conference on Disaster Risk Reduction in the year 2015, as a successor instrument of Hyogo Framework for Actions (2000–2015). SFDRR provides a roadmap for nations for building safer and disaster resilient communities. SFDRR outlines four priority areas to be addressed and seven global targets to be achieved by 2030 by its member states for protecting their development gains from disaster risk. The framework underlines the need for ecosystem-based approaches in disaster risk reduction by emphasising on strengthening sustainable use and management of ecosystems through implementation of integrated environmental and natural resource management approaches incorporating disaster risk reduction at national and local levels (SFDRR 2015). Similarly, another important global policy framework which marks the importance of ecosystem-based approaches is Sustainable Development Goals (SGDs). SDGs were adopted in 2015, under the agenda 'Transforming Our World: The 2030 Agenda for Sustainable Development', providing a blueprint for achieving a sustainable and better future for all. SDGs through its Goal 6 'Clean Water and Sanitation', Goal 14 'Life Below Water' and Goal 15 'Life on Land', incorporate ecosystem-based approaches into planning and developmental processes for meeting the set targets under each of these goals. Among which Goal 6 and Goal 15 set out targets for restoring, conserving and sustainably using ecosystems and services including mountains, forests, wetlands, lakes, rivers, etc., while Goal 14 targets emphasise on sustainable management and protection of marine and coastal ecosystems (SGDs 2015). However, apart from these goals, there remains a wide scope for integration of nature-based solutions across other SGDs as well, which include Goal 2 'Zero Hunger', Goal 3 'Good Health and Well-being', Goal 11 'Sustainable Cities and Communities' and Goal 13 'Climate Action'.

Another important international policy framework which advocates mainstreaming of ecosystem-based approaches for addressing global challenges is Rio Convention. It relates to three conventions which were opened for signature at Rio Earth Summit in 1992, which include: United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biological Diversity (CBD) and United Nation Conventions to Combat Desertification (UNCCD). UNFCCC aims at stabilising greenhouse gas concentration at a level so as to prevent 'dangerous' interface between humans and climatic systems (UNFCCC 1992). UNCCC leads to setting up of Kyoto protocol in 1997 and then Paris agreement in 2015. UNCCC in its climate action plans, reports and recommendations have well recognised the role of ecosystems in climate adaption and advocate adoption of ecosystem-based approaches for climate change mitigation and adaption. UNCCD aims at sustainable land management while linking environment and development for combating desertification, improving living conditions of those affected by enhancing resilience of vulnerable population and ecosystems, and generating global environmental benefits. The convention is implemented through action programmes in affected country parties with an emphasis on local participation in decision-making (UNCCD 2018). CBD aims at promoting conservation and sustainable use of biodiversity while ensuring fair and equitable sharing of associated benefits (CBD 2011). CBD is currently following Strategic Plan for Biodiversity (2011–2020). In both of these conventions UNCCD and CBD, ecosystem-based approaches are a central concept. Both of these utilise ecosystem-based approaches as the primary framework for actions; applying them in developing guidelines for work programmes under the conventions as well as while elaborating and implementing these programmes.

It clearly reflects that at international level, nature-based solutions (NbS) remain a fundamental part of the actions on climate change, biodiversity, disaster risk management and sustainable development. However, for their effective implementation on grounds, these solutions need to be well-integrated and streamlined with national developmental planning and have to be up-scaled into key strategic areas. Over years, these solutions have been increasingly adopted within national governance around the world particularly through national climate action plans and related policy instruments. However, up-scaling of NbS into strategic sectors still require a more focused approach and committed efforts by national agencies so as to provide pathways for integrating these solutions into national and sub-national sectoral policies.

23.1.1 Imperatives for Large-Scale Scaling Up

The world at present is facing more complex and intangible challenges which are deeply rooted into our developmental needs and unsustainable usage of our natural resources. These present-day challenges which include rapid urbanisation, burgeoning population, climate change and increased disaster risk are adding extra stress on natural resources. Meeting our present needs while addressing these challenges and without comprising the needs of our future generations call for developmental solutions that are sustainable. The concept of sustainable development which has evolved from '*Triple Bottom Line Concept*' emphasises on maintaining a balance between three pillars of sustainability which are environmental sustainability, social sustainability and economic sustainability (Klarin 2018). Sustainability of economic development within limited environmental resources while ensuring social equity and justice has always remained a complex issue that demands holistic and well-integrated developmental approaches.

Nature-based solutions can play an important role in maintaining the right balance between three pillars of sustainability. NbS which is rooted in relationship between biodiversity and human well-being promotes actions for protection, sustainable management and restoration of ecosystems which can help in addressing societal challenges including food security, land–water management, climate change, disasters and socioeconomic development. The nature-based approaches can provide solutions for achieving economic growth along with human development, while maintaining environmental sustainability. NbS can play an important role in facilitating economic development based on the principles of social inclusion and equity and resource efficiency and sufficiency within environmental boundaries. Hence, there is need for harnessing the potential of NbS which can sustainably contribute in reducing exposure of people, communities and businesses towards growing risk.

23.1.2 Pathways and Approaches

Policies are actions which contain goals and provide means for achieving them (Howlett and Cashore 2014). These '*means*' are policy instruments which create pathways through which policies are implemented. There are a number of policy instruments through which nature-based solutions can be integrated and implemented into developmental planning and practices. NbS still is a relatively new concept therefore its mainstreaming into developmental planning across sectors remain very limited and scattered essentially due to lack of proper policy support. Implementation of NbS is challenged by limited knowledge on the subject, which often leads to their negligence in policy design and challenges their acceptance on ground. Mainstreaming and upscaling of nature-based solutions demand an integrated and holistic policy framework that can address the gaps and challenges in effective implementation and operationalisation of these solutions at larger scale.

Figure 23.1 introduces a policy framework, which is used to identify the possible entry points for mainstreaming of nature-based solutions into sectoral policies. The framework has been adopted from Naturkapital Deutschland—TEEB DE (Schröter-Schlaack et al., 2016) which on the basis of an international study TEEB (The Economics of Ecosystems and Biodiversity, 2012) introduced a policy framework for enhancing, safeguarding and maintaining biodiversity and ecosystem services. An important feature of this policy framework is that it is framed outside conservation policies and puts forward regulatory and economic-based instruments for upscaling of ecosystem-based approaches. Similar frameworks have been discussed and adopted across different literature on the subject in different settings which include TEEB Manual for Cities: Ecosystem Services in Urban Management (Berghöfer et al., 2011), which used a similar framework for the integration of ecosystem services and biodiversity into local policy and decision-making; and

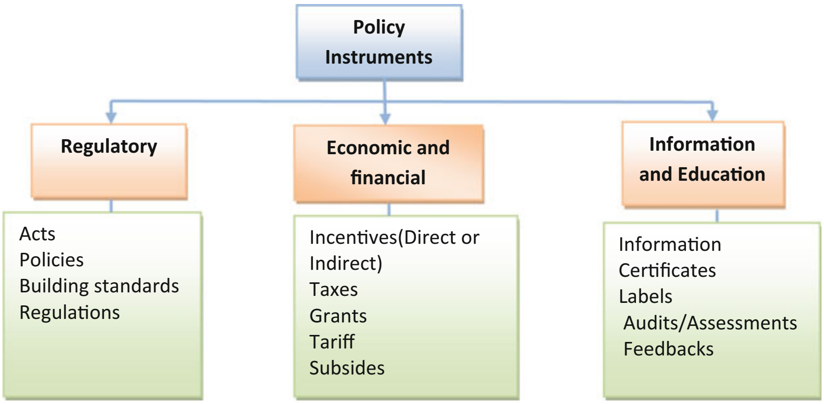

Fig. 23.1 Policy framework for implementing nature-based solutions through sectoral policies. (Adapted from: Schröter-Schlaack et al., 2016)

Droste et al. (2017) which adapted the framework for providing an overview of potential policy instruments for the implementation of nature-based solutions.

Here, this framework would be used to look into potential entry points and pathways across three types of policy instruments: regulatory, economic and financial, and information and education-based at sectoral levels. Regulatory instruments are compulsory measures imposing regulations, restrictions, limits and caps on activities (sectoral) that have implications on ecosystems and their services. These regulations are generally imposed in the form of sectoral policies, acts, laws, building standards, etc. Economic and financial instruments encourage stakeholders to reduce or limit the impact of their activities on ecosystems/environment. These instruments often provide financial/budgetary support for adopting solutions/alternatives which can reduce the impact of their activities. Economic and financial tools include tax, tariffs, subsides, grants and financial incentives (direct or indirect). They are considered to be highly effective than compulsive measures in motivating the desired behaviour in stakeholders. Information and education-based instruments ensure that stakeholders are well-informed about the approach (NbS) and its benefits. These tools can include cost–benefit analysis, public awareness campaigns, demonstration of these solutions on public infrastructures and other such measures that can lead an example in communities enabling an easy acceptance of these solutions on ground.

23.1.3 Sectoral Policies as NbS Opportunities

The latest strategy planning document of India, NITI Aayog (2018) classifies 41 strategically important sectors into four sections, viz. drivers, infrastructure, inclusion and governance. Generally, sectors such as energy, industry, agriculture, water resources, urban development, which have high dependency on natural ecosystems and their services remain much more vulnerable towards climate change and disaster risk. Based on the available literature including National Action Plan on Climate Change (NAPCC, 2008) and report by CARIAA (Patra, 2016), India's most vulnerable sectors towards climate change are water resources, forest, agriculture, health, energy and infrastructure systems. Each of these sectors has different set of policies instruments and tools formulated to address the sector-specific needs and challenges. Therefore, potential entry points for NbS across policy instruments and tools would vary from one sector to another. Thus, entry strategy has to mapped using a sector-specific approach. In this chapter, sectoral case analysis is provided for three vulnerable sectors: energy, urban development and water with an insight into (Fig. 23.2):

- The present scenarios of the sector
- Importance and relevance of nature-based solution in the sector
- Examples of sector-specific policy instruments and tools mainstreaming nature-based solutions drawn from different countries
- Existing sector-specific policy instruments and tools in India providing opportunities for the integration of NbS

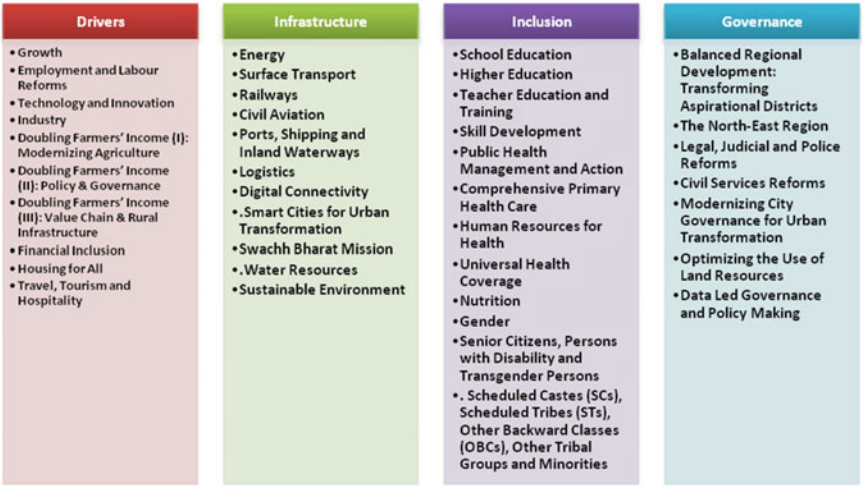

Fig. 23.2 Sectoral classification (NITI Aayog 2018)

23.2 Energy

Energy is one of the key strategic sectors in India and has an important role to play in the country's development. India majorly relies on coal, oil and natural gas for its energy requirements and is currently working on expanding its energy coverage which is followed by huge infrastructural investments. Over the years, India has also started exploring its hydropower and nuclear and renewable resources to meet its energy requirement. As per a report by Australian Government (Varghese 2018) on India's economy strategy, India's energy demand sooner will outpace its domestic supply and would provide the largest contribution (i.e., 30%) to energy demand globally by the year 2035. With this increased demand, the associated greenhouse gas emissions will also see a significant rise (Thambi et al. 2018). As stated earlier, India is highly dependent on fossil fuels particularly coal and oil for its energy needs, but unfortunately the country already lacks sufficient supplies of these resources, and this gap will be much more widened in future, which is well evident from the fact that India would witness an increase in its imported coal from 16% to 30% by the next decade along with this oil imports would increase 4–5 times by the year 2030 (Apostoli and Gough 2016, Dadwal 2010). The major objectives of India's energy policy look forward to achieve change in its energy mix; achieving energy sufficiency and security and energy sustainability matching with its climate change goals.

Table 23.1 Examples of different types of policy instruments in energy sector

Regulatory tools
Renewable Energy Quotas, China • Set out minimum renewable power consumption for each province and enterprises; Target enterprises will receive Green Power (GP) certificate when they purchase renewable energy. • It is mandatory for enterprises to earn GP certificates. • Failing to do so would lead to penalties and higher energy cost for provinces as well as target enterprises. *Energy Efficiency Obligations (EEO), Denmark* • Electricity Distribution Companies (EDC) responsible for promoting energy efficiency by reducing losses in transmission, distribution, metres/regulators, etc. • In return, *white certificates* are issued to EDC for meeting targets. These certificates are tradable which can be sold to other parties who cannot meet assigned targets.
Economic and financial tools
Carbon Tax, Sweden • It is one of the oldest and strongest carbon pricing systems with largest sectoral coverage. • Levied on fossil fuels in relation to their carbon content. • The tax is applied to different sectors including transport, industry, agriculture and buildings based on their energy emission. *Renewable Energy Bonus Scheme, Australia* • Rebate on Solar Hot Water system for eligible households
Education and information-based tool
Eco-Labelling, United States • Promotes information about energy-efficiency and sustainability • Two government-recognised eco-labelling tools practiced in USA are energy guide and energy star, which certify energy-efficiency of appliances *Energy Audit, Algeria* • Mandatory energy audits for transport, industry and service sectors for every 3 years for first two sectors and every 5 years for last one • Audits include assessment of energy performance, consumption, pollution emission of energy facilities and equipment and identification of alternatives for energy saving

Nature-based solutions bring opportunities for operationalising green growth strategies across India's energy the sector. Greening energy sectors is a good way to ensure sustainable energy development with resilience towards climatic risk. NbS can play an important role in promoting green energy which would help in drawing multiple co-benefits including reduced carbon footprints, energy sustainability and lower energy cost. Despite its developmental challenges India has always showed its commitment towards investing in sustainable and low carbon initiatives through different policies tools and instruments. With the aim of addressing growing energy needs, most of the energy policies/regulations and investments promote renewable sources of energy for reducing developmental carbon footprints. Based on the framework discussed in Sect. 23.3, Table 23.1 discusses some of the existing tools across regulatory, economic and financial, and information and education-based policy instruments by drawing examples from other countries, promoting nature-based solutions into the sector.

23.3 Urban Development

With the greater understanding of resilience, the concept of sustainability has also changed particularly in the context of urban spaces which are very dynamic in nature. In such urban spaces, sustainability is challenged to address the resilience capacities (Ahern 2013). In present times, where our cities have become hotspots of vulnerabilities and risks due to burgeoning spatial areas and population; designing and formulating policies for making our development more environment-friendly in urban spaces demands our immediate attention.

In India, there are a number of policies, acts and schemes that influence the development of urban and regional planning in the country. Over years, India has made constant efforts to respond to its urban development needs in a holistic and integrated manner by addressing various cross-cutting issues associated with urban planning such as land use, zone regulation, transportation, industrial development and environment. Like in any other sector, implementation of NbS into urban planning comes with multiple benefits. NbS in urban areas can bring in opportunities for ensuring sustainable urbanisation, restoring degraded ecosystem, developing climate change adaption and mitigation and improving risk management and resilience (European Commission 2015). NbS can be very well integrated into urban development particularly through spatial planning and infrastructural development. Green infrastructure is one of the most effective way to operationalise NbS into urban spaces. Green infrastructures consist of well managed or restored natural biophysical systems delivering range of ecosystem services. Table 23.2 describes some of the green infrastructure initiatives that are widely recognised and tested.

The hybrid structures (green and grey infrastructure) provide cost-effective solutions and increase resilience towards disaster and climatic risks. Integration of green with grey infrastructures helps can also in addressing social and environmental concerns associated with grey infrastructure developments. Table 23.3 discusses some of the policy tools used in different countries for advancing green infrastructures into urban landscape development.

23.4 Water

Water is another most critical sector in India's development because of the cross-cutting issues that are attached with the sector which includes agriculture, disaster management, rural and urban development, equitable distribution of natural capital and transboundary governance. At present India's water sector is critically under stress. As per a report by Central Water Commission (2019), per capita annual water availability has been decreased from 1816 to 1554 cm^3 between the years 2001 and 2011. Based on Falkenmark Water Stress Indicator, with less than per capita availability of 1700 cm^3, India falls under the water-stress condition. Apart from this, India is the largest user of groundwater in world, wherein almost 60% of India's

Table 23.2 Green infrastructure solutions with brief descriptions and key benefits

Green infrastructure	Description	Primary benefit
Green roofs	Rooftop vegetation reduces surface runoff and enhancing building performance	• Reduce stormwater run-off • Reduce heat island effect (energy efficiency)
Green walls	Vertical vegetated structure absorbs air pollution, provides sound proofing and also acts as beautification feature	• Energy saving
Detention basins, swales, green swales and constructed wetlands	Vegetated channel that reduces and filters runoff. Dry swales consist of a filter bed	• Reduce stormwater run-off • Filter/reduce water pollutant
Bioretention—rain gardens, retention ponds	Depressed areas, planted or ornamental rock-filled designed to manage surface runoff by collecting, infiltrating and filtering it.	• Reduce stormwater run-off • Filter/reduce water pollutant • Store stormwater • Absorb greenhouse gases
Permeable pavement systems—porous paving, interlocking block pavers, grassed surfaces	Hard surfaces for pedestrian or vehicular traffic enabling rainwater to infiltrate into the ground	• Reduce stormwater run-off • Filter/reduce water pollutants
Tree canopy	Tree plantation, protection and maintenance increase the total amount of tree canopy, which helps in providing ecosystem services such as clean air, filter water and shade	• Mitigate urban heat island effect • Absorb greenhouse gases
Soakaways, infiltration basins/trenches and chambers	Control surface runoff through infiltration and promoting groundwater recharge	• Store stormwater

Adapted from: The Greenbelt Foundation (2017) and Davis and Naumann (2017)

irrigated agriculture and 85% of drinking water supply depends on groundwater (World Bank 2010). Over years, India's water stress have been exacerbated manifolds due to increased population, unsustainable development and climate change. The major challenges of Indian water sector includes water scarcity and associated conflicts, inadequate infrastructures (supply/delivery) and debilitated management and policy framework.

NbS has a wide scope of integration into the existing programmes and policies and can provide much more sustainable solutions to deal with current water crisis

Table 23.3 Examples of different types of policy instrument in urban development sector

Regulatory tools
Building Environment Index (BEI) Assessment—Green Building Index (GBI), Malaysia • Allocation of extra points for green roofs *Green Area Ratio—Zoning Regulation, District of Columbia* • Sets out requirements for landscapes and site designs for minimising stormwater runoff, mitigating urban heat island effect and improving quality of air • Provides weights to different landscapes elements such as green roofs/walls, bioretention systems, permeable pavements and allows private property owners flexibility to choose
Economic and financial tools
New York City Green Infrastructure Grant Program, New York • Grants offered to property owner in the sewer areas of city for green infrastructures projects including rain gardens, green/blue roofs and porous pavements. • To ensure well-maintenance of these infrastructures grantee has to sign a contract requiring maintenance for 25 years *Grants for Green Building Measures, Austria* • Grants for different target groups such as private properties, commercial new buildings, thermal building renovation for including green roofs and green-living walls
Education and information tools
Strategic Environmental Assessment (SEA), Denmark • In 2014, Denmark integrated SEA policy directive into its planning system • It is applied to all the government bill, project and programme proposals to assess their potential impact on environment *Life Cycle Assessment (LCA), Mexico* • In Mexico, LCA is implemented as a part of sustainable buildings regulations • Requires the impact assessment of whole life cycle of building (including operational phase) on environment

and building future much more resilient. Nature-based approaches are motivated by nature and aim at supporting and managing natural ecosystems to ensure effective delivery of their services. Ecosystems such as vegetation, soil and wetlands play crucial role in managing water resources. NbS incorporated with conventional grey water infrastructures can be very effective in dealing with water-related challenges and water resource management. These solutions can easily work across multiple dimensions to deal with water management, which include ecosystem management, land use and land cover changes, varied hydrology across different ecosystems, biodiversity and green infrastructure. Key benefits of adopting NbS include improved water quality, quantity and water-related disaster risk management. Table 23.4 discusses different types of nature-based solutions that can be adopted for effective water resource management. Whereas, Table 23.5 mentions some of the policy instruments and tools used for water resources management across the world motivated by nature-based approaches.

Table 23.4 Types of nature-based solutions for water resource management

Nature-based solutions	Benefits
Reconnecting rivers to floodplains	• Water supply regulation • Flood mitigation • Water purification • Erosion reduction
Forest conservation/ reforestation	• Water supply regulation • Riverine flood mitigation • Water purification • Erosion reduction (reduced risk of landslides mudflows, etc.)
Soils and vegetated land	• Improved soil structure and stability • Increased drainage and water-holding capacity Reduced rainfall runoff • Reduced pollution of surface waters
Riparian buffers	• Riverine flood mitigation • Water purification • Erosion reduction (bank stabilisation) • Water temperature control
Wetland restoration/ conservation	• Water supply regulation • Flood mitigation • Water purification • Water temperature control

Adapted from: UN-DHI (2018)

23.5 Policy Analysis: Potential Entry Points for Nature-Based Solutions

Each of these strategic sectors has immense scope of integration for nature-based solutions. But, as discussed earlier, the prerequisite for effective integration is an enabling policy environment at sectoral level. In India, the policy framework comprises different types of policy instruments which majorly include regulation-based instruments, economic instruments and awareness-based voluntary interventions. Each sector comprises different set of policy instruments and tools. Table 23.6a–c analyses some of the key policy instruments and tools for energy, urban development and water sectors, respectively, at national level which are majorly implemented by state administration at sub-national levels. The policy tools discussed in the table provide opportunities through which NbS can be mainstreamed and applied into a particular sector. Some of these opportunities provide direct entry points for NbS while others have to be amended and aligned with NbS approaches.

Table 23.5 Examples of different types of policy instrument in water sector

Regulatory tools
Water Framework Directive—River Basin Management Plans, France • Formulation of six French water agencies with a target to seek 'good water' status by: Reducing water pollution; improving water quality; restoring and protecting aquatic, coastal ecosystems; management and distribution of water resources in anticipation of climate change *Salinity Cap, Australia (New South Wales)* • Enacted in the hunter river basin to address the degradation of water quality due to mining activities carried out in the river basin • A limit was set on the amount of saline discharged allowed into the river at a given point of time • Helped in reducing the overall amount of salinity in the river basin
Economic and financial tools
Resource Enhancement and Protection, Pennsylvania • Provides tax credit to farmers for implementing best management practice for improving water quality • Cover the cost of construction, installation, design and engineering planning for a proposed technique • Helped in reduction of nitrogen and phosphorous pollution *Clean Water State Revolving Fund (CWSRF), USA* • Provides financial assistance for range of water-related infrastructure projects • States are eligible for loan for supporting different projects based on effective water management • The programme provide loans for: – Construction of wastewater facilities and treatment system at municipal level – Facilities for reducing water pollution – Green infrastructure – Protection of estuaries and other initiatives for enhancing quality of water
Education and information tools
Water System Audits, Georgia • Assess the amount of Un-Accounted Water (UAW) including losses due to leaks, inoperative water systems, etc.

23.6 Business Continuity Through Nature Based Approach

Businesses now-a-days have a deeper sense of understanding of the fact that their existence in future depends directly or indirectly on natural capital and solely depending on manmade solutions would not be enough to address the future business challenges. Not planning for these challenges now, can lead to severe crisis for businesses which can cascade from one sector to another. Business continuity management is a process of identifying potential risk and vulnerabilities within a business organisation and works on increasing resilience and capacities of business models for their effective response and recovery during crisis. In recent times, business continuity and sustainability have gained attention in business practices. Business continuity and sustainability have much in common and to an extent serve the same purpose of mitigating and reducing risks and ensuring sustainability of business models (Miller 2011). In present times, eco-innovation, eco-efficiency and corporate social responsibility practices define the sustainability agenda for businesses. But considering the long-term social and environmental sustainability, we

Table 23.6 Opportunities for the integration of NbS across (a) energy sector, (b) urban development sector, and (c) water sector policy instruments in India[a]

(a) Energy sector	
Key policy instruments (policies/missions/plans/guidelines)	
• National Electricity Policy **• National Wind-Solar Hybrid Policy** **• National Policy on Biofuels** **• National Solar Mission**	**• National Mission for Enhanced Energy Efficiency (NMEEE)** **• Coal Cess** **• Renewable Energy Certificates**
Policy instrument	**Opportunities for integration of NbS**
National Electricity Policy *Type of tool: Regulatory* Key objectives of policy includes: • Access to electricity • Availability of power • Reliable and quality power supply at reasonable price • Increase in per capita availability • Minimum lifeline consumption • Addressing financial gap and commercial viability of sector • Protecting consumer interest Key issues addressed by policy: Rural Electrification, Generation; Transmission; Distribution Recovery of Cost of Services and Targeted Subsidies; Technology Development and Research and Development (R&D); Competition aimed at Consumer Benefits; Financing Power Sector Programmes Including Private Sector Participation; Energy Conservation, Environmental Issues; Training and Human Resource Development; Cogeneration and Non-Conventional Energy Sources; Protection of Consumer Interests and Quality Standards	**Key issues:** *Energy conservation* • Enactment of energy conservation act and setting up of Bureau of Energy Efficiency • Mandatory periodic energy audits for power intensive industries (as per Energy Conservation Act) • Energy conservation measures such solar heating systems and solar passive architecture shall be adopted in all government buildings • Increasing awareness and adopting more regulatory approach for setting standards (labelling of appliances) to be followed • Promoting energy service companies in implementing energy conservation measures through encouraging and incentivising emergence of such companies *Environmental issues* • Promoting Environmental Impact Assessment (EIA) and implementing Environment Action Plan (EPA) • Catchment area treatment for hydroprojects to be encouraged and monitored • Setting up of coal washeries and utilising fly ash as per environmental guidelines • Ensuring compliance with environmental norms and standards during operations of power plants
National Solar Mission *Type of tool: Regulatory and economic* • Established as one of the eight missions under National Action Plan on Climate Change (NAPCC) with initial aim at deploying 20,000 MW grid connected to solar power by 2022; this target was revised to 10,0000 MW by 2022 Mission also aims at reducing the cost of solar power generation in the country through long term policy interventions, research and development and domestic production of raw material, components and products	Currently mission is running in Phase 2 and the key schemes/policies launched under the mission include: 1. Notification of State Solar Power Policy 2. Concessional Customs Duty Certificate 3. Solar Park Scheme 4. Central Public Sector Undertaking (CPSU) Scheme 5. Defence Scheme 6. Viability Gap Funding (VGF)—750, 2000 and 5000 MW 7. Canal Bank/Canal Top Scheme All the initiatives taken under the mission provide enabling policy environment and

(continued)

Table 23.6 (continued)

	financing mechanisms for uptaking of solar energy as an alternative for conventional energy sources, thereby addressing country's energy security challenges while promoting ecological sustainable energy solutions
Renewable Energy Certificates *Type of tool: Economic (market-based)* • Notified by Central Electricity Regulatory Commission (CERC) to encourage RE generation and creating market for RE in energy sector • The approach seeks to address the gap between variation in availability of RE across states and meeting required Renewable Purchase Obligation compliance • It encourages state with higher RE potential to harness RE beyond RPO level as mandated by State Commission	• For 1 MW electricity generated (from RE beyond RPO level) one REC is created. • This REC allows RE generator to either sell RE at preferential tariffs as fixed by electricity regulatory body or sell electricity generated along with environmental attributes with RE generation to obligated entities (states with no potential for RE obligated to meet REC)
(b) Urban development sector	
Key Policy Instruments (Policies/Missions/Plans/Guidelines)	
• Model Municipal Law, 2003 **• National Mission on Sustainable Habitat** **• Smart City Mission**	**• National Urban Housing and Habitat Policy (NUHHP)** **• Environment Impact Assessment**
Policy instrument	**Opportunities for integration of NbS**
Model Municipal Law, 2003 *Type of tool: Regulatory* It implements the provisions of 74th Constitution Amendment Act on Urban Local Bodies by providing a legislative framework for implementing Urban Reform Agenda Some of key features of law include: • Constitution of municipal area based on population; three-level classification of municipalities and its constitution • Constitution of wards and wards committees • Classification of municipal functions into core municipal functions, functions assigned by government and other functions • Agenda for urban environment management and others	Chapter VI, under the law talks about functional domain of municipalities under which 'other municipal functions' includes interventions in the domain of environment protection[b]: • Reclaiming waste land, promoting social forestry and maintaining open spaces • Establishing and maintaining nurseries for plants, vegetables and trees and promoting greenery through mass participation • Promoting measures for abatement of all kind of pollution The law further defines the role and functions of municipality across other domains including: • Urban environmental infrastructure and services • Urban environmental management, community health and public safety • Environmental sanitation and community health • Disaster management
National Mission on Sustainable Habitat *Type of tool: Regulatory (strategic)* Established as one of the eight missions under National Action Plan on Climate Change (NAPCC) aims at promoting understanding on	Key mitigation and adaption strategies as suggested under the mission include: **Energy efficiency** • Creating educational programmes for students, engineers, urban planners and other

(continued)

Table 23.6 (continued)

climate change, its adaption and mitigation through energy efficiency and natural resource conservation The mission broadly covers the following three aspects: • Extension of the energy conservation building code • Better urban planning and modal shift to public transport • Recycling material and urban waste management Mission provides implementation strategies for climate change mitigation and adaption across various themes which include: Energy efficiency, urban transportation, water supply and sewerage, municipal solid waste management, urban storm water management and urban planning No separate fund is allocated to this mission as the mission is being implemented through four flagship missions which are 1. Atal Mission on Rejuvenation and Urban Transformation (AMRUT) 2. Swachh Bharat Mission 3. Smart Cities Mission 4. Urban Transport Programme	professional on green buildings focusing on regional solutions • Green demonstration projects across key location in country • Consumer awareness programmes on benefits (economical and environmental) of green buildings • Promoting labelling of appliances and marketing BEE-labelled products • Establishing building byelaws at national, state and cities for promoting energy performance standards • Providing financial incentives • Developing standards and technologies for energy-efficient construction **Urban transportation** • Strengthening public transport system through a combination of promotional, regulatory and fiscal measures • Shifting from fossil fuels to natural gas and alternate fuels in commercial vehicles • Implementing fuel efficiency standards for new as well as existing vehicles **Urban planning** • Climate changes to be addressed in planning process at all levels: national, regional and local • Increasing green covers in urban areas • Implementing strategies for reducing heat island effects • Redevelopment of existing urban habitats encouraging mixed land use, multiple transport, integrated and shared social spaces • Developing green belts as envisioned in NUHHP • EIA of master plans and other infrastructure projects
Environment Impact Assessment[c] *Type of tool: Regulatory and information and education-based* • Environment Impact Assessment (EIA) was notified under sub-rule 3 and rule 5 of Environment Protection Act (1986). The notification mandates seeking environmental clearance for developmental projects (those mentioned under the act) • Projects that require prior clearance broadly includes hydroelectric, thermal power, nuclear power, mining, airports, roads and highways, ports and harbour and industrial projects (metallurgical, cement plants, paper, etc.)	It acts as a major tool for minimising the impact of developmental projects/activities on environment

(continued)

Table 23.6 (continued)

• EIA involves four stages: screening, scoping, public consultation and appraisal • EIA notification of 2006 was amended in 2009 and currently 2019 notification is in public domain for comments from states for further streamlining the EIA process	
(c) Water sector	
Key Policy Instruments (Policies/Missions/Plans/Guidelines)	
• National Water Policy **• National Water Mission** **• National River Conservation Plan (NRCP)** **• National Plan for Conversation of Aquatic Ecosystems (NPCA)**	**• Jal Shakti Abhiyan** **• Integrated Water Resource Management (IWRM) Guidelines**
Policy instrument	**Opportunities for integration of NbS**
National Water Policy *Type of tool: Regulatory (strategic)* The policy aims at understanding the existing situation of water resources and their management in the country; proposing a legal and institutional framework for effective water resource planning, development and management Key areas related to water resources management as addressed by NWP-2012 include: 1. Water framework law 2. Use of water 3. Adaptation to climate change 4. Enchaining water available for use 5. Demand management and water use efficiency 6. Water pricing 7. Conservation of river corridor, water bodies and infrastructure 8. Project planning and implementation 9. Management of flood and drought 10. Water supply and sanitation 11. Institutional arrangement 12. Transboundary river 13. Database and information systems 14. Research and training needs	**KA3** • Increased storage capacities in various forms including soil moisture, lakes, ponds, small and large reservoirs • Planning and managing water resources structures (dams, flood and tidal embankment, etc.) incorporating possible climate change strategies **KA4** • Assessment and periodical review of availability of water resources and its usage in various sectors • Addressing the over-exploitation of groundwater through improved technology and techniques of water use, incentivising efficient use of groundwater and promoting community-based management of aquifer • Inter-basin transfers after assessing the environmental, social and economic impacts **KA5** • Project appraisal and environment impact assessment for water usage particularly in case of industrial projects (analysing water footprints for the use) • Recycle and reuse of water • Encouraging and incentivising water saving irrigation techniques and methods including aligning cropping pattern to water resource availability, micro-irrigation, reducing evaporation-transpiration, etc. **KA7** • Restoring and managing encroached and diverted water bodies and drainage channels • Preventing industrial effluents, residual fertiliser and chemical water from reaching groundwater

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Table 23.6 (continued)

	• Effective maintenance and management water resources infrastructure **KA8** • Planning water resource projects considering the social and environmental aspects • Time-bounded environmental and investment clearance **KA9** • Greater emphasis should be paid on rehabilitation of natural drainage systems • Evolving different agricultural strategies for effective management of drought through scientific local research **KA10** • Encouraging rainwater harvesting and de-salinisation for increasing water availability in urban and industrial area
	KA: Key Area
National Water Mission *Type of tool: Regulatory, economic and information and education-based* • Established as one of the missions under National Action Plan on Climate Change (NAPCC) with an objective of conserving water, reducing wastage and ensuring equitable distribution of water (across and within states) through integrated water resource development and management • The mission envision five goals: 1. Comprehensive database on water in public domain and assessing the impact of climate change on water resources 2. Promoting citizen and state actions for conserving, augmenting and preserving water 3. Focusing on vulnerable and over-exploited areas 4. Increasing water efficiency 5. Promoting basin-level integrated water resource management. • With respect to each goal, different implementation strategies and actions points are identified	**Goal 1:** S3: Developing inventory of wetlands S4: Reassessment basin-wise water situation **Goal 2** S2: Promotion of traditional system of water conservation S3: Promotion of water purification and desalination techniques S6: Promotion of participatory irrigation management **Goal 3:** S2: Intensive programme in over-exploited areas on groundwater recharge S3: Intensive programme for addressing quality concerns of drinking water (particularly in rural areas) **Goal 4:** S2: Incentives for recycling of water (including wastewater) S3: Incentivising water neutral and water positive technology S5: Improving efficiency of urban water system S6: Efficient labelling for water appliances and fixtures S7: Promoting water efficient techniques and technologies S8: Incentive for the use of efficient irrigation practices S9: Promoting mandatory water audits (including those for drinking water purpose) S10: Undertaking pilot projects for improving water use efficiency in association with states

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Table 23.6 (continued)

	S11: Incentives as awards for water conservation and efficient use **Goal 5:** S3: Guidelines for use of water for different purposes (irrigation, drinking, etc.) with respect to basin situation S4: Planning principle for integrated water resources development and management
	S: Strategy
National Plan for Conversation of Aquatic ecosystems (NPCA) *Type of tool: Economic instrument* In the year 2013, National Wetland Conservation Programme and National Lake Conservation Programmes were subsumed into NPCA to avoid overlap and promote integrated management of aquatic ecosystems The scheme aims to conserving aquatic ecosystems including lakes and wetlands Key objectives of the plan include: • Developing policy guidelines for conservation and management of wetlands • Supporting, promoting and strengthening conservation of prioritised wetlands • Development of national wetlands inventory and setting up information support system for management of wetlands • Capacity building of stakeholders for effective and sustainable management of wetlands	Key components for integrated management of wetlands: • Wetland boundary delineation and demarcation • Catchment conservation • Water management • Biodiversity conservation and habitat management • Sustainable resource development and livelihood improvement • Institutional development For inclusion of a wetland into the scheme, particular set of criteria under the guidance document has to be met
Integrated Water Resource Management (IWRM) guidelines *Type of tool: Regulatory (strategic)* • Prepared under a strategy for IWRM at river basin level of National Water Mission • IWRM guidelines addresses following key issues related to water resources management: – Water availability and requirement – Water Rights and Priorities – Policy, Legal and Institutional Framework – Project Planning, implementation and prioritisation – Sectoral issues (water for domestic, irrigation, flood control management, hydropower, industrial, navigation and ecological and other uses) – Ground water aspects – Demand management, water pricing and participatory management – Environmental aspects – Rehabilitation and resettlement – Water quality aspects	**Key issues:** *Sectoral issues: Ecological and other use:* • Implementing measures for protecting ecological integrity of ecosystems depended on water • Maintaining water quality and aesthetics around river or water bodies • Preserving riparian rights of the inhabitants along river side *Environmental aspect:* • Mandatory environment protection plan including EIA to be part of master river basin management plan • Taking into consideration environmental needs of Himalayan region, aquatic ecosystems, wetlands, etc. while planning • Catchment treatment programmes as mandatory part of any river basin developmental project • Green belt development along the periphery of reservoir

(continued)

Table 23.6 (continued)

– Inter-basin transfers – Interstate issues – International dimensions – Water resource development and management at local level – Information and knowledge management – Research and development need	

[a]The information provided in the table is taken from various policy documents, guidelines and government website
[b]Implementation of other municipal functions is subject to availability of managerial, technical and financial capabilities
[c]It's a cross-cutting tool that can be applied across different sectors and settings (urban and rural)

need to identify a holistic approach can bring in significant changes in the way businesses operate (Bocken et al. 2014). Nature-based approaches can provide such solutions that can ensure sustainable business operations as well as can take care of business continuity during crisis. There are various reasons why businesses are looking towards switching to NbS; but the two reasons that continue to dominate the discourse are their cost-effectiveness and capability to manage risk.

NbS can provide a good case for sustainable business models. Sustainable environment decision incorporated in business planning increases the resilience of businesses by avoiding exacerbation of direct or indirect losses during any extreme event. In this regard, the concept of Sustainable Business Model (SBM) can provide potential framework for mainstreaming NbS into business cycle. SBM is based on triple bottom line approach, just like sustainability, and can address multi-stakeholder interests, including ecological and social dimensions. In SBM, ecological, economic and social sustainability of a business is assessed through their technological, social and organisational innovation activities. Table 23.7 describes sustainable business model archetypes as developed by Bocken et al. (2014). These archetypes are mechanisms or solutions that can contribute in building sustainable business models. The SBM archetypes are grouped into three categories; each grouping describes a business model innovation type which can be technological, social and organisational oriented innovation. Further, Table 23.7 describes some of the strategies and nature-based solutions corresponding to each archetypes that can be used in sustainable business innovations (the listed strategies and NbS mentioned in the table are not exhaustive).

Table 23.7 Strategies for implementing nature-based solution corresponding to each business model archetypes

Archetypes	Strategies	NbS opportunities
Technological grouping		
Maximise material and energy efficiency	• Low carbon solutions • De-materialisation (of products/packaging) • Increased functionality to reduce number of products required	• Green roofing solutions (green walls) • Urban agriculture
Create value from waste	• Circular economy • Reuse, recycle, re-manufacture	• Use of building waste (water, heat) by rooftop or building-integrated agriculture • Unused brownfield can be temporarily used for urban agriculture
Substitute with renewable and natural processes	• Switching from non-renewable to renewable energy sources • Zero emission initiative • Blue economy	• Solar–wind energy sources • Decreasing rainwater run-off with green solutions • Improving air quality using tree canopy and other green solutions • Reducing heat island effect through green urban spaces • Reducing flood risk through different NbS (bioretention—rain gardens, retention ponds, etc.)
Social grouping		
Deliver functionality rather than ownership	• Product, use, result-oriented PPS • Private finance initiative • Design, build, finance, operate (DBFO)	• Reducing environmental cost of bottling and improving health by access to (unbottled) clean water • Incentives on green solutions
Adopt stewardship role	• Biodiversity protection • Consumer care-promoting health and well-being • Transparency about environmental/sectoral impacts • Resource stewardship	• Involving local residents community farming • Promoting home gardens • Landscaping with native plants caters to preferences of nature-inclined tourists, facilitating eco-tourism • Enhancing tree cover, rejuvenating water resources
Encourage sufficiency	• Consumer education • Responsible product distribution/promotion • Frugal business • Product longevity • Demand management	• Promoting and strengthening local food security by promoting local agriculture to combat poverty and social exclusion and provide recreation and green space
Organisational grouping		
Repurpose for society/environment	• Not for profit • Hybrid business, social enterprises • Alternative ownership: cooperatives, collectives	• Social enterprises set up to facilitate self-sustaining agricultural initiatives • Setting up cooperatives and collectives for facilitating easy adoption of NbS at

(continued)

Table 23.7 (continued)

Archetypes	Strategies	NbS opportunities
	• Social and biodiversity regeneration initiatives • Localisation	local level through financial, technical and other support
Develop scale up solutions	• Collaborative approaches (sourcing, production, lobbying) • Incubators and entrepreneur support models • Licensing, franchising • Open innovative platform • Crowd sourcing/funding	• Providing green roof subsidies to encourage private investment in green roofs • Creating markets for CO_2 abatement (green solutions)

Adapted from: Bocken et al. (2014) and Toxopeus and Polzin (2017)

23.7 Conclusion

Nature-based solutions have immense potential to create multiple environmental, social and economic co-benefits in parallel while addressing the present societal challenges. To what extent our policy framework supports these solutions would ensure their acceptance and effectiveness on the ground. Despite wide and growing experience in the field of NbS as an alternative approach for sustainable development. There are still many challenges that have to be addressed for advancing these solutions into sectoral planning. Foremost, there is a need to create demand and market for green solutions which would require a good accounting system that can assess and evaluate the cost–benefit of services provided by NbS; keeping an account of investments and returns of adopting them. Establishing such evidence base for NbS would help stakeholders in knowing various benefits provided by NbS and making informed decisions.

Second, most of the nature-based solutions across sectors are often implemented on project basis with intensive financial and other assistance from external sources. It requires an enabling policy environment for ensuring that the NbS are well considered in regular policy planning and implementation strategies. The policy framework for the implementation of NbS has to be effective enough to address diverse gaps and challenges in their adoption which would include addressing financial challenges associated with the adoption of these solutions, improving and strengthening knowledge base in the domain and creating an integrated regulatory and legal framework for mainstreaming these solutions across different sectors. Globally, lots of attention is being paid on economic instruments (such as tax instruments, trading systems, etc.) than the regulation or any other instruments for achieving greener development objectives.

Economic instruments are usually considered to be more cost-effective as it gives flexibility to both consumers and producers on ensuring productivity of resources along with lowering their carbon footprints, whereas in case of regulatory instruments, their effectiveness and efficiency depend upon number of factors including type/degree of regulation, entity being regulated and largely on the capacity of that state which implement and enforce these regulations (Gunningham 2013). In this case also for mainstreaming of NbS across sectors, 'standalone' economic instruments might not prove to be as effective and would require a more integrated set of policies in which regulations, public investment, research and development and technology innovations tools also have an important role to play. Remaining confined to one or two instruments might reduce the scope of integration of these solutions. Another important area that policymakers must explore for mainstreaming of NbS is seeking cooperation through private–public partnership since implementation and financing NbS at larger scale can be well supported through public–private partnerships. A holistic approach in planning and implementation of these solutions across different sectors has to be established and adopted for creating an enabling policy environment comprising of right mix of policy instruments and tools. However, a single policy framework cannot be applied for mainstreaming and implementing nature-based solution across different sector, it needs to be sector-specific; formulated keeping in consideration demands and challenges of a particular sector. Identifying and creating opportunities and entry points through relevant existing or new set of policy instruments across a sector that effectively can address the implementation gaps of NbS is the key for effective and successful upscaling of these solutions.

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Chapter 24
New Pathways for NbS to Realise and Achieve SDGs and Post 2015 Targets: Transformative Approaches in Resilience Building

Pritha Acharya, Anil Kumar Gupta, Shalini Dhyani, and Madhav Karki

Abstract The year 2015 saw a momentous transformation in the global environment and development agenda with the signing of Sustainable Development Goals, Sendai Framework for Disaster Risk Reduction and Paris Agreement on Climate Change. These milestone agreements promise to transform the way global community deal with environmental issues and strive to achieve sustainable development. A number of planned other global initiatives such as post 2020 biodiversity framework and IUCN's World Conservation Congress promise additional avenues for realising global goals and targets at ground to global level. This will of course require sustainable approach both in their planning and implementing strategies. Nature-based solution (NbS)-related interventions inspired from nature's tremendous capacity to address the challenges facing the societies today bridges this gap by offering multiple opportunities. For example, to address the complex task of meeting SDGs at a local scale, NbS can provide cost-effective and no-regret solutions. This chapter shares experiences of the key challenges and opportunities in implementing NbS interventions at a local level. It highlights the key entry points for NbS through community-led initiatives and mainstreaming these in government plans and programmes. The chapter contents suggest the road ahead for NbS to address the post 2015 development and post COP 21 climate adaptation agenda and beyond by identifying specific role for communities, private sectors and government agencies.

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24.1 Introduction

Year 2015 saw a momentous transformation in the global development agenda. The transition from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs) marked the roadmap for global development with societal, economic and environmental upliftment as its pillars (ICLEI 2015). The 17 goals and 169 targets under the SDGs are interconnected and provide scopes to integrate cross-cutting approaches and tools to address the current developmental challenges faced by the society. The launch of the Sendai Framework on Disaster Risk Reduction (SFDRR) (UNDRR 2020) along with the commitments of COP 21 Paris Climate Conference in 2015 (UNCC 2020) supported SDGs by providing a set of common standards and achievable targets to reduce carbon emissions, manage the risks of climate change and natural disasters and build back better after a crisis (UNDP, Sustainable Development Goals 2020).

Environmental degradation is reduction of the capacity of the environment to meet social and ecological objectives and needs. Potential effects are varied and may contribute to an increase in vulnerability and the frequency and intensity of natural hazards (Gupta et al. 2013). Resilience to climate change and disasters comes from healthy ecosystems, and maintaining healthy and well-functioning ecosystems requires effective and sustainable conservation and restoration strategies. The role of NbS in successfully restoring natural and manmade ecosystems as well as developing resilience in ecosystems and communities has been well discussed in the previous chapters. Further there is growing interest among academicians as well as discussions on NbS in leading environmental agreements about NbS inclusive planning to reduce disaster risks and addressing climate vulnerability.

Considering its overarching goal to address global societal challenges, NbS has the potential to substantially contribute to the 2030 Agenda (as given in Table 24.1) and help achieve the full range of Sustainable Development Goals (SDGs) (Faivre et al. 2019; Cohen-Shacham et al. 2019) Sendai Framework for Disaster Risk Reduction and National Determined Contributions as part of the promises of COP 21 Paris Climate Conference.

24.2 Need for Localisation of SDGs

SDGs may have provided the global roadmap to attain a sustainable future promoting development in a holistic manner, but the existing environmental and developmental challenges vary at a regional scale. Addressing these complex and diverse challenges demands for localised actions. Thus realising SGD necessitates the need for localisations of its targets through action-based implementation. In addition for adaptations to be transformative and imbibe behavioural change, the aim should be to scale up and advocate community-driven process and address ecological and social complexity prevailing in a particular locality or an ecosystem. There is a need

Table 24.1 DRR-CCA targets in SDGs, Sendai Framework and NbS

Achieving SDG targets through NbS			
Sustainable development goal	Related DRR or CCA target	How Sendai Framework will help to achieve the goal/target	How NbS will help to achieve the goal/target
Goal 1: End poverty in all its forms everywhere	Target 1.5	'To achieve this goal and target Sendai Framework proposes for the promotion and development of social safety nets linked with livelihood enhancement programmes in order to ensure resilience of household and communities to disasters'	NbS promotes protection against climate-related disasters and extreme events, climate regulation, providing alternative sources of income through ecosystem-based adaptation and ecosystem approaches
Goal 2: End hunger achieve food security and improved nutrition and promote sustainable agriculture	Target 2.4	'To achieve this goal and target in context of Sendai Framework relevant actions including strengthening productive assets such as livestock working animals, tools and seeds are required'	Promoting ecosystem-based adaptation, ecosystem approaches promoting and ecological restoration using the provisional and regulatory ecosystem services
Goal 3: Ensure healthy lives and promote well-being for all at all ages	Target 3.d	'This target in particular is complemented by the outcome of Sendai Framework which has placed strong emphasis on the resilience of health systems and integration of disaster risk reduction into health care provision at all levels'	Water quality enhancement through wetlands (ecosystem approaches), harnessing the regulating ecosystem services
Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Target 4.7 and 4.a	'In order to progress these target actions implementation needs to consider promoting disaster risk knowledge at all levels including in professional education and training as recommended by the Sendai Framework'	Cultural ecosystem services provide a scope to enhance personal and spiritual growth for effective and safe learning environment
Goal 6: Ensure availability and sustainable management of water and sanitation for all	Target 6.3, 6.4, 6.5, 6.6, 6.a and 6.b	'Target 6.6 indirectly provides an opportunity to mainstream ecosystem based approaches for disaster risk reduction and further highlight their value as a "win win" and "no regrets" solution to	Utilising all the four types of ecosystem services and application of combinations of ecosystem-based management approaches, ecosystem-based adaptation and ecological

(continued)

Table 24.1 (continued)

Achieving SDG targets through NbS			
Sustainable development goal	Related DRR or CCA target	How Sendai Framework will help to achieve the goal/target	How NbS will help to achieve the goal/target
		the increasing disaster and climate risks underlined in the Sendai Framework'	restoration strategies, NbS can address the targets of goal 6
Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation	Target 9.1 and 9.a	'In order to progress with these targets and goal, the Sendai Framework recommends strengthening disaster resilient public and private investments through structural, non structural and functional disaster risk prevention and reduction measures in critical facilities, in particular schools and hospitals and other physical infrastructure'	Natural infrastructures and green infrastructures based on ecosystem-based adaptations also promote climate resilient infrastructure
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	Target 11.1, 11.3, 11.4, 11.5, 11.b and 11.c	'Measures to achieve these targets and goal, as outlined in the Sendai Framework, require mainstreaming of disaster risk assessments into land use policy development and implementation, including urban planning, land degradation assessments and informal and non-permanent housing, and the use of guidelines and follow up tools informed by anticipated demographic and environmental changes'	Ecosystem services contribute to thriving cities during times of stability, particularly through the provision of cultural ecosystem services that bring social, cultural and community benefits and well-being. Nature-based solutions and urban green spaces provide the location for recreation, social interaction, building community cohesion and contributing to physical and mental health and well-being (Viniece and Omoshalewa 2019)
Goal 13. Take urgent action to combat climate change and its impacts	Target 13.1, 13.2, 13.3, 13.a and 13.b	'In order to achieve these targets and the overall goal, the Sendai Framework recommends to strengthen disaster risk modeling, assessment, mapping, monitoring and multi-hazard early warning systems; promote the	Nature-based solutions promoting green and blue urban areas have significant potential to decrease the vulnerability and enhance the resilience of cities in the light of climatic changes (Kabisch et al. 2016)

(continued)

Table 24.1 (continued)

Achieving SDG targets through NbS			
Sustainable development goal	Related DRR or CCA target	How Sendai Framework will help to achieve the goal/target	How NbS will help to achieve the goal/target
		conduct of comprehensive surveys on multi-hazard disaster risks and the development of regional disaster risk assessments and maps, including climate change scenarios; and maintain and strengthen in situ and remotely sensed earth and climate observation’	
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Target 14.2	‘The Sendai Framework explicitly seeks to account for the environmental damages caused by disasters—in many cases damages are attributable to the removal of disaster waste and to impacts associated with recovery and reconstructions planning that have by-passed existing environmental legislation’	NbS offers coastal protection through ecosystem-based adaptation measures, ecological restoration measures as well as promoting protected areas for sustainable use and to restore and protect the ocean waters and coastal resources
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Target 15.1, 15.2, 15.3, 15.4 and 15.9	‘These targets are also in line with the Sendai Framework’s focus on building environmental resilience through the inclusion of ecosystems in risk analysis and planning. As per marine ecosystems, the Sendai Framework proposes similar priority actions for their terrestrial equivalents—mountains, rivers, coastal flood plain areas, dry lands and wetlands, among others’	Ecosystem-based adaptations, ecosystem-based management practices, protected areas, ecosystem restoration, landscape restoration all these approaches are well aligned to address the challenges of land degradation, halt biodiversity loss, sustainable use of land systems, effectively manage forest and associated landscapes

Adapted from Prime Minister’s Agenda 10: India’s Disaster Risk Management Roadmap to Climate Resilient and Sustainable Development (pp. 21–22), by Gupta et al. 2016, New Delhi and Core principles for successfully implementing and upscaling Nature-based Solutions by Cohen-Scaham et al. 2019, Environmental Science and Policy, pp. 20–29 copyright 2019 by the Authors with permission

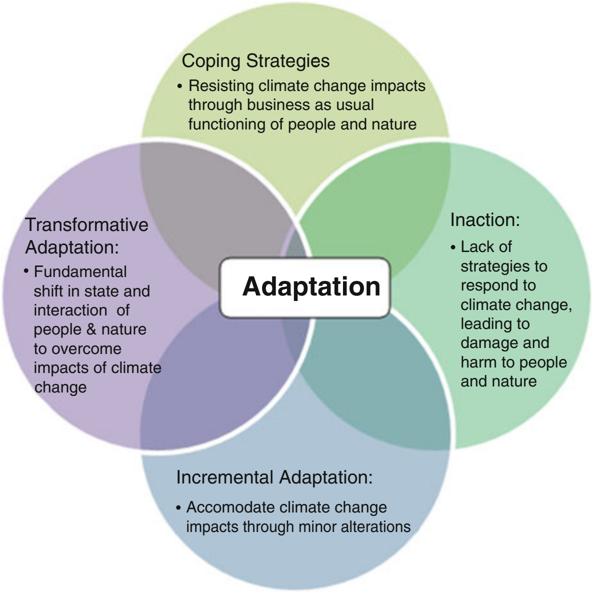


Fig. 24.1 Adaptation strategies. (Adapted from Nature-Based Transformative Adaptation: A Practical Handbook (pp. 6–7), by Fedele et al. 2019, Arlington, USA)

to recognise the relevance of local specificities since adaptation is essentially and inevitably done at local scale (Karki 2017).

Localising is the process of recognising sub-national contexts in the achievement of the 2030 Agenda, from the setting of goals and targets, to determining the means of implementation and using indicators to measure and monitor progress, in addition to raising awareness through advocacy (NITIAayog 2019). As the sub-national governments are suitably placed as connector between national and local communities, their role is established as a critical catalyst in linking global goals with local communities (GTF 2016) (Fig. 24.1).

24.3 Need for a Transformative Approach

Resilience has become the supporting pillar for all global and regional development targets. The importance of community, environmental and economic resilience has been included in global goals like the SDGs, Paris Agreement and Sendai Framework for Disaster Risk (ICLEI 2015). Adaptation can be seen as a way to increase resilience to climate change. However, based on the challenges, needs and behaviour of the local communities, adaptation strategies vary from region to region (refer to Fig. 24.2) (Fedele et al. 2019). Documented practices around the globe (and many as discussed in the previous chapters) support the existing adaptation strategies like the community-based adaptations (CBA), ecosystem-based approaches (EbA), etc. but

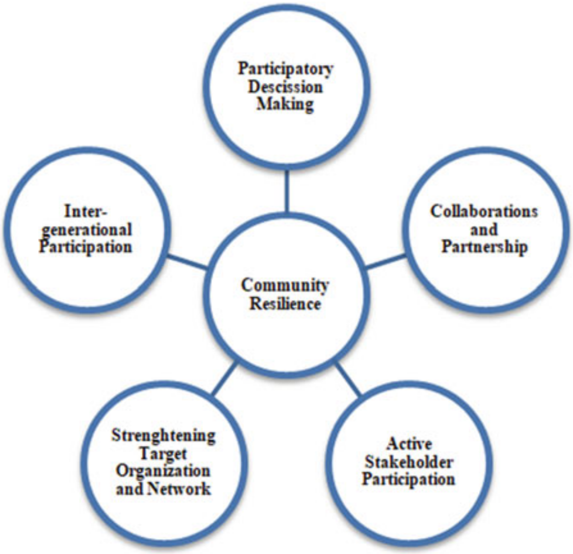


Fig. 24.2 Components enhancing community resilience. (Adapted from Prime Minister's Agenda 10: India's Disaster Risk Management Roadmap to Climate Resilient and Sustainable Development (pp. 21–22), by Gupta et al. 2016, New Delhi)

are often incremental in mature and aimed to address the direct impacts with short-term benefits.

Transformative adaptations provide future proof strategies by addressing the root causes of vulnerability. Transformative adaptations are distinguished from other adaptation approaches by six characteristic features, viz. (a) path-shifting, (b) restructuring, (c) multi-scale, (d) persistent, (e) innovative and (f) system-wide (Fedele et al. 2019).

Transformative adaptations are not restricted to nature; rather they also take into account the social and technical measures. Thus, designing and implementing such adaptation strategies require a holistic approach and an integrative framework. A thorough study of the NbS principles supports its potentials to bring in adaptive transformation through interventions like ecosystem-based adaptation (EbA) (Cohen 2019). Figure 24.3 provides the interrelation of NbS principles with the characteristics of transformative adaptation.

24.4 Achieving SDGs Through NbS

Sustainable development as a function of environmental and social well-being as underlined by the SDG agenda promotes development in a holistic manner, following an inclusive model (UN, Sustainable Development Goals. Knowledge Platform 2019). Mainstreaming SDG targets calls for localised actions through good governance and effective community approaches.

Communities are the key players in understanding the local needs and priorities as well as implementing NbS inclusive conservation actions (van Ham and Klimmek

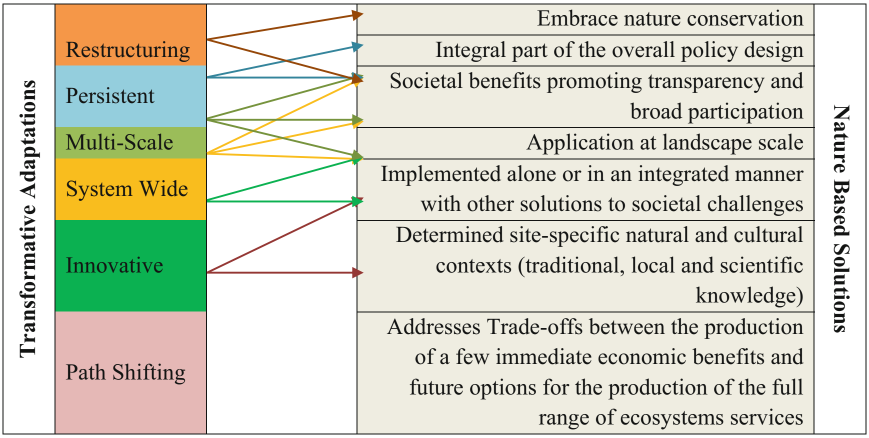


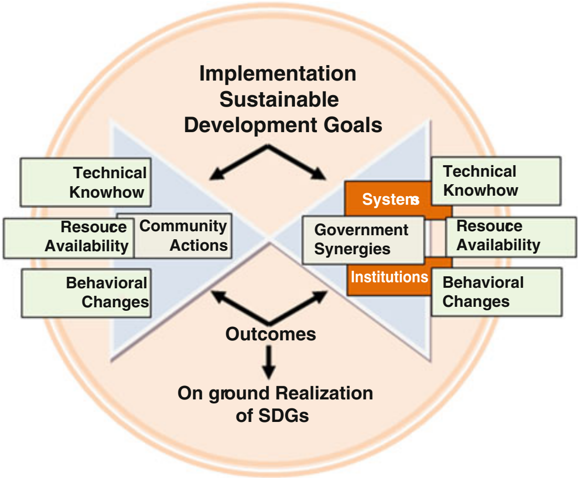
Fig. 24.3 Linking NbS and transformative adaptation

2017). Additionally for any developmental activity—including the SDG agenda and other national targets—to show positive results, it is essential to develop a sense of ownership and active participation of local communities is crucial to promote this sense of ownership (UNEP 2019).

Governance can be seen as an amalgamation of systems comprising of administrative structures/nodes and institutions (sometimes with autonomous rights). Government models may follow different governance approaches; however, the policies and strategic and operational frameworks are at the core of it (Barlow 2016). Mainstreaming NbS into the government structure is based on the availability of resources, realising the practical knowledge and skills, i.e. the knowhow and behavioural transformations.

However, the requirements of the community and government are quite different when realisation of the NbS in concerned. For example the knowhow for community should be action oriented; it should focus on practical knowledge to implement NbS by prioritising and implementing need-specific adaptation models and strategies. Whereas for government knowhow involves effectiveness in planning process and effectively laying out frameworks through policies and plans. Similarly, resources for government include existing standards, protocols, manuals and codes, and community-specific resources comprise incentives, local cooperation, etc. Behavioural transformation focuses on the willingness and acceptance by the communities to take up NbS in local actions, on the other hand it aligns with the exemplary management skills and competencies of the government. Figure 24.4 is an illustration of the above discussions. However, these pose a unique set of challenges which are discussed further in the chapter.

Fig. 24.4 Factors associated with realization of SDGs



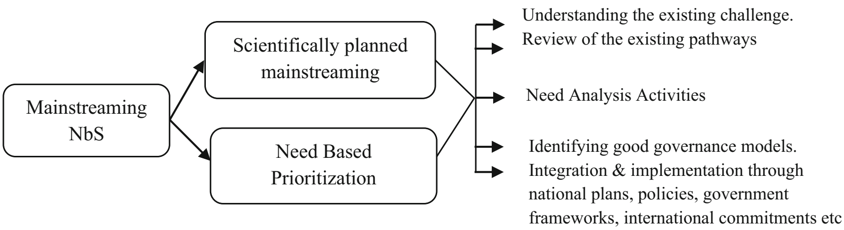


Fig. 24.5 Mainstreaming NbS: broad challenges

24.5 Understanding the Challenges

NbS approaches and categories have been highlighted in both scientific literature and government non-government networks (Cohen 2019). Yet mainstreaming NbS into local actions to achieve the SDGs is challenging. Various sectors may have different set of challenges, but this chapter will focus on government and community-specific challenges. Figure 24.5 draws attention towards the broad challenges to mainstream NbS.

With the business as usual scenario, the biggest challenge when it comes to the South Asian countries like India may be the ineffective planning process. Although the subnational plans (especially the departmental plans) are being revisited, adaptation approaches sometimes are not considered in developing these plans. Lack of participatory procedures, limited knowledge and capacity, and lack of support from technical institutions further adds on to this problem. Moreover, limited resources and unequal allocation of funds pose altogether a different type of challenge to mainstream NbS under the SDG development agenda.

Achieving results of NbS interventions is a time-dependent process. Sometimes the interventions are also not planned keeping in mind the long-term benefits; rather they are designed to get short-term benefits. Such mal-approaches trigger social issues like reduced trust and flexibility to take up NbS interventions by the community. There may be existing examples of successful on-ground implementations like Joint Forest Management (JFM) and Marine Protected Areas (MPAs), however detailed study suggests that effective local governance models for ecosystem service regulation are missing, and even if they are in place, they may not be effectively evaluated. Collaboration within and among the departments/sectors is one of the key strategies for successful implementation of NbS in planning process. However, there is paucity in practical implementation of such collaborative network.

Various case studies across South Asia have highlighted that although the government may have technical understanding in implementing of SDG, monitoring and reporting of the evaluation process is inefficient and lack skills (Open Development Vietnam 2018). Although the private sector and corporates across the globe have shown their commitment towards SDGs and are enthusiastic in taking up NbS, examples from Indonesia suggest that there may be a lack of interest among the private sector to take up NbS interventions in order to achieve SDGs.

Challenges specific to the community includes the willingness to take up NbS interventions. Case studies from European countries focused on NbS in urban spaces highlighted the uptake of NbS interventions only if they were aesthetically appealing to the community. Moreover, community participation may be incentive driven and lack a sense of ownership to take up NbS realising the SDGs. Also, existence of cultural barriers in communities may result in gender skewed community participation. For example, in some communities the participation of women or other weaker sections may be restricted which directly contradicts with idea of SDG as an inclusive and a holistic developmental agenda.

24.6 Opportunities to Mainstream NbS

International Union for Conservation of Nature recently released the new NbS standards. The purpose of the standard is to provide a common and well accepted framework to design, and verify interventions at ground level. It is intended to be a simple yet robust hands-on tool that informs the planning, design and implementation of an NbS, especially as an alternative to other types of development interventions such as hard infrastructure (IUCN 2019). The standard currently has seven criteria and several indicators underlining the processes and practices for successful implementation of NbS interventions. This framework thus provides a good opportunity to mainstream NbS with an aim to address the SDGs.

The NbS standards provide an in-depth framework to report NbS at ground level, another concept of mainstreaming NbS was given by Wamsler et al. 2014. This framework describes a strategy to integrate NbS into governance and planning level.

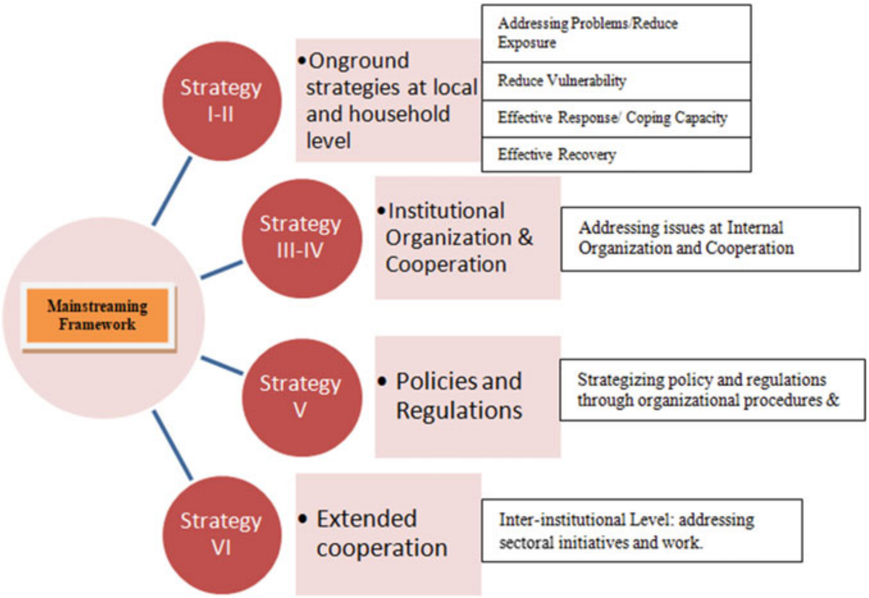


Fig. 24.6 Mainstreaming strategies and framework. (Adapted from Nature-based Solutions to Climate Change A aptation in Urban Areas, Theory and Practice of Urban Sustainability Transitions by Christine, W., Stephan, P., Teresa, Z., Sophie, S., and André, M, 2017, Mainstreaming Nature-Based Solutions for Climate Change Adaptation in Urban Governance and Planning. In N. Kabisch et al. (eds.), pp. 1–11, 2019 copyright 2019 by SpringerNature Switzerland with permission)

Wamsler highlighted four key points for successful adaptation mainstreaming (Christine et al. 2017). At first mainstreaming to be done at the local level, second step includes local, institutional and inter-institutional level, third promotes a combined approach and finally it talks about creating synergies and support. The framework has been explained in Fig. 24.6.

24.7 Key Strategies and Roles

Realising SDGs by mainstreaming NbS at local level calls for an action-based approach which should follow a blend of proactive as well as a reactive approach. This will stimulate prompt decision-making process and will stipulate reallocation of assets and resources streamlined by the priorities of the community. It involves the following strategies.

24.7.1 Key Strategy

The key strategies can be summarised under the following:

- Promotions of replicable models
- Up-scaling of demonstrable pilots
- Mainstreaming adaptation approaches into sectoral planning process
- Improving and customising existing policies
- Establishing synergies within departments and departmental plans

24.7.2 Role of Community

Implementing NbS to achieve SDGs at local-level requires an action-based approach where local communities act as an interface between adoption of the global targets and their implementation through on ground actions. Such targets can be achieved by:

- Follow and uptake of municipality-promoted participatory activities and models
- Active participation of community in the decision-making processes
- Sharing of on-ground success and failure stories
- Continuous comprehensive capacity development
- Abiding by the regulatory, monitoring and reporting standards and frameworks for NbS

24.7.3 Role of Businesses

Private sector is one of the key stakeholders in the context of realising and mainstreaming of SDGs. Natural capital as the foundation of economic growth and prosperity has been acknowledged by businesses globally. According to a survey by Economist Intelligence Unit in 2014, it was found that 90% of global business leaders believe that they have role in building resilience and prepare cities from impacts of climate change (Kongrukgreatiyos 2016; van Ham and Klimmek 2017). Their dependence and impact on natural resources—including essential ecosystems and their services—have pushed them to analyse their business risks and recognise opportunities to transform into a more resilient model. Leveraging the market knowledge, management experience and building upon the existing database and technological support private sector can effectively implement appropriate NbS strategies in their business actions.

24.7.4 Role of National and Sub-National Government

Global Taskforce for regional and local government has attempted to define the role of national government in mainstreaming SGDs (through the roadmap for localising the SDGs). The document suggests that national government serves dual role by (a) implementing SDGs promoting on ground actions following a bottom-up approach and (b) leveraging the SDGs framework to develop national polices and plans. In addition, they should promote national consensus among all levels of the government through establishing inter-sectoral collaborative approach in the national plans and programmes.

Sub-national governments are effective in bridging the gap between the central government and the local communities. Their role has been fairly identified in incorporating the principles of NbS and prioritising need-specific implementation of NbS approaches through departmental plans and providing shared platforms for peer learning of on-ground failures and success stories.

24.7.5 Role of Institutions

Knowledge sharing and capacity enhancement are vital in realising SDGs. It is a continuous process needed for up-scaling on-ground NbS implementations and actions. Local institutions may have defined role in addressing SDGs through NbS localisation by taking up the following activities:

- Designing tools and programme for capacity development
- Resource documentation of success stories through compendium of case study
- Focused training programmes for beneficiaries and relevant stakeholders
- Peer-to-peer learning and sharing of experience
- Promoting scientific research and technical knowhow for implementation
- Communications, outreach and promotion materials to relevant stakeholders
- Enhancing local participation through exchange programmes

24.8 NbS: Sector-Wise Applications and Entry Points

The global population is increasing triggering the demand on the natural resources to meet the developmental as well as provisional requirements of the society. To this the existing climate change scenario is bringing in new dimensions of challenges setting up new sets of responsibilities for the society. Among the most affected sectors, the share of agriculture and water sectors along with the health sector is lofty (WHO 2018). All these sectors are interlinked and share an intricate bonding, challenges of one offsets a series of challenge in the other creating a cascade effect.

NbS has applications in varied sectors due to the plenitude of benefits it offers to address the challenges of mankind. NbS also provides a scope of shared learning through the effective implementation of strategies to reduce vulnerabilities and risks. This section gives an overview of the challenges of three sectors and focuses on a few case studies highlighting how NbS can build climate resilience in these sectors inducing a transformative change through its interventions.

24.8.1 Agriculture Sector

Dependence of agriculture on other resources like land, water, energy, fertilisers and pesticides and livestock makes it more vulnerable to ill effects of climate change as well as natural disasters (GreenFacts 2020). With global population hitting the ten billion benchmark (Worldometer 2019), the food consumption across the globe will increase and may result in a shift in the existing food consumption pattern (moving towards a more protein rich diet). However, feeding the food-deficit pockets will remain a concern. Subsistence farming is commonly practiced in the South Asian countries like Nepal. However, seasonal migration of farming communities due to lack of livelihood, limits the scope for a continuous source of income. Some of the other challenges of the agriculture sector include:

- Bridging the demand gaps, market requirements and in the look for fast outputs, agricultural practices have experienced a higher rate of pesticide and fertiliser utilisation (EU 2020).
- Forty percent of the global share of land is under agriculture which accounts for 70% of the water consumption needs (TERI 2014). This affects the quality of soil along with known health impacts to human beings.
- Monocultures and other conventional farming practices are generally unsustainable and result in environmental degradation.

A through analysis points out that with the present business as usual scenario in context, agriculture sector is facing triple challenge of (a) feeding the poor, (b) livelihood opportunity to farmers and (c) protecting the environment.

24.8.2 Water Sector

Water is crucial for survival, and its requirement in agriculture, industry and domestic use makes it even more valuable as a resource for our existence and development. Despite having ample amount of fresh water, the proportion of usable water is very less and is further being affected by a number of developmental challenges. Overexploitation and mal-practices in certain water dependent sectors have resulted in water stress conditions, thus causing a sharp decline in the per-capita water availability. Influencing the entire dynamics, climate-related extreme events and disasters are an add-on to the water sector. Some sector specific facts and projections are given below:

- The fresh water withdrawal will increase meeting the demand gap and is expected to rise by 50% and 18% in the developing and developed countries, respectively (TERI 2014).
- The heavy dependence of the industries on water will see a rise in water consumption from 725 to 1170 km^3/year by 2050 (TERI 2014).
- In addition, the global development scenario will also see a substantial change in sector-wise dependence (a shift from agriculture to industrial activities) for the developing countries.
- The situation is such that by 2050, the half of the global population will live in water scarce condition (UN n.d.).
- Persistent use of fertilisers and pesticides, discharge of domestic waste, sewage and effluents and natural inflow of micronutrients like fluorides, arsenic and other heavy metals in surface water bodies and ground water aquifers are contributors to increased trends of water pollution (FAO 2020).
- Increase in flood and droughts have affected some of the poorest clusters of the world recording approximately 24.38% of the total global deaths and impacting 46% of the total humans affected (CRED 2019).

To sum up, the water sector faces the following challenges that are in an urgent need to be addressed: (a) equitable distribution, (b) responding to the growing impacts of climate change on water, (c) resource efficiency in water sector and (d) protecting water as a resource.

24.8.3 Health Sector

Health as a sector is a central element of sustainable development for its association with other important sectors. It has been considered as the beneficiary, contributor and key indicator to development (Every Woman Every Child 2015). A list released by the World Health Organization in 2019 has placed environmental degradation, climate change and clean health care as the key concerns to the futuristic health scenario among others. Global assessments suggest that approximately one fourth of the health challenges are due to environmental degradation (The World We Want 2013). Some sector specific facts are given below:

- Climate change affects both the environmental and the social determinants of health including the access to clean air, drinking water, food and shelter.
- Malnutrition, diarrhoea, heat and cold stress are some of the upcoming health challenges that the society is currently facing (WHO 2018).
- Disasters including both manmade and natural affect communities both directly and indirectly through disability, mortality and morbidity. It also impacts the health systems through obstructions and health services through reduced flow.

- Air pollution has aggravated the frequency of chronic diseases, allergic reactions and is reported to kill approximately seven million people globally (DowntoEarth 2018). Similar figures are seen in case of diseases caused by water pollution.

Thus the foremost challenges of the health sector today includes (a) environmental degradation and pollution, (b) climate-aggravated health issues, (c) natural disasters triggering health emergencies and (d) keeping a clean health care system.

24.8.4 Sustainable Coffee Production in Agricultural Landscape: A Case Study of Mexico

Mexico's coffee production is the world's eighth largest production (EqualExchangeCoop) and is primarily concentrated in the south-central to the southern regions of the country. Coffee production requires hot and humid climate with moderate amount of rainfall (150–250 cm) and is susceptible to extreme cold and hot weather and prolonged instances of drought (Reddy 2017). Changing climatic conditions resulting in increased spells of dry season, cold periods, low rainfall and increased frequency of extreme weather events in the Oaxaca and Tuxtla Gutierrez region of Mexico have substantially affected their coffee plantations. Subsequently disease and pest outbreaks—triggered by changing climatic conditions—have hampered the production. As coffee production is the only source of income in the region, the locals migrate in search of alternative revenue sources during times of low income.

With efforts to bring back the vigour of the coffee plantation and support a sustainable coffee production, suitable NbS interventions were applied to bring in transformative adaptation in the plantation model including:

- Introducing Agro-forestry: Designing and implementing suitable models promoting local biodiversity.
- Improving livelihood option: Promoting alternative livelihood options like promoting honey collection and harvesting, ornamental and medicinal flowers, fruits and timber collection.
- Improving water management systems: Water-efficient coffee processing, recycling water using bio-digesters.
- Improving coffee plantation practices: Limiting fertiliser use, promoting organic fertiliser, creating community-based tree nurseries.

Implementing NbS to promote the sustainable coffee production model showed excellent results. Although the primary outcome was enhanced income and revenue of the local farmers, the intangible benefits were substantial. These interventions promoted transformative adaptation through a landscape level planning to manage coffee plantation, enhancing scientific knowledge, integrating multiple stakeholders and integrating multiple sectors, thus diversifying existing livelihood options.

24.8.5 *Payment for Ecosystem Services (PES) in Kuhan: A Case Study from India*

Kuhan is a small village in the Kangra district of Himachal Pradesh in North India. Under normal conditions, the region receives high rainfall but faces water shortage due to lacking storage facilities. The village of Kuhan built a small check-dam in a river creek that runs across the village taking help from the government sponsored watershed development project. The check-dam supported irrigation needs for local agricultural practices including crop and vegetable growth. However, excessive grazing activities further upstream in the Ooch village caused deposition of silt in the reservoirs and reduced its capacity to half. Both the villages came to a consensus and established an agreement promoting Payment of Ecosystem Services (PES). The implementation of NbS model had the following results:

- Ooch banned grazing in 4 hectares of common land for 8 years.
- Ooch promoted plantation of fruit and fodder bearing trees along with bamboo and elephant grass to promote ground water recharge.
- Kuhan paid for the saplings and developed an arrangement to sell irrigation water to Ooch when required.

Implementing this strategy as an NbS intervention helped to restore irrigation by de-silting of the water creek. On a broader view, implementing PES (GlobalUNDP) helped in understanding the ecosystem and the associated ecosystem services—in this case the water—and valuing the services in decision-making. By identifying the ecosystem services people understand the importance, need and their willingness to preserve the particular ecosystem service for longer period of time thus promoting a transformative approach in planning for longer terms.

24.9 Key Entry Points

NbS may find suitable entry points in these sectors in two ways following policy-based approaches and community-led initiatives. The policy-based entry points can further be divided as per the specific goals of SDGs. Table 24.2 provides details about the possible entry points of NbS to achieve SDGs through both community-led initiatives and policy-based frameworks.

24.10 Conclusion and Way Forward

Adaptations lead to benefits, and these benefits may result in achieving long-term, mid-term and short-term targets. Implementing adaptation strategies/practices to achieve immediate results may be helpful in gaining short-term benefits; however,

Table 24.2 NbS entry points to address SDGs

	Using NbS to achieve SDGs		
Sectors	Possible entry points	Policy-based/ global frameworks	Community-led/on-ground initiatives
Agriculture	Land degradation neutrality through sustainable land management practices Sustainable consumption; sustainable production Efficient use of natural resources	UNCCD 2018–2030 strategic framework Paris COP 21 targets Post 2020 global biodiversity framework Nationally defined contributions National missions	Integrated landscape management Landscape restoration Agroforestry models Plantation models Success story: Sustainable and resilient land use management of arid desert, steppe and mountain landscapes in Uzbekistan (UNDP 2019)
Heath	Right to health Health equity Promoting mental well-being Safe living conditions Safe drinking water Improved water and sanitation	Universal health coverage Healthy life expectancy Nationally Defined Contributions National Missions	Constructed wetlands, natural infrastructure, green infrastructure Ecosystem-based risk reduction Success story: Green-grey infrastructure in small island communities in central Philippines (Fedele et al. 2019)
Water	Equitable access Affordable drinking water Water use efficiency Address water scarcity	Post 2020 global biodiversity framework Nationally defined contributions National missions Paris COP 21 targets National missions	Watershed management practices, riparian vegetation, Climate adaptation services Interlinking drainage channels Success story: Improving water efficiency in the irrigated drylands of Egypt (Sonneveld et al. 2018)

such strategies/practices may not be permanent. There may always be a tendency to revert back to the initial state culminating in mal-adaptation practices. Given the current scenario of climate change and associated challenges, SDG targets should be addressed in an integrated and inclusive way to get benefits that are persistent with long-term results. Nature-based transformative adaptations are solutions that offer long-term benefits bringing in systematic changes by: (a) future proofing adaptive strategies; (b) addressing root causes of vulnerability; (c) social and economic upliftment; (d) along with addition to natural resources, it takes into account the social and technical measures. A lot of national and international impetuses have been put into mainstreaming NbS interventions addressing the targets of SDGs and post 2015 development agenda, but often lack scientifically planned mainstreaming and need-based prioritisation of interventions.

Achieving SDGs requires realisation of its targets at local level with an action-oriented approach. It provides for an adequate mechanism for the participation of local government and communities in decision-making and benefit sharing as they are the key interface between the policy planning and implementation strategies. The governance structure and system plays an important role in identifying key entry points and streamlining implementation strategies for NbS into local actions. For example, a three-tier government structure provides three-level entry points (district and local, state and centre) for NbS to localise SDGs through—sector-specific policies, programmes and projects—a trickle-down effect. Success of on-ground initiatives depends on the sense of ownership, and communities need to develop this sense in order to localise NbS and achieve SDGs. Institutions are key players for knowledge assimilation, documentation and capacity enhancement. There is a need for industries and the private sector to focus of developing strategies embracing NbS as they play a pivotal role in contributing towards SDGs through the CSR activities they support. Inter-departmental and cross-departmental linking and affective feed-back mechanisms needs to be implement to (a) peer learning; (b) sharing of co-benefits; (c) reporting and monitoring the progress and (d) providing constructive inputs to refine existing policies as per their need.

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