LAND AND ENVIRONMENTAL MANAGEMENT THROUGH FORESTRY

Edited By
Abhishek Raj
Manoj Kumar Jhariya
Arnab Banerjee
Sharad Nema
Kiran Bargali

Scrivener Publishing

WILEY

Land and Environmental Management through Forestry

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Land and Environmental Management through Forestry

Edited by

Abhishek Raj

Manoj Kumar Jhariya

Arnab Banerjee

Sharad Nema

and

Kiran Bargali

Scrivener Publishing

WILEY

This edition first published 2023 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

Wiley Global Headquarters
111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-119-91040-4

Front cover images supplied by Pixabay.com
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

List of Editors

Abhishek Raj
Pt. Deendayal Upadhyay College of Horticulture & Forestry
Dr. Rajendra Prasad Central Agriculture University
Pusa, Samastipur, India

Manoj Kumar Jhariya
Department of Farm Forestry
Sant Gahira Guru Vishwavidyalaya
Ambikapur, Chhattisgarh, India

Arnab Banerjee
Department of Environmental Science
Sant Gahira Guru Vishwavidyalaya
Ambikapur, Chhattisgarh, India

Sharad Nema
Department of Forestry & Wildlife
Saheed Mahendra Karma Vishwavidyalaya
Bastar, Chhattisgarh, India

Kiran Bargali
Department of Botany, DSB Campus, Kumaun University,
Nainital, Uttarakhand, India

List of Contributors

Akanwa Angela Oyilieze Department of Environmental Management, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra, Nigeria

ArnabBanerjee Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur, Chhattisgarh, India

Manoj Kumar Jhariya Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur, Chhattisgarh, India

Taher Mechergui Faculté des Sciences de Bizerte, Laboratoire des Ressources Sylvo-Pastorales de Tabarka, Tabarka, Tunisie

Prabhat Ranjan Oraon Department of Silviculture and Agroforestry, Faculty of Forestry, Birsa Agricultural University, Ranchi, Jharkhand, India

Abhishek Raj Pt. Deendayal Upadhyay College of Horticulture & Forestry, Dr. Rajendra Prasad Central Agriculture University, Pusa, Samastipur, India

Bharat Lal College of Agriculture, Rani Lakshmi Bai Central Agricultural University, Jhansi (U.P.), India

Annpurna Devi Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur, Chhattisgarh, India

Ghanshyam Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur, Chhattisgarh, India

Akanwa Chimezie David Department of Environmental Management, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, (COOU) Uli Campus, P.M.B. 02, Anambra State, Nigeria

Ana Cristina Gonçalves Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Universidade de Évora, Apartado Évora, Portugal

Joe-Ikechebelu Ngozi Nneka Social Dimensions of Health, School of Public Health & Social Policy, University of Victoria, BC, Canada

Okafor Kenebechukwu Jane Department of Accountancy, Faculty of Management Science, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

Dike Keyna Department of Environmental Management, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, (COOU) Uli Campus, P.M.B. 02, Anambra State
Nkwocha Kelechi Friday Department of Geography, Faculty of Social Sciences, University of Maiduguri, Borno state, Nigeria
Idakwo Victor Iko-Ojo Department of Urban and Regional Planning, Faculty Environmental Sciences, University of Maiduguri Borno State, Nigeria
Omoruyi Fredrick Aideniosa Department of Statistics, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
Enwereuzo Angela Chinelo Department of Sociology and Anthropology, Faculty of Social Sciences, University of Benin, Edo State, Nigeria
Umeh Uche Marian Department of Community Medicine and Primary Healthcare, Chukwuemeka Odumegwu Ojukwu University (COOU) Teaching Hospital (COOUTH), Awka, Anambra State, Nigeria
Ogbuehi Emmanuel Okwudili Department of Parasitology & Entomology, Faculty of Biosciences', Nnamdi Azikiwe University, Awka, Anambra State
Agu Helen Obioma Department of Food Science & Technology, Nnamdi Azikiwe University Awka, P.M.B. 5025 Awka Anambra State, Nigeria
Dinesha S Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India
Suraj R. Hosur University of Agricultural Sciences, Dharwad, Karnataka, India
Toushif P. K. Mizoram University, Mizoram, India
Divya Bodiga Sam Higginbottom University of Agricultural, Technology and Sciences, Uttar Pradesh, India
Deepthi Dechamma N. L. KSN University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India
Ashwath M. N. Kerala Agricultural University, Thrissur, Kerala, India
Devbratha Pradhan Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal, India
Inna Koblianska Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine
Olha Kovalova Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine
Kamlesh Verma ICAR- Central Soil Salinity Research Institute, Zarifa farm, Karnal, India
Prashant Sharma Department of Silviculture and Agroforestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India
D.R. Bhardwaj Department of Silviculture and Agroforestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India

Raj Kumar ICAR-Central Soil Salinity Research Institute, Zarifa Farm, Karnal, India
Nasam Midhun Kumar Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India
Alok Kumar Singh Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India
Liliwirianis N. Faculty of Applied Sciences, Universiti Teknologi MARA Pahang, Bandar Tun Abdul Razak, Jengka, Pahang, Malaysia
Nurun Nadhirah Md. Isa Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia
Mohd Nazip Suratman Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia
Nur Nadiah Md Yusof Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Siti Khairiyah Mohd Hatta Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Siti Hasnah Kamarudin Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Norashirene Mohamad Jamil Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Siti Nurbaya Supardan Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
P. R. Oraon Department of Silviculture & Agroforestry, Faculty of Forestry, Birsa Agricultural University, Ranchi, Jharkhand, India
Vidya Sagar Department of Silviculture & Agroforestry, Faculty of Forestry, Birsa Agricultural University, Ranchi, Jharkhand, India
Kumari Beauty Forest Research Centre for Eco-Rehabilitation, Prayagraj, U.P., India
Pawan Ekka Department of Environmental Sciences, Central University of Jharkhand, Ranchi, India
Subhashree Patra Department of Environmental Sciences, Central University of Jharkhand, Ranchi, India
Purabi Saikia Department of Environmental Sciences, Central University of Jharkhand, Ranchi, India
Manjari Upreti Department of Geoinformatics, Central University of Jharkhand, Ranchi, India
Gajendra Kumar Department of Geoinformatics, Central University of Jharkhand, Ranchi, India

Amit Kumar Department of Geoinformatics, Central University of Jharkhand, Ranchi, India
Venkatesan Shiva Shankar Faculty of Environmental Science, ANCOL, Chakargaon, Port Blair, Andaman and Nicobar Islands, India
Neelam Purti Department of Environment and Forest, Manglutan Range, South Andaman Forest Division, Andaman and Nicobar Islands, Port Blair, India
Satyakeerthy TR IGNOU Regional Centre, Trivandrum, Kerala, India
Sunil Jacob Department of Chemistry, Catholicate College, Mahatma Gandhi University, Pathanamthitta, India
Krishan Pal Singh College of Horticulture and Research Station, IGKV, Bastar, India
Beena Singh S.G. College of Agriculture and Research Station, IGKV, Bastar, India
Anup P. Upadhyay Indian Institute of Forest Management (IIFM), Bhopal (M.P.), India
Bhimappa Honnappa Kittur Indian Institute of Forest Management (IIFM), Bhopal (M.P.), India

Preface

Land degradation and its inappropriate uses affect soil health and other natural resources. Unsustainable land use practices, including intensive agriculture and deforestation activity, deprive soil of its quality, biodiversity and environmental services. Now, land degradation has become a global issue discussed by numerous institutions, and its management is of utmost importance for ensuring environmental sustainability. Large percentages of forest land, 20% of agricultural and 10% of grass land are under land degradation severity due to anthropogenic activities. Similarly, land degradation and desertification affect 2.6 billion people in a hundred countries which cover approximately 33% of the global land surface. Land degradation, climate change and biodiversity losses are strongly linked to poor environmental health and services. Poor environmental health, services and its sustainability are further amplified by land degradation including deforestation and intensive land use practices. Land degradation can be reversed through practicing sustainable forest management including better restoration and rehabilitation. Therefore, sustainable land use and management is a key step towards better environmental sustainability which can be possible through managing forests in sustainable ways. To address such diverse issues of land degradation and how a sustainable land management practices including forestry, agroforestry and other practices can be effectively utilized to minimize negative consequences is the central theme of the book.

This book, *Land and Environmental Management through Forestry,* covers the diverse issues of land degradation in developed and developing nations and its restoration through forestry, agroforestry and other practices. Textbooks are available in the global market that address specific issues on agriculture, its production and associated environmental consequences. The present title would integrate all the concepts into a single dimension from which various scientists, research scholars, academicians, and policymakers can benefit from updated information. New insights are very important in this particular aspect as our very existence depends on forest sustainability and land restoration management.

The present title consists of chapters addressing the issue of land degradation, deforestation, intensive agriculture practices, sustainable intensification, soil and forest related services, land and environmental management, and overall sustainability of the land-related ecosystem. The present book consists of some specific research case studies considering geospatial technologies in monitoring land degradation and its environmental repercussions. Case studies on farmland evaluation for soil quality and land use assessment are also included. Deforestation activities, climate change risks and related consequences along with its mitigation and adaptation are presented in this book. These will provide new insights into the field of land and environmental management. Some titles update the reader about the current scenario on the issue of land/soil degradation, desertification, deforestation, erosion, afforestation activities, agroforestry, food security, sustainable intensification, resource conservation, sustainability and services, and soil and plant management. Therefore, the present title would help to address current issues and their management holistically. The objectives that will be fulfilled by the present title are as follows: (1) present context of land degradation and its problem, (2) identify the key areas of research in the field of land restoration, and sustainable land management including forestry and agroforestry for environmental management, (3) identify the land-based services and their potential role for ecosystem sustainability, (4) raise awareness around the globe in this context so that future policies can be framed from this for the betterment of human civilization, and (5) address sustainable intensification for land and environmental management and services.

This book will be a standard reference work for disciplines such as forestry, agriculture, ecology and environmental science as well as being a way forward towards strategy formulation for combating climate change. It will help academicians, researchers, ecologists, environmentalists, students, capacity builders, and policymakers gain an in-depth knowledge in the diverse field. Eminent academicians and scientists across the globe would be invited related to the theme of the book to share their scientific innovation, research outputs, views, and opinions, an experience that would enlighten the academic community. Each of the chapters has good scientific support in terms of scientific database, diagrams, tables, graphs, images, pictures, and flowcharts as per the requirement with proper recent updated citation. All the chapters would be thoroughly reviewed by the respective individual of a specific discipline which would enrich the chapter content from a future research perspective. The submission would be reviewed by the editorial team for further upgradation. It would set a roadmap for the preparation of sustainability in forestry which ensures eco-restoration of the land degradation in the future. The editors would appreciate receiving comments from readers that may assist in the development of future editions.

Abhishek Raj
Pusa, Samastipur, India
Manoj Kumar Jhariya
Ambikapur, Chhattisgarh, India
Arnab Banerjee
Ambikapur, Chhattisgarh, India
Sharad Nema
Bastar, Chhattisgarh, India
Kiran Bargali
Nainital, Uttarakhand, India

1

Land Degradation and Restoration: Implication and Management Perspective

Abhishek Raj[1], Manoj Kumar Jhariya[2*], Arnab Banerjee[3], Sharad Nema[4] and Kiran Bargali[5]

[1]Pt. Deendayal Upadhyay College of Horticulture & Forestry, Dr. Rajendra Prasad Central Agriculture University, Pusa, Samastipur, Bihar, India
[2]Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[3]Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[4]Department of Forestry & Wildlife, Saheed Mahendra Karma Vishwavidyalaya, Jagdalpur, Bastar (C.G.), India
[5]Department of Botany, DSB Campus, Kumaun University, Nainital (Uttarakhand), India

Abstract
Presently, land degradation is a global concern discussed by numerous institutions and its management is of utmost important for ensuring environmental sustainability. As per ISRO (2019), approx. 97.85 M ha of land is degraded and 3.32 M ha of degradation was reported between 2005 and 2019 (last five years) in India. Almost 30% of the country's geographical areas are under desertification, which is a major environmental problem. Thirty percent of 71 M ha forest land, 20% of agricultural and 10% of grass land are under land degradation severity due to anthropogenic activities. Similarly, land degradation and desertification affect 2.6 billion people in a hundred countries which cover approximately 33% of global land surface. These figures are enough to express a global scenario of land degradation in the world. Land degradation, climate change and biodiversity losses are strongly linked to poor environmental health and services. Poor environmental health, services and its sustainability are further amplified by land degradation including deforestation and intensive land use practices. Land degradation vulnerability (LDV) is also observed due to poor vegetations and soil quality under

**Corresponding author*: manu9589@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (1–22) © 2023 Scrivener Publishing LLC

climate change that jeopardize ecosystem health and environmental sustainability. In this context, land degradation can be reversed by practicing sustainable forest management including better restoration and rehabilitation. Moreover, UNCCD also introduced the term LDN (land degradation neutrality) which represents land management for enhancing ecosystem services including soil-food quality and its sustainability. Therefore, sustainable land use and management is a key step towards better environmental sustainability which can be possible through managing forests in sustainable ways. Constructive policy and institutional supports are required to sustainable land and environmental management through better forestry practices.

Keywords**:** Afforestation, desertification, ecosystem services, land degradation, restoration

1.1 Introduction

Land is a key terrestrial resource that delivers uncountable ecosystem services including food, fiber and shelters. Land degradation is a continuous process propelled by natural, climatic and various anthropogenic activities. Deforestation, intensive agriculture, mining and several other developmental projects deteriorate land quality and related environmental services. Erosion, desertification, waterlogging condition, salinization, and organic matter depletions are key drivers for land quality deterioration [1]. Land degradation affects biodiversity along with ecosystem health and productivity. Land degradation alters physical, chemical and biological properties that affect biology, economy and quality of land. Soil acidity, salinization, lesser SOC, erosion, desertification, soil compactions result in unproductive land which reduces plant health and productivity [2]. Unscientific farming, urban sprawl, improper irrigation, land clearance and overgrazing are key causes of degradation. Moreover, industrial waste and quarrying of sand, stone and minerals resulted in land pollution [3]. Land degradation also affects various environmental services including regulation of fresh water quality, climate regulation, clean air quality, soil fertility, plant productions and recreational opportunities globally [4, 5]. Land degradation also affects hydrological and biogeochemical cycles [6]. Around 60% of global land area has been degraded by various natural and anthropogenic factors [7]. Land degradation deteriorates environmental health and productivity [8]. Nearly 40.0 billion USD has been lost due to annual degradation of land resource in the world [9]. Therefore, it has negative consequences on the environment and affects soil-food-climate security. Approx. 18.10 M Km^2 areas are reported as degraded lands of which 92% and 38% are due to mismanagement and overgrazing of animals [10]. Similarly, 30%, 20% and 10% of forests, arable land and grasslands, respectively, have been affected negatively due to land degradation which influenced 1.50 billion people of the world [11]. A total 50% of arable land comes under moderate to severe degradation. Land degradation affects 1.50 billion people in the world. Every year approx. 15.0 billion tons of soil losses occur, whereas desertification and drought lead to 12.0 m ha^{-1} soil degradation. Land degradation also affects biodiversity through loss of 27,000 species annually. The risk of dry land has been prevalent in 110 countries which affected approximately 250 million people globally. Moreover, a desertification cost was reported as 42 million dollars globally [10].

In this context, land restoration is an urgent need which minimizes negative consequences on our environment. Managing forests is a good weapon to manage land, soil, water and other natural resources in this climate change era. Afforestation activities, ground cover plantations, conservation agriculture, organic agricultural practices, and a sustainable land use system ensure healthy land/soil and related parameters [12]. Thus, land degradation nowadays has become a big environmental challenge which needs a scientific and holistic approach for healthy land management that ensures environmental sustainability and ecological stability on a long-term basis [13].

The present chapter will address the land degradation in developed and developing nation and its restoration through sustainable land use practices. Impacts of land degradation and desertification on soil, water, food and other resource induced environmental changes are also discussed. Land reclamation through forestry by practicing SFM and other sustainable land use system are included in this chapter. It will also focus on new insights related to updated research, development and policy-oriented afforestation activities for combating C footprints and climate change issue for better ecosystem health and productivity through sustainable land management approach.

1.2 Land Degradation in Developed and Developing World

Land is lithospheric component of environment which provides many valuable direct and indirect services including food, air and water for sustaining peoples and biodiversity. Land resource is degraded continuously due to excessive pressure by intensive agricultural practices, deforestation, urbanization and cattle ranching beyond carrying capacity of the land. Unsustainable land use practices and its frequent changes along with its expansion put ecosystem health and its services in danger. The degradation of land and its resources is not confined in limited regions but is expanded throughout the globe, especially in developing countries. Land degradation is maximum in Asia followed by Africa and European countries. A global map has been created by the World Atlas of Desertification for assessment of land productivity and changes during the period 1999-2013 [14]. Similarly, land degradation due to desertification incurred 490 USD billion yr^{-1} of the cost which affects the health and economy of 3.20 billion people. Europe and Central Asia (ECA) countries have a diversified ecosystem for people sustenance but they are facing land degradation issues and various environmental challenges [15]. However, there is a blurred map on the severity and extent of land degradation that countries have been facing from the past [16]. IPBES has also discussed land degradation scenarios in India, Asia, Europe and other countries of the world in its recent report [17]. Approx. 10-60 million Km^2 areas were reported as land degradation globally, which corresponds to ice-free land area of 8-45%. This assessment has been based on a global map sketched by experts, their opinion arrived at by using satellite observatory, biophysical models and abandoned agricultural lands database [18]. Remote sensing-based satellite date including NOAA AVHRR data has reported land degradation with approx. 22-24% of the world ice-free land area in downward trend whereas increasing trends were shown by 16% respectively in the period 1983-2006 [19]. Similarly, 29% of land area is reported as "land degradation hotspots" globally which needs serious attentions for its management. Globally, land degradation affected 3.20 and 1.33 billion people of which 95% were in developing countries [20, 21]. Also, different soil erosion model (RUSLE) was used to identify soil erosion-based land degradation in the regions of Southeast Asia, Africa and South America [22, 23].

1.3 Land Degradation Impacts on Biodiversity and Ecosystem Services

Land degradation and its inappropriate uses destroy soil quality and other natural resources. Unsustainable land use practices including intensive agriculture and deforestation activity deprive soil quality, biodiversity and environmental services. It affects biodiversity and uncountable ecosystem services in extensive ways. It refers to many direct and indirect processes that induce biodiversity losses and decline ecosystem services [24]. An ecosystem services value (ESV) and its reduction percentage under land degradation of the world is depicted in Figure 1.1 [25].

Land is an important terrestrial environmental component which supports many flora and fauna. Many drivers affect land quality which leads to 75% of land degradation globally. It has negative consequences on the well-being of 3.20 billion people along with 10% of global income loss due to poor biodiversity and ecosystem services. Land degradation minimizes the variety of ecosystem services (ES) such as timber, fuelwood and fiber [26]. Therefore, land degradation drivers should be identified for reversing

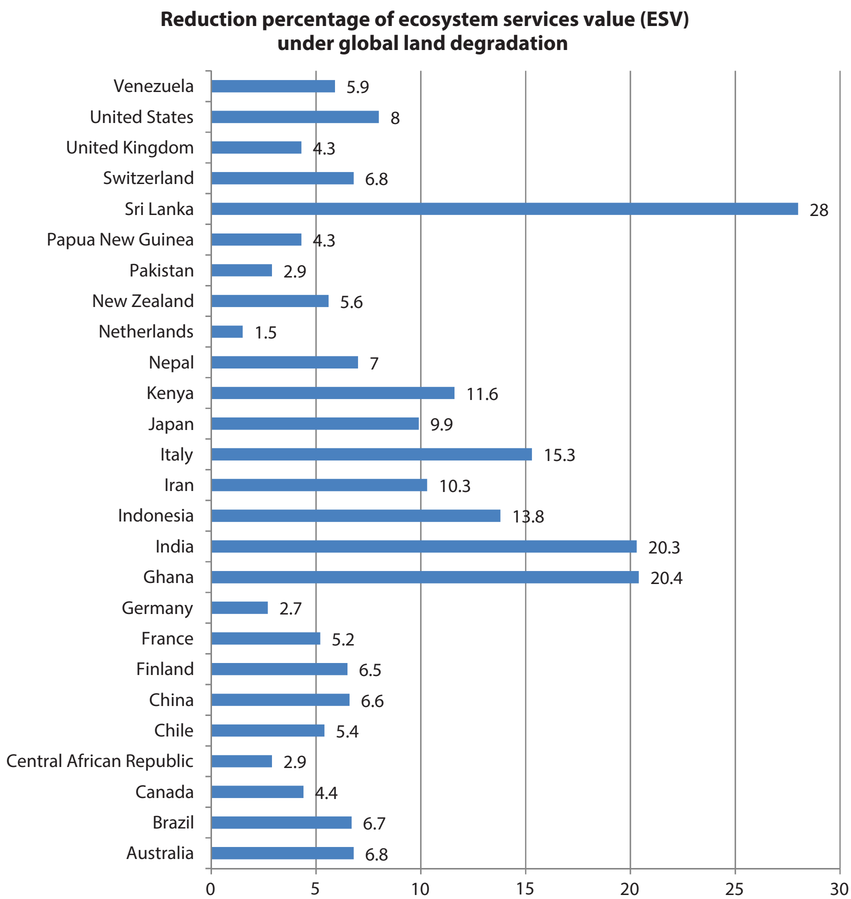

Figure 1.1 Ecosystem services value (ESV) and its reduction percentage under global land degradation [25].

negative consequences on biodiversity which further can be controlled by effective scientific management [27].

1.4 Land Degradation and Restoration: A Response Framework

There is a great link between direct and indirect responses while addressing land degradation. Appropriate indirect responses can support and enable the direct responses which tackle various parameters of land degradation [28]. Anthropogenic assets including human and physical resources, legal framework, regulatory instruments, effective policy, good governance, socio-cultural and financial instruments are indirect responses [29]. These responses include management activities which directly affect various identified degradation drivers or many biophysical processes such as land-soil-water management in sustainable ways. However, both direct and indirect responses are interlinked and dependable and comprise possible response strategies which are more or less suitable as per nature, extant and severity of land degradation [30]. Therefore, effective management of these direct or indirect responses and their proper regulation can help in achieving the goals of land restoration and maintain the resilience of socio-ecological systems [31].

1.5 Soil Erosion and Desertification: Problems and Challenges

Soil erosion is major form of land degradation which becomes a global challenge. It causes loss of agricultural productivity due to heavy loss of essential nutrients. As per one figure of FAO-led Global Soil Partnership, a loss of approximately 75 billion ton (Pg) of soil from agricultural land leads to a heavy economic loss of 400 billion USD yr^{-1} globally [32]. Sheet erosion, mass erosion, water erosion and landslides are various types of soil erosion. Landslides occur frequently due to deforestation, mining, road construction, hydropower projects and several other developmental works [33]. Soil erosion causes loss in plant productivity and surface water quality in an agricultural system [34]. It affects many ecosystem services by reducing soil health and fertility, crop productivity, water quality and overall environmental health and sustainability [35]. Inappropriate land management causes severe soil erosion on 175 million ha of the total geographical area of India. In this context, adopting a sustainable land use system and its scientific management through afforestation, conservation agriculture, and mulching minimizes soil erosion. Moreover, vegetation covers and its litter production along with canopy interception check soil erosion and keep soil healthy and productive for sustainable environment [36, 37]. Similarly, desertification is another form of land degradation that prevailed in arid, sub-humid and semi-arid regions especially in dry lands areas due to climatic and anthropogenic activities. However, the extent and severity of desertification has increased over many decades. As per one figure, approximately 46.20% of world land areas covered by drylands can support 3 billion people. Desertification hotspots have been identified by poor vegetation productivity due to expansion of dryland areas as 9.20%, which directly affected 500 million people globally in 2015. The people of Southeast Asia, Africa, and the Middle East including the Arabian Peninsula are greatly affected by the negative consequences of desertification and land degradation [38].

1.6 Forest Degradation

Deforestation, illicit felling of trees, and overharvesting of timber induce land degradation. Declining forest covers and vegetation losses affect the health and quality of land. Approximately 3% of forest land areas declined in the period 1990-2015 as reported by FRA (Forest Resources Assessment) and FAO [39, 40]. Similarly, 2.80% of forest area losses have been reported in the period 1990-2010 through global remote-sensing assessment. Further, 55,000 km^2/year and 39.61 M km^2 areas of tropical forest and global natural forest was lost in the years 2010 to 2015 and 1990 to 2015 [41]. Both deforestation and land degradation have contributed 77% and 10% of emissions from land use changes since 1850 [42]. Deforestation and land degradation cause CO_2 (GHGs) emissions into the atmosphere resulting in earth's warming, C footprint and climate change. Carbon losses varied from 25 to 70% from deforestation and land degradation [43]. Of the total 2.1 Gt CO_2 yr^{-1} of gross emissions, 53%, 30% and 17% were contributed by illicit timber harvesting, fuelwood removal, and frequent forest fires, respectively [44]. IPCC has reported 23% of anthropogenic GHGs (CO_2, CH_4 and N_2O) emissions in the world contributed by AFOLU [45]. In this context, management and conservation of tropical forest maintains vegetation diversity, biomass and carbon storage and flux within the forest ecosystem [46, 47]. Thus, adopting a climate resilient land use system ensures less C emission, healthy and productive land along with higher forest cover [48].

1.7 Land Restoration

Restoration term represents ecosystem recovery from a degraded state through any intentional activity [24]. Ecosystem restoration through land management is utmost for environmental health and ecological stability. The UN has stressed the slogan "Decade on Ecosystem Restoration" which targeted degraded land restoration and its management. Similarly, SDG 2030 has targeted land restoration activities which are mentioned in Target 15.3 representing achieving land degradation neutrality [49]. The restoration process includes avoiding, reducing and reversing of land degradation through practicing SLM (sustainable land management) system. Addressing land degradation drivers through effective measures and its regulations, planning and management practices comes under "Avoiding land degradation". Land degradation mitigation through sustainable land use system including SFM practices and soil, water management comes under "Reducing land degradation". Rehabilitation and restoration of unproductive lands for ecosystem recovery and greater ecological services comes under "Reversing land degradation" [50]. A Restoration commitment by country (in hectares) is depicted in Figure 1.2 [51]. Afforestation and other cost-effective measures employ degraded and wasteland for reversing land health and quality which further ensures soil, food and climate security for the long term [52]. Soil, water and biodiversity are the key land resources and their health resilience is largely determined by sustainable forest management practices and good governance under environmental changes. IPCC has also emphasized SFM practices for minimizing land degradation and desertification. SFM not only manages land sustainability but also mitigates C footprint and climate change through better C sequestration potential. Thus, SFM ensures land management which entirely enhances biodiversity, soil-food-climate security and other environmental services for the long term [53, 54].

1.8 Ecological Restoration of Degraded Land through Afforestation Activities

Land degradation affects ecosystem health and ecological stability. It minimizes various ecosystem services which is of utmost importance for environmental health and sustainability. Ecological restoration of wasteland or degraded land through sustainable land use system including afforestation techniques would be a viable tool for better land quality. SFM including

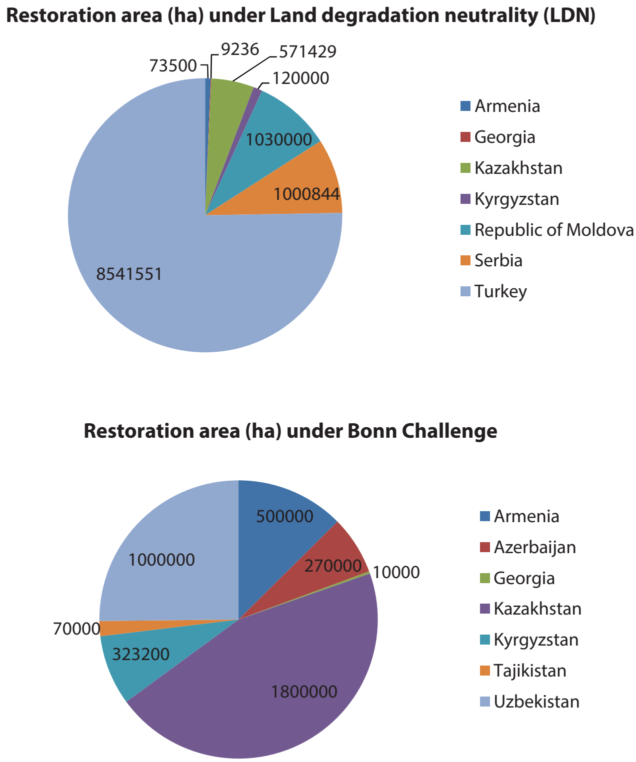

Figure 1.2 Land restoration commitments by country under LDN and Bonn challenge (in hectares) [51].

afforestation or reforestation techniques improves health and quality of land. Afforestation including leguminous or MPTs restore land fertility through better soil quality by addition or decomposition of nutrient rich litters. Litter decomposed continuously releases essential nutrients to plant along with land restoration which maintains ecosystem health and ecological stability [55]. Forest restoration through afforestation helps in ecological restoration of degraded land which provides various ecosystem services. Many degraded lands are targeted for afforestation program for betterment of ecology and environment. Moreover, a CA (Compensatory afforestation) 2 billion ha of land areas were suitable for land restoration program recommended by the World Resource Institute (WRI) [56]. Increasing forest covers through afforestation in parallel to cropland and grazing land reduction on a long-term basis were reported in European countries such as Sweden, the Netherlands, Austria, Romania, Albania, Germany, United Kingdom, Italy and Denmark in the 19th and 20th centuries [57]. However, employing afforestation with SFM techniques, forest conservation and restoration, sustainable intensification with decreasing deforestation can help in reducing land degradation and ensure greater C storage and flux [58]. Thus, promotion of afforestation techniques with SFM minimizes land degradation and leads to greater environmental health and ecological stability.

1.9 Achieving Land Degradation Neutral (LDN) through Sustainable Land Use Management (SLM)

LDN (Land degradation neutral) is the most recent and greatest tool for ecosystem restoration by improving land quality by practicing SLM. The LDN concept was first introduced into the global platform by global talk of UNCCD which was further recognized by the national and international community in Rio+20 conference which was held in 2012 [59]. This concept was considered as part of the 2030 agenda for SDG in 2015 [60]. A total 122 countries have adopted LDN under different policies and governance for land restoration and rehabilitation. A sustainable land use system including SFM, afforestation program, agroforestry practices and conservation agriculture ensures LDN which is economically, socially and politically sound. Land restoration through SLM ensures higher SOC pools by effective C sequestration which promise climate resilient ecosystem [61, 62]. SLM comprising agroforestry practices ensure climate resilient ecosystem which restore land quality [63, 64]. Many national and international organizations have supported the LDN concept which is the pillar for land restoration and its sustainability. UNCCD, GSP (Global Soil Partnership), GEF (Global Environmental Fund) and WOCAT have complemented the LDN concept. These organizations targeted land restoration globally by achieving LDN through practicing SLM. Moreover, SDG 15 (life on land) especially 15.3 has targeted to achieve LDN by 2030 [15]. Similarly, the LDN concept also mitigates C footprint and climate change issue along with ecosystem restoration of degraded land through SLM practices [65, 45]. Similarly, a different model, its scale and types were used to assess the SLM effects on ecosystem, which is depicted in Table 1.1 [2].

Table 1.1 Models to assess the effects of sustainable land management on ecosystem [2].

Models	**Scale**	**Type of models**	**Descriptions**
CropSyst model	At field scale	A process-based model (PBM)	This model assessed the SLM effects on both productivity and environment
DNDC model	From plot to field scale	Biogeochemistry computer simulation (BCS) based model used in agro-ecosystems	This model assessed GHGs emissions, SOC pools and plant productivity in agricultural system
APSIM model	From field to farm scale	Identified as "agro-ecosystem process-based model"	This model analyzed management effects on agro-ecosystem diversity and its productivity which comprises plant, soil, animals, water, nutrient, and other resources. Different soil processes, erosion and N and P transformations are also assessed in this model
CENTURY model	From field to farm scale	Identified as "agro-ecosystem process-based model"	This model analyzed management effects on dynamics of nutrients under farm scale
EPIC model	From field to farm scale	Identified as "agro-ecosystem process-based model"	This model analyzed management effects on water, pesticides and soil nutrients movements in different agro-ecosystems
APEX model	At watershed scale	Landscape-based model	This model analyzed management effects on watershed sustainability, water quality and its supply, different soil state and its erosion, economics, etc.

(*Continued*)

Table 1.1 Models to assess the effects of sustainable land management on ecosystem [2]. (*Continued*)

Models	**Scale**	**Type of models**	**Descriptions**
DSSAT model	From farm to regional scale	Cropping system model (CSM) based software	Used to assessed precision management along with analyzing climatic variability and its impact on cropping systems
STICS model	From plot to regional scale	A process-based model (PBM)	This model assesses environmental impacts by analyzing GHGs emissions and nitrate leaching
LPJmL model	At world scale	Identified as "Dynamic global vegetation models" (DGVM)	This model analyzed terrestrial carbon cycle and assessed climate change impacts on vegetation patterns for agricultural ecosystems
ORCHIDEE model	From local to world scale	Identified as "Dynamic global vegetation models" (DGVM)	This model assessed water energy and carbon dynamics under both natural and human managed ecosystems from site to globe scale
CARAIB model	At regional scale	Identified as "Dynamic global vegetation models" (DGVM)	Quantified the net primary productivity of forest vegetation
World3 model	At world scale	IGM (Integrated global model)	This model involves five different sectors including agriculture, capital, population, non-renewable resources, and pollution in the environment

(*Continued*)

Table 1.1 Models to assess the effects of sustainable land management on ecosystem [2]. (*Continued*)

Models	Scale	Type of models	Descriptions
IMAGE model	At world scale	IGM (Integrated global model)	This model works at global scale and incorporates different earth components comprising atmosphere, hydrosphere (oceans), anthroposphere and biosphere
IF model	Regional scale	IGM (Integrated global model)	This model includes seven different sub-models such as agriculture, environment, population, energy, economy, social, international policy
TARGETS model	At world scale	IGM (Integrated global model)	This model consists of five different sub-models which include population, energy, land, food, and water
GUMBO model	At world scale	IGM (Integrated global model)	This was first model that works on a global scale which includes the economical production system and its consistent welfare, ecosystem services of goods and dynamic feedbacks among human technology

1.10 Sustainable Soil/Land Management: Challenge and Opportunities

Land degradation is a big challenge faced by many countries globally. Sustainable soil/land management supports many organisms or resources including forest, agriculture, soil, animals, etc. These resources in integrated form perform better ecosystem function for ensuring environmental sustainability. Deforestation, intensive agriculture practices, overexploitation of land/soil resources beyond carrying capacity, soil erosion and mismanagement practices destroy land quality, which become major challenges. However, a great opportunity exists for land or soil management through scientific techniques including SFM, sustainable agriculture practices, afforestation and conservation agriculture. SLM includes key strategies that integrate all resources such as water, soil, and livestock for ensuring higher productivity and profitability through greater biodiversity. This concept improves land quality and provides many tangible and intangible services including food, fiber, NTFPs along with soil and climate management [66]. Thus, SLM is a great opportunity for researchers, policy makers and scientists for rejuvenating soil health and fertility by minimizing the extent and severity of land degradation.

1.11 Policy and Roadmap For Land Management and Sustainability

The extent of land degradation, its severity and consequences have already been discussed by policy makers, researchers, academicians, and stakeholders at national and international platforms. However, a policy and future roadmap must be reformed as per the nature and severity of land degradation. An effective policy is needed for minimizing negative consequences of land/soil degradation which occurs due to many anthropogenic or natural drivers. Intensive agriculture practices, deforestation, excessive timber felling and resource exploitation induce soil and water erosion, landslides and other losses. These consequences affect biodiversity and ecosystem services globally. In this context, policy-oriented strategies and a roadmap must be sketched scientifically to promote climate resilient land use practices that ensure greater land quality with higher productivity, profitability and environmental sustainability. However, the success of a land restoration program is quietly dependent on social, economic, biophysical and political considerations [67].

A location-specific scientific design is employed for a successful land restoration program. Degraded land must be carefully targeted for ecosystem restoration which can be possible through practicing SFM, sustainable agriculture and afforestation program. A restoration investment must be framed in current and future roadmaps for avoiding, reducing or reversing land degradation. Minimizing soil erosion and desertification, climate change mitigation, poverty eradication and enhancing food security are benefits that can be achieved through a land restoration program [38]. A good policy, governance and institutional support are needed for proper management of land/soil which promises soil-food-climate security in sustainable ways. Therefore, recent policy construction and its timely implementation are prerequisites for healthier and more productive land [68].

1.12 Conclusion

Land degradation is the biggest challenge of the world and needs proper care and management for ecosystem restoration. Poor land quality minimizes ecosystem services due to less productive soil and biodiversity. Deforestation and unsustainable land use practices including intensive agriculture system destroy soil fertility and emit GHGs into the atmosphere, which causes C footprint and climate change. Desertification, soil erosion, water instability, climate change and less SOC pools were negative consequences due to land degradation. In this context, a sustainable land use system including SFM, conservation agriculture, and afforestation ensures healthier and productive lands that maximize environmental health and sustainability. SFM ensure land restoration and soil, food and climate security along with addressing environmental health issues. Climate resilient land use practices would be promoted in degraded land and desertification areas in the tropics. Therefore, a good policy and effective governance are needed to regulate land degradation consequences and its scientific management promise greater biodiversity and ecosystem services.

References

1. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021, ISBN 978-981-15-9495-3, pp. 221-246, 2021.

2. Turner, K.G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., Dominati, E., Kubiszewski, I., Ogilvy, S., Porfirio, L. & Ratna, N., A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. *Ecological Modelling*, *319*, 190-207, 2016.
3. Eswaran, H., Lal, R. & Reich, P.F., Land degradation: an overview. *Responses to Land* Degradation. 10, 20-35, 2001.
4. UNEP, Inclusive Wealth Report 2012. *Measuring Progress Toward Sustainability*. Cambridge University Press, Cambridge, 2012.
5. Von Braun, J., Gerber, N., Mirzabaev, A. & Nkonya, E., The Economics of Land Degradation ZEF Working Paper Series. In: *Working Paper* 109, 2013.
6. Brevik, E.C., Cerdà, A., Mataix-Solera, J., Pereg, L., Quinton, J.N., Six, J. & Van Oost, K., The interdisciplinary nature of SOIL. *Soil*, 1(1), 117-129, 2015.
7. Pimentel, D., Soil erosion: A food and environmental threat. *Environment, Development and Sustainability*, 8, 119-137, 2006.
8. UNEP, United Nations Environment Program, Global Environment Outlook (GEO-4), Nairobi, p. 572, 2007.
9. ELD Initiative, The rewards of investing in sustainable land management. Interim Report for the Economics of Land Degradation Initiative: A global strategy for sustainable land management, The Economics of Land Degradation (ELD) Initiative. 2013.
10. Hamdy, A. & Aly, A., Land degradation, agriculture productivity and food security. In Fifth International Scientific Agricultural Symposium. Presented at the Agrosym. 2014.
11. Bai, Z., Dent, D., Olsson, L. & Schaepman, M.E., *Global Assessment of Land Degradation and Improvement. 1. Identification by Remote Sensing*. Wageningen, The Netherlands, 78 pp, 2008.
12. Toor, M.D., Adnan, M., Raza, A., Ahmed, R., Arshad, A., Maqsood, H., Abbas, F., Shehzad, M.H. & Zafar, M.K., Land degradation and its management: A review. *International Journal of Environmental Sciences & Natural Resources*, *25*(2), 63-66, 2020.
13. Pandit, R., Parrotta, J.A., Chaudhary, A.K., Karlen, D.L., Vieira, D.L.M., Anker, Y., Chen, R., Morris, J., Harris, J. & Ntshotsho, P., A framework to evaluate land degradation and restoration responses for improved planning and decision-making. *Ecosystems and People*, 16(1), 1-18, 2020.
14. Cherlet, M. *et al*., *World Atlas of Desertification*. 3rd edition. Publication Office of the European Union, Luxemburg, 248 pp, 2018.
15. FAO, Overview of land degradation neutrality (LDN) in Europe and Central Asia. Rome. 2022. https://doi.org/10.4060/cb7986en
16. van der Esch, S., ten Brink, B., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H., van den Berg, M., van den Born, G.J. & Doelman, J., *Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: scenarios for*

the UNCCD Global Land Outlook. Netherlands Environmental Assessment Agency, The Hague, The Netherlands, 116 pp, 2017.
17. Montanarella, L., Scholes,R. & Brainich, A., *The IPBES Assessment Report on Land Degradation and Restoration. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, Bonn, Germany. 744 pp, 2018. doi: 10.5281/zenodo.3237392.
18. Gibbs, H.K. & Salmon, J.M., Mapping the world's degraded lands. *Appl. Geogr*., 57, 12–21, 2015. doi:10.1016/J.APGEOG. 2014.11.024.
19. Bai, Z.G., Dent, D., Olsson, L., Tengberg, A., Tucker, C. &Yengoh, G., A longer, closer, look at land degradation. *Agric. Dev.,* 24, 3–9, 2015.
20. Le, Q.B., Nkonya, E. & Mirzabaev, A., Biomass Productivity-Based Mapping of Global Land Degradation Hotspots. In: *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development* [E. Nkonya, A. Mirzabaev, and J. Von Braun, (eds.)]. Springer International Publishing, Cham, Switzerland, pp. 55–84, 2016.
21. Barbier, E.B. & Hochard, J.P., Land degradation and poverty. *Nat. Sustain*., 1, 623–631, 2018. doi:10.1038/s41893-018-0155-4
22. Labrière, N., Locatelli, B., Laumonier, Y., Freycon, V. & Bernoux, M., Soil erosion in the humid tropics: A systematic quantitative review. *Agric. Ecosyst. Environ*., 203, 127–139, 2015. doi:10.1016/J.AGEE.2015.01.027.
23. Borelli, P., Panagos, P., Märker, M., Modugno, S. & Schütt, B., Assessment of the impacts of clear-cutting on soil loss by water erosion in Italian forests: first comprehensive monitoring and modeling approach. *CATENA* 149, 770–781, 2017.
24. IPBES, Summary for policymakers of the assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services. Scholes R, Montanarella L, Brainich A, Barger N, TenBrink B, Cantele M, Erasmus B, Fisher J, Gardner T, Holland TG, *et al*., editors. Bonn (Germany): Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; p. 44. 2018.
25. Sutton, P.C., Anderson, S.J., Costanza, R. & Kubiszewski, I., The ecological economics of land degradation: Impacts on ecosystem service values. *Ecological Economics*, 129,182-192, 2016.
26. Kadykalo, A.N., López-Rodriguez, M.D., Ainscough, J., Droste, N., Ryu, H., Ávila Flores, G., Harmáčková, Z.V., Muñoz, M.C., Nilsson, L. & Rana, S., Disentangling 'ecosystem services' and 'nature's contributions to people'. *Ecosyst People,* 15(1), 269–287, 2019. doi:10.1080/26395916.2019.1669713.
27. Lal, R., Safriel, U.& Boer, B., Zero net land degradation: a new sustainable development goal for Rio+ 20. A report prepared for the secretariat of the United Nations convention to combat desertification, 2012. http://www.unccd.int/Lists/SiteDocumentLibrary/secretariat/2012/Zero%20Net%20Land%20Degradation%20Report%20UNCCD%20May%202012%20background.pdf

28. Millennium Ecosystem Assessment (MEA), *Ecosystems and human well-being: synthesis*. Washington (DC): Island Press, 2005.
29. SERI, The SER international primer on ecological restoration, 2004. www.ser.org
30. Mansourian, S. & Parrotta, J.A., The need for integrated approaches to forest landscape restoration. In: Mansourian S, Parrotta JA, editors. *Forest landscape restoration: integrated approaches to support effective implementation*. New York (USA): Routledge; pp. 3–15, 2018.
31. Sala, J.E. & Torchio, G., Moving towards public policy-ready science: philosophical insights on the social-ecological systems perspective for conservation science. *Ecosyst People*. 15(1), 232–246, 2019. doi:10.1080/26395916.2019.1657502
32. GSP. Global Soil Partnership Endorses Guidelines on Sustainable Soil Management 2017. Available at: http://www.fao.org/ global-soilpartnership/resources/highlights/detail/en/c/416516/ (accessed 15 October 2021)
33. Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K.M.& Franzluebbers, A.J., Soil degradation in India: Challenges and potential solutions. *Sustainability*, *7*(4), 3528-3570, 2015.
34. Issaka, S. & Ashraf, M., Impact of Soil Erosion and Degradation on Water Quality: A Review. *Geol. Ecol. Landsc.*, 1, 1–11, 2017.
35. Lal, R., Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability*, 7, 5875–5895, 2015.
36. Oliveira, P.T.S., Nearing, M.A. & Wendland, E., Orders of magnitude increase in soil erosion associated with land use change from native to cultivated vegetation in a Brazilian savannah environment. *Earth Surf. Process. Landf.*, 40, 1524e1532, 2015.
37. Anache, J., Wendland, E., Rosalem, L., Youlton, C. & Oliveira, P., Hydrological Trade-Offs Due to Different Land Covers and Land Uses in the Brazilian Cerrado. Hydrol. *Earth Syst. Sci.*, 23, 1263–1279, 2019.
38. Mirzabaev, A., Wu, J., Evans, J., García-Oliva, F., Hussein, I.A.G., Iqbal, M.H., Kimutai, J., Knowles, T., Meza, F., Nedjraoui, D., Tena, F., Türkeş, M., Vázquez, R.J. & Weltz, M., Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley (eds.)]. In press, 2019.
39. Sloan, S. & Sayer, J.A., Forest resources assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. *For. Ecol. Manage.*, 352, 134–145, 2015. doi:10.1016/J. FORECO.2015.06.013.

40. FAO, Global Forest Resources Assessment 2015. *How Are the World's Forests Changing?* K. MacDicken, Ö. Jonsson, L. Pina, and S. Maulo, Eds. Food and Agricultural Organization of the UN, Rome, Italy, 44 pp, 2016.
41. Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A. & Lindquist, E., Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *For. Ecol. Manage*., 352, 9–20, 2015. doi:10.1016/J.FORECO.2015.06.014.
42. Houghton, R.A. & Nassikas, A.A., Negative emissions from stopping deforestation and forest degradation, globally. *Glob. Chang. Biol.,* 24, 350–359, 2018. doi:10.1111/gcb.13876.
43. Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D. & Houghton, R.A., Tropical forests are a net carbon source based on aboveground measurements of gain and loss. *Science,* 358, 230–234, 2017. doi:10.1126/science.aam5962.
44. Pearson, T.R.H., Brown, S., Murray, L. & Sidman, G., Greenhouse gas emissions from tropical forest degradation: An underestimated source. *Carbon Balance Manag*., 12, 3, 2017. doi:10.1186/s13021-017-0072-2.
45. IPCC, Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, 2020. (also available at https://www.ipcc.ch/ srccl/)
46. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India, *Landscape and Ecological Engineering*, 17(1), 1-13, 2021a. https://doi.org/10.1007/s11355-021-00450-1
47. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, P. 112829, Elsevier, 2021b. https://doi.org/10.1016/j.jenvman.2021.112829
48. Sanquetta, C.R., Dalla Corte, A.P., Pelissari, A.L., Tomé, M., Maas, G.C.B. & Sanquetta, M.N.I., Dynamics of carbon and CO2 removals by Brazilian forest plantations during 1990–2016. *Carbon Balance Manag.,* 13, 2018. doi:10.1186/s13021-018-0106-4.
49. ADB, Strengthening the environmental dimensions of the sustainable development goals in Asia and the Pacific: stocktake of national responses to sustainable development goals 12, 14, and 15. Manila (The Philippines): Asian Development Bank (ADB), 2019.
50. UNCCD, The global land outlook. Bonn (Germany): United Nations Convension of Combating Desertification (UNCCD), 2017.
51. Fagan, M.E., Reid, J.L., Holland, M.B., Drew, J.G. & Zahawi, R.A., How feasible are global forest restoration commitments? *Conservation Letters*, 13, e12700. 2020. https://doi.org/10.1111/conl.12700
52. Raj, A., Jhariya, M.K. & Khan, N., *Forest for soil, food and climate security in Asia*. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in*

Asia, Vol. 2; South and Middle Asia. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
53. Jhariya, M.K.,Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
54. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN:9781771888110. Pp. 400, 2020. https://doi.org/10.1201/9780429276026
55. Singh, K., Pandey, V.C., Singh, B. and Singh, R.R., 2012. Ecological restoration of degraded sodic lands through afforestation and cropping. *Ecological Engineering*, *43*, pp. 70-80.
56. Silva, L.N., Freer-Smith, P. & Madsen, P., Production, restoration, mitigation: a new generation of plantations. *New For*. 2019. https://doi.org/10.1007/s11056-018-9644-6
57. Gingrich, S., Niedertscheider, M., Kastner, T., Haberl, H., Cosor, G., Krausmann, F., Kuemmerle, T., Müller, D., Reith-Musel, A., Jepsen, M.R. & Vadineanu, A., Exploring long-term trends in land use change and aboveground human appropriation of net primary production in nine European countries. *Land Use Policy*, *47*, 426-438, 2015.
58. Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., Woodbury, P., Natural climate solutions. *Proceedings of the National Academy of Sciences*, 114(44), 1645-11650, 2017.
59. UNCCD, Land degradation neutrality: resilience at local, national and regional levels [online], 2015. https://www.unccd.int/sites/default/files/relevantlinks/2017-08/v2_201309-unccd-bro_web_final.pdf
60. UNCCD, Achieving land degradation neutrality [online], 2021. https://www.unccd.int/actions/achieving-land-degradation-neutrality
61. Chotte, J.L., Aynekulu, E., Cowie, A., Campbell, E., Vlek, P., Lal, R., Kapović-Solomun, M., von Maltitz, G., Kust, G., Barger, N., Vargas, R. & Gastrow, S., Realising the Carbon Benefits of Sustainable Land Management Practices: Guidelines for Estimation of Soil Organic Carbon in the Context of Land Degradation Neutrality Planning and Monitoring. A report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, pp. 105, 2019.
62. Cowie, A., Guidelines for land degradation neutrality: a report prepared for the Scientific and Technical Advisory Panel of the Global Environment Facility. UNCCD, Washington, D.C., 2020.
63. Raj, A., Jhariya, M. K., Yadav, D. K., Banerjee, A. & Meena, R. S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (Eds.), *Sustainable Agriculture, Forest and Environmental Management*,

Springer Nature Singapore Pte Ltd. 2019. ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4

64. Raj, A., Jhariya, M.K.,Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
65. Orr, B.J., Cowie, A.L., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G.I., Minelli, S., Tengberg, A.E., Walter, S. & Welton, S. F., *Scientific conceptual framework for land degradation neutrality.* Report of the Science-Policy Interface. Bonn, United Nations Convention to Combat Desertification (UNCCD). 128 pp.
66. World Bank, Sustainable Land Management: Challenges, Opportunities, and Trade-offs. Agriculture and Rural Development. Washington, DC: World Bank. © World Bank. 2006. https://openknowledge.worldbank.org/handle/10986/7132License: CC BY 3.0 IGO
67. Stanturf, J.A., Kleine, M., Mansourian, S., Parrotta, J., Madsen, P., Kant, P., Bolte, A.& Bolte, A., Implementing forest landscape restoration under the Bonn challenge: a systematic approach. *Ann For Sci.*, 76(2), 2019. doi:10.1007/s13595-019-0833-z
68. Löf, M., Madsen, P., Metslaid, M., Witzell, J. & Jacobs, D.F., Restoring forests: regeneration and ecosystem function for the future. *New For.* 50(2),139–151, 2019. doi:10.1007/s11056-019-09713-0

2

Land Resources and Its Degradation in Asia: Its Control and Management

Liliwirianis N.[1]*, Nurun Nadhirah Md. Isa[1] and Mohd Nazip Suratman[2,3]

[1]Faculty of Applied Sciences, Universiti Teknologi MARA Pahang, Bandar Tun Abdul Razak, Jengka, Pahang, Malaysia
[2]Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia
[3]Institute for Biodiversity and Sustainable Development, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

Abstract
Land resources represent the direct and indirect advantages of human existence. In general, the resources support most fundamental human needs and everyday sustenance, ensuring that ecosystems flourish and function effectively. However, many issues have been raised as humans pursue modernization and urbanization. Land resource degradation is one of the most underlying and ongoing environmental issues. It has become significantly worse in recent decades because of the rising population, which demands the cultivation of secondary lands to fulfill the growing food demand. Globally, the leading causes of land resource degradation are due to direct and indirect human intervention. The intervention is deforestation, overexploitation of the trees for domestic use, and agricultural and industrial activities. Other interferences involve overpopulation, pollution, waste, and technological development. Significant threats to the conservation of land resources are health effects, global climate change, destruction of forests, extinction of animals and plants, loss of elements and minerals, scarcity of water, and many more. In order to reduce all the threats, urgent measures should be implemented to prevent the degradation process. On top of that, the effort will ensure the restoration of productivity of land resources so that the land resources can be conserved to provide livelihood and environmental security to the next generation of humankind. This chapter aims to review types of land resources, causes of land resource

**Corresponding author*: liliwirianis@uitm.edu.my

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (23–46) © 2023 Scrivener Publishing LLC

degradation, significant degradation threats, and activities to control the degradation, and management options for better land resource conservation.

***Keywords*:** Land resources degradation, climate change, deforestation, environment, resource management.

2.1 Introduction

The most important natural resource comes from the land. The land provides many resources to supply essential needs for societies and economies to flourish—the abundance of land resources available in nature's most precious gifts to us. More than 95% of the world's food supply and all of humanity's needs for wood, both for fire and construction, are met by the resources provided by land resources [1]. However, the rise of the industrial age has resulted in coal, oil, and minerals being replaced for part of the fuel, building, and fiber needs. However, this has in no way abolished the fundamental reliance of civilization upon the land's resources. There has always been competition for land, and this rivalry has occasionally escalated into violent confrontation. After gaining control, often at considerable expense, individuals would subsequently destroy the exact resource they depend on to survive. That, depending on hunting, showed some form of territoriality among the animal population in prehistoric times, which still happens now. When people live in poverty, more pressure is placed on the land, which, combined with a low level of technology, low inputs, and low outputs may lead to a destructive cycle of forest degradation. Forest loss is happening in developing countries nowadays.

In recent decades, there was a time when the term "forestry" was synonymous with the practice of conserving the local flora and animals. At other times throughout relatively recent human history, harvesting wood from forests was the primary focus. There has been a natural change in the significance and value of forests in human civilization. There are substantial variations of opinion about how forests and land resources should be managed. How people use land resources and how they think about forests and other land resources have led to numerous global issues and threats. Furthermore, impoverished developing countries are to blame for the ozone hole, global warming, and natural catastrophes induced by climate change.

The staggering economic losses that have been incurred as a direct consequence of the degradation of ecosystem services are almost hard to assess fully. New studies have shown that, over the past few decades, annual economic losses associated with the degradation of terrestrial (and marine) eco-services, which are caused by changes in global land use, ranged from US$4.3 trillion to $20.2 trillion [2]. The value calculated was a direct result of global land use changes. As a result, the economy resulting from land degradation is massive worldwide, with many negative socio-economic consequences.

The harvest, control, and use of natural resources have always been essential to human history. Demand for natural resources has grown to such an extent in recent decades that it is now primarily seen as a significant danger to our economic and social balance. Land resources are also affected by increasing land use for agricultural purposes. The agricultural topic is one of the ways that the community may address its issues, particularly the scarcity of food and other necessities. Almost all the land has been developed at this point. In Southeast Asia, 45% of tested oil palm plantations were previously forest regions [3]. This chapter reviews different types of land resources and the causes of their degradation. In addition, it discusses the major threats and control measures of land degradation and suggests options for sustainably managing and conserving these valuable resources.

2.2 Types of Land Resources

The Food and Agriculture Organization of the United Nations [4] described "land resources" as structural, physiological, ecological, infrastructural, and political and social components of natural land entities. This definition also includes freshwater resources on or near the surface that are important for management. The degree to which the various parts of land resources interact is critical in determining agroecosystems' productive capacity and long-term viability. The condition of the land resource components and their interconnections will affect the system's capacity to survive and adapt to both natural (such as climatic change and variability) and anthropogenic (such as economic change) changes and fluctuations (for example, land use and management).

In addition, land resources refer to the resources that can be obtained from the land, such as flora and fauna, soil, water, and minerals. Additionally, the agricultural lands that contain natural fertilizer for the growth of the crops that have been sown are all included in land resources. They make direct and indirect contributions to the overall organism inhabiting space. Land resources comprise not only the physical resources of the land, such as climate, water, soils, landscapes, woodlands, grassland, and animals, but also the environmental resources that rely on rural land use for agriculture, logging, and other kinds of rural land utilization.

A resource is defined as any substance potentially to be altered that increases both value and utility. If something meets our needs, it will be considered a resource, and of course, nature gives us many things and services. Land resources are also known as environmental resources. Climate, terrain, geological formations, soils (including soil hydrology), water (including geohydrology), manufactured objects of a stable character, and vegetation and associated biological traits are the essential land resources in agriculture [5]. On top of that, land resources serve as a dumping ground for the overwhelming bulk of the wastes produced by contemporary civilization.

Two categories may be applied to land resources; these are the categories of renewable resources and non-renewable resources. Non-renewable resources such as oil, fossil fuels, and coal are examples of resources that may be found across a vast region yet have a limited quantity. A land resource is known to be non-renewable if there is a limited quantity of that resource on the planet and there is no natural mechanism to replenish it (at the very least, not within a significant time frame) [6]. As a result, the supply of non-renewable resources might eventually run out. Meanwhile, a renewable resource is only accessible in finite quantities, but its collection is continually renewed thanks to a natural regeneration process. Therefore, the stock of a renewable resource may be maintained at an almost constant quantity if it is not overexploited. Some renewable resources include animal populations, plant and tree populations, and groundwater supplies.

2.3 Causes of Land Resources Degradation

2.3.1 Urbanization

In recent years, land resources have been subjected to intense pressure because of highly competitive demands coming from a growing population. These demands include the need to satisfy food, fodder, and fuel requirements and the increasing number of claims on the land to accommodate settlement, urban growth, industrial expansion, and infrastructure development. Population growth inside the nation and in the proximity of forests is a significant driver of forest resource depletion. The problem occurs due to rising population pressures and the rapid pace of human activities, including urbanization and other economic activities.

South Asia is seeing a reduction in the amount of arable land available per person and an increase in agricultural intensification. The intrusion continues with releasing of forest areas for various development and farming purposes. While this process has massively increased food supply to meet the growing demands, it has also resulted in significant damage to the physical environment, including deterioration and scarcity of land resources and uncontrolled use of land and water resources, among other consequences. The destruction will also lead to land leasing, and at the same time, there will be an illegal encroachment of the forest land. Many invasions of the forest land also affected the forest resources. The scarcity of land resources at the community level is reflected in population density. Rapid urbanization and industrialization have boosted China's land resource exploitation and consumption [7]. For example, one of Myanmar's most critical proximal causes was the construction of infrastructure, specifically roadways, bridges, communication networks, and educational and healthcare facilities [8]. The combination of deprivation and the dense population is often cited as a critical cause of land destruction. Rapid population expansion is part of the engine driving these mechanisms, leading to land degradation and poverty [9]. There is little room for debate that the population of rural areas will rise in the not-too-distant future. Furthermore, the pursuit of rent and poverty are two of the most important contributors to the irresponsible utilization of land and the deterioration of land resources.

2.3.2 Deforestation

Deforestation is mainly a problem for countries in the tropics. Deforestation permanently changes land use from forest to something else, like farming, grazing, or urban development. Generally, deforestation changes the amount of carbon that moves through the soil, plants, and air. Deforestation destroys the soil, releases carbon dioxide from decomposing plants, reduces albedo, and produces hydro-meteorological dangers. High deforestation rates have been linked to population expansion, highlighted as a significant contributing factor. Pearce and Brown [10] pointed out that two important factors contribute to deforestation: the conversion of forest land to many other uses (like food production, infrastructural facilities, urban development, and industry) and the inability of economic systems to reflect the genuine environmental value of land resources accurately.

As a result, many of tropical forests' benefits go primarily unnoticed in policymaking. As happened dramatically in Southeast Asia, the forest loss rates ranged from 0.0006% to 1.186% (mean = 0.47%), with the greatest being comparable to depletion of 814 m^2 per second or 4.9 hectares every minute [11] as in Figure 2.1.

Agriculture is thought to be the immediate cause of approximately 80% of the world's forest loss, which ultimately results in the degradation of land resources. The most significant factor contributing to deforestation in Latin America is commercial agriculture, which accounts for almost two-thirds of the region's total deforested area. It is responsible for around one-third of the deforestation in Africa and (sub)tropical Asia, and it is equally crucial to subsistence agriculture [12]. Between 1995 and 2016, there were 78% cases of agricultural expansion in Myanmar [8].

Unmanaged deforestation may have significant negative externalities, such as the loss of biodiversity, an increase in the danger of erosion and flooding, and a decrease in the water level in the ground, all of which contribute to global climate change [13]. Additionally, the elimination of habitat for game species, changes to the local climate and watersheds, and the destruction of essential stores of fuel, fodder food, and construction materials are all ways in which deforestation may harm the wellbeing of people who utilize forests. When maize production and distance to cities, highways, and markets diminish, deforestation becomes an increasingly appealing option for financially deprived populations, as happened in Mexico [14].

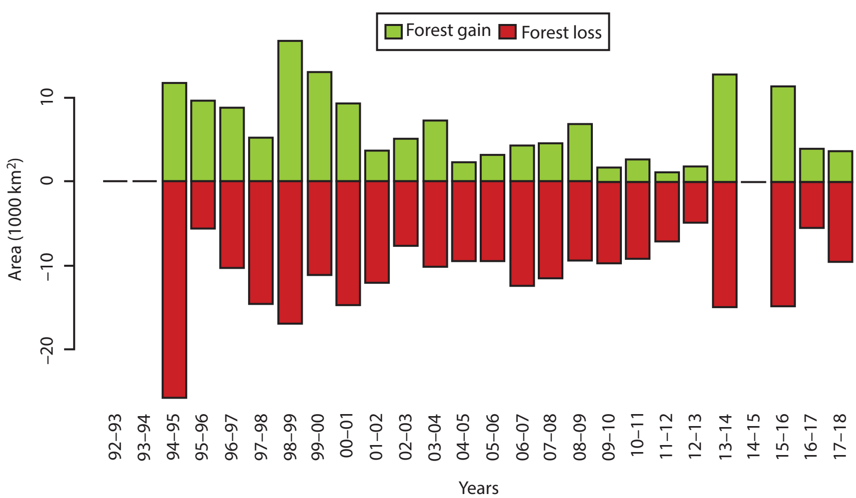

Figure 2.1 Total gain and loss of forest cover area in Southeast Asia throughout consecutive years [11].

2.3.3 Land Clearing

On the other hand, tribal people's cultivation activities such as slash and burn contribute to this problem. In addition to having a negative influence on the regeneration of evergreen forests, slash and burn has the potential to reinforce soil erosion in some areas. As a result of these and other factors, the local population is experiencing a scarcity of land resources (food, fuel, wood, and water), compounding poverty's adverse effects on their lives. Some factors contribute to factories' supply of pulp and hardboard mills to fulfill the demand by the human being as well as firewood supply for burning activities. However, the other factor that is the main contribution to the problem comes from refugees and political upheavals.

2.3.4 Security of Access

Land tenure is the rights and institutions governing land access, use, and other resources [15]. When farmers are assured of continued access to the land they cultivate, they have a greater incentive to invest in practices that promote ecologically sound land management [16]. Open-access situations frequently emerge in locations where access is neither secure nor broken down. These conditions almost always lead to overexploitation and degradation.

2.3.5 Overgrazing and Overharvesting

When plants face heavy grazing for lengthy periods (there is not enough time for recovery), a condition known as overgrazing arises. More than 70% of the environmental damage in Latin America and (sub)tropical Asia is caused by industrial logging and wood harvesting for commercial purposes [12]. The most significant contributors to the deterioration of vast portions of Africa's forest cover are livestock grazing in the area's woodlands. Economies of scale lead to an increase in overharvesting, which reduces animal habitat. Overgrazing in areas prone to soil erosion leads to soil loss, which reduces the land's ability to store water and hinders the performance of plants [17]. Over 500,000 rural people create chronic disruptions to one of the world's most biologically diverse and sensitive tropical forests by extracting biomass from tiny forest remnants for fuelwood, as occurred in the northern section of the Brazilian Atlantic Forest [18].

Due to overharvesting, the amount of water stored in the ground is decreasing at an alarming rate. It points to the fact that the natural recharge potential in South Asia is currently lower than the amount of groundwater extracted. There was a significant reduction in the amount of groundwater stored each year at the rate of 60 billion cubic meters (BCM) [19]. To a far greater extent than the effects of climate change, groundwater extraction was the primary factor in the Mississippi Embayment's (ME) diminishing water supply [20].

2.3.6 Pollution

It is estimated that the cumulative effects of pollution and other three factors (land use and land cover change, biological disturbances, and extractive activities) have affected more than 75% of the land on Earth [21] as well as almost all parts of the waters throughout the planet [22]. Human needs development, agricultural activities, industrial developments, urbanization, and urban sprawl all contribute to the production and release of pollutants. Each pollution, whether it originated in the air or on land, has a great potential to make its way into the ocean. Toxic compounds are dissolved, suspended, or deposited in lakes, streams, rivers, seas, and other water bodies. The combination accumulated will cause water contamination, damaging aquatic habitats. Pollutants may also contaminate groundwater.

2.3.7 Quarrying of Stone, Sand, Ore, and Minerals

An explosion of deep drilling to get to sand, ore, or other minerals can deplete the land of its vegetation and cover, which leads to land degradation. For example, Tanzania, a country rich in minerals, suffers greatly from this. In the country's Mbeya region, which was cleared for limestone mining, the presence of a massive mining pit was discovered in the research area. This pit covered around 38.25 hectares of formerly forested land. Another illustration utilizing high-resolution satellite imagery and GIS indicated that quarrying operations were responsible for losing 402.855 hectares of green cover in Ebonyi, Nigeria. [23]. The quarrying activity resulted in the topsoil piling up and soil loss. All happened because of the disposal of mine wastes and the structure of the ground itself.

2.3.8 Climate Change

There was a considerable decrease in the quantity of groundwater stored annually, and the pace of this loss was 60 billion cubic meters (BCM). Additionally, there was a rise of 0.2 degrees Celsius in the yearly average temperature of the air and an increase of 1 billion cubic meters in the amount of runoff and evapotranspiration [24]. In addition, forest plots that could be free of direct human activities are still, to varying degrees, stripped of their land resources. It would suggest the existence of a factor responsible for the loss of forest cover, most likely an increase in the mean monthly average temperature, which has been recorded in Brunei over the last 30 years [25].

2.3.9 Agricultural

The agricultural expansion was recorded as a proximate cause of forest loss or degradation [8]. Most agricultural concessions were awarded on land that was a densely forested area. Numerous human populations in several tropical biodiversity hotspots [26] are in this predicament. They depend on forests that are disappearing, shrinking, and becoming fragmented to fulfill their needs for agriculture and the consumption of animal protein [27]. Increasing the quantity of land utilized for agricultural purposes has other effects on land resources. The agrarian issue is one way the community may solve its problems, such as the lack of food and other requirements. Almost all the land has been developed at this point. The Jengka Triangle Project, which involved clearing primary forest and replacing it with oil palm, was initiated in 1965 by the government of Malaysia with help from foreign organizations [28]. Current global opinion and the policies of international agencies vehemently reject any approval for this.

Land deterioration in the current year is affected by agricultural output in the current year, but land degradation in the past, as indicated in initial soil nutrient stock and depth, is responsible for the impact on agricultural productivity in the current year. The production of food also influences the income of households. The income of farmers' households is impacted when land degradation occurs on their land because of the negative effect it has on agricultural productivity. Agriculture is also responsible for the depletion of soil nutrients because of improper agricultural methods, such as leaving bare patches of soil after harvesting that are trampled on by heavy machinery.

2.4 Major Threats, Implications, and Effects

2.4.1 Economy

The destruction of forests and the cutting down of trees bring about significant economic issues. In a regional livelihood like Bangladesh's, the deprivation of forests has significantly impacted the growth in many ways. The problem occurs, including a critical shortage of fuelwood and high utilization of agricultural wastes as fuel, which depleted the soil's nutrients. The diminished source of timber and poles for rural infrastructure and construction also caused a scarcity of building material for properties in the neighborhood, a lowered resource of electrical conduits, and increased electricity costs [29].

2.4.2 Food Sources

Agricultural productivity and water use must increase to meet the anticipated increases in food demand by the year 2050 [30]. As a result, agricultural and urban water competition will intensify, and land degradation will exacerbate the situation. According to a global assessment, 40% of the world's agricultural land has already deteriorated to the extent that agricultural production has been drastically reduced. Another 9% of agricultural land was destroyed to the level where it can no longer be recovered for profitable use at the field scale. Water productivity is negatively impacted by land degradation, which in turn influences water availability, water quality, and water storage. Land degradation can be caused by soil erosion and nutrient depletion [16]. Degradation of land resources will either result in a loss of agricultural output or the transformation of the land into one that cannot support agriculture. The combination of a rising population and falling productivity will ultimately result in a state of food insecurity because of the prevalence of the problem in developing nations.

2.4.3 Loss of Biodiversity

It is possible to generalize the effects of the many types of deforestation in tropical forests. For instance, industrial logging depletes carbon stores [31] and alters biodiversity, often leading to species loss [32]. Biodiversity in Ethiopia is declining because of several interconnected impacts of population pressure, intensive farming, population movement, growing urbanization, resettlement, global warming, and industrial contamination, which is detrimental to the ecosystem's ability to operate appropriately [33]. The rapid expansion of oil palm cultivation in Malaysia and Indonesia has resulted in unprecedented biodiversity loss [34], as well as massive levels of degradation and carbon footprints.

2.5 Management of Land Resources

As a result of rising human influence, land resources are experiencing increasingly high levels of pressure. Land resource depletion is humanity's most significant issue this millennium. Since the beginning of human society, the management of land, including the land's soil, water, forests, pastures, and animals, has been an essential component. A lack of appropriate and effective policies (policy failure) has resulted in the excessive exploitation of subsurface water resources, which has resulted in environmental deterioration [35]. Weather variations, degradation of soil quality, globalization, and the liberation of market economies have all intermingled to affect sustainable land resource management and land use planning. At the United Nations Earth Summit, the term "sustainable land management" (SLM) was coined to describe managing land resources such as soils, water, animals, and plants. It maximizes their long-term production capabilities while preserving their environmental functions. [36]. It encourages complementary methods appropriate to the biophysical and socioeconomic environment to protect, conserve, and sustainably use resources (soil, water, biodiversity) and restore degraded land resources and ecosystem processes.

2.5.1 Management of Deforestation

One of the best ways to mitigate the adverse effects of deforestation is to increase the number of trees in an area that was previously devoid of forest cover by planting new trees there. It has the potential to minimize soil erosion. Another option is the process of afforestation, in which croplands or marginal areas are transformed into forests, which is responsible for the sequestration of carbon [37]. Afforestation is an important United Nations (UN) climate-change mitigation strategy. Although afforestation increases evapotranspiration (ET), reducing the near-surface temperature, deforestation decreases ET, increasing temperature. Exceptions are locations with little ET water [38]. Afforestation increases carbon storage, which reduces atmospheric CO_2 and cools the Earth. Afforestation transforms the surface vegetation is reflecting characteristics from grassland to forest. This increase in forest radiation absorption increases radiative forcing, warming the planet [39]. The net impact of reduced albedo and carbon storage on radiative forcing relies on their respective magnitude.

Reducing Emissions from Deforestation and forest Degradation (REDD+) is an influential agenda that is key to mitigating human climate change. REDD+ carbon property rights would need to be formed and distributed, with accountability assigned for the possible loss of climatic benefits from deforestation carbon reversal [40]. A study revealed that the policy is most effective concerning deforestation and helps identify opportunities to improve policy implementation in Indonesia [41]. In the scenario in Malaysia, research revealed that deforestation might be effectively decreased by creating vertical housing, which refers to the construction of buildings on areas of land that are narrower than traditional residences [42].

Protected areas will be forever the most effective strategy for conserving land resources. Protected areas have the advantage of already being efficient, successful, and cost-effective instruments for sustainable ecosystem management, with related laws and policies, management and governance structures, expertise, people, and capacity [43]. They sustain a greater spectrum of ecosystem services than other locations and have more security than unmanaged, uncontrolled areas prone to fast deterioration and change. Within officially protected areas, there is a lower rate of deforestation than in the regions that surround such areas [44], and numerous studies have concluded that protected areas are an efficient means of lowering the amount of forest loss due to roads [45]. Increasing protected areas worldwide has proven beneficial, particularly in temperate regions. Deforestation rates have also significantly dropped in the tropical zones of emerging nations. On top of that, protected areas were initially designed to preserve habitats of plants and the animals that inhabited them [46] but nowadays, it is predicted that protected areas will meet an increasingly broad set of conservation, social, and economic goals. Figure 2.2 shows the

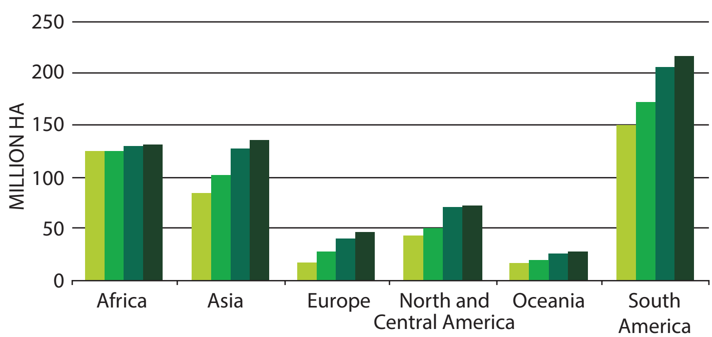

Figure 2.2 Regional changes in forest area within protected areas [47].

region's dynamics in protected forest areas from 1990 to 2020 [47]. In addition, communities would need to establish incentives to attract the conservation of the natural resources that are crucial to their wellbeing. Land resource planning tools enable decision-makers to utilize land resources based on their inherent potential, avoiding unsustainable exploitation and additional deterioration. The integrated land resource management continuum includes land-use planning as one of its components.

2.5.2 Agricultural Intensification Management

In recent years, there has been a rise in the population of both humans and animals. The growth leads to an increase in the diversity of human needs, which has further intensified the rivalry for the limited land resources. Hence the problem has resulted in the importance of concerns about the use of land. The intensification of agriculture requires careful management to have a minimal impact on the surrounding environment. The issue can be accomplished by the farmers' participation in educational programs [48]. For the sake of ensuring food security, intensification is essential, particularly in nations that are still developing. It is feasible to implement with the necessary environmentally friendly technologies.

For sustainable agricultural intensification, it is essential to execute incorporated pest and fertilizer management, regulations for raising revenue on synthetic fertilizers, high return varieties, conservation tillage, legume mixed cropping, contour hillsides, crop varieties, crop residues, and crop selection, including the use of organic and inorganic fertilizers for sustainable agricultural development [49]. In addition, resource-conserving agriculture practices include organic farming, conservation agriculture, Eco agriculture, agroforestry, integrated pest management, and many more. These are just a few examples of systems essential to raising water production and sustainability in several ways.

For instance, soil management practices that enhance infiltration and soil water storage (like zero till) may improve water usage efficiency by 25–40%, while nutrient management can raise it by 15–25% [50]. In addition, it will be essential to make sure that any future increases in agricultural production, whether through expansion or intensification, take place in locations that are not in priority regions for the preservation of forests.

2.5.3 Management of Overgrazing

Managed techniques such as developing water supplies, salt and supplement placement, fertilizer application, fencing, and burning may be used to control overgrazing [48]. Overgrazing can be reduced by controlling the time that elapses between grazing periods and allowing sufficient time for re-vegetation. It is possible to curb excessive grazing by limiting the time livestock spends in a pasture to no more than four days. It is also necessary to exercise control over the animal population density in each grazing area [51].

2.5.4 Management of Irrigation

Controls for irrigation systems, such as those used for drip irrigation, can be used to help prevent soil erosion. Water with varying salt concentrations was the most successful method for preserving the clay soil's productive potential. Excessive irrigation frequently results in the loss of nutrients and the top layer of rich soil along with the water [52]. Among essential things that can be done to maintain the soil's quality is to ensure that irrigation is carried out correctly. Land degradation is a severe problem of poor irrigation and agricultural growth that threatens soil fertility. Irrigated regions are mainly concerned. Alkalinization, salinization, and waterlogging have degraded a significant area of farmland. The growing number of major dams developed as multifunctional schemes, meeting the demands of energy generation, irrigation, household supply, and flood control, is another way water and land resources are linked.

2.5.5 Management of Mining

It is possible to lessen the impact by practicing responsible management of the mining process and employing cutting-edge technology instead of more traditional approaches. In order to repair the mining area, it is necessary to do extensive backfilling and then put soil over the top [53]. The ground that has been refilled might be used for tree planting. If the topsoil is not used, it might be piled up and saved for use on a plantation later. It is possible to shield it from seeping away during the rain effectively.

2.5.6 Management of Inventory Data

An inventory of land resources gives an understanding of the possibilities and constraints of land, which is necessary for efficient planning, exploitation, and management [54]. A database should be developed to compile all the information on land resources. By compiling all the records and data by numerous researchers, many improvements and precautions can be taken into consideration to prevent land resource depletion.

2.6 Policy Strategies and Future Roadmap against Land Degradation

Land degradation is amongst the most alarming environmental concerns in the world. It is directly linked with soil health, food resources, and climate change [55]. In the absence of prompt corrective action, the situation will deteriorate. Globally, a series of intergovernmental organizations have contributed to fighting land degradation by ensuring the protection (prevention of land degradation), restoration (full recovery of land ecosystems to their pre-degradation state), or rehabilitation of lands. The UN Assembly's 73rd session officially approved a resolution designating 2021–2030 as the UN Decade on Ecosystem Restoration (UN-DER), intending to prevent, stop, and reverse global ecosystem deterioration. Figure 2.3 shows strategy recommendations from the United Nations for the 10-year term of UN-DER (2021 to 2030) [56].

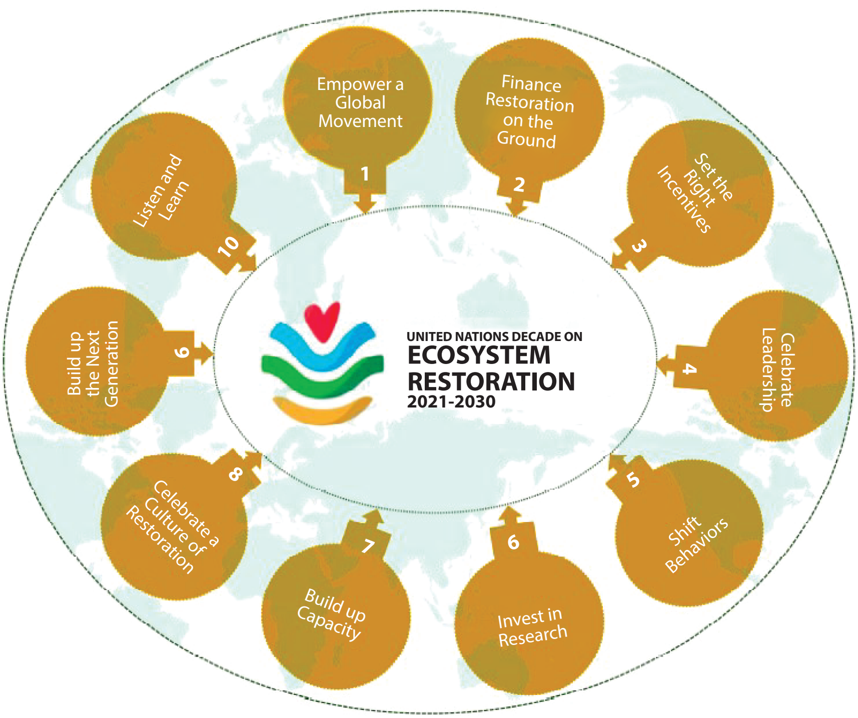

Figure 2.3 United Nations strategy suggestions for the ten years of UN-DER [56].

Moreover, the United Nations 2030 Agenda for Sustainable Development developed the SDGs in 2015. The conservation and sustainable management of forests and their biodiversity are directly linked to SDG 15, "Life on Land". Nations Convention to Combat Desertification (UNCCD) along Land Degradation Neutrality (LDN) approach offers a structural solution to land degradation (LDN). LDN is SDG 15.3's aim. International NGOs, knowledge institutes, and financing channels assist governments in developing and executing LDN objectives [57]. LDN aims to preserve or improve the quantity and quality of land resources by compensating for land degradation within defined time and spatial scales. As for Malaysia, economic, social, and environmental priorities have always been intimately linked to the country's national development plan. The SDGs must be implemented to fit with how future policies will be made.

Global Soil Partnership, a joint project of the Food and Agriculture Organization (FAO) and the United Nations Environment Program (UNEP), is another crucial UN impact in combating land degradation. Through the Aichi Biodiversity Target 15, which seeks to repair at least 15% of the world's damaged ecosystems, the Convention on Biological Diversity (CBD) also plays an essential role in the stability of terrestrial ecosystems [58], and Target 11 intends to protect at 17% of land by 2020 [59].

Additionally, Forest Europe is the national brand for the Ministerial Conference on the Protection of Forests. It is a consensual pan-European high-level political process for consultation and collaboration on European forest policies. Forest Europe helps its 47 signatory nations (46 European countries and the EU) protect and manage their forests in a good way for the environment [57]. Moreover, forest cover has risen dramatically in countries like China, Costa Rica, Korea, and Vietnam because of government-led forest policies or initiatives. Land-sparing and land-sharing approaches may be used to simultaneously meet the needs of food production and biodiversity conservation [60]. For example, in productive agroforestry systems, food production and biodiversity conservation can occur on the same piece of land [61–63]. Similarly, managing forests helps in biomass production, maintaining soil carbon storage and flux, and provides excellent food and climate security in the tropics [64–67]. Moreover, leguminous tree species in any farming system restore land quality by improving soil nitrogen and carbon status and enhancing ecosystem productivity [68–71].

In the context of climatic, illness, and market concerns, it may provide many advantages for biodiversity and farmers, including shade and microclimate modulation, soil fertility, disease control, and income variety [72]. National policies to combat land degradation are equally crucial for global land conservation. As part of international efforts or national policies, countries have various strategies for tackling land degradation within national borders. On top of that, effective governance is vital for land conservation and seems to be the most significant determinant of success in land-oriented initiatives.

2.7 Conclusion

Land resources face tremendous problems daily since many human activities affect the most expensive sources from the planet Earth. Numerous studies and efforts are implemented to prevent and conserve land resources with the hope that they will be renewed for the future generation. However, not all land resource issues can be managed adaptively. Non-adaptive management is appropriate if there is minimal ambiguity regarding management actions and expected consequences or if there is no method to build an effective monitoring program or feedback of monitoring and evaluation into the management plan. Successful adaptive management implementation relies on completing its standards. Using management as an experiment may be the only way to improve it. Adaptive management is neither difficult nor complicated. It requires users to accept uncertainty and maintain an operational environment that reduces it via planning, assessment, and learning. Long term, these operations' upfront expenditures are offset by better resource management. Public and business institutions engaging with civil society to govern social resilience and security should present innovative ideas on strategic planning, collaboration, motivations, and commitment when building dynamic international priorities and coordinating operations across states and organizations.

References

1. Young, A., *Land resources: now and for the future*. Cambridge University Press. 2000.
2. Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S. & Turner, R.K., Changes in the global value of ecosystem services. *Glob. Environ. Chang.* 26, 152–158, 2014.
3. Vijay, V., Pimm, S. L., Jenkins, C. N., & Smith, S. J., The impacts of oil palm on recent deforestation and biodiversity loss. *PloS One*, 11(7), e0159668. 2016.
4. Land & Water. Food and Agriculture Organization of the United Nations. Retrieved May 20, 2022, from https://www.fao.org/land-water/land/en/ 2022.

5. Vink, A. P. A., Land Resources. In: *Land Use in Advancing Agriculture. Advanced Series in Agricultural Sciences*, vol 1. Springer, Berlin, Heidelberg. 1975. https://doi.org/10.1007/978-3-642-66049-8_4
6. Groth, C., A new-growth perspective on non-renewable resources. In *Sustainable resource use and economic dynamics* (pp. 127-163). Springer, Dordrecht. 2007.
7. Ahmed, Z., Le, H. P., & Shahzad, S. J. H., Toward environmental sustainability: how do urbanization, economic growth, and industrialization affect biocapacity in Brazil? *Environment, Development and Sustainability*, 1-21, 2021.
8. Lim, C. L., Prescott, G. W., De Alban, J. D. T., Ziegler, A. D., & Webb, E. L., Untangling the proximate causes and underlying drivers of deforestation and forest degradation in Myanmar. *Conservation Biology*, 31(6), 1362-1372, 2017.
9. Nkonya, E., Pender, J., Kaizzi, K. C., Kato, E., Mugarura, S., Ssali, H., & Muwonge, J., Linkages between land management, land degradation, and poverty in Sub-Saharan Africa: The case of Uganda (Vol. 159). *Intl Food Policy Res Inst*. 2008.
10. Pearce, D. & Brown, K., Saving the world's tropical forests. In: *The Causes of Tropical of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forest*, eds. Brown, K. and Pearce, D. pp. 2-26. UCL Press. 1994.
11. Paradis, E., Forest gains and losses in Southeast Asia over 27 years: the slow convergence towards reforestation. *Forest Policy and Economics*, 122, 102332, 2021
12. Kissinger, G. M., Herold, M., & De Sy, V., Drivers of deforestation and forest degradation: a synthesis report for REDD+ policymakers. *Lexeme Consulting*. 2012.
13. McKean, C., Gibson, C., Margaret, A. & Ostrom, E., *People and forests: Communities, institutions, and governance*. MIT Press, 2000.
14. Perez-Verdin, G., Kim, Y. S., Hospodarsky, D., & Tecle, A., Factors driving deforestation in common-pool resources in northern Mexico. *Journal of Environmental Management*, 90(1), 331-340, 2009.
15. Maxwell, S. & Weibe, K., Land tenure and food security: exploring dynamic linkages. *Development and Change* 30, 825–849, 1999.
16. Bossio, D., Geheb, K., & Critchley, W., Managing water by managing land: Addressing land degradation to improve water productivity and rural livelihoods. *Agricultural Water Management*, 97(4), 536-542, 2010.
17. Kosmas, C., Detsis, V., Karamesouti, M., Kounalaki, K., Vassiliou, P., & Salvati, L. Exploring long-term impact of grazing management on land degradation in the socio-ecological system of Asteroussia Mountains, Greece. *Lan*d, 4(3), 541-559, 2015.
18. Specht, M. J., Pinto, S. R. R., Albuquerque, U. P., Tabarelli, M., & Melo, F. P. Burning biodiversity: Fuelwood harvesting causes forest degradation in

human-dominated tropical landscapes. *Global Ecology and Conservation*, 3, 200-209, 2015.

19. Chinnasamy, P., Hsu, M. J., & Govindasamy, A., Satellite-Based Analysis of Groundwater Storage and Depletion Trends Implicating Climate Change in South Asia: Need for Groundwater Security. In *Civil Engineering for Disaster Risk Reduction* (pp. 17-26). Springer, Singapore. 2022.
20. Ouyang, Y., Wan, Y., Jin, W., Leininger, T. D., Feng, G., & Han, Y. Impact of climate change on groundwater resource in a region with a fast depletion rate: the Mississippi Embayment. *Journal of Water and Climate Change*, 12(6), 2245-2255, 2021.
21. Ellis, E. C., & Ramankutty, N., Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, 6(8), 439-447, 2008.
22. Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E. & Fujita, R., A global map of human impact on marine ecosystems. *Science*, 319(5865), 948-952, 2008.
23. Akanwa, A. O., Okeke, F. I., Nnodu, V. C., & Iortyom, E. T., Quarrying and its effect on vegetation cover for a sustainable development using high-resolution satellite image and GIS. *Environmental Earth Sciences*, 76(14), 1-12, 2017.
24. Kandissounon, G. A., Karla, A., & Ahmad, S., Integrating system dynamics and remote sensing to estimate future water usage and average surface runoff in Lagos, Nigeria. *Civil Engineering Journal*, 4(2), 378, 2018.
25. Becek, K., & Odihi, J. O. Identification and assessment of factors affecting forest depletion in Brunei Darussalam. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 37(B2), 209-214, 2008.
26. Bouget, C., Lassauce, A., Jonsell, M., Effects of fuelwood harvesting on biodiversity- a review focused on the situation in Europe. *Can. J. Forest. Res.*42, 1421–1432. Revue Canadienne De Recherche Forestiere, 2012.
27. Peres, C. A., Gardner, T. A., Barlow, J., Zuanon, J., Michalski, F., Lees, A. C., Vieira, I. C. G., Moreira, F. M. S., & Feeley, K. J., Biodiversity conservation in human-modified Amazonian Forest landscapes. *Biol. Conserv.* 143, 2314–2327, 2010.
28. Douglas, I., Hydrological investigations of forest disturbance and land cover impacts in South–East Asia: a review. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 354(1391), 1725-1738, 1999.
29. Chowdhury, M. K., & Mahat, T. B. S., Agroforestry in farming systems of Bangladesh. BARC-Winrock International Research Report Series (Bangladesh), 1993.
30. Konuma, H., Status and outlook of global food security and the role of underutilized food resources: Sago palm. In Sago palm (pp. 3-16). Springer, Singapore, 2018.

31. Berry, N. J., Phillips, O. L., Lewis, S. L., Hill, J. K., Edwards, D. P., Tawatao, N. B. Ahmad, N., Magintan, D., Khen, C.V., Maryati, M., Ong, R.C. & Hamer, K. C., The high value of logged tropical forests: lessons from northern Borneo. *Biodiversity and Conservation*, 19(4), 985-997, 2010.
32. Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A., & Sodhi, N. S., Prospects for tropical forest biodiversity in a human-modified world. *Ecology letters*, 12(6), 561-582, 2009.
33. Wassie, S. B., Natural resource degradation tendencies in Ethiopia: a review. *Environmental Systems Research*, 9(1), 1-29. 2020.
34. Taheripour, F., Hertel, T. W., & Ramankutty, N., Market-mediated responses confound policies to limit deforestation from oil palm expansion in Malaysia and Indonesia. *Proceedings of the National Academy of Sciences*, 116(38), 19193-19199, 2019.
35. Reddy, V. R., Costs of resource depletion externalities: a study of groundwater overexploitation in Andhra Pradesh, India. *Environment and Development Economics*, 10(4), 533-556, 2005.
36. Ruiz, I., Almagro, M., de Jalón, S. G., del Mar Sola, M., & Sanz, M. J., Assessment of sustainable land management practices in Mediterranean rural regions. *Journal of Environmental Management*, 276, 111293, 2020.
37. Arora, V. K., & Montenegro, A., Small temperature benefits provided by realistic afforestation efforts. *Nature Geoscience*, 4(8), 514-518, 2011.
38. Strandberg, G., & Kjellström, E., Climate impacts from afforestation and deforestation in Europe. *Earth Interactions*, 23(1), 1-27, 2019.
39. Kirschbaum, M. U. F., Whitehead, D., Dean, S. M., Beets, P. N., Shepherd, J. D., & Ausseil, A. G., Implications of albedo changes following afforestation on the benefits of forests as carbon sinks. *Biogeosciences*, 8(12), 3687-3696, 2011.
40. Palmer, C., Property rights and liability for deforestation under REDD+: Implications for 'permanence' in policy design. *Ecological Economics*, 70(4), 571-576, 2011.
41. Santika, T., Meijaard, E., Budiharta, S., Law, E. A., Kusworo, A., Hutabarat, J. A Indrawan, T.P., Struebig, M., Raharjo, S., Huda, I. and Ekaputri, A.D., Community Forest management in Indonesia: Avoided deforestation in the context of anthropogenic and climate complexities. *Global Environmental Change*, 46, 60-71, 2017.
42. Omran, A., & Schwarz-Herion, O., Deforestation in Malaysia: the current practice and the way forward. In *Sustaining our Environment for Better Future* (pp. 175-193). Springer, Singapore. 2020.
43. Stolton, S., Dudley, N., Avcıoğlu Çokçalışkan, B., Hunter, D., Ivanić, K. Z., Kanga, E Kettunen, M., Kumagai, Y., Maxted, N., Senior, J. & Wong, M., Values and benefits of protected areas. *Protected Area Governance and Management*, 145-168, 2015.
44. Gaveau, D. L., Wandono, H., & Setiabudi, F., Three decades of deforestation in southwest Sumatra: Have protected areas halted forest loss and logging, and promoted re-growth? *Biological Conservation*, 134(4), 495-504, 2007.

45. Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., Dietzsch, L., Merry, F., Bowman, M., Hissa, L. and Silvestrini, R., & Maretti, C., Role of Brazilian Amazon protected areas in climate change mitigation. *Proceedings of the National Academy of Sciences*, 107(24), 10821-10826, 2010.
46. Watson, J. E., Dudley, N., Segan, D. B., & Hockings, M., The performance and potential of protected areas. *Nature*, 515(7525), 67-73, 2014.
47. FAO and UNEP. The State of the World's Forests 2020. Forests, biodiversity and people. Rome. https://doi.org/10.4060/ca8642en 2020
48. Barman, D., Mandal, S. C., Bhattacharjee, P., & Ray, N., Land degradation: Its control, management and environmental benefits of management in reference to agriculture and aquaculture. *Environ Ecol*, 31(2C), 1095-1103, 2013.
49. Raut, N., Sitaula, B. K., Bajracharya, R.M., Agricultural intensification: Linking with livelihood improvement and environmental degradation in mid-hills of Nepal. *J Agric and Environ*11, 83-91, 2010.
50. Hatfield, J. L., Sauer, T. J. & Prueger, J. H., Managing soils to achieve greater water use efficiency: a review. *Agronomy Journal* 93 (2), 271-80, 2010.
51. Czegledi, L. &Radacsi, A., Overutilization of pastures by livestock. Acta Pascuorum (Grassland studies) 3, 29-36, 2005.
52. Crescimanno, G., Irrigation practices affecting land degradation in Sicily. PhD thesis. Wageningen Univ, pp. 169, 2001.
53. Elliott, S., Navakitbumrung, P., Kuarak, C., Zangkum, S., Anusarnsunthorn, V.&Blakesley, D., Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance. *Forest Ecol and Manag* 184, 177-191, 2003.
54. Reddy, G. O., Patil, N. G., & Chaturvedi, A. (Eds.), *Sustainable management of land resources: An Indian perspective*. CRC Press. 2017.
55. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, RS, Land Footprint Management and Policies. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer, ISBN 978-981-15-9495-3, pp. 221-246, 2021. https://doi.org/10.1007/978-981-15-9496-0_7
56. Abhilash, P. C., Restoring the unrestored: strategies for restoring global land during the UN Decade on Ecosystem Restoration (UN-DER). *Land*, 10(2), 201.2021.
57. Debonne, N., van Vliet, J., Metternicht, G., & Verburg, P., Agency shifts in agricultural land governance and their implications for land degradation neutrality. *Global Environmental Change*, 66, 102221, 2021.
58. Navarro, L.M., Marques, A., Proenca, V., Ceauşu, S., Goncalves, B., Capinha, C., Fernandez, M., Geldmann, J., Restoring degraded land: contributing to Aichi Targets 14, 15, and beyond. *Curr. Opin. Environ. Sustain*. 29, 207-14, 2017.
59. Joppa, L.N., Visconti, P., Jenkins, C.N., Pimm, SL, Achieving the Convention on Biological Diversity's goals for plant conservation. *Science* 341, 1100-1103, 2013.

60. Phalan, B., Onial, M., Balmford, A., & Green, R. E., Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science*, 333(6047), 1289-1291, 2011.
61. Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Agroforestry and Climate Change: Issues and Challenges*. Apple Academic Press Inc., CRC Press, a Taylor and Francis Group, US & Canada. ISBN:978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book), pp. 335. 2019.https://doi.org/10.1201/9780429057274
62. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press- a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383. 2020. https://doi.org/10.1201/9780429286759
63. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., Sustainable Intensification for Agroecosystem Services and Management. Springer Singapore, pp. 748. eBook ISBN: 978-981-16-3207-5. 2021. DOI: 10.1007/978-981-16-3207-5.https://www.springer.com/gp/book/9789811632068
64. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, P. 112829, Elsevier, 2021.https://doi.org/10.1016/j.jenvman.2021.112829
65. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, Springer Nature, 17(1), 1-13, 2021.https://doi.org/10.1007/s11355-021-00450-1
66. Raj, A., Jhariya, M.K. & Khan, N., Forest for soil, food and climate security in Asia. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
67. Jhariya, M.K., Meena, R.S., Banerjee, A. & Meena, SN, *Natural Resources Conservation and Advances for Sustainability*. Elsevier, 2022. Academic Press. ISBN: 9780128229767. https://doi.org/10.1016/C2019-0-03763-6.
68. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
69. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: RS Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
70. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: RS Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc.,

pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X

71. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
72. Schroth, G., Izac, A. M. N., Vasconcelos, H. L., Gascon, C., da Fonseca, G. A., & Harvey, C. A. (Eds.), *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press. 2004.

3

Deforestation Activities in Ezekoro Forest: Implications for Climate Change Risks in Anambra State, Southeast Nigeria

Joe-Ikechebelu Ngozi Nneka[1,2]*, Akanwa Angela Oyilieze[3], Akanwa Chimezie David[4], Okafor Kenebechukwu Jane[5], Dike Keyna[6], Idakwo Victor Iko-Ojo[7], Omoruyi Fredrick Aideniosa[8], Nkwocha Kelechi Friday[9], Enwereuzo, Angela Chinelo[10], Umeh, Uche Marian[11], Ogbuehi, Emmanuel Okwudili[12] and Agu, Helen Obioma[13]

[1]Social Dimensions of Health, School of Public Health & Social Policy, University of Victoria, BC, Canada
[2]Department of Community Medicine and Primary Healthcare, Chukwuemeka Odumegwu Ojukwu University (COOU) Teaching Hospital (COOUTH), Awka, Anambra State, Nigeria
[3]Department of Engineering, Institute of Management and Technology, (IMT), Enugu, Enugu State
[4]Department of Environmental Management, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, (COOU) Uli Campus, Anambra State, Nigeria
[5]Department of Accountancy, Faculty of Management Science, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[6]Department of Environmental Management, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, (COOU) Uli Campus, Anambra State, Nigeria
[7]Department of Urban and Regional Planning, Faculty Environmental Sciences, University of Maiduguri, Borno State, Nigeria
[8]Department of Statistics, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[9]Department of Geography, Faculty of Social Sciences, University of Maiduguri, Borno State, Nigeria
[10]Department of Sociology and Anthropology, Faculty of Social Sciences, University of Benin, Edo State, Nigeria

**Corresponding author*: nn.ikechebelu@coou.edu.ng

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (47–76) © 2023 Scrivener Publishing LLC

[11]Department of Community Medicine and Primary Healthcare, Chukwuemeka Odumegwu Ojukwu University (COOU) Teaching Hospital (COOUTH), Awka, Anambra State, Nigeria
[12]Department of Parasitology & Entomology, Faculty of Biosciences, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[13]Department of Food Science & technology, Nnamdi Azikiwe University Awka, Awka, Anambra State, Nigeria

Abstract

Globally, forests serve as the largest storehouses for (non) indigenous trees, and are essential for the ecosystems' sustenance, yet, increased deforestation practices associated with activities, such as tree logging, agriculture, and urban expansion continue to put pressure on existing forest areas, leading to massive land use cover change. Ezekoro Forest has been declining at an alarming rate. Detecting the land use cover change, and examining the drivers can assist in informing policies, thereby reducing climate risks since trees are essential in regulating global temperature, rainfall, oxygen, carbon, and environmental protection. They protect against (non) disasters, such as floods, desertification, and erosion. For this chapter, we examined deforestation and environment degrading activities in Ezekoro Forest and their implications for climate change risks in Southeast Nigeria using primary and secondary data sources. Using environmental justice as a lens, we used qualitative methods of field observation, random in-depth interviews, and photographic images with key informants. Also, Geographic Information Systems (GIS), remote sensing and satellite images covering a 20-year period (2001-2021) using Landsat 7 image of 2001 and Landsat 8 image of 2021 was employed. Besides predominating strong winds that have reduced the vegetation cover, we found clear evidence(s) of environmental degrading actions that have reduced the quantity of woody bamboo trees to 30%, heightening erosion and flooding activities and a low crop yield of 20%. About 35% of the harvested bamboo trees and other tree species were majorly cut for fuel wood, construction materials and trading, 30% was used for farming activities, 20% were used for building construction activities, and 10% and 5% were employed for hunting and dumping of refuse, respectively. Findings from satellite image showed drastic changes in the landuse/landcover of Ezekoro Forest. Whereas bare surface indicating deforested (loss of trees and vegetation) areas was 1.3% in 2001, it increased to 23.5% in 2021, a change of 22.2%. Similarly, built-up area was 4.4% in 2001 but rose to 30.1%, a change of 25.7%. However, vegetation cover was 94.3% in 2001 but decreased tremendously to 46.4%, a change of 47.8%. This is an indication of intense deforestation over the years. In lieu of environmental justice and social change, it is critical to aim for environment-climate based actions, such as participatory action research and inclusion of women in forest governance through appropriate forest development structures, to enable co-production of local and scientific climate-related knowledge.

***Keywords*:** Deforestation, tree felling/loss, climate risks, desertification, Ezekoro Forest, environmental justice, satellite images

3.1 Introduction

Trees are essential. In the environment, trees play a vital role by improving the quality of air, absorbing, and preserving water, bettering the climate via uptake of greenhouse gases, besides the preservation of wildlife, supply of oxygen, storage of carbon, and production of food [1, 2]. Yet, *deforestation* is a huge concern, particularly in the nations of the global South, with worsening environmental outcomes from felled trees, besides the impact on human and animal life from the non-sustained trees [3, 4]. Deforestation occurs when a forest land is cleared intentionally for human purposes, with no intention to replace the trees [5]. Following the deforestation activities, the quality of the forest relative to density, tree structure, ecology, biomass, and species diversity is affected [6, 7]. Research has proven that extensive deforestation practices are a contributing factor to the world's rising temperature and climate disasters, yet there are increasing demands that lead to aggressive deforestation.

The GIS approach uses a set of tools made up of hardware, software, data and users, which captures, stores, manages and analyzes digital information, as well as makes graphs and maps, and represents alphanumeric data. For decades, GIS have been applied in land use cover studies in detecting changes in natural resource management problems as applicable to this present study on deforestation. It is expedient to capture the extent of human degradation of forest resources over time to enable proper management practices, policy making and climate solutions. The importance of trees to an ecosystem's sustainability is critical, as trees provide the essential habitat for vulnerable terrestrial and aquatic animals and wildlife [8], besides serving as a naturally occurring habitat for diverse species of trees/plants and providing rich medicinal plants, vegetable foods, and products of high quality [9]. Unfortunately, trees are diminishing by about 5% every decade, particularly in the tropical forests, and this impacts global mean temperature. Primarily, forests are known as terrestrial carbon sinks, as the CO_2 is absorbed via the trees into their woody stem and soil. The amount of carbon stored by the forest trees is more than the amount emitted into the environment from worsening deforestation acts, such as fossil fuels burning, timber harvesting, and burning of forests. These activities contribute, further, to more atmospheric CO_2 with a potential to release, annually, over two billion tons of carbon [10], (in) directly sustaining life on earth. Global warming results from heightening atmospheric concentrations of greenhouse gases (GHG), such as carbon dioxide and methane as the trees that sequester atmospheric carbon by removing a vast amount of carbon dioxide from the atmosphere are felled. As tree felling worsens, atmospheric greenhouse gases, such as CO_2 and methane, continue to increase, heightening average temperature.

Further, deforestation is intensified by rapid population growth, where forest areas are converted to residential areas to accommodate the teeming population. For example, in Nigeria, deforestation rate is placed at 3.5% and 400,000 hectares annually [11], and about 40% of forestlands are deforested annually with less than 10% of land hectares being reforested [12]. According to the International Union for Conservation of Nature (IUCN) assessment from 1991 to 2012, forest loss was approximately 7920km^2, reflecting a 12% decline [13]. The need for cheap fuel wood in some natural resources production, such as mining [14], and charcoal production continue to place forest resources under pressure, depleting the forest at a rate faster than it can replenish naturally [15]. The forest trees are also logged and cleared to provide resources, such as wood products needed for mining, cattle grazing, agricultural activities, and fuel wood [14], heightening the dire need for justice on behalf of our threatened forests and their communities that could be described as "environmental victims".

For an environmental victim, the victim is affected by anthropogenic activities that are facilitated and enabled by the environment with consequent restriction access placed on and by the environment [16]. As such, this justifies the need for justice. Justice, as a historical reality, must be taken into consideration in present experiences with strategies to rectify oppressive and exploitative harm within the society [17]. In their definition of environmental justice, the United States Environmental Protection Agency [18] incorporated the intersection of social identities and the environment relative to the fair treatment of people, as well as their genuine involvement in planning, implementing, and enforcing of laws and regulations irrespective of their social status and position. Global carbon coverage is being accentuated mostly by deforestation, intensified agricultural practices and the use of fossil fuels [14]. Of note, these associated human actions have introduced climatic and ecological problems that heighten global warming and cause increasing precipitating weather outcomes, such as heat, rising sea level, and flooding events.

To avoid the adverse impacts of climate change, the Paris Agreement was adopted by world leaders in 2015, where it was agreed to limit the current global warming to 1.5°C. The success of this goal requires meeting the "net zero target" carbon emissions by 2050 through immediate reduction actions in greenhouse gas emissions. These actions are expected to protect the forests through conservation, reforestation, renewable sources of energy and technology and provide electricity and transportation as some of the means of cleaning and sequestering carbon from the atmosphere to meet the net zero carbon vision in 2050. Hence, the need to examine deforestation activities in Ezekoro Forest and its implications on climate change risks in Southeast Nigeria became the goal of this study.

3.2 Concept of Environmental Justice and Indiscriminate Deforestation/Tree Loss

Environmental justice is a consequence of community struggle relative to injustice(s) within and around their environment with an aim toward mobilizing for social change. Environmental justice actualizes power back to the disprivileged community as their ability to participate in decision making on inequities in their environment is enabled, going beyond listing of community environmental discrepancies [19]. Historically, the movement of environmental justice came through a crusade four decades ago, when there was a disproportionate imbalance of environmental inequities regarding pollutants from industries, power plants, and waste disposal sites sited majorly near communities inhabited by marginalized populations, primarily people of color. This social movement sought to address this inequity of environmental protection in their communities [20], and a cascade of motions ensued to ensure there was a fair and even distribution of environmental burdens and benefits among the socially and non-socially dominant groups irrespective of their social status and positions [21]. Further, this movement extended also to the academy, which has helped to widen its reach and has incorporated several conceptual nomenclatures, such as ecological debt, political ecology, environmental racism, climate justice, food sovereignty, corporate accountability, ecocide, and sacrifice zones [22].

With two distinctive uses, the term environmental justice emphasizes fairness when environmental burdens are distributed, while the other use is the interplay of diverse social science pedagogical works that incorporate environment and justice frameworks, as well as environmental laws that can be implemented in environment initiatives of policy and planning, political ecology and governance towards environmental sustainability and development. However, justice is broadly comprehended as a social model. The universal call for justice is evident with numerous unsettled multilevel issues with ecological components, such as humans and animals interacting with one another [23]. Of note, there are conflicts and disagreements, implicating the society and its institutions, as the struggle with (non) complex issues continue, further justifying the complaints and the cries for justice. In essence, environmental justice is an expansion of rights-based laws and approach, because human rights laws have not been able to optimally manage the challenges of balancing the rights of humans and the protection of the environment. For example, environmental initiatives, such as codifying healthy environments to incorporate the protection of the environment with human rights laws may not have been helpful. With human actions of tree felling, the annual rate of deforestation is at 10 million hectares per year for the world's forest compared to about 16 million hectares annually in the 1990s.

Consequent upon human actions, the area of primary forests has decreased by over 80 million hectares since 1990 [24], leading to a significant recommendation on deforestation activities in the African region. According to a principal researcher with the International Institute for Environment and Development in 2015, the forest cover of African forest land is rapidly decreasing; although driven by agricultural development, the loss of land was over 16 million hectares between 2010 and 2015 [25].

Forest trees are decreasing alarmingly and this can be attributed to a population that relies majorly on the by-products of the forest to meet their energy needs, as well as reduced access to affordable alternative energy sources. In Africa, more than 50% of energy needs and demands are produced from the by-products of forest trees [26], and over 3.4 million hectares of forests land per year [27] are exploited resulting in a vast change in the cover of the forest. With more than 30% of the African population depending on the resources of the forests for their socio-economic needs, Africa's intentional tree felling is worrisome [3], besides the fact that most environmental laws, particularly in the nations of the global South, which Nigeria is a part of, do not provide explicitly for the natural habitats, such as trees and water bodies. Hence, the issue of deforestation has become prevalent and its consequences are damaging to the society. Considerably, the indiscriminate exploitation of our forests and the poor approach to the protection of forest rights in Nigeria is a great concern for the future of lands, trees, rivers, biodiversity, ecosystems, and climate change. With the rate of high rate of tree felling activities in Nigeria, the country has lost over 410,000 hectare per year in the last two decades [12] with activities such as agriculture, logging, and mining main being the main drivers of deforestation [28].

According to Global Forest Resources Assessment, forests contributed about 2.5% to the Gross Domestic Products [27]. Forest by-products, such as timber and non-timber products, constituted employment for more than 10% of the Nigerian people, while over 100,000 people are working in industries related to wood logging and processing, especially in the southeast region of Nigeria. Nigeria has abundant forest resources, but the intensified deforestation and tree logging activities is fast changing the situation, making it unlike the pre-industrial years. Then, the forest coverage was within 15.6% of the earth's surface. However, poverty in the African region has continued to impact the loss of tree covers in Africa [29]. Besides agriculture, [25], urbanization and industrialization have contributed to the depletion of the world forest cover, reducing it to 9.4%, which is about 30% of the total land area [30]. Relatedly, Global Forest area of about 4 billion hectares corresponds to 0.62 hectares per capita and declined at a fast rate of 13 million hectares a year with a total loss of about 7.3 million hectares of forest land in the period 2010-2015 [31] in comparison to the annual 8.9 million hectares lost from 2005 to 2010 [32]. Undoubtedly, there is a need to integrate environmental protection into human rights' laws, despite daunting challenges [19]. Of note, environmental justice for the future of our forests and trees can be pursued through local movements condemning injustices related to environmental conditions. This will aid in achieving local, national, and global initiatives through policies that are centered on sustainable development objectives, social equality in the protection of the environment, especially our forests, trees, and their inhabitants [33].

3.3 Study Area

Our study area, Ezekoro Forest, is in Achina within Saint Peter University (See Plate 3.1). Achina is located in the southern part of the Aguata local government area of Anambra State. It is bounded in the east by Enugu Umuonyia and Umuomaku towns in Orumba North LGA, on the west by Amesi and Akpo towns, in the north by Onneh and Ogboji towns in Orumba North LGA and on the south by Umuchu town (see Figures 3.1, 3.2 & 3.3). Achina, a tropical rainforest zone in Nigeria, experiences two climatic seasons, which are related to the two predominating winds of the nation.

Plate 3.1 The location of Ezekoro Forest positioned close to Saint Peter University at Achina.

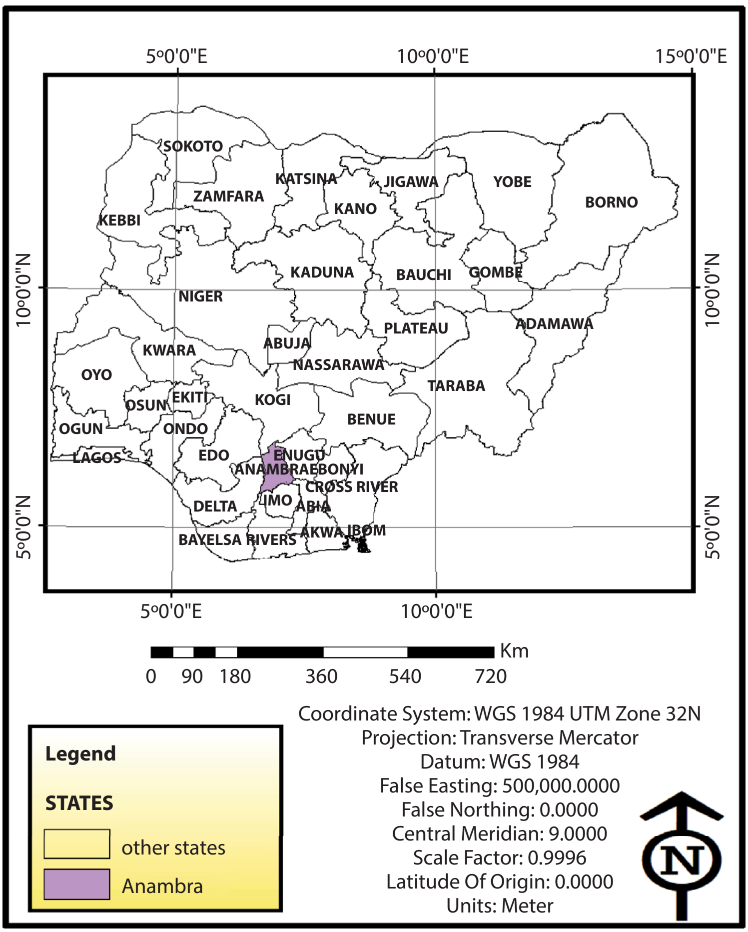

Figure 3.1 Location of Anambra State in the Map of Nigeria.

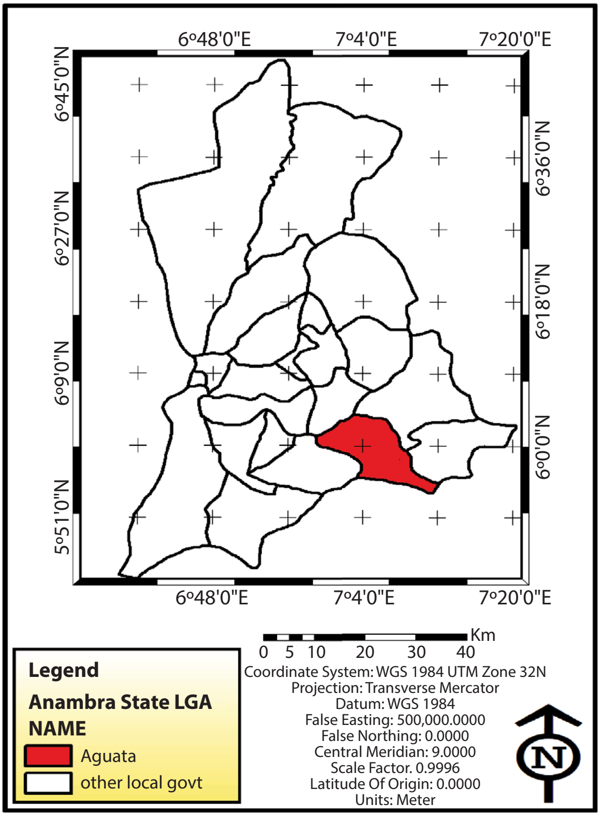

Figure 3.2 Location of Aguata Local Government Area in the Map of Anambra.

These winds, the southwestern monsoon winds from the Atlantic Ocean and the northeasterly dry wind from the Sahara Desert, create the eight months of heavy tropical rains occurring between late March to late November, and the dry season that arises from late November to mid-March. The Harmattan season, popularly referred to as "Ugulu" is followed from late November to mid-March. In Achina, from June to December, the temperature is generally within the 27-30°C range, but, between January and April, the temperature can increase up to 32-34 degrees, besides the last few months of dry season that is marked by intense heat. The relative humidity of Achina varies normally within the period of the year, and it ranges from 80%-85% within March-November (wet season) and from 60%-69% during the (dry season) November-March. According to the 1991 population census, the population of Achina was estimated at 40,193 people. The population of the study area was projected to be 60,820 people in 2006, at 3.2% approved annual population growth rate [34] by the

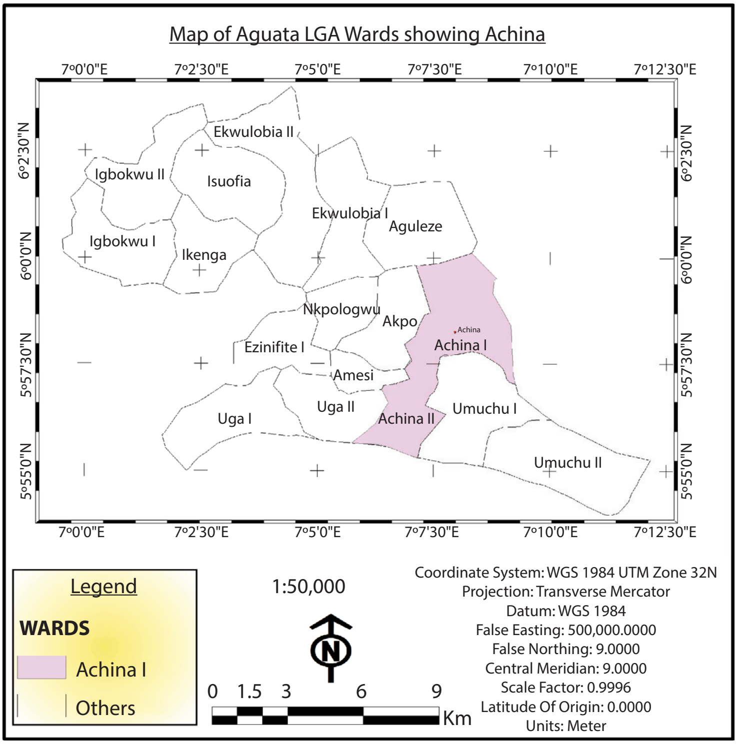

Figure 3.3 Location of Achina in the Map of Aguata Local Government.

National Population Commission in 2006; the population of Achina was 97,553 people in 2021.

3.4 Materials and Method

I. Qualitative method

Qualitative and GIS and remote sensing methods were employed in this chapter to examine the deforestation activities in Ezekoro Forest and its implications for climate change risks in Southeast Nigeria. The researchers aim to apply a qualitative method in this study for an in-depth, idiographic, and nomothetic understanding of the phenomenon [35]. Moreover, the remotely sensed data in GIS domain was employed to determine the extent of deforestation activities for over a period of 20 years in the study area.

For our study, our primary and secondary sources of data was used, as well as the socio-demographic and forest use data that were collected. We used a qualitative approach covering sampling strategies such as data collection analysis, field observation, random semi-structured in-depth interviews of key informants (see Plate 3.2) and photographs (see Plates 3.1, 3.2, 3.3 & 3.4). For the purposive sampling technique, it involved the convenient and snowball methods [36]. Twenty participants were recruited who were directly or indirectly involved in Ezekoro Forest and its resources.

Plate 3.2 Interview interaction between researcher(s) and community participants (women and elders).

Plate 3.3 Evidence of uncontrolled felling of trees, harvest of tender Bamboo trees for construction purposes and vast deforestation activities.

Plate 3.4 Parts of the Ezekoro forest where buildings construction is taking place.

The following inclusion criteria for the 20 participants were: 18 years of age and above, confirmed residents of 20 years and above, participants living within the community forest area and their ability to understand and speak English. We interviewed a total of 20 persons covering married/single people, firewood suppliers, plywood business suppliers, forest guide, farmers, community heads, heads of households, women leaders, women, and youth representatives among others. These specific people were ideal based on the characteristics, knowledge, experience, and perspectives they brought to the study. The interview guide included questions on income levels, deforestation, causes of deforestation, tree logging, environmental degradation and other human activities that have been going on for several decades in the community forest.

II. Satellite Images

In this analysis, Landsat 7 Thematic Mapper (TM) datasets from 2001 and Landsat 8 OLI/TRIS datasets from 2021 were obtained from the United States Geological Survey (USGS) portal for the execution of LU/LC dynamics. Since atmospheric and radiometric correction are the best procedures for obtaining error-free satellite images, this dataset underwent preprocessing to account for atmospheric conditions, distortion, and inaccuracies. A 20-year time frame was used in this investigation to compare the dynamics and phenomena of LU/LC.

III. LU/LC Retrieval
The study Area was covered by satellite images taken in 2001 (Landsat TM) and 2021 (Landsat 8), which were used to retrieve the LU/LC data. Four distinct classes were identified for this LU/LC classification using the ArcGIS 10.3 software's supervised classification method based on the maximum likelihood algorithm. Built-up Area, Vegetated Land, Bare Surface, and Water Body are the four categories.

IV. Statistical Analysis
In the Statistics analysis, the ArcGIS Field Calculator was used to calculate areas and percentages of four classes using the formulas (1 & 2) for the two different time points. By subtracting 2021 from 2001 in Ms Excel, percentage changes were calculated to determine the percentage gains and losses of the four classes.

$$\frac{Cell\ Count \times size\ of\ 1\ cell}{10000} \tag{3.1}$$

$$\frac{\frac{Cell\ Count \times size\ of\ 1\ cell}{10000}}{Total\ Area} \times 100 \tag{3.2}$$

From relevant papers, journals, or publications, we obtained our secondary data relative to deforestation, tree logging and climate change risks.

3.5 Results and Discussion

3.5.1 Sample Characteristics

The summary of socioeconomic and forest use data gathered from semi-structured interviews of 20 participants was analyzed and presented in charts and Table 3.1. For our variables, we used the following demography, such as sex, income, age and education and household size; other discussions, observations and photographs were also presented in the study.

Table 3.1 summarized the key characteristics of participants. For the highest age distribution, 35% of the participants were between 30 to 40 years, while the lowest age group was 15% ranging between 50-60 years and above. Also, 70% of the participating population were males, while the

Table 3.1 Socioeconomic/environmental data.

Variables	**Percentage (100%)**
Age	
18 - 30 years	30
30 - 40 years	35
40 - 50 years	20
50 - 60 years above	15
Gender	
Male	70
Female	30
Education Level	
FSLC	30
WAEC/WASC	35
NCE/OND	20
NO EDUCATION	15
Marital Status	
Single	30
Married	45
Widow/ed	15
Divorced/separated	10
Number of Children	
1-3	25
3-5	30
5 and above	45
Income Level (monthly)	
₦10,000 - ₦20,000	05
₦20,000 - ₦30,000	15

(*Continued*)

Table 3.1 Socioeconomic/environmental data. (*Continued*)

Variables	Percentage (100%)
₦30,000 - ₦40,000	20
₦40,000 - 50,000	30
₦50,000 and above	25
Indigenous uses of community forest	
Farming	30
Buildings	20
Timber harvesting	35
Refuse dump	05
Hunting	10
Consequences of deforestation	
Tree loss	30
Flooding	15
Erosion	25
Low crop yield	20
Low vegetation cover	10

female participants were 30%. Further, 35% of the study population had finished their secondary school education, namely West African School Certificate (WASC), and 30% had completed their primary school education, namely First School Leaving Certificate (FSLC); 15% had no formal education, and 35% of the study population had completed their secondary school education.

Findings showed that married participants represented 45% of the population, unmarried/single population was 30% and 15% were widows and 10% were divorced or separated (no longer with their spouse). Also, 45% was the largest household size with 5 and above persons, 25% was the lowest household size with 1-3 persons, while 30% had 3-5 household size, showing a large size family for the majority of the participants, who would demand more food and resources, thereby placing pressure on the community forest. Also, using [37], the highest monthly income for 30%

of the participants was between 40,000-50,000 Naira (USD 121.23), while the lowest income for the 5% was within 10,000-20,000 naira (USD 48.49) while 15%, 20% and 25% earned monthly incomes ranging from 20,000-30,000 (USD 72.74), 30,000-40,000 (USD 96.98) and 50,000 naira (USD 121.23) and above, respectively. Findings on drivers of deforestation activities in the community forest showed that 35% of the sampled population cut down trees for fuel wood, 30% for farming, 20% for residential buildings, 10% for hunting and 5% for dumping of refuse (see Plates 3.3, 3.4, 3.5 and 3.6). Further, results of consequences of deforestation showed that 30% reported tree loss, 25% indicated erosion problems, 20% revealed low crop yield, 15% indicated flooding and 10% low vegetation cover.

Plate 3.5 Evidence of access created by farmers and ongoing farming activities carried out in parts of the forest and a building project.

Plate 3.6 Parts of the forest area used as dumpsite and pathways showing human intrusion.

3.5.2 Discussion

From this study, our findings revealed that 70% of the sampled population within Ezekoro Forest community were males, 45% of them were married, and 35% fell in the age range of 30-40 years. 35% had also completed their secondary school education, while 45% had large families of more than five children and 55% had a monthly income within 50,000 naira and above (USD 121.23) (see Table 3.1). Notably, men dominated the sample population; men were 70% and women 30%. Of note, purposive sampling was employed in recruiting participants; however, it further buttressed the fact that the majority of the people (in)directly involved in exploiting community forest resources were men. Apparently, activities such as tree logging, farming and wood business are male dominated. As a patriarchal society, Nigeria features traditional and cultural structures that support men [38]. This structure, with its set of social interactions, is based on a foundation that enables men to overshadow and control women [39]. Further, in 2020, Nigeria's male population was slightly above the female; male population was approximately 104.47 million and female population was approximately 101.67 million people [40].

Globally, the male population is slightly higher than the female population, although this varies by country. According to a UN report [40] in 2019, the population of females in the world is estimated at 3.905 million, representing 49.58% of the world population. The world has 65.51 million more males than females. Obviously, there are more males in Nigeria and globally compared to a lower population of females. More so, the study area is in southeastern Nigeria, where the Igbo tribe is dominant and male preference is a governing feature of the Igbo culture [41].

Notably, the majority of the males serve as household heads influencing decision making. This study has noted the necessity to close the gap between low participation of female gender and male dominance in contributing solutions to research studies. This also relates to education and income in this study as the men have higher outcomes, and this can be perceived as a form of injustice, because it can lower the success of sustainable forest management. The issue of the inclusion of women in deforestation studies can be perceived as a central thrust to fight environmental degradation and climate change risks [42, 43]. Ideally, the concept of environmental justice is a demand on people, communities, and the society to treat all fairly, irrespective of social status and positions, such as age, ethnicity, class, and gender. It covers the human relational and interactive patterns with the environment. Also, an International Monetary Fund (IMF) report opines that closing the gender gap can produce and achieve higher economic growth in the economy to improve productivity and stabilize the economy [44]. Also, the majority of the study population have more than five children. This finding is confirmed by the study that reports on the characteristic male-dominant and patrilineal traditions in local communities in Nigeria that support large family size [45].

The Nigeria minimum wage is 30,000 Naira (USD 72.26) and the monthly value for basic food products alone for adult healthy living in Nigeria, presently, is 40,980 Naira (USD 98.70), but the monthly income of 55% of the study population is USD 121.23, which is poor [46], representing a 15.89% increase compared to previous years. Of note, the study area is basically rural, in addition to the large family sizes. Unfortunately, the monthly income of USD 121.23 can barely cover all their basic needs. Additionally, the population of the study area is under 100,000 people [34] presently, but with high levels of increased cost of living. Typically, a rural Nigerian family may be able to feed themselves with 138,678 Naira (USD 365) monthly; it is obvious the sample participants can hardly experience a decent standard of living. It can be deduced that there are high levels of poverty with our study population. A relatable study [47] agrees to the study and reported that more than 40% of the Nigerian people live in extreme poverty, even less than the international poverty line of USD 1.90 per person per day [48] (www.statista.com). Presently, 1 US dollar equals 415.186 naira [37] (http://www.xe.com). Increasing population and high poverty levels are major factors that place greater pressure on community forest resources considering that the majority of the residents are farmers as was learned during in-depth interviews. The reliance of these people on the ecosystem is for their daily sustenance [48], with minimal interest in managing their environment, besides low environment perception that worsens their environmental problems, and this cascades into a communal poverty cycle. Resource depletion in northeastern Nigeria is mostly within the poor and illiterate and this is the major consequence of natural resource degradation [49]. For the majority of the world's rainforest regions, the poorest people are found in these areas all over the planet. An Ethiopian work showed that forest resources generated about 39% of income. The rural poor farm, harvest fruit and wood, and hunt wildlife to feed their families, besides the extracted forest land resources paid for by companies that work within the forest [50]. They are mostly poor, possess average education levels with low qualifications to secure well-paid jobs and hence, there is aggressive deforestation and exploitation on forests and wildlife. This is because the extraction of these resources takes minimal technological skills, making it an attractive income generation prospect for households in rural communities [51]. This suggests why 35% of the participants in this study harvest timber (see Plate 3.3) mostly for cooking and selling in the local market as inferred during discussion and interviews.

Clearly, the rising cost of cooking gas has placed demand on the use of firewood for cooking. The majority of southeasterners have resorted to firewood and charcoal as a substitute for cooking gas since its increase by 50% [52]. Although gas is produced in Nigeria, it is refined and imported into Nigeria. A 6kg cylinder previously sold at 2,000 naira presently cost 4,200 naira, while a 12.5kg cylinder that was sold for 6,800 naira is sold for 10,200 naira (USD 25), and the prices keep increasing. It is reported that only about 17% of Nigerians use cooking gas [53]. There is need for a transition to renewable and clean energy sources such as solar energy to reduce deforestation and tree losses, besides providing a permanent solution to the country's chronic electricity shortage.

Further, 20% of the sample population indicated that they make use of forest woods for construction and building purposes (see Plate 3.4). Population growth and a large market for timber is attracting major development in the area such as the newly developed St. Peter University (see Plate 3.1). Clearly, this indicates the high level of indiscriminate mismanagement of our woody resources. A closer look at (Plate 3.3) shows fallen trees harvested as firewood and tender and partially grown bamboo trees that are harvested for construction materials. Rapid rural expansion is also responsible for encroachment into community forests. However, unregulated clearance of trees and vegetation cover makes the study area liable to uncontrolled runoff during wet seasons.

The study on the impact of deforestation on socioeconomic development of Akwanga Nasarawa State [54] stated that the clearance of bushes and trees for infrastructural development has brought loose soil, heightening its susceptibility to flooding. Further, deforestation in Enugu State, Nigeria found that 81% of the original forest cover has been removed due to rapid expansion of infrastructures [55]. Also, 30% and 10% of the sample populace deforest and de-reserve the community forest for farming and hunting purposes, respectively (see Plate 3.5). For Achina people, their main occupation is farming and petty trading, besides their dependence on agriculture and commerce as a major source of income generation, employment, and livelihood.

Presently, there is a wide range of agricultural activities in the study area where the laterite soil type is characterized by rolling undulating terrain that supports agriculture. In addition, the lowland areas have abundant rivers and streams that irrigate these farms. As part of the Igbo culture and heritage most Achina people have "mbubo" (known as home garden) and "ubi" (as an out-station garden) and "ikpa" (very far from home) where they usually cultivate their farm products like cassava, vegetables, pepper, garden eggs, cocoyam, maize, yam, melon, oil, and raffia palm in commercial quantities.

Findings from the study proved that Ezekoro Forest serves as an “ubi” and “ikpa location for farming. Notably, the location of Achina in a tropical rainforest region presents an ecological framework in their production of tropical agricultural products. Findings also indicated that 5% of the participants use parts of the forest area as a refuse dump for plastic waste (see Plate 3.6). Obviously, the level of environmental degradation in Ezekoro Forest area is detrimental to plants and animal life, planetary health of ecosystems and biodiversity. Generally, deforestation has brought about huge consequences where tree loss according to the findings in this study is 30%, erosion is 25% (see Plate 3.7), low crop yield is 20% while flooding and low vegetation cover were 15% and 10%, respectively.

Erosion network and floods have intensified since the large, tall trees that serve as buffer during river flooding have been removed. This exposes the land areas to floods; also, farming along stream channels loosens the soil and makes soil erosion rampant igniting an environmental disaster in Anambra State with a large presence of sheet, rills, channel, and gully erosion (see Plate 3.7). This further causes stream/river siltation, thereby polluting water bodies. Worse still, deforestation makes soil layer weak, loose, and vulnerable, thereby, low crop yield becomes inevitable. Generally, this affects the level of crop productivity.

However, gross deforestation activities in the study area are fast changing the formally tropical rainforest vegetation to a derived savannah (see Figure 3.4) where there is vast grassland void of tall trees. From the land use map (Figure 3.4), the green area is mostly vegetation and farmlands, followed by the “red” areas showing the built-up area consisting of developments in Achina.

Findings from the land use cover detection result of satellite images (Figures 3.4 & 3.5). Tables 3.2, 3.3 & 3.4 showed the dramatic changes in Ezekoro forest. It showed in 2001 (Table 3.2), the Bare surface indicating deforested (loss of trees and vegetation) areas was (1.3%) but increased to

Plate 3.7 Erosion network along parts of the de-vegetated Ezekoro Forest area where gullies are fast springing up.

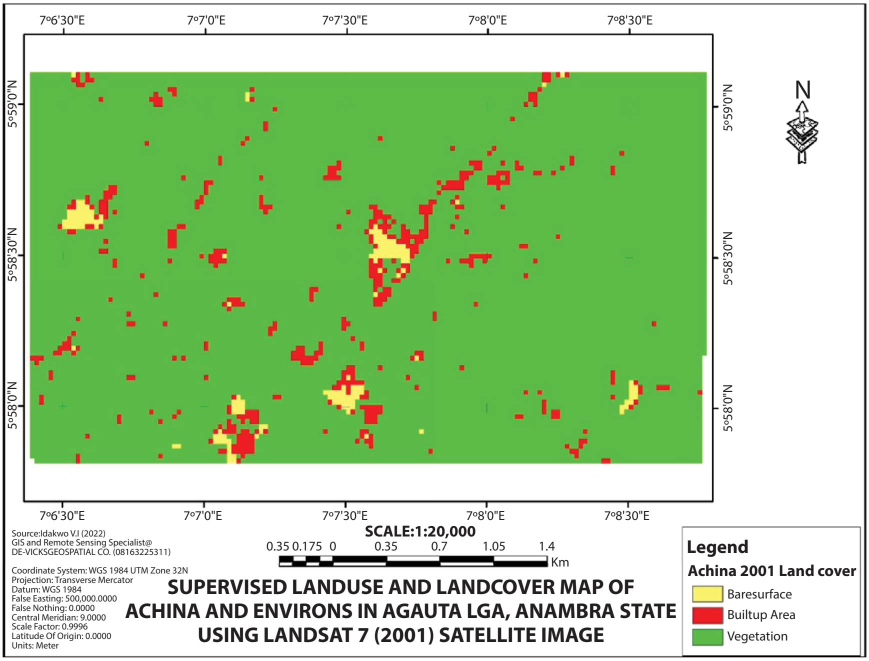

Figure 3.4 Land use map of the study area.

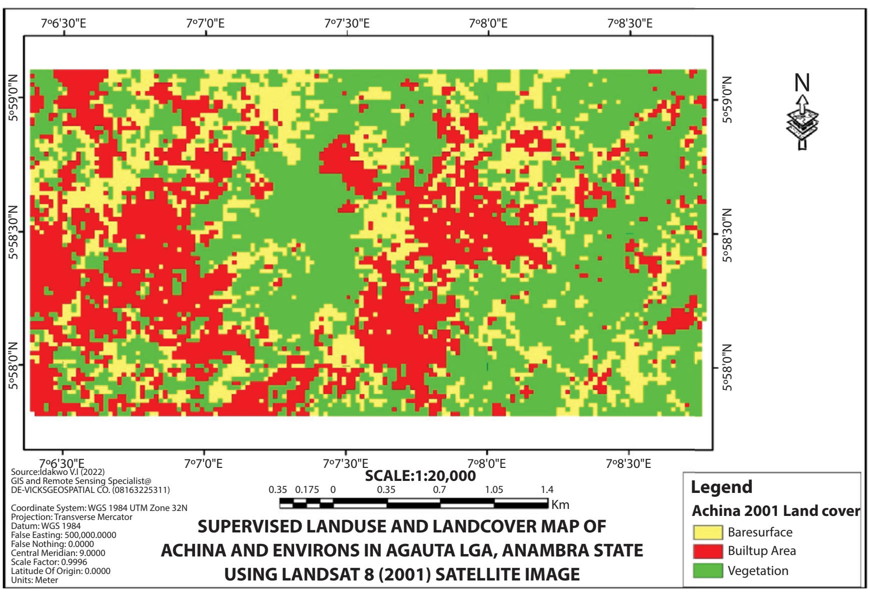

Figure 3.5 Land use map of the study area.

Table 3.2 Statistical result of classified image for 2001 of land use/ land cover for Achina.

Landuse	Area	Percentage
Baresurface	14.1	1.3
Builtup Area	46.4	4.4
Vegetation	990.9	94.3

Table 3.3 Statistical result of classified image for 2021 of land use/land cover for Achina.

Land use	Area	Percentage
Baresurface	247.0	23.5
Builtup Area	316.3	30.1
Vegetation	488.1	46.4

Table 3.4 Percentage Change of classified images for 2001 and 2021 of land use/ land cover for Achina.

Land use	2001		2021		Percentage change (2021-2001)
	Area	Percentage	Area	Percentage	
Bare surface	14.1	1.3	247.0	23.5	22.2
Built-up area	46.4	4.4	316.3	30.1	25.7
Vegetation	990.9	94.3	488.1	46.4	-47.8

(23.5%) in 2021 (Table 3.3) showing a percentage change of 22.2 % for 20 years (Table 3.4). Similarly, built up area was (4.4%) in 2001 (Table 3.2) but rose to (30.1%) in 2021 (Table 3.3) showing a percentage change of 25.7% in 20 years (Table 3.4). However, vegetation/forest cover was (94.3 %) in 2001 (Table 3.2) but decreased tremendously to (46.4%) (Table 3.3) showing a percentage decline of -47.8% in 20 years (Table 3.4). This is an indication of intense deforestation over the years where the forest cover declined by 47%. Our findings correspond with the result from the qualitative data where agricultural activities and tree logging are responsible for the bare surfaces of land use cover change of 22.2%. Human encroachment through residential developments has increased the degradation of the forest area to 25.7%. These activities are responsible for the decline of forest resources to

47%. The declining forest coverage has huge environmental consequences such as climate change and human health risks.

Deforestation is a great threat to the environment and uncontrolled cutting down of trees results in the loss of soil essential nutrients, plants, and animals thereby impacting agricultural productivity and food security [56–58], as well as diminishing resilience to climate risks [57]. Restoring forest maintains biomass production and enhances carbon storage which helps in reducing land, energy and climate footprint [59–62]. Also, forest restoration ensures soil, food and climate security for environmental sustainability [63–66]. The drivers that brought about deforestation activities in Anambra State, Nigeria [30] resulted in deforestation that has caused massive destruction of the terrestrial, arboreal and aquatic ecosystem impacting food, medicinal, and water systems, as well as disrupting essential microbial milieu. The loss of biodiversity and soil degradation encourages floods, as heavily deforested areas are left bare at the expense of runoffs during rainfall. Notably, fragmentation impacts from deforestation and forest degradation influence local climatic elements such as rainfall and temperature, exacerbating flooding and erosion problems in Anambra State [67, 68]. Forest is essential in moderating temperature; however, temperature increase will continue to occur if forest areas are totally cleared, and trees harvested without applying replanting and reforestation approaches. This reduces the evaporative cooling effect that trees provide, thereby escalating local warming in dry periods and floods in wet seasons [69]. This is responsible for the prevalent floods and erosion disasters in Anambra State, as Anambra State has been shown to be vulnerable to extreme weather events as demonstrated by intense climate variability and confirmed by the Nigerian Meteorological Agency (NIMET). The rising climatic variability and unpredictability as it relates to rainfall is exacerbated by vast deforestation activities. Unfortunately, failing forest governance worsens deforestation activities, enhances illegal logging and trade, and exacerbates rural poverty, heightening inflation of food products and prices of cooking gas, amid drivers of institutional corruption that undermine sustainable forest management and growth, development, and environmental conservation [54, 70] in developing countries like Nigeria.

3.6 Conclusion

Comprehending environmental justice, a key to the battle for quality and safe environment for generations now and to the eighth generation is critical to enable all life to continue to inhabit the Earth. The study confirmed that an intensified deforestation practice in Anambra State has escalated the removal of trees for the purposes of fuelwood, farming, and construction, thereby reducing forest area. This has had negative effects on Ezekoro Forest, such as tree loss, erosion, low crop yield, flooding, and low vegetation cover. The high levels of poverty and increased inflation and low access to cooking gas has worsened the situation. The dependence on agriculture as a major source of livelihood in the rural areas is worrisome, as population growth has placed forest areas at a disadvantage due to consistent human intrusion. There is a need to encourage a greater amount of women in forest studies and management, particularly in interventional initiatives in Nigerian forest policy and environmental justice is expedient. Considering that, achieving a level of security and justice over forests in Anambra State can confer some level of protection against environmental and health hazards. More so, environmental justice can confer equal access to the processes of decision-making, particularly in the governance process needed for a healthy environment for multilevel functioning. Finally, there should be positive social change implication in the sense that policymakers' attention should be drawn toward forest degradation and climate risks, especially regarding the people of Anambra State.

References

1. Fiset, N., Harmful Effects of Deforestation. https://ezinearticles.com/?Harmful-Effects-of-Deforestation&id=526763. 2007.
2. Ogundele, A. & Adebisi, O., Deforestation in Nigeria: The Needs for Urgent Mitigating Measures", *IlLARD International Journal of Geography and Environmental Management*, 2, 1, 2016.
3. Global Forest Watch. Global Forest Watch. World Resources Institute. Available: www.globalforestwatch.org. 2016.
4. Global Forest Watch. Tree Cover Loss (Retrieved 28th January 2019) www.globalforestwatch.org. 2019.
5. Renate, S., "A scientific and Ethical Argument against Deforestation in Latin America: Costa Rica as a Case Study", a Thesis submitted to Regis College, The Honors Program in partial fulfilment of the Requirements for Graduation with Honors. 2017
6. Chazdon, R.L., Brancalion, P.H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I.C.G. & Wilson, S.J., When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*, *45*(5), 538-550, 2016.
7. Henok, K., Dondeyne, S., Poesen, J., Frankl, A. & Nyssen, J., Transition from Forest based to Cereal-based Agricultural Systems: A Review of the

Drivers of Land use Change and Degradation in Southwest Ethiopia. *Land Degradation and Development,* 28, 431–449, 2017

8. Hombegowda, H.C., van Straaten, O., Köhler, M. & Hölscher, D., On the Rebound: Soil Organic Carbon Stocks Can Bounce Back to Near Forest Levels When Agro-Forests Replace Agriculture in Southern India. *Soil*, 2, 13, 2016.
9. Global Witness and environmental Investigation Agency. Investigation into the Global Trade in Malagasy Precious Woods: Rosewood. Ebony and Pallisander. 2013
10. Houghton, R.A., Carbon Emissions and the Drivers of Deforestation and Forest Degradation in the Tropics. *Current Opinion in Environmental Sustainability*, 4(6), 597-603, 2012.
11. International Institute of Tropical Agriculture (IITA), Deforestation: Nigeria ranked worst in the World. Retrieved from http://www.thisdaylive.com/articles/deforestation- Nigeria-ranked-worst-in-the world/103321. 2011.
12. Ogunwale, A.O., "Deforestation and Greening the Nigerian Environment" *Nigeria Institute of Social and Economic Research*, Ibadan Nigeria. 2015
13. Radhika, K., Natural resource and environmental issues. *Journal of Ecosystem and Ecography,* 6(2), 196-203, 2016
14. Akanwa, A.O. & Joe-Ikechebelu, N., The Developing World's Contribution to Global Warming and the Resulting Consequences of Climate Change in these Regions: A Nigerian Case, In: *Global Warming and Climate Change*. Edited by John Tiefenbacher, Intech Open, London, United Kingdom, 2020. DOI: http://dx.doi.org/10.5772/intechopen.85052. 2020b
15. Mohammed, A. & Bekele, L. Changes in carbon stocks and sequestration potential under native forest and adjacent land use systems at Gera: South-Western Ethiopia. *Global Journal of Science Frontier Research,* 14, 11–20, 2014.
16. Penz, P., Environmental Victims and State Sovereignty: A Normative Analysis, in Williams, C. (ed.) *Environmental Victims*. Earthscan: London. 1998.
17. Ali, A., A conceptual framework for environmental justice based on shared but differentiated responsibilities, CSERGE Working Paper EDM, No. 01-02, University of East Anglia, The Centre for Social and Economic Research on the Global Environment (CSERGE), Norwich. 2001.
18. United States. Environmental Protection Agency. http://www.epa.gov/environmentaljustice/). Retrieved August 9, 2020, https://www.energy.gov/lm/services/environmental-justice/what-environmental-justice. 2014.
19. Colquette, K.M, Robertson, E. & Henry, A., "Environmental Racism: The Causes, Consequences, and Commendations" (https://www.jstor.org/stable/43291103). *Tulane Environmental Law Journal.* 5 (1): 153–207. JSTOR 43291103. 1991.
20. TheNational Resources Defense Council (NRDC) The Environmental justice Movement. https://www.nrdc.org/stories/environmental-justice-movement. 2016

21. Schlosberg, D., *Defining Environmental Justice: Theories, Movements, and Nature*. Oxford University Press. 2007.
22. Martinez-Alier, J., "Between Activism and Science: Grassroots Concepts for Sustainability Coined by Environmental Justice Organizations". https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/56698/IDL-56698.pdf?sequence=2. doi:10.2458/v21i1.21124. 21: 19-60. 2014.
23. Low, N. & Gleeson, B., *Justice, Society and Nature: An Exploration of Political Ecology*. Routledge: London. 1998.
24. Food and Agricultural Organization of the United Nations. State of the World's Forests: Enhancing the Socioeconomic Benefits from Forests, FAO, Rome, https://www.fao.org/3/i3710e/i3710e.pdf. 2014
25. Franks, P., Food Demands and Forests in sub-Saharan Africa. https://www.iied.org/food-demand-forests-sub-saharan-africa.
26. RES4A, IRENA & UNECA. Towards a Prosperous and Sustainable Africa: Maximizing the Socio-Economic Gain of Africa's Energy Transition. RES4Africa Foundation. Rome. 2022.
27. FAO. Global Forest Resources Assessment 2020 – Key findings. Rome. https://doi.org/10.4060/ca8753en. 2020.
28. Nestle. Sustainability at Nestle. www.nestle.com/sustainability
29. Global Forest Resources Assessment. Country report: Nigeria. www.fao.org
30. Anyanwu, J. C., E. A. Nwobu, and B. O. Osuiwu. "Analysis of factors responsible for deforestation in Anambra state of Nigeria." *IOSR J. Environ. Sci. Toxicol. Food Technol* 5: 23-31. 2013.
31. Goncalves, M.P., Panjer, M., Greenberg, T.S. & Magrath, W.B., *Justice for Forests: Improving Criminal Justice Efforts to Combat Illegal Logging*. World Bank Publications, 2012.
32. Ibrahim, A., Iheanacho, A.C. & Bila, Y., Econometric analysis of causes and impact of deforestation on agriculture in Nigeria. *Journal of Agricultural Economics, Environment and Social Sciences*, *1*(1), 142-150, 2015.
33. Blanchon, D., Moreau, S. and Veyret, Y., "Understanding and building environmental justice." In *Annales de geographie*, 665666 (1), 35-60. Armand Colin, 2009.
34. UmuchuDailyView. http://umuchudailyview.blogspot.com/2017/04/history-of-achina-in-anambra-state-must.html. 2017.
35. Neuman, C. & Rossman, G.B., "Basics of social research methods qualitative and quantitative approaches, 2006.
36. DeCarlo, M., *Scientific Inquiry in Social Work*. Open Social Work Education, 2018.
37. Ex-Rate. Exchange Rate for Today. www.ex-rate.com
38. Okpe, Okpe. "Mainstreaming gender in the African Development process: a Critic of NEPAD and the Women Question." *Education" in Africa Atlases (Nigeria) Paris-France, Les Editions JA* 115 (2005): 118.

39. Aina, I.O., "Women, culture and Society" in Amadu Sesay and Adetanwa Odebiyi (eds.). *Nigerian Women in Society and Development.* Ibadan Dokun Publishing House. 1998
40. United Nations. World Population Prospects. https://population.un.org/wpp/Download/Standard/Population. 2019.
41. Ohagwu, C.C., Eze, C.U., Eze, J.C., Odo, M.C., Abu, P.O. & Ohagwu, C.I., Perception of male gender preference among pregnant Igbo women. *Annals of Medical and Health Sciences Research*, 4(2), 173-178, 2014.
42. Klasen, S., Low schooling for girls, slower growth for all? Cross-country evidence on the effect of gender inequality in education on economic development. *World Bank Economic Review*, *16*(3), 345-373, 2002.
43. UNDP. "Africa human development report 2016", Advancing Gender Equality and Women's Empowerment in Africa, Regional Bureau for Africa, 1 UN Plaza, New York, NY 2015.
44. Adegbite, O.O. & Machethe, C.L., Bridging the financial inclusion gender gap in smallholder agriculture in Nigeria: An untapped potential for sustainable development. *World Development*, *127*, p. 104755, 2020.
45. Isiugo-Abanihe, U.C., Reproductive motivation and family-size preferences among Nigerian men. *Studies in Family Planning*, 149-161,1994.
46. Nwanne, C. New minimum wage of N30, 000 takes effect. https://guardian.ng/saturday-magazine/new-minimum-wage-of-n30-000-takes-effect/
47. Dokua, D.S., People living in extreme poverty in Nigeria 2016-2022 by gender. Accessed February 1, 2022. https://www.statista.com/statistics/1287827/number-of-people-living-in-extreme-poverty-in-nigeria-by-gender/. 2022.
48. Young People trusts for the Environment (YTPE). Rainforests: Why are they important? https://ypte.org.uk/factsheets/rainforests/why-are-rainforests-important. 2022.
49. Uyanga, J., Resource depletion in Northeastern Nigeria: Analysis of trend and sustainable environmental management. *Proceedings for 2014 Environmental Management Association of Nigeria Conference,* pp. 181-190, 2014.
50. Mamo, G., Sjaastad, E. & Vedeld, P., Economic dependence on forest resources: A case from Dendi District, Ethiopia. *Forest policy and Economics*, *9*(8), 916-927, 2007.
51. Heubach, K., Wittig, R., Nuppenau, E.A. &Hahn, K., The economic importance of non-timber forest products (NTFPs) for livelihood maintenance of rural west African communities: A case study from northern Benin. *Ecological Economics*, *70*(11), 1991-2001, 2011.
52. News Agency of Nigeria (2021) Cooking Gas: Nigerians to resort to firewood for cooking as prices soar. Accessed October 18th, 2021. premuimtimesng.com
53. Clowes, W., Nigerians Turn to Firewood and Charcoal as Gas Prices Surge. 9 November 2021.

54. Aliyu, A., Modibbo, M.A., Medugu, N.I. & Ayo, O., Impacts of deforestation on socioeconomic development of Akwanga Nasarawa State. *International Journal of Science, Environment and Technology*, *3*(2), 403-416.2014.
55. Nzeh, E., Eboh, E. & Nweze, N.J., Status and trends of deforestation: An insight and lessons from Enugu State, Nigeria. *Net Journal of Agricultural Science*, *3*(1), 23-31. 2015.
56. Akanwa, A.O., Mba, H.C., Ogbuene, E.B., Nwachukwu, M.U. & Anukwonke, C.C., Potential of agroforestry and environmental greening for climate change minimization. In *Climate Change and Agroforestry Systems* (pp. 47-86). Apple Academic Press. 2020.
57. Akanwa, A.O., Mba, H.C., Jiburum, U. & Ogboi, K.C., Strategies for combating climate change. In *Sustainable Agriculture, Forest and Environmental Management* (pp. 393-435). Springer, Singapore. 2019.
58. Nneji, L.M., A Review of the Effects of Desertification on Food Security. *Rep Opinion*, 5(10), 27-33, 2013.
59. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 2021a, Elsevier. https://doi.org/10.1016/j.jenvman.2021.112829
60. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1): 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
61. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer, ISBN 978-981-15-9495-3, pp. 221-246. 2021a. https://doi.org/10.1007/978-981-15-9496-0_7
62. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer, ISBN 978-981-15-9495-3, pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-0_14
63. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, Pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
64. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888110, pp. 400, 2020. https://doi.org/10.1201/9780429276026
65. Raj, A., Jhariya, M.K. & Khan, N., *Forest for soil, food and climate security in Asia*. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D.

and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3

66. Jhariya, M.K., Meena, R.S., Banerjee, A., Meena, S.N., *Natural Resources Conservation and Advances for Sustainability*. Elsevier, 2022. Academic Press. ISBN: 9780128229767. https://doi.org/10.1016/C2019-0-03763-6.
67. Akanwa, A. & Ezeomedo, I. C., Changing climate and the effect of gully erosion on Akpo community farmers in Anambra state. *Journal of Ecology and Natural Resources*, 2(6), 1-12, 2018.
68. Akanwa, A.O., Okedo-Alex, I.N., Joe-Ikechebelu, N.N. & Chatterjee, U., Persistent climate-driven floods: a voiced case of indigenous women experiencing ecosocial and health risks in a South-East community in Anmabra state, Nigeria. In *Indigenous People and Nature* (pp. 495-523). Elsevier. 2022.
69. Akanwa, A.O. & Joe-Ikechebelu, N.N., Sustainable natural resources exploitation: Clay/sand mining on diminishing greener security and increased climate risks in Nigeria. In *Natural Resources Conservation and Advances for Sustainability* (pp. 545-562). Elsevier, 2022.
70. Yeshaneh, G.T., Assessment of micronutrient status in different land use soils in Maybar lake watershed of Albuko District, South Wello Zone, North Ethiopia. *American Journal of Environmental Protection*, *3*(1), 30-36, 2015.

4

Land Degradation and Its Impacts on Biodiversity and Ecosystem Services

Pawan Ekka[1], Subhashree Patra[1], Manjari Upreti[2], Gajendra Kumar[2], Amit Kumar[2] and Purabi Saikia[1]*

[1]Department of Environmental Sciences, Central University of Jharkhand, Ranchi, India
[2]Department of Geoinformatics, Central University of Jharkhand, Ranchi, India

Abstract
Land degradation is a big challenge that has an impact on ecosystem integrity with reference to diminishing long-term ecological productivity, native biological diversity, and resilience. It is considered a major environmental issue around the world due to its adverse impacts on climate change, habitat and biodiversity loss, poverty, environmental hazards, and adaptive capacities. Human-induced processes including land use transformation, overexploitation of natural resources, population enhancement, economic development, human-induced climate change, ineffective laws, insecure tenure, and lack of agreements directly or indirectly cause land degradation. Around two-thirds of the carbon contained in both vegetation and soil has vanished due to land degradation since the 19th century, adding considerably to global warming. Biodiversity is impacted by land use transformation primarily through habitat loss or modification, changes in species diversity and abundance, soil quality degradation, depletion of water resources, and overexploitation of endemic species. Weak policy and governance result in the dissuasion of sustainable management of land and the deprivation of previously sustainably governed areas. Various methods and techniques have been developed to conserve and maintain the sustainability of land resources through nature-based solutions, including sustainable land management (SLM), ecosystem-based perspective, conservation based on range and unit area, etc.

***Keywords*:** Land degradation, biodiversity, ecosystem services, ecology and sustainable land management

**Corresponding author*: purabi.saikia@cuj.ac.in

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (77–102) © 2023 Scrivener Publishing LLC

4.1 Introduction

Lands are complex systems on Earth operating on spatio-temporal scales globally and their conversion may result in the increase of certain provisioning services, mostly food, but often at the cost of reducing some major ecological services [1]. Around 1.5 billion global population residing in degraded land depending on natural resources for their subsistence, food, and economic security with minimum adaptation options are specifically susceptible to land degradation [2]. The United Nations Sustainable Development Goal (SDG) 15 emphasizes protecting, restoring, and encouraging wise use of terrestrial ecological community through sustainable forest management, combating desertification, putting a halt to and reversing land degradation with restoration practices, and preventing biodiversity loss [3], thereby promoting biodiversity-based livelihoods and capacity building [4]. The changes in the land surfaces in response to the natural and anthropogenic disturbances deteriorate their natural potential which ultimately affects the ecosystem integrity [2] and has an enormous effect on biodiversity and related ecosystem services [5]. It has been found that about 23% of the global land area has reduced productivity due to land degradation [6] by deforestation, desertification, soil erosion, loss of productive potential or fertility, and soil pollution and it is also accelerated by the major gaps in education, learning, awareness, and lack of agreements related to sustainable land management [7]. The degradation affects the delivery of uncountable ecosystem services from terrestrial biodiversity, and carbon sequestration, to other provisioning, or regulating functions [8]. The conversion of naturally vegetated land into cropland, grazing land, and unsustainable land management practices are the most significant and direct causes of land degradation, while other driving factors include effects of climate change, land use transformation, mining, etc., that lead to per-capita demand from growing populations for protein, fibre, and bioenergy [9]. Land degradation is a global environmental problem that affects humankind through a food shortage, hiking food prices, climate change, environmental threats, and losing biological resources and ecosystem services [10]. Soil characteristics play a major role in habitat creation and modification and it has been reflected in the development and growth of agriculture [11].

During the process of land degradation soil carbon and nitrous oxides are released into the atmosphere, which makes land degradation an important contributor to climate change [12]. Approx. ~60% of the ecosystem services (ES) are destroyed because of the increasing global food supply [13]. Both nutrient depletion and erosion are reported as a good indicator of land degradation [14] and the association of these indicators with the ecosystem functions help to identify the target areas where the soil characteristics and nutrient holding capacity has been significantly reduced to low levels for ecosystem restoration and needs to be improved [15]. The disappearance of biodiversity in association with habitat fragmentation and land-use changes leads to deterioration in ecosystem services (ES) [16]. Loss of global biodiversity including >10% of the overall gross productivity per year, species extinction, poor ecosystem services and changing climate scenarios are comprehensively assessed due to the severity of land degradation [17]. The intensive agricultural activities, overexploitation of natural resources for industries, urbanization, and environmental pollution [18] contribute to the reduction in soil biota [19] that lead to changes in biogeochemical cycles [20]. Land degradation stresses ecological functions and their contribution to the maintenance of ecological balance [21].

4.2 Land Degradation: Causes and Consequences

Land degradation is a deterioration of ecosystem services (ES) in terms of net primary productivity (NPP) [22]. It is a global phenomenon of qualitative loss in soil characteristics that is caused by soil erosion, loss of organic carbon, nutrient loss, soil contamination and pollution, acidity and alkalinity, soil compaction and desertification, ecological degradation, biodiversity loss, etc., that eventually brings a negative impact on people's livelihoods and overall biodiversity [23]. About 25% of the earth's surface, excluding the ice cover areas, is affected by land degradation [24]. Both natural and anthropogenic activities lead to land degradation. Natural causes are earthquakes, landslides, floods, forest fires and other calamities, whereas deforestation, illicit timber cutting, intensive agriculture practices, mining and several other developmental projects are key anthropogenic and man-made causes of land degradation. These causes not only destroy land quality but also pollute the environment and affect its sustainability. A linkage between major consequences of land degradation is depicted in Figure 4.1 [25].

Soil is an important biologically active natural resource that forms a functioning medium for terrestrial ecosystems [26]. It is an important basis for food production, filters for contaminants, and reservoirs of water, nutrients, and carbon provide habitat, and form landscapes [27].

Soil erosion initiates land degradation by three different processes including detachment, transport and topsoil deposition due to water and

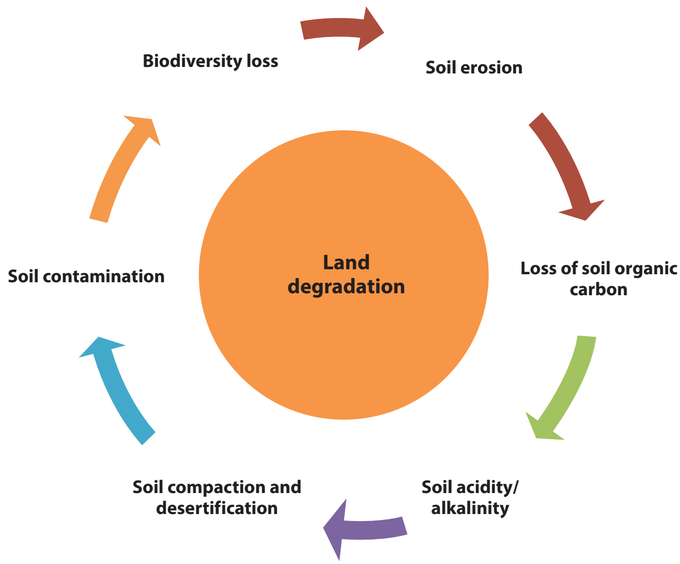

Figure 4.1 Linkages between major consequences of land degradation [25].

wind actions [28, 29]. Major causes of soil erosion are long-duration rainfall, land topography, inadequate vegetative cover, inappropriate agriculture, and poor water management [30]. The main factors that have raised the risk of soil erosion and decreased soil productivity are intensive agricultural practices and climate change [31]. Soil erosion affects the structure and compaction of soil mass. Desertification and soil degradation decline ecosystem services and productivity in the long term. Poor organic matter and nutrient content, less infiltration, unstable water-holding capacity and less biological diversity are reported under soil erosion. A major consequence of soil erosion is depicted in Figure 4.2 [32].

Soil erosion causes the relocation of the organic materials, nutrients, and soil organism-rich topsoil [30]. It also causes flooding, pollution, and siltation in aquatic bodies which prohibits plant growth, recreation, supply of agricultural produce, and water quality [33]. Fewer microorganisms and poor diversity of flora and fauna are reported in soil due to ongoing series of soil erosion [34] and help in the transportation of non-point environmental contaminants, heavy metals (HMs), and chemicals from agricultural fields leading to increased sediment levels, eutrophication, and disturbance in aquatic ecosystems [35]. It also results in increased use of fertilizers inputs in agriculture leading to greater costs of goods and services [36].

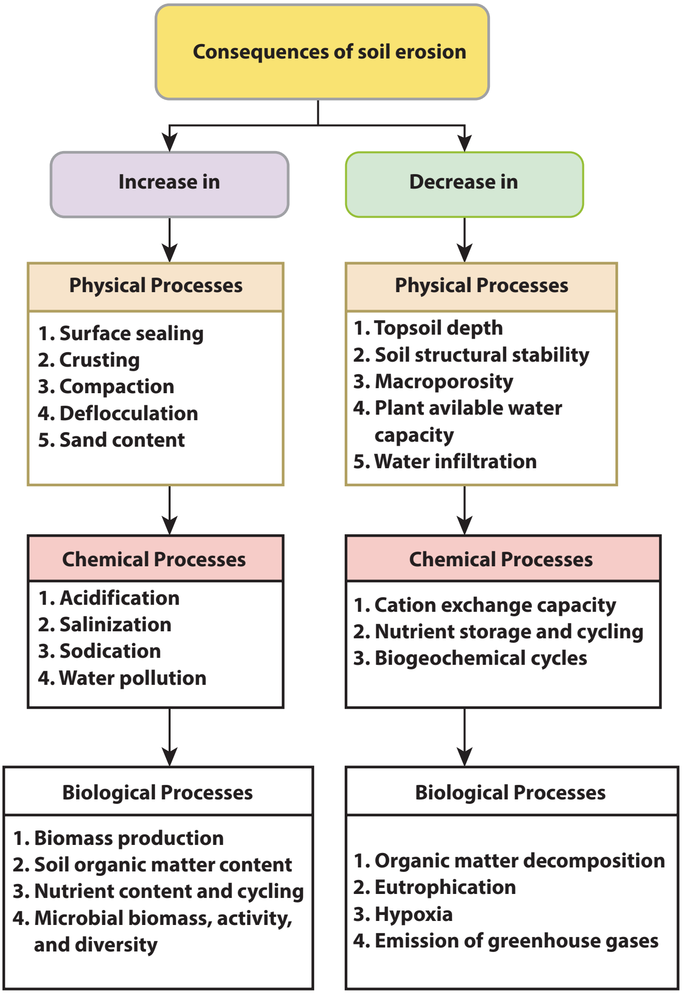

Figure 4.2 Major consequences of soil erosion [32].

Soil organic carbon (SOC) is a functional edaphic characteristic that helps to determine soil fertility, health, productivity, and stability of soil [37]. It is an essential component of the global carbon budget accounting for 62% of the global soil carbon, acting as a source and sink of atmospheric carbon that plays a significant role in global warming, climate change, and atmospheric carbon equilibrium [38]. SOC can help to improve soil structure, nutrient reserves, biotic activity, species diversity, moisture availability, and strengthen the biogeochemical cycling of essential nutrients [39] with decreases in proneness to drought, reduced soil compaction, and increased physio-chemical activity, and buffering capacity [40]. Land degradation results in loss of SOC that directly affects fertility, productivity, soil fauna, and overall soil quality [41]. Depletion of SOC mainly occurs due to degradation of grassland, forest, farmlands, land-use change by urbanization, soil erosion by water, and construction of buildings and roads [42]. Clearing natural forests and grassland for cultivation can reduce SOC, thereby reducing soil biological activities as a result of the decline in gross primary productivity and increase in soil respiration [43]. Cultivation for a long time also affects the storage of SOC and the availability of essential nutrients, e.g., potassium and phosphorus [44]. Loss of SOC due to soil degradation has a significant impact on food production and is associated with food shortages, hunger, malnutrition in poor countries, the decline in ecosystem services, water availability, and energy security [45], biomass productivity, and environmental sustainability [46]. A loss in the SOC pool affects various soil physicochemical parameters including structure along with water nutrient retention capacity [47]. Changes in SOC can significantly affect large-scale carbon cycling and economic development through agricultural productivity; therefore immediate conservation measures should be taken to maintain soil health [48] which can be maintained by forest management, crop rotation, conservation tillage, agroforestry, government schemes, and integrated soil management practices [49].

Soil pollution has become a major environmental issue in developing countries due to mismanagement of land resources, environmental pollution, deforestation, urban expansion and intensive agricultural practices [50]. It is mainly associated with improper waste disposal from industries, municipalities, and intensive fertilizer, weedicide, and insecticide use in agriculture that pollutes the environment through the leaching of hazardous substances by rainwater [51]. Mining activities create a large sum of overburden and dust particles (Figure 4.3), while the processing of coal releases hazardous substances like polycyclic aromatic hydrocarbons (PAHs) that accumulate in the dump yards and can cause soil contamination [52] that affects plant growth, food production, ecosystem services, biogeochemical cycling of nutrients, human health, economy, and overall biodiversity [53]. Mining of gold, copper and nickel results in acid mine drainage that exposes cyanide and HMs to the soil [54]. Soil acidity is a common phenomenon in humid regions that occurs due to the leaching of bases and salts as a result of heavy rain [55] that affects nearly 50% of the global arable soil [56]. Soils of the degraded site easily become acidic due to increased concentration of stable metallic oxide and leaching of carbonic acid through rain and irrigation [57]. Besides, the use of acid-forming

Figure 4.3 Land degradation by mining activities, overburden, and soil compaction due to the movement of heavy traffic in different mining sites of Jharkhand, India

fertilizers and higher microbial activities on polluted sites contribute to soil acidity by producing nitric and sulfuric acids [58].

The presence of metal contaminants such as Al, Mn, Ca, and Mg increases the soil acidity, making soil unsuitable for cultivation [59] that reduces the production of staple crops, thereby impacting food security [60]. Soil pH has a combined effect on the growth, reproduction, nutrient uptake, disease outbreak, and mineral deficiencies in soil [55] and a pH of <5 can affect the growth of selective flora by suppressing the transport of minerals and nutrients through roots [61]. Moreover, soil compaction is the degradation of a soil's physical characteristics such as bulk density, porosity, and strength that inhibits the normal growth of plants, water and air infiltration, hindering root penetration, and soil biodiversity [62]. Impermeability of air and water creates anaerobic soil layers that are toxic to roots which significantly reduces vegetation cover and crop yield [63]. Globally, soil compaction accounts for ~68 Mha of soil, mainly due to heavy vehicular traffic and agronomic machinery movement for timber harvesting, construction activities, mining, and land transformation [64]. It is also associated with the harvesting of forest resources, urban expansion, pipeline installation, land restoration, and trampling and overgrazing by livestock and wildlife [63]. Soil compaction deteriorates the physical, chemical and biological properties of soil which causes poor organic matter, less water and nutrient content and higher pollution. Soil compaction leads to crusting, hard-setting, slaking and anaerobism [65] and increases the cost and consumption of energy during crop production and agricultural operations [66]. Soil compaction favours soil-borne diseases, denitrification, mineral deficiency in crops, surface runoff, flooding, and lessens recharging of groundwater [64]. It has long-term effects in terms of energy, economy, food production, and environmental sustainability [67].

Desertification is a type of land degradation reported in dry regions due to the combined effect of the socio-economy, anthropogenic activities, and climate change that destroys the biological wealth of soils and disrupts ecosystem services [68]. Annually 10% of the global GDP is lost due to desertification affecting almost 3.2 billion people [69]. The rate of desertification triggers by increasing urbanization, industrialization, tourism, drought, shortage of water, over-extraction of groundwater for irrigation, agricultural, industrial, and household activities, mismanagement of land resources, and traditional agricultural practices, loss of vegetation, over-exploitation of natural resources, and degradation of soil physicochemical and biological properties [68]. Land-use changes are directly linked to the loss of indigenous plant species and soil biota [70] disturbs multiple ecosystem services, plant diversity, nutrient retention, and biogeochemical cycling [71]. Land degradation reduces sediment flow that directly affects mangroves, coral reefs, and seagrasses and alters aquatic biodiversity that triggers the invasion of exotic species that affect soil biota including earthworms, rhizobia, and mycorrhizae that accelerates the rate of further land degradation [72].

4.3 Land Degradation and Major Environmental Challenges

Land degradation refers to the deterioration of biological diversity, ecosystem services, soil productivity, vegetation cover, and water resources of terrestrial ecosystems that eventually leads to adverse consequences for the environment, human society and ecological systems [73]. The deterioration of soil nutrient status affects humanity through food insecurity, climate change, environmental hazards, limited livelihoods, extinction of species, and imbalance in ecosystem services [10]. A range of anthropogenic activities leading to the depletion of natural resources resulted in ecosystem disruption [74]. Modern agricultural practices have caused major environmental changes, altering lands' natural productivity, water and mineral cycling, and drought patterns [75]. Land degradation leads to poor ecosystem services (ES) or the de-vitalization of land as a result of over-exploitation [76], which tremendously affects the ecosystem and the biophysical environment. Depending on the intensity of the degradation, land productivity may be diminished either temporarily or permanently [77]. Drought, flooding, chemical abuse, nutrient loss, intensive but unscientific agricultural practices, deforestation, urbanization, overgrazing, water pollution, solid waste accumulation, and non-biodegradable waste disposal are the major contributors to land degradation [10]. Anthropogenic, physicochemical, and biological processes are the natural risks leading to the land quality deterioration [10, 78]. The radical change of natural landscapes, forests, and grasslands into agricultural land including the transformation of natural vegetation cover to intensive commercial croplands for coffee, cotton, palm oil, soybeans, and wheat cultivation has accelerated the rate of soil erosion, exceeding its natural ability to recover and maintain its characteristic features [79, 2]. Soil erosion is an important environmental and economic concern as it severely impacts ~10 M ha of agricultural lands every year, resulting in a significant decrease in global food production that leads to malnourishment of >3.7 billion people, globally [80]. As per one figure, approximately 3.0, 5.5 and 6.6 billion tons of soil are lost annually in the regions of the US, China and India. However, the soil erosion rate is 10-40 times faster than its formations [80]. In the last 150 years, compaction, depletion of soil, nutrient shortages, and soil salinization [81, 10] have resulted in the loss of about half of the planet's topsoil [82]. About 52% of the world's farmland, or even beyond 2.0 billion hectares, is deteriorated, impacting 1.5 billion people and adversely affecting women, children, and the poor in rural areas [83]. Land degradation caused by mineral extraction through mining activities results in enormous swaths of degraded land leading to considerable loss of habitat and biodiversity, severe dust load in the atmosphere, air and water pollution, groundwater contamination, effluent discharges, acid drainage, and metal toxicity around the mining sites with various negative consequences on vegetation and wildlife [74, 84].

4.4 Restoration of Degraded Land

Ecological restoration enables ecosystem rehabilitation which has been deteriorated, mutilated, or devastated [85]. End land use, determination of limiting factors, and attenuation, planning, and execution are the three main components of the degraded land restoration process [86]

(Figure 4.4). Bioremediation using microorganisms and various hyperaccumulating plant species, crop rotations process, agroforestry technique, reduced tillage method, cover crops technology, vegetative filter strips, residue, and no-till are some of the widely used biological and agro-economic strategies to restore degraded land. Land restoration through bioremediation and technological intervention is depicted in Figure 4.5 [87, 88, 92].

Bioremediation is the removal, eradication, and detoxification of various physicochemical contaminants from the degraded lands by the action of microorganisms present in the soil and rhizospheric zone of plants [89, 90]. It is a desired waste management strategy that allows for partial purification, preservation of biological activity, the physical structure of soils, restoration of soil biota, and site rehabilitation [91]. Microbial biomass helps in assessing the restoration status of damaged sites [92]. Phytoremediation is an environmentally friendly strategy that removes, modifies and sequesters heavy metals pollutants through plants and microbes [93, 94]. Phytoextraction, phytovolatilization, phytostabilization, phytodegradation, rhizofiltration, and rhizodegradation are key important Phytoremediation processes which are based on different remediation mechanisms (Figure 4.6) [91]. Plants and their associated microbes naturally break down and absorb organic and inorganic contaminants on-site [95] which is cost-effective as it saves money by eliminating the excavation and transportation of contaminated soil [96]. It can be applied to treat all solid, liquid, and gaseous contaminants such as metals, herbicides, pesticides, drainage water, agricultural runoff, etc. [95]. Adopting fast-growing tree species under plantation and afforestation activities restores degraded land and provides various ecological and economic benefits [97]. Economically important tree species, particularly bioenergy crops, act as a significant influence in land reclamation and carbon sequestration in degraded soil [98]. A different restoration technique and its purposes are depicted in Table 4.1.

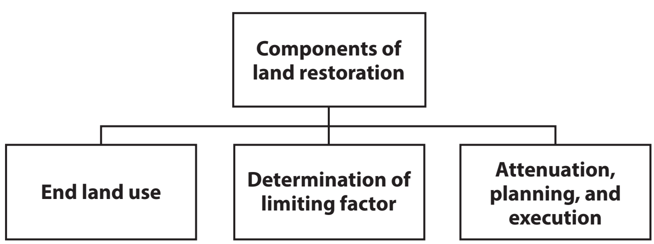

Figure 4.4 Components of land restoration [86].

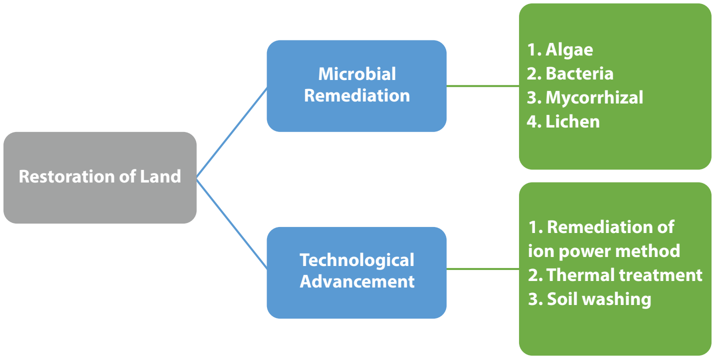

Figure 4.5 Different processes of restoration of degraded land [87, 88, 92].

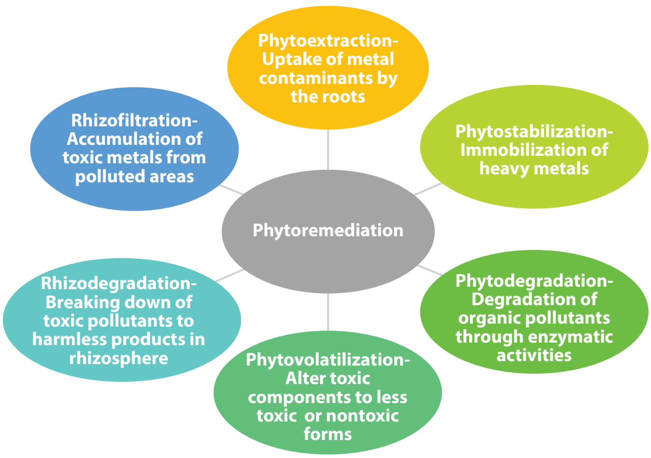

Figure 4.6 Different types of plant-assisted bioremediation processes [91].

4.5 Sustainable Land Management

Conservation of soil resources is critical to all living beings as it is important for food production, human well-being, biodiversity conservation, and healthy ecosystem services [107] and also helps in minimizing the impacts on the ever-increasing human population and decreasing biodiversity. Soil erosion can be managed through practical and comprehensive strategies including watershed management, creation of filter strips, grass barriers, buffers, field borders, windbreaks, etc., and also through scientific evaluation and monitoring of infrastructure development, land-use changes, resource exploitation, and hydrological cycles prior to any developmental

Table 4.1 Different restoration techniques and their purpose.

Restoration techniques	**Purpose**	**Sources**
Crop management	Reduce wind and water erosion	[99]
Inter-cropping	Increases regeneration properties and reduces soil erosion	[99]
Crop selection	Increases stability, reduces soil erosion, improves soil property	[99]
Crop rotation	Avoid soil nutrition depletion, improvement of soil structure and fertility, reduce disease and pest, add humus to the soil, control erosion	[99]
Cover Cropping	Improve organic matter content, check soil erosion and involve in temperature regulation in soils	[100]
Shelterbelts	Protection of irrigated and rainfed farm, increases micro-climate, fruit production, and livestock yields	[99]
Strip Cropping	Reduce soil erosion and runoff, increases water infiltration	[99]
Mulching	Conserve moisture and reduce soil erosion	[101]
Strip seeding	Soil erosion reduction	[99]
Terrace farming	Stabilize the slope and control water erosion	[102]
Vegetative cover	Minimize erosion losses and improve infiltration rate	[103]
Deep plowing	Increase water retention and infiltration process	[104]
Micro-catchment	Control runoff and infiltration rate	[105]
Temporary control measures	Hydroseeding, silt fence, top seeding, soil binders, sediment pit and riprap structure are used	[106]

activities [108]. The UNCCD and the UN Environment Programme joined forces to commemorate the implementation of the "2030 Agenda for Sustainable Development" by the UN General Assembly, which highlighted the role of achieving Land Degradation Neutrality (LDN) in accordance with best practices toward various UN Sustainable Development Goals (SDGs) [109]. LDN has been recognized by the UNCCD Conference of Parties as a concept that can assist communities, corporations, and governments in reconciling the need to enhance food production without harming land resources [110]. LDN is essentially about more sustainably managing land to reduce degradation while boosting rates of land restoration to achieve a net-zero rate of land degradation [111]. The Sustainable land management (SLM) programme was commenced by the Brundtland Commission [112] with the purpose of balancing the parallel aims and provisions of environmental, and socioeconomic opportunities for existing and future generations, while conserving and increasing the land resource quality [113]. Scientific technology, future policy, and land use planning are the three major components of SLM [114] that incorporated most aspects of land evaluation including social, economic, and ecological factors to round out the vision [112]. SLM practices including forest plantation and afforestation program help in biomass production and carbon management in the ecosystem that enhance biodiversity conservation along with soil, food and climate security [115–117]. Climate resilient agroforestry practices in degraded land also help in ecosystem restoration and environmental sustainability by minimizing carbon, land and energy footprint [118–125]. Moreover, integrating leguminous and multipurpose tree species ensures eco-restoration of degraded land by improving soil health and quality by

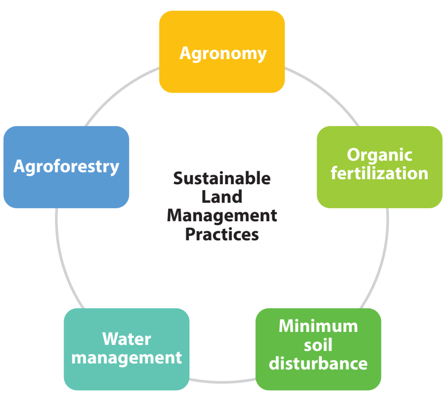

Figure 4.7 Various land management practices under SLM [131].

enriching carbon and nitrogen status in the soil [126–129]. Thus, the interdisciplinary framework of restoration programs based on broader social and cultural perspectives is necessary for decisions and policymakers that assure sustainability of the natural and managed ecosystems [130]. Various land management practices are depicted in Figure 4.7 [131].

4.6 Recommendation and Future Research Prospects

The future trends in land management and its resilience for recovery depend on the prolonged effects of land degradation [132]. Therefore, the efficiency and performance of ecological indicators in combination with socioeconomic principles [15] seem to be promising for future research perspectives. Biomass production in degraded areas has the potential to provide significant environmental and social advantages [133]. There is an urgent need for promoting ecological intensification practices which improve crop yield by aiming to reduce the extent of degraded lands and promote food security in an environmentally sustainable manner [134]. The degree of afforestation based on the LDN report is very challenging and expensive to achieve in the future [111]. Therefore, human-assisted natural regeneration with community involvement on abandoned fields and degraded landscapes would be less expensive and more beneficial to recovering biodiversity, conditions of soil, and simultaneously the changing climate resilience [135].

4.7 Conclusions

Land degradation is observed as a challenging global problem directly or indirectly linked with human activities. Mismanagement and overexploitation of land resources have major propounding impacts on crop productivity, food security, biodiversity, environment, wildlife habitat, ecosystem services, economy, human health, and the quality of life. Extensive agriculture and its intensification, urbanization, and globalization are the key factors responsible for land degradation. Besides, lack of strict policy intervention, institutional frameworks related to sustainable land management (SLM), and rapid change in the natural landscape are the major causes leading to land degradation that affect the ecosystem integrity, climate, environmental sustainability, and economic stability of developing countries. Sustainable land management through integrating engineering and ecological approaches can prevent land degradation. Scientific knowledge, innovative technology, resource management, impact assessment, standardized methodology, effective international collaborations, public participation from different ecological zones, strict government policy, expert knowledge involving decision-makers and conservation professionals, and practical restoration practices can bring fruitful results in preventing land degradation and supporting sustainable land management (SLM).

References

1. Verburg, P. H., Crossman, N., Ellis, E. C., Heinimann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K. H., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D. C., Chowdhury, R. R., Shibata, H., Thomson, A. & Zhen, L., Land system science and sustainable development of the earth system: A global land project perspective. *Anthropocene*, 12, 29-41, 2015.
2. Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., Hermans, K., Jobbagy, E., Kurz, W., Li, D., Sonwa, D. J., & Stringer, L., "Land Degradation. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, Shukla, P. R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H. O., Roberts, D. C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., & Malley, J. (eds.), pp. 345-436, 2019.
3. UN, Transforming our World: The 2030 Agenda for Sustainable Development. Population Fund. United Nations, 2015. https://www.unfpa.org/resources/transforming-our-world-2030-agenda-sustainable-development
4. UNDP, The Future We Want: Biodiversity and Ecosystems-Driving Sustainable Development. United Nations Development Programme Biodiversity and Ecosystems Global Framework 2012-2020. New York, 2012. https://www.cbd.int/financial/mainstream/undp-globalframework2012-2020.pdf.
5. Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T. M., Bonin, C., Bruelheide, H., de Luca, E., Ebeling, A., Griffin, J. N., Guo, Q., Hautier, Y., Hector, A., Jentsch, A., Kreyling, J., Lanta, V., Manning, P., Meyer, S. T., Mori, A. S., Naeem, S., Niklaus, P. A., Polley, H. W., Reich, P. B., Roscher, C., Seabloom, E. W., Smith, M. D., Thakur, M. P., Tilman, D., Tracy, B. F., van der Putten, W. H., van Ruijven, J., Weigelt, A., Weisser, W. W., Wilsey, B. & Eisenhauer, N., Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature*, 526(7574), 574-577, 2015.
6. UNCCD, Data and facts about recent assessments of land degradation, n.d. Available at URL. https://www.unccd.int/sites/default/files/relevant-links/2019-06/Summary_Assessement_Land_Degradation.pdf.

7. IUCN, Land Degradation Neutrality: implications and opportunities for conservation, Technical Brief Second Edition 27/08/2015. Nairobi: IUCN, pp. 19, 2015. Available at URL. https://www.iucn.org/sites/dev/files/media-uploads/2018/03/tech_brief_land_degradation_neutrality_.pdf .
8. Stanturf, J. A., Landscape degradation and restoration. In: *Soils and Landscape Restoration*, Stanturf, J. A., & Callaham, M. A. (eds.), Academic Press, USA, pp. 125-159, 2021.
9. El-Zein, A., On dangerous ground: land degradation is turning soils into deserts. *The Conversation*, 2018. https://theconversation.com/on-dangerous-ground-land-degradation-isturning-soils-into-deserts
10. Gupta, G. S., Land degradation and challenges of food security. *Review of European Studies*, 11, 63, 2019.
11. De Deyn, G. B., & Kooistra, L., The role of soils in habitat creation, maintenance and restoration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 376(1834), 1-9, 2021.
12. GEF, Land Degradation. Global Environment Facility, n.d. https://www.thegef.org/what-we-do/topics/land-degradation
13. MEA, *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press, pp. 1-137, 2005.
14. Kairis, O., Kosmas, C., Karavitis, C., Ritsema, C., Salvati, L., Açıkalın, S., Alcalá, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Solé-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, J., Ermolaeva, O. & Ziogas, A., Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Types of Degradation, Causes, and Implications for Management. *Environmental Management*, 54, 971-982, 2014.
15. Cerretelli, S., Poggio, L., Gimona, A., Yakob, G., Boke, S., Habte, M., Coull, M., Peressotti, A., & Black, H., Spatial assessment of land degradation through key ecosystem services: The role of globally available data. *Science of the Total Environment*, 628-629, 539-555, 2018.
16. Yan, F., Zhang, S., Liu, X., Chen, D., Chen, J., Bu, K., Yang, J. & Chang, L., The Effects of Spatiotemporal Changes in Land Degradation on Ecosystem Services Values in Sanjiang Plain, China. *Remote Sensing*, 8(11), 1-24, 2016.
17. UNEP-WCMC, Land Degradation and Decline of Biodiversity Poses Threat to Human Well Being, 2018. https://www.unep-wcmc.org/news/land-degradation-and-decline-of-biodiversity-poses-threat-to-human-well-being.
18. Ponge, J.F., Pérès, G., Guernion, M., Ruiz-Camacho, N., Cortet, J., Pernin, C., Villenave, C., Chaussod, R., Martin-Laurent, F., Bispo, A., & Cluzeau, D., The impact of agricultural practices on soil biota: A regional study. *Soil Biology and Biochemistry*, 67, 271-284, 2013.
19. Culman, S.W., Young-Mathews, A., Hollander, A.D., Ferris, H., Sánchez-Moreno, S., O'Geen, A.T. & Jackson, L.E., Biodiversity is associated with indicators of soil ecosystem functions over a landscape gradient of agricultural intensification. *Landscape Ecology*, 25(9), 1333-1348, 2010.

20. Prince, S., Von Maltitz, G., Zhang, F., Byrne, K., Driscoll, C., Eshel, G., Kust, G., Martínez-Garza, C., Metzger, J. P., Midgley, G., Moreno-Mateos, D., Sghaier, M., & Thwin, S., Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem functions. In: *The IPBES assessment report on land degradation and restoration*. Montanarella, L., Scholes, R., & Brainich, A. (eds.), Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, pp. 221-338, 2018. https://ipbes.net/sites/default/files/2018_ldr_full_report_book_v4_pages.pdf.
21. Reed, M.S., Stringer, L.C., Dougill, A.J., Perkins, J.S., Atlhopheng, J.R., Mulale, K., & Favretto, N., Reorienting land degradation towards sustainable land management: Linking sustainable livelihoods with ecosystem services in rangeland systems. *Journal of Environmental Management*, 151, 472-485, 2015.
22. Abdel Rahman, M.A., Afifi, A.A., & Scopa, A., A Time Series Investigation to Assess Climate Change and Anthropogenic Impacts on Quantitative Land Degradation in the North Delta, Egypt. *ISPRS International Journal of Geo-Information*, 11(30), 1-21, 2021.
23. Mishra, P.K., Rai, A., Abdelrahman, K., Rai, S.C., & Tiwari, A., Land Degradation, Overland Flow, Soil Erosion, and Nutrient Loss in the Eastern Himalayas, India. *Land,* 11, 1-12, 2022.
24. IPCC, Summary for policymakers. In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*; IPCC: Geneva, Switzerland, 2019.
25. Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K. S., Lalitha, M., Hat, K. M. & Franzluebbers, A.J., Soil degradation in India: Challenges and potential solutions. *Sustainability*, 7(4), 3528-3570, 2015.
26. Golubović, T.D., Environmental Consequences of Soil Erosion. In: *Prevention and Management of Soil Erosion and Torrential Floods*, Milutinović, S., & Živković, S. (eds.), IGI Global, pp. 112-131, 2022.
27. Dominati, E., Patterson, M. & Mackay, A., A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological economics*, 69, 1858-1868, 2010.
28. Hudson, N. W., Factors determining the extent of soil erosion. In: *Soil Conservation and Management in the Humid Tropics*, Greenland, D. J., & Lal, R. (eds.), Chichester, Sussex (UK) Wiley, pp. 11-16, 1977.
29. Bullock, P., Climate Change Impacts. In: *Encyclopedia of Soils in the Environment*, Hillel, D., Rosenzweig, C., Powlson, D. S., Scow, K. M., Singer, M. J., & Sparks, D. L. (eds.), Elsevier: Oxford, UK, pp. 254-262, 2005.
30. Issaka, S. & Ashraf, M. A., Impact of soil erosion and degradation on water quality: a review. *Geology, Ecology, and Landscapes*, 1(1), 1-11, 2017.

31. Paul, C., Kuhn, K., Steinhoff-Knopp, B., Weißhuhn, P. & Helming, K., Towards a standardization of soil-related ecosystem service assessments. *European Journal of Soil Science*, 72(4), 1543-1558, 2021.
32. Petito, M., Cantalamessa, S., Pagnani, G., Degiorgio, F., Parisse, B., & Pisante, M., Impact of Conservation Agriculture on Soil Erosion in the Annual Cropland of the Apulia Region (Southern Italy) Based on the RUSLE-GIS-GEE Framework. *Agronomy*, 12(2), 281, 2022.
33. Liu, Y., Landscape connectivity in Soil Erosion Research: concepts, implication, quantification. *Geographical Research*, 1, 195-202, 2016.
34. Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Sphpritz, L., Fitton, L., Saffouri, R. & Blair, R., Environmental and economic costs of soil erosion and conservation benefits. *Science*, 267, 1117-1123, 1995.
35. Bing, H., Wu, Y., Liu, E. & Yang, X., Assessment of heavy metal enrichment and its human impact in lacustrine sediments from four lakes in the mid-low reaches of the Yangtze River, China. *Journal of Environmental Sciences*, 25(7), 1300-1309, 2013.
36. Karuku, G.N., Soil and water conservation measures and challenges in Kenya; A review. *International Journal of Agronomy and Agricultural Research* (IJAAR), 12(6), 116-145, 2018.
37. Prăvălie, R., Nita, I.A., Patriche, C., Niculiță, M., Birsan, M.V., Roșca, B. & Bandoc, G., Global changes in soil organic carbon and implications for land degradation neutrality and climate stability. *Environmental Research*, 201, 111580, 2021.
38. Martin, M.P., Wattenbach, M., Smith, P., Meersmans, J., Jolivet, C., Boulonne, L., & Arrouays, D., Spatial distribution of soil organic carbon stocks in France. *Biogeosciences*, 8(5), 1053-1065, 2011.
39. Bronick, C. J. & Lal, R., Soil structure and management: a review. *Geoderma*, 124, 3-22, 2005.
40. Lal, R., Feeding 11 billion on 0.5 billion hectares of area under cereal crops. *Food and Energy Security*, 5(4), 239-251, 2016.
41. Dlamini, P., Chivenge, P., Manson, A. & Chaplot, V., Land degradation impact on soil organic carbon and nitrogen stocks of sub-tropical humid grasslands in South Africa. *Geoderma*, 235, 372-381, 2014.
42. Xie, Z., Zhu, J., Liu, G., Cadisch, G., Hasegawa, T., Chen, C., Sun, H., Tang, H. & Zeng, Q., Soil organic carbon stocks in China and changes from 1980s to 2000s. *Global Change Biology*, 13, 1989-2007, 2007.
43. Reinsch, T., Loges, R., Kluß, C. & Taube, F., Effect of grassland ploughing and reseeding on CO_2 emissions and soil carbon stocks. *Agriculture, Ecosystems & Environment*, 265, 374-383, 2018.
44. Berhane, M., Xu, M., Liang, Z., Shi, J., Wei, G., & Tian, X., Effects of long-term straw return on soil organic carbon storage and sequestration rate in North China upland crops: A meta-analysis. *Global Change Biology*, 26, 2686-2701, 2020.

45. Stockmann, U., Padarian, J., McBratney, A., Minasny, B., de Brogniez, D., Montanarella, L., Hong, S.Y., Rawlins, B.G. & Field, D.J., Global soil organic carbon assessment. *Global Food Security*, 6, 9-16, 2015.
46. Lal, R., Soils and food sufficiency. A review. *Agronomy for Sustainable Development*, 29, 113-133, 2009.
47. Lal, R., Soil carbon sequestration impacts on global climate change and food security. *Science*, 304, 1623-1627, 2004.
48. Fang, J., Piao, S. & Zhao, S., CO_2 missing carbon sink and carbon pool in the land ecosystem with medium latitude in the Northern Hemisphere. *Journal of Plant Ecology*, 25(5), 594-602, 2001.
49. Srinivasarao, C., Venkateswarlu, B., Lal, R., Singh, A.K., Kundu, S., Vittal, K.P.R., Kogganur, R. & Gajanan, G.N., Long-term effects of crop residues and fertility management on carbon sequestration and agronomic productivity of groundnut–finger millet rotation on an Alfisol in southern India. *International Journal of Agricultural Sustainability*, 10(3), 230-244, 2012.
50. Van Straalen, N.M., Assessment of soil contamination–a functional perspective. *Biodegradation*, 13, 41-52, 2002.
51. Eijsackers, H.J.P., Soil quality assessment in an international perspective: generic and land-use based quality standards. *AMBIO: A Journal of the Human Environment*, 27, 70-77, 1998.
52. Masto, R.E., Sheik, S., Nehru, G., Selvi, V.A., George, J. & Ram, L.C., Assessment of environmental soil quality around Sonepur Bazari mine of Raniganj coalfield, India. *Solid Earth*, 6, 811-821, 2015.
53. Sridharan, S., Kumar, M., Bolan, N.S., Singh, L., Kumar, S., Kumar, R. & You, S., Are microplastics destabilizing the global network of terrestrial and aquatic ecosystem services? *Environmental Research*, 198, 111243, 2021.
54. Fashola, M.O., Ngole-Jeme, V. M. & Babalola, O.O., Heavy metal pollution from gold mines: environmental effects and bacterial strategies for resistance. *International Journal of Environmental Research and Public Health*, 13, 1-20, 2016.
55. Uchida, R. & Hue, N.V., Soil acidity and liming. In: *Plant nutrient management in Hawaii's soils*, Silva, J.A., Uchida, R., (eds.), CTAHR, University of Hawaii, pp. 101-111, 2000.
56. Kochian, L.V., Hoekenga, O.A. & Pineros, M.A., How do crop plants tolerate acid soils? Mechanisms of aluminum tolerance and phosphorous efficiency. *Annual Review of Plant Biology*, 55, 459-493, 2004.
57. Agegnehu, G., Amede, T., Erkossa, T., Yirga, C., Henry, C., Tyler, R., Nosworthy, M. G., Beyene, S. & Sileshi, G.W., Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. *Acta Agriculturae Scandinavica*, Section B-Soil & Plant Science, 71(9), 852-869, 2021.
58. Behera, S. K. & Shukla, A. K., Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. *Land Degradation & Development*, 26(1), 71-79, 2015.

59. Barber, S. A., Liming materials and practices. In: *Soil Acidity and Liming*, Volume 12, Second Edition, Adams, F., (ed.), American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA, pp. 171-209, 1984.
60. Haile, W. & Boke, S., Response of Irish potato (*Solanum tuberosum*) to the application of potassium at acidic soils of Chencha, Southern Ethiopia. *International Journal of Agriculture and Biology*, 13(4), 595-598, 2011.
61. Chauhan, D.K., Yadav, V., Vaculik, M., Gassmann, W., Pike, S., Arif, N., Singh, V.P., Deshmukh, R., Sahi, S. & Tripathi, D.K., Aluminum toxicity and aluminum stress-induced physiological tolerance responses in higher plants. *Critical Reviews in Biotechnology*, 41(5), 715-730, 2021.
62. Nawaz, M.F., Bourrie, G. & Trolard, F., Soil compaction impact and modelling. A review. *Agronomy for Sustainable Development*, 33, 291-309, 2013.
63. Batey, T., Soil compaction and soil management–a review. *Soil Use and Management*, 25, 335-345, 2009.
64. Hamza, M.A. & Anderson, W.K., Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research*, 82, 121-145, 2005.
65. Hartemink, A. E., Soils are back on the global agenda. *Soil Use and Management*, 24, 327-330, 2008.
66. Aipov, R.S., Yarullin, R.B., Gabitov, I.I., Mudarisov, S.G., Linenko, A.V., Farhshatov, M.N., Khasanov, E.R., Gabdrafikov, F.Z., Yukhin, G.P. & Galiullin, R. R., Mechatronic system linear swing vibrating screen of a Grain Cleaner. *Journal of Engineering and Applied Sciences*, 13(S8), 6473-6477, 2018.
67. Horrigan, L., Lawrence, R.S. & Walker, P., How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives*, 110(5), 445-456, 2002.
68. Wainwright, J., A review of European Union funded research into the history and evolution of Mediterranean desertification. *Advances in Environmental Monitoring and Modelling*, 1(4), 1-87, 2004.
69. UNCCD, Land degradation neutrality, 2022. https://www.unccd.int/actions/achieving-land-degradationneutrality
70. Stavi, I. & Lal, R., Achieving zero net land degradation: challenges and opportunities. *Journal of Arid Environments*, 112, 44-51, 2015.
71. Wagg, C., Bender, S.F., Widmer, F. & van der Heijden, M.G., Soil biodiversity and soil community composition determine ecosystem multifunctionality. *Proceedings of the National Academy of Sciences*, 111(14), 5266-5270, 2014.
72. Sharma, S.K. & Dube, L.C., Climate Change and India: Impacts on Biodiversity". In: *Plant Diversity in India*, Bhatnagar, A. K., & Kapoor, R. (eds.), I. K. International Publishing House Pvt. Ltd., New Delhi, pp. 497-519, 2018.
73. Conacher, A., Land degradation: A global perspective. *New Zealand Geographer*, 65(2), 91-94, 2009.

74. Singh, L., Thul, S.T. & Manu, T.M., Development of bamboo biodiversity on mining degraded lands: A sustainable solution for climate change mitigation". In: *Phytorestoration of abandoned mining and oil drilling sites*, Bauddh, K., Korstad, J., & Sharma, P. (eds.), Elsevier, pp. 439-451, 2021.
75. Stavi, I. & Lal, R., Agriculture and greenhouse gases, a common tragedy. A review. *Agronomy for Sustainable Development*, 33(2), 275-289, 2013.
76. Prăvălie, R., Exploring the multiple land degradation pathways across the planet. *Earth-Science Reviews*, 220, 103689, 2021.
77. Zika, M. & Erb, K.H., The global loss of net primary production resulting from human-induced soil degradation in drylands. *Ecological Economics*, 69(2), 310-318, 2009.
78. Hasan, M., Mawa, Z., Ul-Hassan, H., Rahman, M., Tanjin, S., Ahmed Abro, N., Gabol, K., Bashar, M., Jasmine, S., Ohtomi, J. & Hossain, M., Impact of eco-hydrological factors on the growth of the Asian stinging catfish Heteropneustusfossilis (Bloch, 1794) in a Wetland Ecosystem. *Egyptian Journal of Aquatic Biology and Fisheries*, 24(5), 77-94, 2020.
79. FAO, Soil Portal, Key Definitions, 2018a. http://www.fao.org/soils-portal/about/all-definitions/en/.
80. Pimentel, D., Soil erosion: a food and environmental threat. *Environment, Development and Sustainability*, 8(1), 119-137, 2006.
81. Gregory, A.S., Ritz, K., McGrath, S.P., Quinton, J.N., Goulding, K.W.T., Jones, R.J.A., Harris, J.A., Bol, R., Wallace, P., Pilgrim, E.S. & Whitmore, A.P., A review of the impacts of degradation threats on soil properties in the UK. *Soil Use and Management*, 31, 1-15, 2015.
82. Pal, S.C. & Chakrabortty, R., Modelling of water-induced surface soil erosion and the potential risk zone prediction in a sub-tropical watershed of Eastern India. *Modeling Earth Systems and Environment*, 5(2), 369-393, 2019.
83. FAO, Land and Water, 2018b. http://www.fao.org/land-water/land/httpwww faoorgsoils-portalen/en/.
84. Juwarkar, A.A., Singh, L., Kumar, G.P., Jambhulkar, H.P., Kanfade, H. & Jha, A.K., Biodiversity promotion in restored mine land through plant-animal interaction. *Journal of Ecosystem & Ecography*, 6(176), 2, 2016.
85. Society for Ecological Restoration International Science (SER) & Policy Working Group, The SER International Primer on Ecological Restoration (available from http//www.ser.org). Society for Ecological Restoration International, Tucson, Arizona, 2004. https://www.ctahr.hawaii.edu/littonc/PDFs/682_SERPrimer.pdf.
86. Bell, R.W., Restoration of degraded landscapes: principles and lessons from case studies with salt-affected land and mined revegetation. *CMU Journal*, 1(1), 1-21, 2002.
87. Lamb, D., Erskine, P.D. & Parrotta, J.A., Restoration of degraded tropical forest landscapes. *Science*, 310(5754), 1628-1632, 2005.
88. Harshvardhan, A. & Saikia, P., Microbial Bioremediation: A sustainable approach for restoration of contaminated sites. In: *Microbes in Agri-Forestry*

Biotechnology, Molina, G., Usmani, Z., Sharma, M., Yasri, A., & Gupta, V.K. (eds.), Chapter 10, CRC Press (Taylor & Francis Group) Boca Raton, USA (in press), 2022.

89. Sharma, I., Bioremediation techniques for the polluted environment: concept, advantages, limitations, and prospects. In: *Trace Metals in the Environment: New Approaches and Recent Advances*, Murillo-Tovar, M. A., Saldarriaga-Noreña, H., and Saeid, A. (eds.), IntechOpen, Books on Demand, UK, pp. 221-236, 2020.
90. Saikia, P. & Pandey, V.C., Moso bamboo (*Phyllostachys edulis* (Carrière) J.Houz.)-One of the most valuable bamboo species for phytoremediation. In: *Phytoremediation Potential of Perennial Grasses*, Pandey, V. C., & Singh, D. P. (eds.), Chapter 12, Elsevier Inc., pp. 245-258, 2020.
91. Kumar, V., Shahi, S.K. & Singh, S., Bioremediation: an eco-sustainable approach for restoration of contaminated sites. In *Microbial bioprospecting for sustainable development*, Singh, J., Sharma, D., Kumar, G., & Sharma, N.R. (eds.), Springer, Singapore, pp. 115-136, 2018.
92. Singh, A., Vaish, B. & Singh, R.P., Eco-restoration of degraded lands through microbial biomass: an ecological engineer. *Acta Biomedica Scientia*, 3(1), 133-135, 2016.
93. Salt, D.E., Smith, R.D. & Raskin, I., Phytoremediation. *Annual Review of Plant Biology*, 49(1), 643-668, 1998.
94. Segura, A. & Ramos, J.L., Plant–bacteria interactions in the removal of pollutants. *Current Opinion in Biotechnology*, 24(3), 467-473, 2013.
95. Pilon-Smits, E., Phytoremediation. *Annual Review of Plant Biology*, 56, 15-39, 2005.
96. Khan, F.I., Husain, T. & Hejazi, R., An overview and analysis of site remediation technologies. *Journal of Environmental Management*, 71(2), 95-122, 2004.
97. Edrisi, S.A., El-Keblawy, A. & Abhilash, P.C., Sustainability analysis of *Prosopis juliflora* (Sw.) DC based restoration of degraded land in North India. *Land*, 9(2), 59-77, 2020.
98. Edrisi, S.A. & Abhilash, P.C., Exploring marginal and degraded lands for biomass and bioenergy production: an Indian scenario. *Renewable and Sustainable Energy Reviews*, 54, 1537-1551, 2016.
99. Saturday, A., Restoration of degraded agricultural land: a review. *Journal of Environment and Health Science*, 4(2), 44-51, 2018.
100. Saxton, K.E. & Rawls, W.J., Soil water characteristics estimated by texture and organic matter for hydrologic solutions. *Soil Science Society of America Journal*, 70(5), 1569-1578, 2006.
101. Bashir, S., Javed, A., Bibi, I. & Ahmad, N., Soil and water conservation. In: *Soil Science Concepts and Applications*, Sabir, M., Akhtar, J., & Hakeem, K. R. (eds.), Pakistan University of Agriculture, Faisalabad, Pakistan, pp. 263-286, 2017.

102. Wei, W., Chen, D., Wang, L.X., Daryanto, S., Chen, L.D., Yu, Y., Lu, Y. L., Sun, G. & Feng, T.J., Global synthesis of the classifications, distributions, benefits and issues of terracing. *Earth-Science Reviews*, 159, 388–403, 2016.
103. Raya, A.M., Zuazo, V.D. & Martínez, J.F., Soil erosion and runoff response to plant-cover strips on semiarid slopes (SE Spain). *Land Degradation & Development*, 17(1), 1-11, 2006.
104. Alcántara, V., Don, A., Well, R., & Nieder, R., Deep ploughing increases agricultural soil organic matter stocks. *Global Change Biology*, 22(8), 2939-2956, 2016.
105. Paricha, A.M.P., Sethi, K.C., Gupta, V., Pathak, A. & Chhotray, S.K., Soil water conservation for micro catchment water harvesting systems. In: *Soil Health Restoration and Management*, Meena, R. S. (ed.), Springer, Singapore, pp. 383, 2017.
106. Balasubramanian, A., Soil Erosion – Causes and Effects: Technical report. Centre for Advanced Studies in Earth Science, University of Mysore, Mysore, pp. 1-7, 2017.
107. Lal, R., Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability*, 7, 5875-5895, 2015.
108. Sadeghi, S.H.R., Soil erosion in Iran: State of the Art, Tendency and Solutions. *Agriculture & Forestry*, 63(3), 33-37, 2017.
109. Sims, N.C., Newnham, G.J., England, J.R., Guerschman, J., Cox, S.J.D., Roxburgh, S.H., Viscarra Rossel, R.A., Fritz, S. & Wheeler, I., Good Practice Guidance. SDG Indicator 15.3.1, Proportion of Land That Is Degraded Over Total Land Area. Version 2.0". United Nations Convention to Combat Desertification, Bonn, Germany, 2021. https://www.unccd.int/sites/default/files/relevant-links/2021-03/Indicator_15.3.1_GPG_v2_29Mar_Advanced-version.pdf.
110. FAO and UNCCD, Technical Guide on the Integration of the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security into the Implementation of the UNCCD and Land Degradation Neutrality. FAO, Rome and UNCCD, Bonn, 2022.
111. Schulze, K., Malek, Ž. & Verburg, P.H., How will land degradation neutrality change future land system patterns? A scenario simulation study. *Environmental Science & Policy*, 124, 254-266, 2021.
112. Hurni, H., Assessing sustainable land management (SLM). *Agriculture, Ecosystems & Environment*, 81(2), 83-92, 2000.
113. Smyth, A.J. & Dumanski, J., FESLM: An international framework for evaluating sustainable land management. A discussion paper. World Soil Resources Report 73. Food & Agriculture Organization, Rome, Italy, pp. 74, 1993. http://www.faoswalim.org/resources/Land/FESLM.pdf.
114. Bouma, J., The land-use systems approach to planning sustainable land management at several scales. *ITC Journal*, 3(4), 237-242, 1997.

115. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, 112829, 2021a. Elsevier. https://doi.org/10.1016/j.jenvman.2021.112829
116. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1): 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
117. Raj, A., Jhariya, M.K. and Khan, N., *Forest for soil, food and climate security in Asia*. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
118. Jhariya, M.K.,Bargali, S.S. & Raj, A., *Possibilities and Perspectives of Agroforestry in Chhattisgarh*, pp. 237-257. In: *Precious Forests-Precious Earth*, Edited by MiodragZlatic (Ed.). ISBN: 978-953-51-2175-6, 286 pages, 2015. InTech, Croatia, Europe, DOI: 10.5772/60841.
119. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, Pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
120. Raj, A. & Jhariya, M.K., Sustainable agriculture with agroforestry: adoption to climate change. In: P. Suresh Kumar, Manish Kanwat, P.D. Meena, Vinod Kumar and Rajesh A. Alone, editors. *Climate Change and Sustainable Agriculture*. New India Publishing Agency (NIPA), New Delhi, 2017. ISBN No. 9789-3855-1672-6, pp. 287-294.
121. Raj, A., Jhariya, M. K., Yadav, D. K., Banerjee, A. & Meena, R. S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (Eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore Pte Ltd. 2019. ISBN ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4
122. Raj, A., Jhariya, M.K. & Bargali, S.S., Climate Smart Agriculture and Carbon Sequestration. In: C.B. Pandey, Mahesh Kumar Gaur and R.K. Goyal, editors. *Climate Change and Agroforestry*. New India Publishing Agency, New Delhi, India. pp. 1-19, 2017.
123. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226. Pp. 383, 2020. https://doi.org/10.1201/9780429286759
124. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.), editors. *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021, ISBN 978-981-15-9495-3. Pp. 221-246, 2021a. https://doi.org/10.1007/978-981-15-9496-0_7

125. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al.* (eds.), editors. *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021, ISBN 978-981-15-9495-3. Pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-0_14
126. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), editors. *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
127. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc, pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
128. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
129. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc. Pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
130. Pandit, R., Parrotta, J.A., Chaudhary, A.K., Karlen, D.L., Vieira, D.L.M., Anker, Y., Chen, R., Morris, J., Harris, J. & Ntshotsho, P., A framework to evaluate land degradation and restoration responses for improved planning and decision-making. *Ecosystems and People*, 16(1), 1-18, 2020.
131. Branca, G., Lipper, L., McCarthy, N. & Jolejole, M.C., Food security, climate change, and sustainable land management. A review. *Agronomy for Sustainable Development*, 33(4), 635-650, 2013.
132. Bridges, E.M. & Hannam, I.D., Future responses. In: *Response to Land Degradation, Bridges*, E. M., Hanna, I. D., Roel Oldeman, L., Penning de Vries, F. W. T., Scherr, S. J., Sombatpanit, S., Leslie, N. R., Compo, T. & Prueksapong, A. (eds.), CRC Press, Boca Raton, pp. 536, 2019.
133. Plieninger, T. & Gaertner, M., Harnessing degraded lands for biodiversity conservation. *Journal for Nature Conservation*, 19(1), 18-23, 2011.
134. Ajayi, A.S., Land degradation and the sustainability of agricultural production in Nigeria: A review. *Journal of Soil Science and Environmental Management*, 6(9), 234-240, 2015.
135. Chazdon, R.L., Lindenmayer, D., Guariguata, M.R., Crouzeilles, R., Benayas, J. M.R. & Chavero, E.L., Fostering natural forest regeneration on former agricultural land through economic and policy interventions. *Environmental Research Letters*, 15(4), 043002, 2020.

5

The Vulnerability of Forest Resources to Climate Change

Faezah Pardi[1,2*], Hasya Hannani Ruziman[2] and Mohd Nazip Suratman[1,2]

[1]Institute for Biodiversity and Sustainable Development, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
[2]Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

Abstract

Climate change has become a complex issue with profound impact on biodiversity and ecosystems. Changes in climate also strongly affect forest ecosystems, making them vulnerable in many aspects such as forest productivity loss and ecosystem services. As a result, species migration will occur from their ranges into regions where they are not usually found. Species distribution models suggested that species adaptation to future climate change varies, with some species expanding optimal habitat and others decreasing theirs. A significant change in regional climate factors results in changes of ecosystems. For instance, an exotic species from locations with the same edaphoclimatic conditions may have stronger competitive potential, therefore replacing native species from its natural settings. The inevitable consequences may include not just the biodiversity loss, ecosystem or ecological service but also an effect on other population. For example, direct effect on the productivity loss of a certain species in a forest, or an indirect impact, such as the growth of pyrophytic species due to the occurrence of rural fires in the forest. In addition, the ecological changes might have cascade impacts on the forest products industry, such that forest provides raw materials of wood and non-wood products that can be contributed as its monetary value. These impacts are dependent not just on natural responses to climate change, but also on socioeconomic issues which will definitely arise in the future decades or centuries. Thus, combating climate change is a critical necessity, as the only way to reverse its disastrous effects is by mitigation activities for a sustainable forest.

**Corresponding author*: faezahpardi@uitm.edu.my

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (103–132) © 2023 Scrivener Publishing LLC

Keywords**:** Climate change, forest, forest productivity, sustainable forest management, tree species

5.1 Introduction

Climate change refers to the changes in the composition of the global atmosphere, such as temperature change, rainfall and precipitation patterns that occur over a period of time [1]. This phase is also attributed to anthropogenic or impact from human activities besides natural climate variability that alters the physical environment. This issue is under hot debate as scientists review past climate change and the difficult challenges involving natural and human factors in the present state [2]. Climate change is a serious and urgent matter that must be solved in order to minimize the impact of global rising temperatures, sea levels and melting glaciers [3, 4] Further, it also has exacerbated current ecological effects, which are loss of topsoil and land degradation, major soil erosion and deforestation, all of which have hindered crop production [3]. Climate change can be driven by any factor that modifies the radiation emitted by the sun, which modifies the processes of energy transfer within the atmosphere as well as between the atmosphere, land, and ocean [2, 3]. Hence, anthropogenic "signal" must be differentiated from the "noise" of natural climatic variations with the aim of differentiating between human and natural climate change [2].

Human activities such as deforestation, industrial pollution, land degradation, and rapid industrialization are known to be contributing factors to the adverse effects of climate change. Since the pre-industrial period, human-caused greenhouse gas emissions have risen mostly due to present economic and higher population growth [5]. As reported by IPCC [6], levels of greenhouse gases (CO_2, CH_4, N_2O) have increased, causing the Earth to warm and to be less efficient in cooling the space. Although there are plenty of climate change mitigation measures, total anthropogenic GHG emissions increased between 2000 and 2010 [5]. This is because the impacts of anthropogenic activities are overlaid with the natural climate forcings that take place over a period. Further, natural variations in climate can arise due to the changes in the climate system component, such as aerosol emitted by volcanic eruptions. Not only that, but there are also inconsistent weather patterns of temperature, precipitation, and soil moisture in the world [2]. Thus, it is challenging to identify and determine the impact from the natural climate variation or anthropogenic activities. Thus, important factors remain unknown [7].

An unmitigated climate change scenario can result in major changes of Earth's temperature, and hence will increase the occurrence of extreme heat events or heat waves over most land areas [5]. Heat waves are associated with extreme temperature and can be characterized by the frequency of heat days and high night-time temperature due to the release of anthropogenic emissions. Extreme heat may also cause other devastating implications in the ecosystem such as drought, wildfire disaster and mass mortality events. In order to achieve reduction in carbon emissions, costs will also be incurred soon. However, these will lead to difficulty in quantifying the cost/benefit ratio of the climate change mitigation measures. Climate change is a phenomenon that could impact the global economy as well; hence, in order to address this issue, economies of all sizes need to work together. Furthermore, impacts are not evenly distributed, most notably in the loss of forest productivity and ecosystem services.

5.2 Causes of Climate Change

According to EPA [3], natural processes and human activities have led to changes in the energy balance of Earth and consequently climate change. The influence of natural processes on the climate includes the amount of sunlight hitting the Earth, intensity of the reflected light of Earth's atmosphere and land surface. This also includes natural sources of greenhouse gas released by plant respiration and decomposition which affects the energy flows in the Earth's atmosphere. In addition, human activities have also fundamentally increased the concentration of greenhouse gases in the atmosphere [3]. These activities include the combustion of fossil fuels, the destruction of forests and the development of land for farms, towns and highways. As a result, large amounts of carbon dioxide as anthropogenic emissions are released and consequently alter the composition of Earth's atmosphere [3]. Anthropogenic factors are human factors that are responsible for climate change such as land-use change, deforestation, emission of greenhouse gas and urbanization. The effects of anthropogenic activities in the global carbon cycle of 2008-2017 are depicted in Figure 5.1 [8].

5.2.1 Land-Use Change

Changes in land use are a process by which human activities transform the natural landscape, such as the conversion of forest area for economic activities. Urbanization and agriculture have dramatically transformed

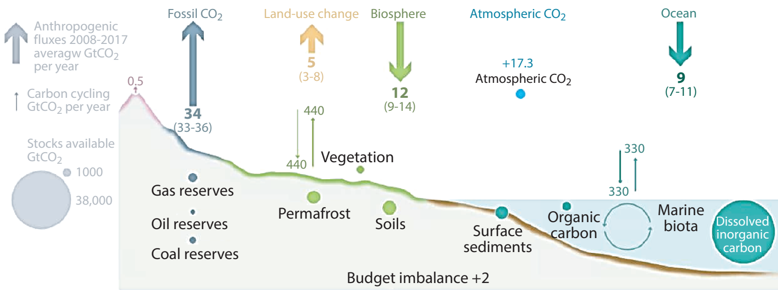

Figure 5.1 Schematic representation of the effects of anthropogenic activities in the global carbon cycle of 2008-2017 [8].

one-third to one-half of the Earth's surface, altering the face of the Earth. Tropical forest has been cleared and grazing has been established; meanwhile rivers' courses have also been changed. Thus, rapid changes in global patterns of land use consequently threaten biological diversity of the forests.

The NRC (National Research Council) report refers to land-use and land-cover processes as climate forcing where landscape variations might inevitably affect physical landscape and adversely impact climate on a global scale. In fact, changes in forest area due to land use significantly impacts living organisms by destroying their habitats and ecosystems, resulting in biodiversity loss and loss of ecosystem services [9–11]. Agricultural expansion and intensification are leading factors in global biodiversity loss and species extinction. The conversion of forest to agricultural land affects the services functions and values of the ecosystem such as water or hydrologic cycles, and accelerated soil erosion which reduce soils' productivity and contaminates with sediment loads. Further, these activities have resulted in increased carbon fluxes in the biomass and soil to the atmosphere, accounting for an additional 10 to 15% of total CO_2 emissions [12]. Thus, unsustainable land management and land use have had significant economic consequences which are exacerbated by climate change.

5.2.2 Deforestation

Forest ecosystems are crucial in addressing climate change because trees are composed of approximately 50% of carbon in their dry weight whereby the increased size of standing timber directly correlates with increases in bound carbon during photosynthesis [13, 14]. Trees are the major contributor with 78% of the total biomass in the forests reflecting the forest's productivity by the rate of carbon exchange between forest ecosystem and the atmosphere [15, 16]. Forests serve as carbon sink as they absorb the atmospheric carbon from anthropogenic factors including the use of fossil fuels and convert it to the terrestrial carbon sink. Therefore, deforestation leads to the release of stored carbon and consequently becomes the major contributor to human-caused climate change. This is because carbon dioxide is a greenhouse gas, which means that rising concentrations of atmospheric carbon dioxide raise the surface temperature or cause global warming.

According to Siyum [17], tropical forests contain 25% of the global terrestrial carbon, hence they are an important reservoir in mitigating regional and global climate dynamics [18, 19]. The map in Figure 5.2 shows the deforestation rates across the world, particularly in Asia [12]. Recent research, however, indicates that tropical forests suffer massive losses and, rather than being a carbon sink, they have now become a carbon source due to the atmospheric carbon emissions [20]. Despite being the most biologically diverse terrestrial ecosystems, they are especially vulnerable to the impacts from deforestation and degradation with losses of biodiversity and ecosystem services including carbon storage.

Further, deforestation contributes to climate change. The burning or clearing of forests for the purpose of agriculture, infrastructure or urban development affects the global carbon cycle from the atmosphere into the forest [21]. Forest biomass left in the forest, such as remaining twigs or branches after harvesting, will decay and eventually release its stored carbon into the atmosphere. For the past several years, the current rate of deforestation led to a significant rise in CO_2 levels in the atmosphere. Changes in forest cover can have a direct impact on Earth's surface

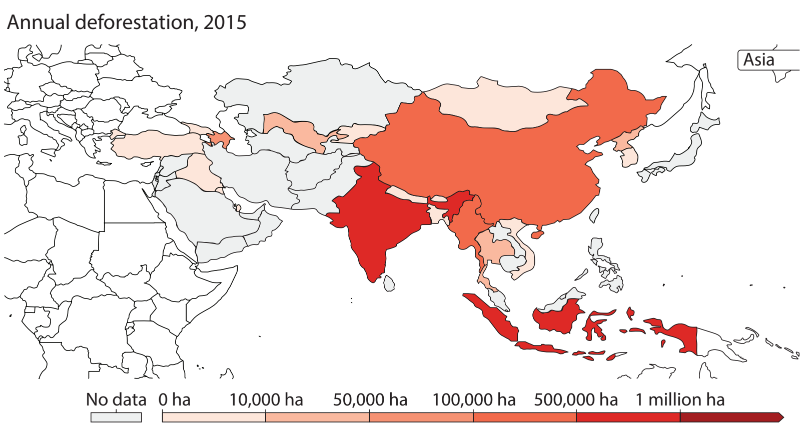

Figure 5.2 The annual deforestation in Asia [12].

temperature through water and energy exchanges [6]. As such, the reduction of forest area affects climate on a global and regional scale, resulting in severe storms and longer droughts [22].

5.2.3 Emissions of Greenhouse Gases

The greenhouse effect is mainly governed by the concentrations of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and halogenated compounds such as CFCs, HFCs and PFCs. The atmospheric concentrations of anthropogenic greenhouse gases have increased over centuries. These activities consequently produce a positive climate forcing or global warming effect, which results in increased temperatures on Earth. In addition to that, most developed countries release continuous greenhouse gases which may also result in sea-level rise, seasonal unpredictability and hydrometeorological events [23]. Figure 5.3 depicts the atmospheric concentration of major greenhouse gases with high lifetime in the last 2,000 years [7].

Economic and human population growth have been the primary contributors to the increase of CO_2 emissions in Earth's atmosphere due to burning of fossil fuels. According to EPA [24], emissions of carbon dioxide have increased by almost 90% since 1970. of which fossil fuel burning and industrial activities account for approximately 78% of the overall increase in greenhouse gas emissions from 1970 to 2011. In addition, the agricultural food sector utilizes about 30% of global energy consumption, becoming a source of greenhouse gases in the atmosphere [25]. This industry is primarily represented by fossil fuels which generate about 22% of total anthropogenic greenhouse gas emissions [12]. As a consequence, this

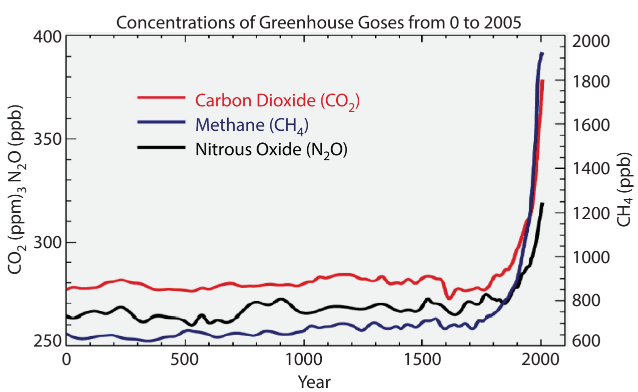

Figure 5.3 The atmospheric concentration of major greenhouse gases with high lifetime in the last 2,000 years [7].

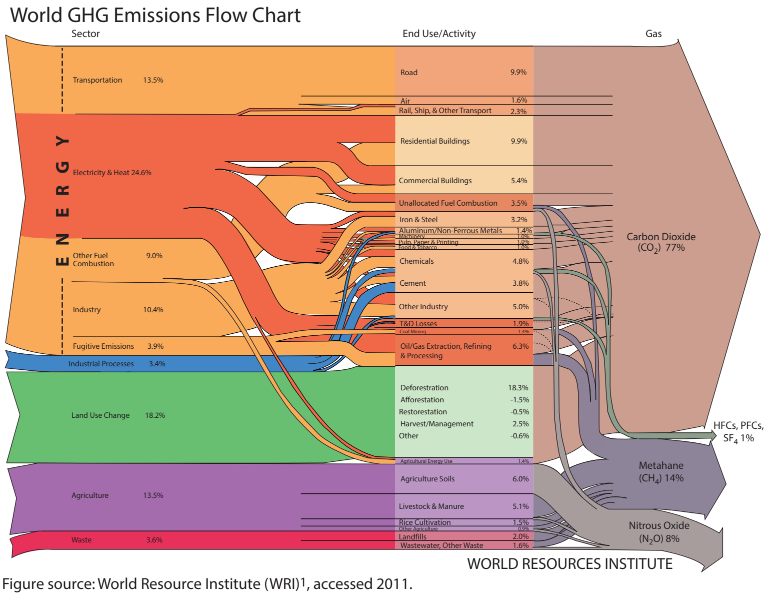

Figure 5.4 The sources and flows of greenhouse gases [19].

leads to the Earth's global warming as these activities contribute to more heat-trapping greenhouse gas released to the atmosphere. Hence, the concentration of these gases will increase as the fossil fuel usage increases. Other activities, in addition to the burning of fossil fuels, influence the carbon cycle by contributing additional atmospheric carbon dioxide. Thus, these activities disrupt the function of forests as carbon sink in regulating levels of carbon dioxide in the atmosphere. The sources and flows of greenhouse gases are depicted in Figure 5.4 [19]. As such, the increase in CO_2 concentration could be the largest contributor to global warming [25].

5.2.4 Urbanization

Urbanization is a driving factor for economic growth, allowing the relocation of excess workers to the urban industrial sector from the rural agricultural sector [26]. Even so, lack of proper planning of urbanization can have a detrimental influence on the economy, causing deforestation and environmental pollution and leading to global warming and climate change [27]. Aside from an increased population in large cities, the population in regional to mid-sized cities will also increase by 2030, making them prominent economic centres. A global urban population by city size

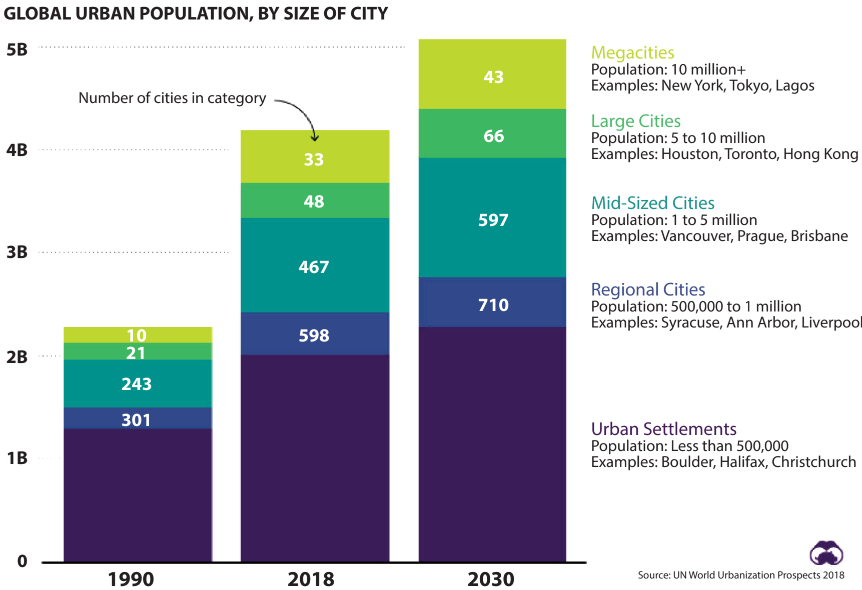

Figure 5.5 Global urban populations by city size [26].

is depicted in Figure 5.5 [26]. Urbanization is found to have climate change effects because of the implementation of green technologies, increased efficiency in the use of fossil fuels, reduced traffic congestion and increased usage of public transportation through improved road and public infrastructure. In addition to that, urbanization can exacerbate warmth such as the heat island effect in towns, especially during heat waves or heat-related phenomena.

The changes in land use due to urban development may also expose people to flood risks. This is mainly related to runoff generated from extreme weather events such as heavy precipitation which affects overflow of rivers and streams [28, 29]. In fact, the occurrence and severity of continuous rainstorms, more frequent droughts, and higher coastal storm surges might occur if the climate change persists [30, 31].

5.2.5 Emissions of Pollutants

Other than greenhouse gases, some agricultural operations release pollutants that result in aerosols which are tiny pieces of particles in the air [6]. Some aerosol particles can have an impact on cloud formation by their warming or cooling effect. A conceptual model is depicted in Figure 5.6

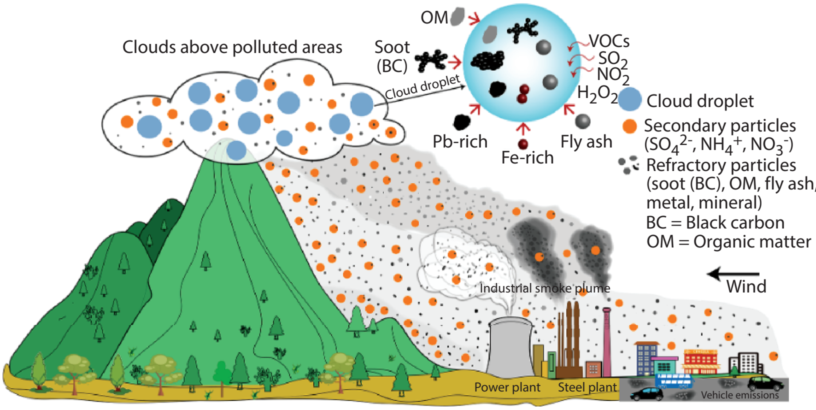

Figure 5.6 A conceptual model to illustrate the mechanisms of interactions among aerosol-cloud which is influenced by anthropogenic pollutants [35].

to illustrate the mechanisms of interactions among aerosol-cloud which is influenced by anthropogenic pollutants [35]. F gases refer to a family of gases containing fluorine such as hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), chlorofluorocarbons (CFCs), sulphur hexafluoride (SF6) and perfluorocarbons (PFCs).

They are the most potent greenhouse gases, having significantly more global warming potentials than carbon dioxide. They are commonly utilized as refrigerants in air-conditioning, refrigeration systems, aerosol propellants and heat pumps [7]. These F-gases are emitted in small amounts as compared to other GHG gases, but they may persist a long period in the atmosphere and some of their emissions are among the longest-lasting greenhouse gases [32, 33]. Other than that, global warming is being driven by atmospheric particulate matter such as black carbon. The burning of fossil fuels caused the release of black carbon particles or soot, which is also a climate forcing agent. The warming effect is due to the direct impact of black carbon being able to absorb sunlight and converting solar radiation to heat the environment. Further, it also impacts cloud formation as well as regional circulation and rainfall patterns [7, 34].

5.2.6 Agriculture

Agricultural activities are among the significant contributors to anthropogenic global warming by releasing carbon dioxide (CO_2), nitrous oxide

(N_2O) and methane (CH_4) into the atmosphere. Agriculture released 5.1-6.1 billion tons of CO_2 in 2005, accounting for 10-12% of all human-caused releases of greenhouse gas emissions in that year. Not only that, but agriculture also contributes about 47% of global CH_4 and 58% of N_2O. The emission of methane in the atmosphere is from the range of anthropogenic and natural sources. Anthropogenic sources such as grazing livestock, and the decomposition of organic waste in landfill potentially increase methane concentration. In terms of natural sources, the release of atmospheric methane is from the anaerobic decomposition of ruminants, natural wetlands and leakage of fossil fuel industry [6]. According to EPA [3], recent human activities caused an increase in CH_4 concentrations to be double that of pre-industrial levels.

Agriculture is responsible for two-thirds of total anthropogenic nitrous oxide (N_2O) global emissions [36]. Direct sources such as cultivated soils and fertilized as well as grazed grassland systems emit N_2O directly into the atmosphere. Indirect emissions may be caused by the transport of N. such as from agricultural fields into surface and groundwater via drainage and surface runoff. Also, the emission of ammonia or nitrogen oxides, causing an increase in N_2O production. The presence of N_2O has the potential effect of global warming because of its ability in trapping Earth's radiant heat as well as depleting the ozone layer. It was also found that N_2O is more potent than carbon dioxide which might as well become an increasing climate threat to the atmosphere.

5.3 Climate Change Affecting Forest Ecosystems

Forest ecosystems are anticipated to undergo significant structural and compositional change as climate change progresses [5]. Industrialization, particularly, leads to an increase of carbon dioxide emissions and this consequently affects the ecological function of forests. Rising CO_2 levels may cause changes in temperature and precipitation patterns which may impact forest disturbance patterns. Some forests may endure greater drought, meanwhile increasing rainfall improves tree growth conditions, thus allowing the expansion of dry forest regions. It can be noted that climate change may benefit forest in some locations while increasing mortality due to the drought and potentially lead to forest fire in other forest regions. Forest management plans might vary depending on the silviculturists or foresters. For example, they recommend the adaptive potential of trees to the changing climate. As such, the successional processes might occur which lead to the change in the tree species composition and stand structure. Other silviculturists might consider planning immediate action in mitigating the serious impacts of climate change. Others might plan for forest management strategies such as changes in harvesting tree age for ecological sustainability of the forest.

The main contributing factors for the carbon emission into the atmosphere are emissions from fossil fuel and cement production, accounting for 1,281 billion tonnes of CO_2 emissions between 1900 to 2010. In addition, deforestation represents 448 billion tonnes of CO_2 emissions, contributing to roughly 26% of total gas emissions [37, 38]. Despite the massive magnitude of deforestation, forest restoration has stimulated more significant carbon sink, removing 540 billion tonnes of atmospheric CO_2. This is because of the conversion of former agricultural land to forest [39], carbon fertilization effect and forests were managed for the timber industry [37, 38]. Consequently, all deforestation emissions between 1900 and 2010 were more than offset by forest regeneration because of market dynamics and carbon fertilization [37].

The ecological role of forest is considered as a carbon sink because the forest trees are able to remove atmospheric carbon by their carbon storage in their standing biomass. In tropical forests, about half of the carbon is stored in the form of tree biomass and the remaining half in the forest soil. Following this achievement, there is broad optimism to consider the expansion of forest areas such as converting other agricultural land to forests as well as enhanced forest management, which would result in increased global climate mitigation [40]. Tropical forests are ecologically important for being the most biodiverse terrestrial ecosystem. However, temperature change and climate extremes are anticipated to have serious impacts on the biodiversity loss of tropical forests by 2100 [41, 42]. Most of Asia's tropical forests are degraded and fragmented as a result of massive forest conversion for agriculture [43]. As such, tropical forests are potentially susceptible to the existential threats of changing climate [41, 44] and identifying its hazardous effects is crucial for the forest management and conservation plans. The effects differ significantly based on the type of forest, the stand structure of the forest, particularly the tree species composition, disturbance range, history and phenology. In addition, biodiversity loss due to change in forest cover is projected to worsen as the world's population continues to rise. Thus, this becomes the greatest overall threat to remaining tropical biodiversity [44, 45]. Not only that, fragmented forests due to deforestation also result in the decline of biodiversity. For instance, in tropical deciduous forests in Asia, where the alteration of forest structure and species composition is due to the tree mortality as a result of climate change [46]. Continued emission of greenhouse gases will become a great threat and forest habitats are predicted to be more susceptible due to climate change and other issues, including anthropogenic disturbances.

Climate change affects a wide range of ecosystem functions and processes such as the forest fragment dynamics, taxonomic composition, forest health, distribution of tree species and above ground biomass [44]. Further, the climate variability such as cyclones, hurricanes and typhoons will cause a change in the stand structure of trees in Central America's forest [47, 48]. Meanwhile in Africa, climate change has caused negative impacts in forests, such as changes in forest biomass and vegetation phenology [49].

5.4 The Migration of Tree Species

Temperature change influences the tree species distribution as well as forest structure, such as the composition and the diversity of tree communities in the forests. The changes of distribution of tree species affect the ecosystem processes and the available timber to the forest industry in the long term. The ability of trees to migrate varies individually, although a shift in species distribution is often a long and slow process. This biogeographic response of plants towards climate change is also related to the niche needs of trees to colonize new settings [50, 51].

Global climate changes have profound impact on the geographical range of trees in forest habitats and therefore their response to these climate changes could include species-specific tree migration. The research on the migration of tree species has been widely documented since the last age [52]. Yet, present and projected future climatic circumstances showed the improbable ability for tree species to migrate at the same rate as climate change. Tree species are known to have adaptation for changing climate independently, such that there is coexistence of some tree species at geographical scales, perhaps resulting in future North American biomes with no existing analog [53, 54]. For instance, in India forest where temperature increase causes the distribution shift of tree species such as *Taraxacum officinale, Berberisa siatica, Jasminum officinale* to a higher elevation in Nainital. Meanwhile in central India, Sal trees are projected to replace Teak trees in the forest and deciduous trees have the potential to replace the conifers [55]. The rapid rate of climate change, along with particular tree species' reactions, may result in loss or extinction of tree species. As a consequence, this results in biodiversity loss which leads to a profound impact in altering the habitats of the species.

To date, contemporaneous tree movement has been recorded along elevational gradients in a region of the eastern United States [56] and observed internationally [57]. The migration of trees in higher elevation gradients may occur more frequently and impact relatively limited geographic areas. On the other hand, the migration of trees latitudinally occurred less, which affected large areas particularly in flat terrain [58, 59].

The rise in mean annual temperature even at 1°C, for example, may equate to elevation of 100 to 200 m as compared to 150 kilometres latitudinally. As additional inventory data became available, the research on the range of tree species was begun across latitudinal for the eastern United States' forest. It was discovered that the range for tree species is relatively static along their margins in the eastern United States; on the other hand, higher densities of tree species of some seedlings are found in the northern part of their range. This causes the tree seedlings to have a slight northward shift which is different from their adult counterparts in their mean latitudinal location [60].

It is well recognised that global warming and anthropogenic activities are major factors in the range contraction of many species, which keeps tree ranges static and potentially causes tree regeneration to fail [61]. The range contraction is projected in the montane ecosystems because of the failure of tree regeneration in the area [62]. Emerging research suggests that such a dynamic is now taking place for some species [63]. The widespread prevalence of exotic trees, combined with the enhanced stand growth [64], implies that recruitment tree regeneration may be problematic in future as native tree species are mostly prone to deer herbivory. Hence these have caused the decline in the quantity of tree regeneration in eastern US forests since the last decade [65].

Rapid extinction of tree species with constrained ecological niches is projected to occur along their southern range if climate change continues or worsens. As a result, the absence of young trees and the failure of tree regeneration (i.e., young trees are unable to replace old trees) can be expected. Further, maladaptation of tree species might also be observed as climate change impacts. For instance, conifer species of *Pseudotsuga menziesii* (Pinaceae) may not be maladapted in the western United States [66, 67], resulting in growth loss [68]. However, there are also some populations that may benefit from the effect of climate change, for example, specific subpopulations of western larch. This is because they are better genetically adapted to future temperature than other species and might serve as seed supplies for management actions [69]. Although they have different subpopulations over time to adapt to local circumstances, climate change may cause them to be less suited to their environment. As a result, maladaptation influences the composition of forest stands in terms of species and tree size. Thus, the expected carbon sequestration, timber volume yields, and the efficiency of ecosystem services would be reduced if climate change recovers [70].

In response to rising temperatures, the migration of species is commonly observed to occur at northwards in latitude or upwards in latitude [71]. For example, palaeoecological research has reported the climate variability and habitats provided by mountainous regions in Southern Europe as crucial refugia for migrating species during climate change episodes [72]. The current rate of climate change appears to be quicker than at any time in previous centuries [73]. Shugart [74] discovered that plants migrated northwards at rates ranging from 5 to 150 km per century; however, it appears now that that range shifts to the scale of 500 km per century to enable plants to keep up with climate change [75]. As a result, many tree species will be beyond their suitable climatic range by the end of the century if this projection is correct [76].

However, tree species are slow to migrate from their range, thus many tree species have less abundance at their existing geographical range borders, limiting the likelihood of successful colonization at the borders. Besides, the pace of migrating species and their migratory patterns varied greatly across trees based on their particular sensitivity [73]. This statement nevertheless seems to back up earlier evidence by stating that migrations will take place species by species, following their unique preferences for environmental circumstances, rather than in massive ecosystem or biome alterations [72]. Existing ecosystems will then be characterized by the occurrence of new species, declining patterns of some species as well as changes in the species dominance [75]. Due to the long time period between stand establishment and replacement for many northern tree species, boreal and temperate forests are at risk of not surviving. Forests will face more stress as climate changes more quickly than most tree species can adapt [71], and the probability of some boreal and temperate tree species becoming extinct will rise significantly [76].

Tropical ecosystems are exceptionally vulnerable to climate change. In particular for lowland rainforest tree species, they have specialized ecological niches on restricted climatic variables [77–80]. Thus, the intraspecific variation in climatic tolerance is considered low for this tropical tree species. As such, future climates are expected to rapidly alter beyond the conditions range currently encountered by tree species, leading to the projected distributions of novel climates [77, 78] and time [79, 80]. Previous research showed that, regardless of the rate of climate change, the novel climates are often projected to be quicker in high latitudes than low latitude tropics. Further, it was claimed that tropical forests experience the highest rate of climate change, which can be measured in terms of the difference between current and future climates [81]. For example, it is highly predicted that average crop period in the tropics would be higher in the year 2080 than even the highest severe seasonal temperatures currently seen in these places [82].

5.5 The Replacement of Native Species by Exotic Species

The changing climate may promote biological invasions by altering the possibility of species establishment beyond its distribution range, which can further worsen the impact on local and regional biodiversity [83, 84]. It is profoundly modifying the concentration of atmospheric carbon dioxide, global temperature change, the intensity and frequency of precipitation, and thus preventing native species from thriving [85, 86]. Hence, these alterations may create possibilities for the colonization of non-native species and native species may be particularly at risk from invasions [87–89]. Non-native species have already colonised new settings due to their existence in introduced habitats. Successful colonization of non-native species is attributed to their adaptation traits in a new environment. These species are characterised by relatively great ability to disperse, less reliance on specialised mutualists, faster growth, and high tolerance to external conditions as well as phenotypic plasticity. For instance, in European plant ecosystems, variation characteristics of temperature and precipitation contribute to more than 40% species turnover rates [90]. In contrast, decreased precipitation, increased drought incidence, and CO_2 driven increases in nitrogen limitation led to the changes that diminish resource availability, which may impede non-native species.

Variations of outcomes or consequences of climate change are projected for native and non-native species (introduced species) across regions and taxa. In aquatic environments increased CO_2 is related to lower pH which then frequently inhibits calcification and growth development. In contrast, for terrestrial plants, increased CO_2 levels enhance carbon availability which leads to promoting species growth and significantly benefits non-native species [88]. As for temperate aquatic and mesic regions of terrestrial ecosystems, global warming promotes the rate of growth non-native species [91, 92]. As such, the ability of native species to succeed in the new environment is expected to be determined by both environmental changes that restrict or encourage native species as well as the presence of native and non-native species that are best fitted to changing and new circumstances [93, 94]. Thus, incorporating concerns of non-native species as key target elements of the management or conservation plans is essential for the mitigation strategy of the climate change impacts.

5.6 The Economic Loss in the Forest Products Industry

Climate variability not only affects ecological or natural processes of the ecosystem, but it is also likely to alter the productivity of forests particularly in the timber industry. The global area of production forests will have an increase around 60% between 2010 and mid-century which accounts for 15 million km^2 [95]. In contrast, primary forests are expected to decline further. The productivity of production forests is influenced by water availability, location, the impacts of CO_2 fertilization and tree species. Many producers will benefit from enhanced forest plantation output if the adaptation is successful. However, the advantages to farmers will vary depending on latitude and region where only producers in low to mid latitude gain benefit from climate change but mid to high latitude producers would be harmed by reduced market prices [5]. Globally, the benefits of physical changes such as climate change and forestry are predicted to exceed the disadvantages [5].

The implications are dependent not just on natural reactions to climate change, but also on socioeconomic issues, which will surely alter over the next century. Economy-based policies are implemented as well as wood products market which is also important in socioeconomic issues [96]. Climate change could threaten commercial tree species, with some being more resilient than others. If the forest products sector in the Midwest can adapt successfully, the net effect of climate change may be positive. For instance, white oak is an economically and environmentally significant tree species that grows in grassland and broadleaf forest ecoregions. However, the decline in harvest oak species was attributed to causes from fire control and drought to pests and diseases, in addition to changing climate. White oak species are popular harvest species, and it was reported that 36% of yearly harvest in Illinois was contributed by oak species in 2005. Oak species are also dominant harvest species in Ohio, thus becoming the forest products that create monetary value for the forest communities.

The species' sensitivity to climatic conditions varies over its whole range, underscoring the fact that associations can vary spatially for widely distributed species [95]. The significant changes of abundance and distribution are predicted to occur for commercial species, namely aspen, hickory and sugar maple [97, 98]. There will be significant potential changes in the presence of commercial species which may cause challenges for the forestry timber markets if they occur rapidly, combined with the unprepared industry. These tendencies are important in order to investigate other commercially significant species in the forestry sector, as well as the benefits of the forest sector if there are potential possibilities of merchantable species in the region.

5.7 Policy Strategies and Future Roadmap against Forest Vulnerability to Climate Change

The implementation of forest management plans and policies is essential for the maintenance of forest ecosystem health with respect to mitigating the climate change impacts [99–101]. Managing forest helps in offsetting C footprint along with biomass production and carbon balance in the environment [102, 103]. However, policies for promotion of sustainable forest management (SFM) ensure soil, food and climate security which help in maintaining environmental sustainability [104]. Adopting sustainable intensification for forest management maximizes health and productivity along with resource conservation which promise healthier ecosystem and services [105–107]. Also, forest plantation including afforestation techniques by leguminous tress helps in combating climate change and restoring degraded land through maintenance of nitrogen and carbon status in the soils [108–110]. A roadmap must be constructed for forest management which helps in mitigating carbon, land and energy footprints for strengthening climate security [111, 112]. Recognizing that climate change offers increasing threats to the environment, more than 141 countries enacted policies to tackle the problem and unite in order to adapt to its consequences (Table 5.1). As such, these policies influence the forested area, promoting biodiversity conservation, forest exploitation, timber products industry, all of which can make the forest more vulnerable or less vulnerable due to climate change.

Forest policies and strategies must be structured sustainably in accordance with the United Nations: Sustainable Development Goals notably SDG 13: Climate Action to achieve a climate-neutral world. Policy reviews are needed as part of the policy and procedure management to ensure its efficiency and implications for the forest vulnerability. The policies also

Table 5.1 The implementation of policy strategies and future roadmap in Asia countries.

Country	Policy	Strategies	Future roadmap
Malaysia	Forestry Policy of Peninsular Malaysia, 2020 [113]	Increasing the capacity of forests to mitigate the effects of climate change.	(a) Forest inventories for monitoring carbon stocks. (b) Restoration of degraded forest by tree planting. (c) Conserving wetlands and uplands forest to improve carbon storage. (d) Implementing forest management approach with regard to the carbon balance in accordance with regional or international laws.
India	National Forest Policy, 1988 [114]	Encouraging the ecological balance for sustainable environment.	(a) Transformation to conservation-based forestry. (b) Increased emphasis on forest expansion, promoting forestry for community and agriculture. (c) Acknowledgment of forest trees for the purpose of forest conservation. (d) Strict controls to prohibit industries from forest exploitation.
	The National Wildlife Action Plan, 2002–2016 [115]	To protect and conserve flora and fauna in their natural habitats.	(a) Identification of essential forest ecosystems and species, as well as the implementation of actions to maintain their conservation, both *in-situ* and *ex-situ*. (b) Integrating climate change considerations into the forest management plan.

(*Continued*)

Table 5.1 The implementation of policy strategies and future roadmap in Asia countries. (*Continued*)

Country	Policy	Strategies	Future roadmap
Indonesia	Nationally Determined Contribution, 2016 [116]	To protect, restore and improve land management strategies.	(a) To reduce carbon emission from land-use and energy sectors. (b) The development of renewable energy and alignment of government policies.
Thailand	Thailand's Climate Change Master Plan (2013-2050) [117]	To address mitigation, adaptation and cross-cutting issues.	(a) Strengthening community adaptation capacity (b) Supporting climate change adaptation plans locally and internationally. (c) Encouraging the conservation of indigenous species and ecosystems.

must be revised on a regular basis in order to accommodate future implementing regulations and to ensure that the legislation is in line with the recent advancements at the global level.

5.8 Conclusion

Forests are a stabilising force for the climate. They are important in the natural processes of the carbon cycle, ecologically maintaining biodiversity, supporting livelihoods by supplying goods and services that can drive sustainable growth. However, the forest areas have been slowly decreasing, thus making it to be the major source of atmospheric CO_2 emissions. High levels of CO_2 in the atmosphere are responsible for roughly two-thirds of the overall energy imbalance that is leading the Earth's temperature to increase. Hence, climate change is said to be among the world's greatest challenges, as this phenomenon is characterised by extreme climatic weather, which in turn affects the forest function of ecosystem services and natural processes for the terrestrial ecosystem. Further, climate change also influences the tree species distribution, the growth rate and the forest structure. Thus, the inevitable consequences may include not just the loss of biodiversity, forest resource productivity, ecological process and ecosystem service, but also the economic contributions of forest. Forest is important to human well-being because it provides the raw materials such as wood and non-wood products that can be commercialized and can contribute to the monetary value. Therefore, the management of forests needs to be conducted in a sustainable way for future generations despite the fast pace of climate change.

Sustainable Development Goal, SDG 13, established by the United Nations in 2015, is one of 17 Sustainable Development Goals that focus on climate action. The mission statement for SDG13 is "take urgent action to combat climate change and its impacts". Hence, SDG 13 may be achieved by implementing related actions such as limiting gas emissions and balancing the levels of greenhouse gases and protecting forest from deforestation. Forests act as carbon sinks, which play a vital role in carbon sequestration or removing atmospheric carbon dioxide from the atmosphere. Hence, it is a necessity for the forests to be managed in a way that ensures the sustainability of the forests. Sustainable forest management (SFM) is part of sustainable land management which aims to maintain land productivity by reducing land degradation. This is also a holistic approach regarding the maintaining or enhancing of forest functions as forest carbon stocks and forest carbon sinks. Other important parameters which are to be considered regarding the urgent actions to combat the negative impacts of climate change include (i) reducing anthropogenic activities especially involves lowering the amount of heat-trapping greenhouse gases released into the atmosphere, and (ii) estimations and projections of future emissions of greenhouse gases. By conducting these mitigation strategies, human intervention will no longer be affecting the climate system.

References

1. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007 – The Physical Science Basis*, p. 1007, Cambridge University Press, Cambridge, 2007.
2. Houghton J.T., Jenkins G.J. & Ephraumis J.J., *Climate Change. The IPCC Scientific Assessment*, Report Prepared for IPCC by Working Group I, Press Syndicate of the University of Cambridge, 1990.
3. United States Environmental Protection Agency (EPA), Climate Change Science Facts, https://www3.epa.gov/climatechange/Downloads/Climate_Change_Science_Facts.pdf , 2010.
4. National Research Council (NRC), *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*, p. 298, National Academies Press, Washington, DC, US, 2011.
5. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* p. 151, IPCC, Geneva, Switzerland. 2014.
6. Intergovernmental Panel on Climate Change (IPCC), *Climate Change and Land, An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems;* Summary for Policymakers, 2020.
7. Braman, L., Climate change adaptation: integrating climate science into humanitarian work. *Int. Rev. Red Cross,* 92, 693-712, 2010.
8. Corinne Le Quéré, *Global carbon budget 2018*, Earth System Science Data 10, 2018.
9. Milà i Canals, L., Romanyà, J. & Cowell, S. J., Method for assessing impacts on life support functions (LSF) related to the use of 'fertile land' in Life Cycle Assessment (LCA). *J. Clean. Prod.,* 15(15), 1426-1440, 2007.
10. Alkemade, R., van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M. & Ten Brink, B., GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosyst.*, 12(3), 374-390, 2009.
11. de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L. & Hussain, S, Global

estimates of the value of ecosystems and their services in monetary units. *Ecosystem Serv*., 1(1), 50-61, 2012.
12. United Nations Food and Agricultural Organization (FAO), '*Energy-Smart' Food for People and Climate,* Issue paper, Rome, FAO, http://www.fao.org/3/i2454e/i2454e00.pdf, 2011.
13. Brown, S, *Estimating biomass and biomass change of tropical forests,* Rome, FAO, 1997.
14. Napaldet, J.T. & Gomez, R.A., Biomass Characterization and Allometric Model Development for Aboveground Carbon Stock of Benguet Pine (*Pinus kesiya*). *Ecosyst. Dev. J.,* 8(1), 15-21, 2018.
15. Normah, A.B., Suardi, H., Phua, M.H., James, D., Mazlin, M. & Ahmed, M.F., Carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. *For.,* 11, 210, 2020.
16. Watson, R.T., *Land Use, Land-Use Change and Forestry,* UK, Cambridge University Press, Cambridge, 2000.
17. Siyum, Z.G., Tropical Dry Forest Dynamics in the context of climate change: Syntheses of drivers, gaps, and Management Perspectives. *Ecol. Processes,* 9(1), 1-16, 2000.
18. Lewis, S. L., Lloyd, J., Sitch, S., Mitchard, E. T. A. & Laurance, W. F., Changing ecology of tropical forests: Evidence and drivers, *Annu Rev Ecol Evol Syst.,* 40(1), 529-549, 2009.
19. Zhou, X., Fu, Y., Zhou, L., Li, B. & Luo, Y., An imperative need for Global Change Research in tropical forests. *Tree Physiol.,* 33(9), 903-912, 2013.
20. Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., Houghton, R. A., Tropical forests are a net carbon source based on above-ground measurements of gain and loss. *Science,* 358, 230-234, 2017.
21. Brack, D., *Forests and Climate Change*. Background study prepared for the fourteenth session of the United Nations forum on forests, p. 56, 2019.
22. Strasser, U., Vilsmaier, U., Prettenhaler, F., Marke, T., Steiger, R., Damm, A., Hanzer, F., Wilcke, R.A. & Stötter, J., Coupled component modeling for inter- and trans-disciplinary climate change impact research: Dimensions of integration and examples of interface design. *Environ Model Softw,* 60,180-187, 2014.
23. Yuksel, G., Sea surface temperature anomalies at the Mediterranean Coast of Turkey (Period: 1968–2010), *Procedia Soc Behav Sci.,* 31, 476-486, 2014.
24. United States Environmental Protection Agency (EPA), Global Greenhouse Gas Emissions Data, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data, 2002.
25. Karwacka, M., Ciurzyńska, A., Lenart, A. & Janowicz, M., Sustainable development in the Agri-food sector in terms of the carbon footprint: A review. *Sustainability,* 12(16), 6463, 2020.
26. Muntasir, M. & Syed Y.S., Effects of Urbanization on Climate Change: Evidence from Bangladesh. *J. Nat. Sci. Res.,* 8, 1-8, 2018.

27. Zhang, N, Yu, K. & Chen, Z., How does urbanization affect carbon dioxide emissions? A cross country panel data analysis, *Energy Policy,* 107, 678-687, 2017.
28. Chen, F. & Chen, Y., Urban Climate Research and planning applications in China: A scientometric and long-term review (1963-2018) based on CiteSpace. *Clim. Res.,* 81, 91-112, 2020.
29. Yang, Q., Zheng, X., Jin, L., Lei, X., Shao, B. & Chen, Y., Research progress of urban floods under climate change and urbanization: A Scientometric analysis, https://www.mdpi.com/2075-5309/11/12/628¸2021.
30. Li, R., Zheng, H., Huang, B., Xu, H. & Li, Y., Dynamic Impacts of Climate and Land-Use Changes on Surface Runoff in the Mountainous Region of the Haihe River Basin, China. *Adv. Meteorol.*, 1-10, 2018.
31. Xu, H., Wang, C.C., Shen, X. & Zlatanova, S., 3D Tree Reconstruction in Support of Urban Microclimate Simulation: A Comprehensive Literature Review. *Buildings,*11, 417, 2021.
32. United Nations, *World urbanization prospects: The 2018 revision*. 2019.
33. United States Global Change Research Program (USGCRP), *Global Climate Change Impacts in the United States*, Thomas R. Karl, Jerry M. Melillo, & Thomas C. Peterson (Eds.), Cambridge University Press, New York, 2009.
34. Sims, R., Gorsevski, V. & Anenberg, S., Black carbon mitigation and the role of the Global Environment Facility: A STAP advisory document, 2017.
35. Liu, L., Zhang, J., Xu, L., Yuan, Q., Huang, D., Chen, J., Shi, Z., Sun, Y., Fu, P., Wang, Z. & Zhang, D., Cloud scavenging of anthropogenic refractory particles at a mountain site in North China. *Atmospheric Chem. Phys.,*18(19), 14681-14693, 2018.
36. Wang, C., Amon, B., Schulz, K. & Mehdi, B., Factors that influence nitrous oxide missions from agricultural soils as well as their representation in simulation models: A Review. *Agronomy,* 11(4), 770, 2021.
37. Houghton, R. A., House, J. I., Pongratz, J., Van Der Werf, G. R., DeFries, R. S., Hansen, M. C., Quéré, C. L. & Ramankutty, N., Carbon emissions from land use and land-cover change. *Biogeosciences,* 9(12), 5125-5142, 2012.
38. Mendelsohn, R. & Sohngen, B., The Net Carbon Emissions from Historic Land Use and Land Use Change. *J. For. Econ.,* 34, 263-283, 2019.
39. Scheiter, S. & Higgins, S.I., Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Glob. Chang. Biol,.*15, 2224-2246, 2009.
40. Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P. & Woodbury, P., Natural Climate Solutions. *Proc. Natl. Acad. Sci.*, 114(44), 11645-11650, 2017.
41. Sodhi N. S., Koh L. P., Brook B. W & Ng P. K., Southeast Asian biodiversity: an impending disaster. *Trends Ecol. Evol.,* 19, 654-660, 2004.

42. Deb, J., C., Phinn, S., Butt, N. & Mca lpine C., The impact of climate change on the distribution of two threatened Dipterocarp trees. *Ecol. Evo.,* 7, 2238-2248, 2017.
43. Ashton, M.S., Goodale, U.M., Bawa, K.S., Ashton, P.S. & Neidel, J.D., Restoring working forests in human dominated landscapes of tropical South Asia: an introduction. *For. Ecol. Manag.,* 329, 335-339, 2014.
44. Laurance, W.F., Forest-climate interactions in fragmented tropical landscapes. Philosophical Transactions of the Royal Society of London B. *Biol. Sci.,* 359, 345-352, 2004.
45. Corlett, R.T & Lafrankie-Jr, J.V., Potential impacts of climate change on tropical Asian forests through an influence on phenology. *Clim. Change,* 39, 439-453, 1998.
46. Margrove, J.A., Burslem, D.F., Ghazoul, J., Khoo, E., Kettle C.J. & Maycock, C.R., Impacts of an extreme precipitation event on Dipterocarp mortality and habitat filtering in a Bornean tropical rain forest. *Biotropica,* 47, 66-76, 2015.
47. Anadon, J. D., Sala, O. E. & Maestre, F. T., Climate change will increase savannas at the expense of forests and treeless vegetation in tropical and subtropical Americas. *J. Ecol.,*102, 1363-1373, 2014.
48. Shiels, A.B & González, G., Understanding the key mechanisms of tropical forest responses to canopy loss and biomass deposition from experimental hurricane effects. *For. Ecol. Manag.,* 332, 1-10, 2014.
49. Scheiter, S. & Higgins, S.I., Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Glob. Chang. Biol.,* 15, 2224-2246, 2009.
50. Clark, J.S, Lewis, M. & Horvath, L., Invasion by extremes: population spread with variation in dispersal and reproduction. *Am. Nat.,* 157, 537-554, 2001.
51. Ibanez, I., Clark, J.S. & Dietze, M.C., Estimating colonization potential of migrant treespecies. *Glob. Chang. Biol.,* 15, 1173-1188, 2009.
52. Clark, J.S., Fastie, C., Hurtt, G., Jackson, S.T., Johnson, C., King, G.A., Lewis, M., Lynch, J. Pacala, S., Prentice, C. & Schupp, E.W., Reid's paradox of rapid plant migration: Dispersal theory and interpretation of paleoecological records. *Bioscience,* 48, 13-24, 1998.
53. Gibson, J., Individualistic responses of piñon and juniper distributions to projected climate change, unpublished M.S. Thesis, Utah State University, Logan, Utah, USA, 2011.
54. Rehfeldt, G.E., Crookston, N.L., Saenz-Romero, C. & Campbell, E.M., North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecol. Appl.,* 22(1), 119-141, 2012.
55. Prakash, S. & Srivastava, S., Impact of climate change on biodiversity: An overview. *Int. J. Biol. Innov.,* 01(02), 60-65, 2019.
56. Beckage, B. Osborne, B. Gavin, D.G. Pucko, C. Siccama, T. & Perkins, T., A rapid upward shift of a forest ecotone during 40 years of warming in the

Green Mountains of Vermont. P*roc. Natl. Acad. Sci. U.S.A.,*105, 4197-4202, 2008.

57. Harsch, M.A., Hulme, P.E., McGlone, M.S. & Duncan, R.P., Are treelines advancing? A global meta-analysis of treeline response to climate warming. *Ecol. Lett.,*12, 1040-1049, 2009.
58. Jump, A.S., Matyas, C. & Penuelas, J., The altitude-for-latitude disparity in the range retractions of woody species. *Trends Ecol. Evol.,* 24, 694-701, 2009.
59. Loarie, S.R., Duffy, P.B., Hamilton, H. Asner, G.P., Field, C.B & Ackerly, D.D., The velocity of climate change. *Nature,* 462, 1052-1055, 2009.
60. Woodall, C.W., Oswalt, C.M., Westfall, J.A., Perry, C.H., Nelson, M.D. & Finley, A.O., An indicator of tree migration in forests of the eastern United States. *For. Ecol. Manag.,* 257, 1434-1444, 2009.
61. Woodall, C.W., Westfall, J.A., Zhu, K. & Johnson, D.J., Assessing the effect of snow/water obstructions on the measurement of tree seedlings in a large-scale temperate forest inventory. *Forestry*. 86, 421-427, 2013.
62. Crookston, N.L., Rehfeldt, G.E., Dixon, G.E., & Weiskittel, A.R., Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. *For. Ecol. Manag.,* 260, 1198-1211, 2010.
63. Zhu, K., Woodall, C.W. & Clark, J.S., Failure to migrate: lack of tree range expansion in response to climate change. *Glob. Chang. Biol.,* 18, 1042-1052, 2012.
64. Woodall, C.W. Perry, C.H. & Miles, P.D., Relative density of forests in the United States. *For. Ecol. Manag.,* 226, 368-372, 2006.
65. Woodall, C.W., Zhu, K., Westfall, J.A., Oswalt, C.M., D'Amato, A.W., Walters, B.F. & Lintz, H.E., Assessing the stability of tree ranges and influence of disturbance in eastern US forests. *For. Ecol. Manag.,* 291, 172-180, 2013.
66. St Clair, J.B., Mandel, N.L. & Vance-Borland, K.W., Genecology of Douglas Fir in Western Oregon and Washington. *Ann. Bot.,*96, 1199-1214. 2005.
67. St Clair, J.B. & Howe, G.T., Genetic maladaptation of coastal Douglas-fir seedlings to future climates. *Glob. Chang. Biol.* 13, 1441-1454, 2007.
68. Leites, L.P., Robinson, A.P., Rehfeldt, G.E., Marshall, J.D. & Crookston, N.L., Height-growth response to climatic changes differs among populations of Douglas-fir: a novel analysis of historic data. *Ecol. Appl. ,*22, 154-165. 2012.
69. Rehfeldt, G.E. & Jaquish, B.C., Ecological impacts and management strategies for western larch in the face of climate change. *Mitig. Adapt. Strateg. Glob. Chang.,* 15, 283-306. 2010.
70. Crookston, N.L., Rehfeldt, G.E., Dixon, G.E. & Weiskittel, A.R., Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. *For. Ecol. Manag.,* 260, 1198-1211, 2010.
71. Evans, A.M. & Perschel, R., A review of forestry mitigation and adaptation strategies in the Northeast U.S. *Climat. Chang.,* 96, 167-183, 2009.
72. Hewitt, G.M., Post-glacial re-colonization of European biota. *Biol. J. Linn. Soc.,* 68, 87-112, 1999.

73. Iverson, L., Schwartz, M.W. & Prasad, A., How fast and far might tree species migrate in the eastern United States due to climate change? *Glob. Ecol. Biogeogr.,* 13, 209-219, 2004.
74. Shugart, H.H., Antonovsky, M.Y., Jarvis P.G. & Sandford A.P., CO_2 climatic change and forest ecosystems, in: *The Greenhouse Effect, Climatic Change and Ecosystems*, Bolin, B., Doeoes, B.R., Jaeger, J. & Warrick R.A. (eds.), John Wiley and Sons, New York, 1986.
75. Gayton, D.V., Impacts of climate change on British Columbia's biodiversity: a literature review. *J. Ecosyst. Manag.,* 9(2), 26-30, 2008.
76. Li, M.H., Krauchi, N. & Gao, S. P., Global warming: can existing reserves really preserve current levels of biological diversity? *J. Integr. Plant Biol.*, 48(3), 255-259, 2006.
77. Janzen, D.H., Why Mountain passes are higher in the tropics. *Am. Nat.,* 101, 233-249, 1967.
78. Terborgh, J., On the notion of favourableness in plant ecology. *Am. Nat.,* 107, 481-501, 1973.
79. Fine, P.V.A. & Ree, R.H., Evidence for a time-integrated species-area effect on the latitudinal gradient in tree diversity. *Am. Nat.,* 168, 796-804, 2006.
80. Sunday, J.M., Bates, A.E. & Dulvy, N.K., Global analysis of thermal tolerance and latitude in ectotherms. *Proc. Royal Soc. Biol. Sci.,* 278(1713), 1823-1830, 2010.
81. Williams, J.W. & Jackson, S.T., Novel climates, no-analog communities, and ecological surprises. *Front. Ecol. Environ.,* 5(9), 475-482, 2007.
82. Battisti, D.S., & Naylor, R.L., Historical warnings of future food insecurity with unprecedented seasonal heat. *Science,* 323(5911), 240-244, 2009.
83. Diez, J.M., D'Antonio, C.M., Dukes, J.S., Grosholz, E.D., Olden, J.D., Sorte, C.J., Blumenthal, D.M., Bradley, B.A., Early, R., Ibáñez, I. & Jones, S.J., Will extreme climatic events facilitate biological invasions? *Frontiers in Ecology and the Environment*, 10(5), 249-257, 2012.
84. Huang, D., Haack, R.A. & Zhang, R., Does global warming increase establishment rates of invasive alien species? A centurial time series analysis. *PLoS ONE,* 6(9), 52-59, 2011.
85. Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F., Ecological responses to recent climate change. *Nature,* 416, 389-395, 2002.
86. Parmesan, C., Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.,* 37, 637-669, 2006.
87. Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C. & Pounds, J.A., Fingerprints of global warming on wild animals and plants. *Nature,* 421, 57-60, 2003.
88. Dukes, J.S. & Mooney, H.A., Does global change increase the success of definitions? *Divers.,*6, 93-107, 1999.
89. Thuiller, W., Richardson, D.M. & Midgley, G., Will climate change promote alien plant invasions? In *Biological Invasions*. (ed. Nentwig, W.), Springer-Verlag, Berlin, pp. 197-211, 2007.

90. Thuiller, W., Richardson, D.M., Pysek, P., Midgley, G.F., Hughes, G.O. & Rouget, M., Niche-based modeling as a tool for predicting the risk of alien plant invasions at a global scale. *Glob. Chang. Biol.*, 11, 2234-2250, 2005.
91. Sorte, C.J.B., Williams, S.L. & Zerebecki, R.A., Ocean warming increases threat of invasive species in a marine fouling community. *Ecology*, 91, 2198-2204, 2010.
92. Rahel, F.J. & Olden, J.D., Assessing the effects of climate change on aquatic invasive species. *Conserv. Biol.,* 22, 521-533, 2008.
93. Bradley, B.A., Blumenthal, D.M., Early, R., Grosholz, E.D., Lawler, J.J., Miller, L.P., Sorte, C.J., D'Antonio, C.M., Diez, J.M., Dukes, J.S. & Ibanez, I., Global change, global trade, and the next wave of plant invasions. *Frontiers in Ecology and the Environment*, 10(1), 20-28, 2012.
94. Byers, J., Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. *Oikos*, 97, 449-458, 2002.
95. Kok, M.T., Alkemade, R., Bakkenes, M., van Eerdt, M., Janse, J., Mandryk, M., Kram, T., Lazarova, T., Meijer, J., van Oorschot, M. & Westhoek, H., Pathways for agriculture and forestry to contribute to terrestrial biodiversity conservation: a global scenario-study. *Biological Conservation*, 221, 137-150, 2018.
96. Irland, L.C., Adams, D., Alig, R., Betz, C.J., Chen, C.C., Hutchins, M., McCarl, B.A., Skog, K. & Sohngen, B.L., Assessing Socioeconomic Impacts of Climate Change on US Forests, Wood-Product Markets, and Forest Recreation: The effects of climate change on forests will trigger market adaptations in forest management and in wood-products industries and may well have significant effects on forest-based outdoor recreation. *BioScience*, 51(9), 753-764, 2001.
97. Goldblum, D., The geography of White Oak's (*Quercus alba* L.) response to climatic variables in North America and speculation on its sensitivity to climate change across its range. *Dendrochronologia*, 28(2),73–83, 2010.
98. Iverson, L.R., Prasad, A.M., Matthews, S.N. & Peters, M. Estimating potential habitat for 134 eastern us tree species under six climate scenarios, *For. Ecol. Manag.*, 254(3), 390–406, 2008.
99. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
100. Jhariya, M.K., Yadav, D.K. & Banerjee, A., Agroforestry and Climate Change: Issues and Challenges. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group. ISBN:978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book), pp. 335, 2019b. https://doi.org/10.1201/9780429057274
101. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888110, pp. 400, 2020. https://doi.org/10.1201/9780429276026

102. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, 112829, 2021a. Elsevier. https://doi.org/10.1016/j.jenvman.2021.112829
103. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1): 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
104. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management.* Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019a. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
105. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management.* Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
106. Jhariya, M.K., Meena, R.S. & Banerjee, A., *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore. eISBN: 978-981-334-203-3, Hardcover ISBN: 978-981-334-206-6, pp. 655, 2021. Doi: 10.1007/978-981-33-4203-3.
107. Jhariya, M.K., Meena, R.S., Banerjee, A. & Meena, S.N., *Natural Resources Conservation and Advances for Sustainability*. Elsevier, Academic Press. ISBN: 9780128229767, pp. 650, 2022. https://doi.org/10.1016/C2019-0-03763-6
108. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), editors. *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
109. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
110. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
111. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021a, ISBN 978-981-15-9495-3, pp. 221-246, 2021a. https://doi.org/10.1007/978-981-15-9496-0_7
112. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al*. (eds.). *Agroecological Footprints Management for Sustainable*

Food System, Springer Nature Singapore Pte Ltd. 2021b, ISBN 978-981-15-9495-3, pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-0_14
113. MyBIS, *Malaysia Policy on Forestry,* Ministry of Energy and Natural Resources, Malaysia, https://www.mybis.gov.my/pb/4825, 2022.
114. Climate Change and Forests Vulnerability Adaptation Strategies and Mitigation Role, https://www.ignfa.gov.in/document/reading-material-climate-change-and-indias-forests-vulnerability-adaptation-strategies-and-mitigation-role.pdf , 2022.
115. National Wildlife Action Plan (2002-2016), https://www.forests.tn.gov.in/tnforest/app/webroot/img/document/legislations/NATIONAL%20WILDLIFE%20ACTION%20PLAN%20(2002-2016).pdf , 2022.
116. World Research Institute, How Can Indonesia Achieve Its Climate Change Mitigation Goal? An Analysis of Potential Emissions Reductions from Energy and Land-Use Policies, https://files.wri.org/d8/s3fs-public/how-can-indonesia-achieve-its-climate-change-mitigation-goal-analysis-potential-emissions-reductions-from-energy-land-use-policies_0.pdf , 2022.
117. Community forestry adaptation roadmap to 2020 for Thailand, https://www.recoftc.org/sites/default/files/publications/resources/recoftc-0000199-0001-en.pdf, 2022.

6

Impact of Continuous Cover Forestry on Forest Systems

Ana Cristina Gonçalves

MED – Mediterranean Institute for Agriculture, Environment and Development & CHANGE – Global Change and Sustainability Institute, Instituto de Investigação e Formação Avançada, Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Universidade de Évora, Évora, Portugal

Abstract

The forests' large spatial and temporal frame makes them unique. Their management developed over time through a large set of methods and techniques. Up to the 13th century, forests were able to provide products and services. From the 13th century onwards, regulations were made in order to preserve the forests and their products and services. Later on, in the 19th and 20th centuries, the increasing demand of woody and non-woody products and services changed the paradigm of forest management. The result was the development of several approaches to multiple use management, among which was continuous cover forestry. These approaches are based on complex systems, continuity of crown cover in space and time, and natural regeneration. This review describes the principles, the management options and the challenges to the implementation of continuous cover forestry.

***Keywords*:** Silviculture, management, stand structure, sustainability, and productions

6.1 Introduction

Forests and forest stands have two features that make their management unique: temporal scale and spatial scale. Silviculture has to work in an

Email: acag@uevora.pt

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (133–160) © 2023 Scrivener Publishing LLC

integrated way with short-, medium- and long-term temporal scale, and with small, medium and large spatial scale. This integrated approach makes the bridge between growth, productivity, sustainability, products, and services. Silviculture and forest management developed over time as a result of scientific knowledge of the forest ecosystems and the demand of products by the market.

Until the 9th century, the forests were able to provide the need for wood and services. The increase of population, the development of agriculture and the intensification of demand for woody products, firewood, naval construction and industry from the 9th until the 19th centuries, augmented the pressure on forests to provide increasing quantities of wood (though with some fluctuations corresponding to periods of wars and human pandemics). The pressure on forest diminished in the 20th century with the use of oil as a source of energy. From the 13th century onwards, the increasing demand for forest products and the need for more area for agriculture led to the degradation and reduction of the forest area. This brought about an increasing concern towards the preservation of the forests and their products, which resulted in regulations [1]. The development of forest science enabled the development of methods and techniques to manage forests according to a set of objectives, always considering wood production, perpetuity, other forest products and services, and more recently sustainability [1, 2]. The approaches to silviculture can be divided into two broad classes: monofunctional and multifunctional. The *monofunctional* approach has one main goal, timber production. It is characterised by stands with high density; frequently of one species (pure stands); with management towards homogeneous trees dimensions (even aged stands); high productivities and mechanised harvesting, associated with clear-cut systems and many times to artificial regeneration [1, 2]. The *multifunctional* approach has multiple goals, which have to be ranked in order to optimise the management investments. It is frequently associated with mixed and/or uneven aged stands; management that favours the stand irregularity, both horizontal and vertical; several forest systems can be used, from clear-cut (in small areas) to selective systems, although preference is given to selective and irregular shelterwood systems; and regeneration is preferably natural, though artificial regeneration can be used. Harvesting cycles are defined by a target (threshold) diameter and quantity of volume removed should correspond approximately to volume increment during the time between two successive cuts. In this approach the sustainability of the stands, forests and their products and services is a central issue [3].

The multifunctional silviculture dates back to the 18th century and derived from the concerns of forest conservation (or sustainability) [1]. From this concern, several approaches were developed and have been subject to a continuous discussion on their advantages and disadvantages and implementation.

In literature, a vast number of publications can be found on multifunctional silviculture. Furthermore, the terminology used is vast [4, 5]. Different authors group the several approaches to multifunctional silviculture according to different categories, definitions and goals. While [5] used six categories (continuous cover forestry, ecosystem management, structural diversity, retention, thinning/harvesting methods and philosophically driven), [4] used five categories, three for stand level approaches (timber oriented, nature based, global change driven), one for landscape level and one for conceptual level.

A standard term that includes all the approaches and the definition has not yet been presented in literature. This is due to the variability between the different approaches [4, 5]. Yet, broadly speaking it can be said multiple products and services define that multifunctional silviculture; with species adapted to the site; in pure, mixed, even aged and/or uneven aged stands; and selective or shelterwood systems, though clear-cut might be used in small areas. The goals of this approach are the sustainability of the stands and productions, increase of the system resilience and diversification by risk partitioning and complementarily of functions. Some of the approaches are presented in Table 6.1, including three conceptual ones. The rationale behind these approaches is an integrated holistic vision of the ecosystem and the interaction among the components in a spatial-temporal perspective.

Table 6.1 Approaches to multifunctional forestry.

Approach	**References**
Continuous cover forestry	[3, 6–9]
Close to nature silviculture/forestry	[10–15]
Retention systems	[16–20]
Adaptative forestry/silviculture	[21, 22]
Climate-smart forestry	[23–25]
Ecological forestry	[26, 27]
New forestry	[28]
Holistic forestry	[29]
Systemic silviculture	[30–32]

The goal of this review is to revise the state of the art on the stand level of the continuous cover forestry, both for forest systems for timber and other non-woody products and services and their implications to forest management. The study is divided into the following sections: continuous cover forestry (section 6.2), forest management under continuous cover forestry (section 6.3), and challenges of continuous cover forestry (section 6.4).

6.2 Continuous Cover Forestry

Continuous Cover Forestry (CCF) and Close to Nature Silviculture (CNS) were founded on the studies Adolphe Guarnaud and Henry Biolley did on uneven aged stands in the 19th century [1, 5]. These two approaches converged with the work developed under Pro Silva, a European federation of foresters (https://www.prosilva.org/), and may be considered synonyms [8, 14]. For simplicity, these two approaches will be referred to as continuous cover forestry.

Continuous cover forestry is not a forest system but rather an approach guided by a set of principles [5, 8, 14, 33], oriented towards the forest ecosystem, enhancing their horizontal and vertical variability while ensuring their stability [14]. The seven principles (Figure 6.1) associated with continuous cover forestry are [3, 5, 8, 14, 33]: i) use of native species adapted

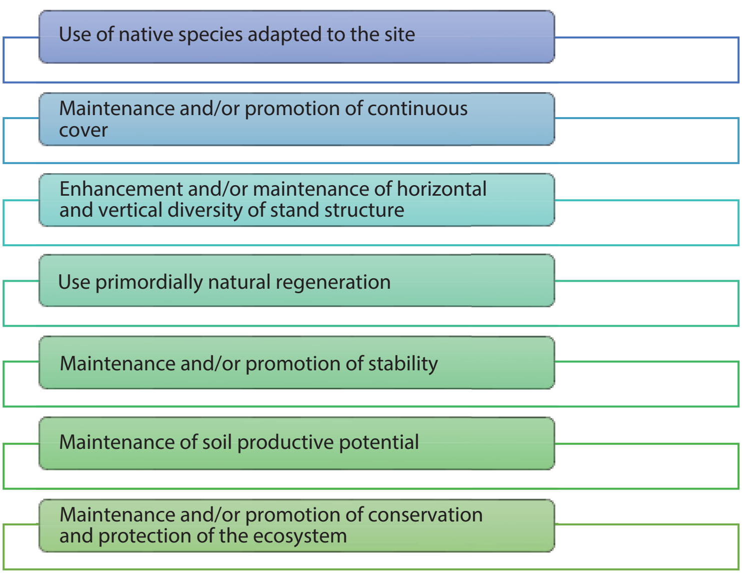

Figure 6.1 Principles of continuous cover forestry.

to the site; ii) maintenance and/or promotion of continuous cover, with the avoidance of clear felling; iii) enhancement and/or maintenance of the horizontal and vertical diversity of stand structure, both in composition and structure; iv) use primordially natural regeneration, although artificial regeneration can be used to complement natural regeneration; v) maintenance and/or promotion of stability, as a way to minimize disturbances (biotic and abiotic) damages; vi) maintenance of soil productive potential, by minimizing the practices of site management; vii) maintenance and/or promotion of conservation and protection of the ecosystem, especially the most sensitive sites and/or under protection or conservation status.

The *use of species adapted to the site* is related to the adaptation and resilience of the forest system. The goal is to develop or maintain stands which can withstand disturbances and maintain the system [12]. Native species and/or provenances that are in sites within the range of their ecological traits are considered better suited as they are less prone to biotic and abiotic disturbances and are better suited to the perpetuity and sustainability of the system [5, 10, 34]. Both natural and/or site adapted tree species can be used. Non-native species can be used in admixtures in small proportions [15].

Maintenance and/or promotion of continuous cover is associated with the maintenance of the stand sustainability and their productions. It is related to the continuity of timber production, both in quantity and quality, but also to other productions and services expected from the forests. In fact, conservation and protection of sites, habitats, flora and fauna species is many times interlinked with the sustainability of the forest systems [8, 14, 33].

Maintenance and promotion of the horizontal and vertical diversity of the stand, in composition and structure, enhance the stand perpetuity and sustainability; maintain periodical timber harvests; the diversity of timber size classes is higher; and tree and stand stability is, in general, higher [5, 15, 35].

The *use of natural regeneration* is related to its potential better adaptation to the site, development of well-established root system and reduction of the installation costs. Species adapted to the site, in general, have higher survival rates and development [3, 36]. Inversely to plantations, the root system of the natural regeneration seedlings establishes well in the soil, thus enhancing the uptake of water and nutrients and consequently the seedling growth [36–38]. Generally the costs of natural regeneration are low [3, 39] and are frequently associated with the control of spontaneous vegetation or improving the seedbed [36, 40].

Stability maintenance and/or promotion is linked to the effect of disturbances (abiotic and biotic) on the forest system. It is related to the dynamics of regeneration; ecological stability, including species adapted to the sites and species admixtures that are able to preserve the genetic variability; resilience of the system; mechanical stability of the individual trees, in particular the future trees that are in free growth, and also stand stability [1, 10, 34, 41].

Maintenance of soil productive potential is linked to canopy cover and site management practices. The positive effect of crown cover on the forest microclimate is well known: reduction of erosion risk and enhancement of carbon storage [35, 42]. Inversely, site management practices, such as soil tillage, can affect the physical, chemical and biological soil properties, reduce carbon stocks in the soil and promote erosion [2, 43].

Maintenance and/or promotion of conservation and protection of the ecosystem comprise an integrated and holistic management rather than managing only for the forest component. It has implications on the maintenance of the sustainability by identifying the sensitive areas, such as transition areas between different land uses, riparian areas, and conservation and protection areas. This is related to the maintenance of habitats for flora and fauna species, which is especially important for those with at-risk status. The minimization of disturbances, especially silvicultural practices, by prescribing practices that minimize stand structure changes and use of methods that are similar to the natural disturbances, can help to maintain the stand structure [5, 15]. It is also connected with the maintenance and promotion of biodiversity, which can be achieved by retaining trees (amenity), deadwood (standing or lying), protection (habitats, fauna and flora), and transition zones between different land uses (ecosystems services) [44].

As mentioned earlier, continuous cover forestry is not a silvicultural system, but rather an approach guided by a set of principles. It encompasses mainly two silvicultural systems: selection and shelterwood [3, 8, 14, 33, 45]. The latter is frequently used during the transformation process to enable higher structural diversity [3]. These two systems are those that enable reaching the target stand structure and their sustainability. Yet, the clear cut with standards system can be used in some cases [3, 46, 47]. It also fosters a wide range of thinning methods, intensities and frequencies. From the existing thinning methods, the better suited are those that maintain or increase the structural diversity of the stands, such as the thinning from above, selective, variable density [3]. One or several thinning methods, intensities and frequencies can be used in space and time, throughout the production cycle. For further details on thinning see [48].

The diversity of stand structures that can be found in forest systems managed under continuous cover forestry makes it difficult to generalise the models of silviculture. Yet, the set of principles of continuous cover forestry provide the guidelines for the development of the management options. Models of silviculture (Figure 6.2) of continuous cover forestry

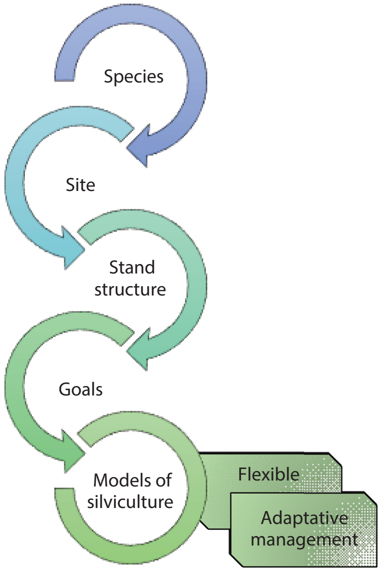

Figure 6.2 Features to take into consideration in the models of silviculture.

stands need to be flexible and interlinked with adaptive management [33]. The variability of species, stand structure, sites, goals and management derive from a wide range of continuous cover forestry systems. Thus, it is not feasible to generalise models of silviculture. Considering the wide range of options, during the production cycle, management options can be analysed and evaluated with growth and production models. These models can be used to simulate different models of silviculture and its effects on tree and stand growth and yield as well as in other products and services.

One of the alternatives in terms of structure is to manage stands under Plenter (or selection) system, which corresponds to a negative exponential distribution of diameter [3]. It was applied successfully in some European countries (Table 6.2).

The stand diameter distribution may not follow a negative exponential. Other curves are also admissible, such as rotated sigmoid, unimodal, and are related to the number of cohorts and their proportion in the stands [54, 55]. The target diameter distribution is reached gradually by harvest, whether thinning or cuttings [3]. As stand develops, depending on the type, intensity and frequency of the harvests (including thinning and cuttings), more than one alternative can be considered. The growth and production models are of help in developing, analysing and choosing the better suited silvicultural practices as a function of the target structure and the stand structure dynamics [12].

Table 6.2 Countries where continuous cover forestry is used.

Country	Reference
Switzerland	[10]
France	[49]
Germany	[49]
Austria	[49]
Italy	[50]
Slovakia	[51]
Denmark	[52]
Slovenia	[49, 53]
Bulgaria	[53]
Croatia	[53]
Romania	[53]
Bosnia and Herzegovina	[53]
FJR of Macedonia	[53]
Montenegro and Serbia	[53]

Regeneration is linked to gap openings. These should be small and the area of 0.25 ha has been proposed [38]. Yet, this value though can be used as a reference to enable the maintenance of the microclimate in the forest stand, should not be used as a rule. First, the area of the gaps has to be evaluated with the number of gaps and their spatial distribution [56–58]. Second, gap size is dependent on the species traits one desires to regenerate [57, 58]. Third, as one of the goals of continuous cover forestry is promoting mixed and/or uneven aged stands, different gap sizes are better suited than just one gap size [10, 14]. For example, shade intolerant species need larger gaps for a successful regeneration [3]. Thus, a reduced number of larger gaps than 0.25 ha can be acceptable [59].

One constraint that can be pointed out regarding natural regeneration is that it is not always possible to have seedlings of all the desired species [36, 37, 57], because of the lack of seed source, seed production or inadequate site and stand conditions [58, 60, 61]. Thus, it can be admissible to use artificial regeneration (seeding or planting) to promote species which are difficult to regenerate naturally, in which case gap size has to be suited to their ecological traits, for example, larger gaps for shade intolerant species [62].

Herbivory is another concern when regenerating stands. The damages to seedlings are related to the animal density, palatability of the tree species and the alternative vegetation [6, 37, 56, 63, 64]. One way to overcome browsing pressure is either to fence the regenerating areas or to use individual tree shelters [65].

Continuous cover forestry was developed for timber-oriented stands. Yet, many of its principles are already implemented in agroforestry systems in the Mediterranean basin. These systems are multiple uses oriented for bark and fruit production to which is frequently associated agriculture and/or grazing. The stands have low density and irregular spacing. Three frequent species are *Quercus suber*, *Quercus ilex* and *Pinus pinea* [66–68] whether in pure or mixed stands, mainly even aged, but uneven aged stands are also present [69, 70]. The stands of these three species are managed for a target crown cover of 40-60% throughout the production cycle. Several reasons can be pointed out: the species are shade intolerant; annual drought season (from June to August); and to allow agricultural crops and/or grazing [66, 68, 71, 72]. Regeneration is dependent on seed production and spring precipitation in the first years after germination [37].

In the management of these systems several continuous cover forestry principles (Figure 6.3) are applied, namely the species are native,

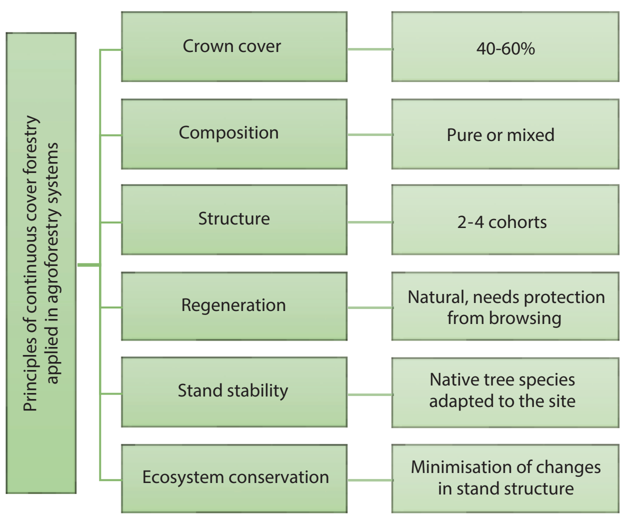

Figure 6.3 Principles of continuous cover forestry applied in agroforestry systems.

continuous cover is maintained throughout the production cycle, natural regeneration is used, stability is enhanced [69, 70] and conservation of the ecosystem is promoted [73]. The principle that is less implemented is the development of uneven aged stands [69, 70]. In fact, their development is a challenge due to the need of synchrony of good seed production and spring precipitation that enable natural regeneration establishment. In addition, measures have to be taken in regard to the protection of natural regeneration from browsing. In spite of the limitations, uneven aged stands of the aforementioned species are found [69, 70].

Composition can be either pure or mixed. The latter has advantages in what concerns the increase of diversity and resilience of the stands and their productions while maintaining conservation of soil and water, habitats and flora and fauna species. Considering the aforementioned, the number of cohorts in agroforestry systems has to be a balance between the periodicity of natural regeneration, species traits, site and other land uses. Thus, structures with two to four cohorts seem to be the best suited. One of the advantages of these uneven aged stands are the maintenance of the production, contrary to what happens in the even aged stands where full production is attained at an age of about 30 to 40 years for *Quercus suber*, *Quercus ilex* and *Pinus pinea*. Another advantage is that as crown cover is maintained the conservation and protection of the soil, habitats and species both of flora and fauna, is enhanced. Crown cover is particularly important in the Mediterranean as precipitation is prevalent in autumn and winter and torrential rainfalls are common, while a drought season occurs in the summer (June to August). Typically, the best-suited crown cover is between 40% and 60%. A number of cohorts larger than four may have disadvantages. First, natural regeneration has to occur with success with shorter periodicity. This might not be possible as regeneration period has to be long (circa 10 years or more) to enable several years of good seed production and suitable spring precipitation. Second, browsing has to be reduced, either by exclusion or individual tree shelters. Third, the three species are shade intolerant, site has periodic droughts and soils are frequently of poor quality, thus restricting stand density and consequently the number of possible cohorts. Fourth, agricultural crops and grazing conditions the number of cohorts. Consequently, it seems more feasible to implement structures of two to four cohorts [71].

6.3 Forest Management under Continuous Cover Forestry

Forest management under continuous cover forestry will be addressed with two cases (Figure 6.4): existing stands and transformation of existing regular forest management systems. Costs and returns of the continuous cover forestry approach when compared to regular forest management will also be discussed.

The *management of existing continuous cover forestry* has to take into account several features of mixed and/or uneven aged stands, so that the system is maintained, namely regeneration, composition and structure and harvests. Natural regeneration depends on a set of factors, namely flowering, fruiting, germination, seedling survival and development, which are linked to stand structure and site [37, 74–76]. Flowering and fruiting are related to stand structure as trees with well-developed crowns produce

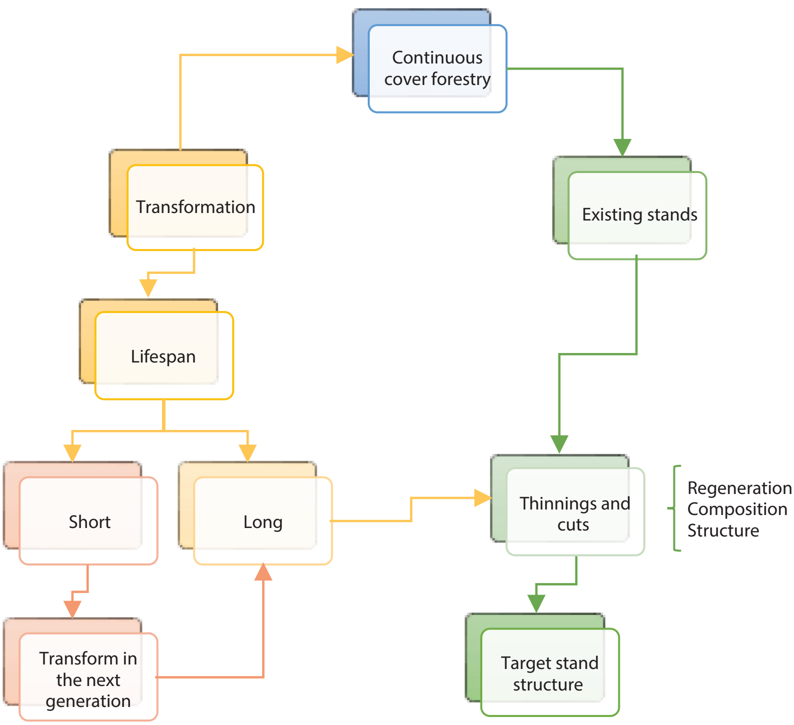

Figure 6.4 Existing continuous cover forestry management and transformation of stands into continuous cover forestry.

more flowers and fruits, mainly in the outer crown [77, 78]. Furthermore, seed availability is related to the fruit production cycles, with some species with masting years with shorter periodicity than others [60]. Germination is dependent on the seedbed conditions, light and water availability. Frequently two limiting factors have been specified: light for stands in higher latitudes, and drought in Mediterranean climates [36, 37, 40, 79]. The seedling survival and development is related to the growing space available and the species traits. For example, shading is a limiting factor, the stronger the more intolerant are the species. Similarly, competition for water and nutrients by the overstorey individuals and by understorey vegetation is another limiting factor. Yet, shade can have a protective role against water stress and frost. Likewise, browsing damages can be diminished by the protection offered by the understorey vegetation [37, 80, 81].

Natural regeneration has to be ensured, in quantity and quality, as well as composition and spatial distribution. Several silvicultural measures can be prescribed to enhance the success of natural regeneration, including opening gaps in the canopy with different sizes that enable the regeneration, growth and recruitment of species with different shade tolerance [57, 58, 82]; control of browsing to reduce the damages and growth reduction of the seedlings and saplings, with for example individual tree shelters, exclusion and/or reduction of the animal density [6, 37, 63, 65]; control of spontaneous vegetation to reduce the competition between seedlings/saplings and the former [36, 40]; and thinning to reduce competition amongst regeneration and overstorey trees [81, 83].

Target composition and structure is attained with thinning and cuts. Thinning controls the proportion of species in mixed stands and composition, especially of the future trees so that they are, during the production cycle, in free growth [3, 14, 33]. Several methods can be used, namely, thinning from below, thinning from above, selective thinning, variable density thinning and free thinning. One or several methods can be used in the stand, both in space and time [48]. This is related to the variability of composition and structure in the stand [3]. Thinning intensity and frequency is dictated by the competition the future trees are suffering and also the need to release the best trees of the younger cohorts [3, 48]. The cuts are related to the silvicultural system as well as the moment when the future trees are mature, that is, when they are financially mature [3]. Several silvicultural systems can be used. Selection systems, whether with single tree or group selection, have been described by several authors (e.g., [10, 49, 50, 53, 84]). Irregular shelterwood system has also been used with continuous cover forestry management (e.g., [14, 46, 54]). The choice of the system is related to the site characteristics, species traits and target stand structure.

One silvicultural practice that is relevant to wood quantity and quality is pruning. The continuous cover forestry approach relies on natural pruning. This can be achieved by shading the lower stem level. Thus, care should be taken not to open canopy gaps that increase direct sunlight in the lower parts of the stem as the trees tend to maintain and develop more or less heavy branching, especially those at the border of the gaps [12, 85–87]. Also, species with weak epinastic control tend to form heavy branching [34, 88].

Of importance are also the broadleaved tree species that are frequently found in small proportions, whether as individual stems or in groups, but that can have a pivotal importance in continuous cover forestry systems. These tree species (e.g., from the genera *Prunus*, *Fraxinus*, *Acer*, *Alnus*, *Carpinus*, *Castanea*, *Juglans*, *Sorbus*, *Tilia*, *Ulmus*) can play a primordial role to the heterogeneity, diversity, stability and resilience of the stands and forests. In addition, their timber is of high quality, the production cycles are relatively short, and timber quality has a high-added market value. Details on the silvicultural practices associated with continuous cover forestry can be found in [87].

Overall, the management of existing continuous cover forestry stands is dependent on stand structure, site and growth conditions; disturbances, which should be of short periodicity and light intensity; and the use of combined silvicultural methods and techniques [10]. Moreover, for the maintenance of the target stand structure is of primordial importance the continuous management and monitoring [84]. Rather than imposing silvicultural practices on a fixed schedule, continuous cover forestry relies on the analysis of the dynamics of the stand structure, through continuous monitoring and adaptative and flexible models of silviculture that drive the stands gradually to the target stand structure or that maintain it, with the best suited silvicultural practices in time and space.

The *transformation of regular forest management stands into continuous cover forestry* is dependent on the structural differentiation of the stand. Schütz [34] refers four steps: i) main stand stability, which is related to the intensity and periodicity of thinning operations that enable to open the canopy to promote natural regeneration, without risk of tree falling; ii) duration of the trees that constitute the main canopy, which should remain during the time the transformation takes place; iii) promotion of differentiated regeneration, which ensures auto-regulations and diverse age classes (or cohorts); iv) adequacy to the target stand structure, including number of cohorts and species, their proportion, and horizontal and vertical distribution.

The conversion of structure and transformation according to [34] can be broadly divided into two stages: i) give enough time (often more than

50 years) to the process to follow a sequence of four stages, namely differentiation, promotion of regeneration, structural development and structure achievement; and ii) decide whether alteration of structure and composition is done in the actual generation or in the next one, as function of the life span of the trees of the overstorey.

In practice the transformation of regular forest management to continuous cover forestry can be attained by the following sequential steps [3] (Figure 6.5): i) in the first step, young even aged stands a set of thinning from below are carried out to promote stem exclusion stage; ii) in the second step, a suite of thinning that change progressively from thinning from below to crown thinning are done. The result is twofold, development of regeneration cohorts and have revenues as large trees are removed; iii) in the third step, is made the removal of the trees of the overstorey that are competing with the future trees. At the same time a set of thinning are carried out in the younger cohorts of regeneration; whenever there is the slowdown or stall of the regeneration there should be opened canopy gaps with wide dimensions, the larger the more shade intolerant are the tree species; and iv) in the fourth step, is carried out the removal of mature trees with shelterwood system, with intensity depending on natural regeneration density, spatial distribution and development.

The transformation should take into consideration the potential risks. For example, in stands prone to wind damage [89] suggests three short periodicity thinning, the first to enable accessing the stand, and the latter two (from above) for the identification and promotion of the trees with higher probability of becoming dominants. After the third thinning it

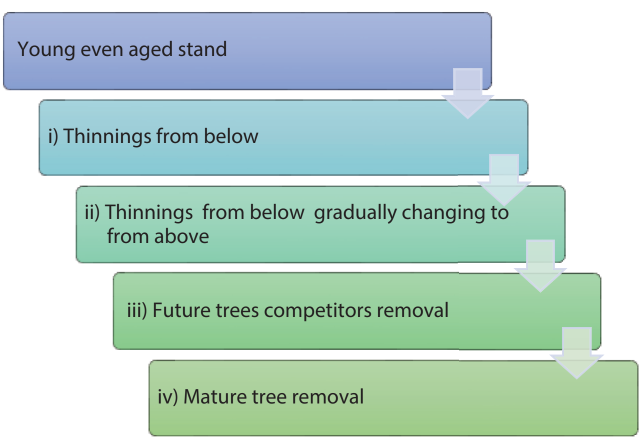

Figure 6.5 Transformation of even aged stands into continuous cover forestry.

should be given time for stand recovering. When this is achieved, thinning, in variable number, should be done to promote diversity in structure that is to enhance natural regeneration. The natural regeneration is promoted by enabling suitable light levels in the understorey and reducing competition of spontaneous vegetation [90, 91].

For the successful transformation, the flexibility of the model of silviculture and the continuous evaluation of the management practices schedule have to be done. These silvicultural practices can be anticipated or retarded according to the stand structure and market dynamics, which implies adaptative management. Thus, to combine the model of silviculture with monitoring and make the necessary alterations whenever needed but bearing in mind the target stand structure [84, 92].

Managing continuous cover forestry stands or transforming regular forest management into continuous cover forestry stands have *costs and returns*. These are closely linked to the silvicultural practices. When compared with regular forest management, the continuous cover forestry, in theory, has two financial benefits [3]: i) costs of installation are reduced as it uses natural regeneration, and ii) uneven aged stands enable the production of large high-quality timber. The cost savings in installation are considerable. McMahon *et al.* [39] referred that installation represents 20-30% of the investment and its return is only attained at final harvest in even aged stands.

The transformation of forests into continuous cover forestry evaluated with net present value (NPV), assuming a successful natural regeneration, both with field trials [93] and simulation studies [94] attained similar results, with higher profitability for continuous cover forestry when compared with regular forest management. This is related to the higher price of the saw logs (of larger dimensions) in continuous cover forestry. Another distinctive feature of continuous cover forestry that influences its revenues is the periodicity of cuts and the dimension of the trees removed. As continuous cover forestry is based in the selection of the future trees, in thinning trees of large sizes are removed, thus allowing higher incomes with shorter periodicity when compared with regular forest management [3]. Continuous cover forestry is also characterised by the partitioning of risks because a wider assortment of timber products is available which also enables a more flexible adjustment to fluctuations of timber market value. According to [3] the financial benefits of continuous cover forestry are: the profitability of continuous cover forestry is higher than that of regular forest management and increases with the increase of the rates of discount; when trees reach maturity (financial) they can be harvested; in continuous cover forestry most trees are cut when they are financially mature, while in regular forest management that does not happen. The potential to produce high-quality timber in continuous cover forestry is related to the selection of the best producers [85]; the natural pruning derived from shading casted by the neighbours' trees on the lower part of the stem [12, 87]; and the small proportion of juvenile wood [85]. Furthermore, wider range of externalities are attained by continuous cover forestry than by regular forest management, without the reduction of the net present value [95].

6.4 Challenges and Future Outlook of Continuous Cover Forestry

According to [8] the regular forest management, with clear cut or uniform shelterwood systems, was the most common in 66% of the European countries analysed, while in 25% of the countries the most common was continuous cover forestry, mainly in central and southeastern Europe. Also, transformation of regular forest management in continuous cover forestry was present in 15 countries, and combinations of regular forest management and continuous cover forestry were reported by the majority of the studied countries [8]. There are also examples of application of continuous cover forestry in other regions outside Europe, for example China, Chile, Mexico and South Africa [3]. The comparison of continuous cover forestry and regular forest management was done by several authors [96, 97], with the analysis of the dynamics of stand structure, based on the intensity of management. However, with different methods the studies identified the differences of the forest management approaches in what concerns the silvicultural practices, their intensity and frequency, and their impacts of stand structure dynamics.

The use of the regular forest management approach is related to the best scientific and practical knowledge of the systems; timber quality and quantity; and economic performance [8, 98]. Yet, the knowledge of the mixed uneven aged stands questions the superiority of the regular forest management when compared with continuous cover forestry, in terms of sustainability of the forest systems [35]; quantity and quality of timber [3, 85] and economic performance [95, 99]. Furthermore, the superiority on non-timber products, services and diversity is associated with complex systems such as continuous cover forestry [35, 44]. However, quantifying biomass, C storage and flux in the forest ecosystem is also a challenging task, which is linked with site quality (soil properties) and can be managed through sustainable forest management [100, 101]. Moreover, forest management is an urgent need for resource conservation and environmental protection, which ensure sustainability in soil, food and climate security [102–104].

Nonetheless, constraints to the implementation of continuous cover forestry have been described, which are related to lack of knowledge and obstacles (Figure 6.6). Some of the limitations identified in knowledge are ([8] and references therein): i) climate change, related to the selection of the best-suited species, development and growth of the individuals and stands, and selection of the silvicultural system and management options; ii) resistance and resilience of the stands, linked to the continuous cover forestry higher sustainability when compared with regular forest management stand, in particular under climate change scenarios; iii) mechanisation, associated with the harvest systems and their applicability to continuous cover forestry; iv) awareness by professionals, related to the limitation of the continuous cover forestry approach both theoretical and practical, and the limited number of examples; and v) economy, which refers to limited economic data on timber quality and quantity under continuous cover forestry approach, including investments and properties of wood.

The six primordial obstacles to implementation of continuous cover forestry found were: i) limitations on the knowledge of continuous cover forestry and difficulties to transfer knowledge amongst forest practitioners and workers [8, 98, 105–108]; ii) lack of skills amongst forest practitioners and workers [8, 98, 105, 106]; iii) browsing, which can jeopardise the success of natural regeneration [8]; iv) economic concerns, connected to

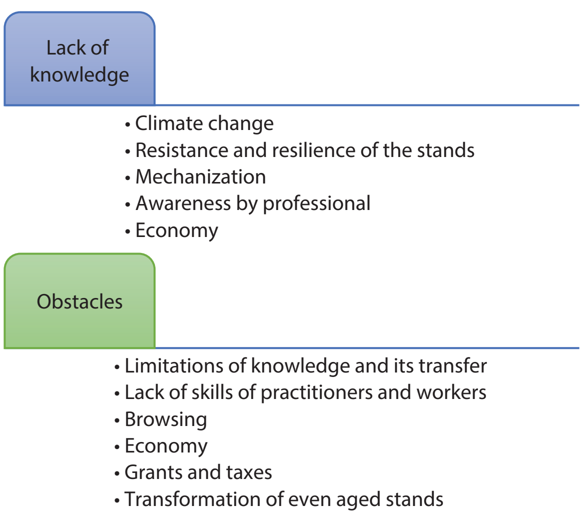

Figure 6.6 Constraints on the implementation of continuous cover forestry.

timber prices [8, 98]; v) grant and tax schemes, related to their adequacy to the long time frame needed to implement continuous cover forestry [8]; vi) transformation of regular forest management into continuous cover forestry, especially of stands which are homogeneous and have little species richness [8, 84].

Monitoring is of primordial importance in continuous cover forestry as it enables the evaluation of stand structure and allows the making of the necessary changes in the silvicultural practices to drive the stand to the target structure. It is implemented with forest inventory and can include both quantitative (dendrometric) and qualitative (descriptive) variables [109–111]. Several protocols have seen described in literature as well as the advantages and disadvantages of each one [111]. In spite of their costs, the stand monitoring, with 4-6 years of periodicity, is fundamental in the evaluation of the stand structure dynamics, and thus in their management [84, 111].

The aforementioned highlights the need to have more research on continuous cover forestry systems, whether on the dynamics of stand structure, yields, impacts of silvicultural practices, sustainability, diversity and economics, either for timber oriented or agroforestry systems. Moreover, it is necessary to have formal (classes or courses) and informal (field work and marteloscopes) training, both for forest practitioners and forest workers to enable them to understand the target stand structure, the dynamics of stand structure associated with silvicultural practices, and the effects of natural and artificial disturbances on the system.

6.5 Conclusions

Continuous cover forestry approach has proved feasible in several countries in Europe, Asia, Africa and America. It is an approach (not a silvicultural system) guided by a suite of principles that can be applied to timber oriented and agroforestry systems. It is directed to the use of native species, continuous cover, horizontal and vertical diversity of the stand structure, natural regeneration, stability, maintenance of site potential productivity and conservation of species and habitats. Due to the wider diversity of stand structures and thus models of silviculture and management, some obstacles and limitations to continuous cover forestry implementation have been identified. Overall, the stands managed under continuous cover forestry have higher structural complexity, higher diversity, are sustainable, more resilient to disturbances, and more profitable than rotation forest management.

The development and implementation of models of silviculture for continuous cover forestry existing stands and stands being transformed into continuous cover forestry brings about challenges. The pivotal features of the silvicultural models are adaptation and flexibility that enable to cope with stand dynamics while maintaining the target stand structure. Moreover, monitoring, enabling the evaluation of the development of the stand, enables making the necessary changes that drive or maintain the target stand structure.

From the aforementioned there is the need to suit financial support to continuous cover forestry stands' timeframe; improve the awareness of continuous cover forestry; promote training of continuous cover forestry principles, methods and techniques; offer formal classes, visits to continuous cover forestry trails and practical classes that can help to understand continuous cover forestry; create and maintain a network of trails, preferably long term, associated with documentation to serve as demonstration sites; and maintain and promote research.

Funding

This work is funded by National Funds through FCT - Foundation for Science and Technology under the Project UIDB/05183/2020.

References

1. Schütz, J. Ph., *Sylviculture 1. Principesd'Éducation des Forêts*, p. 245, Presses Polytechniques et UniversitairesRomandes, Lausanne, Switzerland, 1990.
2. Smith, D. M., Larson, B. C., Kelty, M. J. & Ashton, P. M. S., *The Practice of Silviculture. Applied Forest Ecology*, 9th edition, p. 560, John Wiley & Sons, Inc., New York, USA, 1997.
3. Schütz, J. Ph., Historical Emergence and Current Application of CCF, in: *Continuous Cover Forestry*, T. Pukkala & K. v. Gadow (Eds.), pp. 1–28, Springer Science+Business Media B.V., 2012.
4. Messier, C., Bauhus, J., Doyon, F., Maure, F., Sousa-Silva, R., Nolet, P., Mina, M., Aquilué, N., Fortin, M.-J. & Puettmann, K., The functional complex network approach to foster forest resilience to global changes. *Forest Ecosystems* 6, 21, 2019.
5. Pommerening, A. & Murphy, S. T., A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. *Forestry*, 77, 27–44, 2004.

6. Diaci, J. (Ed.), *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation*, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
7. Mason, W., Implementing Continuous Cover Forestry in Planted Forests: Experience with Sitka Spruce (*Picea Sitchensis*) in the British Isles. *Forests*, 6, 879–902, 2015.
8. Mason, W. L., Diaci, J., Carvalho, J. & Valkonen, S., Continuous cover forestry in Europe: usage and the knowledge gaps and challenges to wider adoption. *For. Int. J. For. Res.*, 95, 1–12, 2022.
9. Stokes, V. & Kerr, G., The evidence supporting the use of CCF in adapting Scotland's forests to the risks of climate change, Forestry Commission, p. 53, CCF & Climate Change, 2009.
10. Schütz, J. Ph., Close-to-nature silviculture: is this concept compatible with species diversity? *Forestry*, 72, 359–366, 1999.
11. Schütz, J. Ph., Development of close to nature forestry and the role of ProSilva Europe, Zb. GozdarstvaLesar, 94, 39–42, 2011.
12. Schütz, J. Ph., Opportunities and strategies of biorationalisation of forest tending within nature-based management, in: Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation, J. Diaci (Ed.), pp. 37–46, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
13. Schütz, J. Ph., Silvicultural tools to develop irregular and diverse forest structures, *Forestry*, 75, 329–337, 2002.
14. Schütz, J. Ph., Saniga, M., Diaci, J. & Vrška, T., Comparing close-to-nature silviculture with processes in pristine forests: lessons from Central Europe. *Ann. For. Sci.* 73, 911–921, 2016.
15. Spathelf, P., Bolte, A. & Maaten, E. C. D. van der, Is Close-to-Nature Silviculture (CNS) an adequate concept to adapt forests to climate change? *Landbauforsch. - Appl. Agric. For. Res.*, 65(3-4), 161–170, 2015.
16. Fedrowitz, K., Koricheva, J., Baker, S.C., Lindenmayer, D.B., Palik, B., Rosenvald, R., Beese, W., Franklin, J.F., Kouki, J., Macdonald, E., Messier, C., Sverdrup-Thygeson, A., & Gustafsson, L., Can retention forestry help conserve biodiversity? A meta-analysis. *J. Appl. Ecol.*, 51(6), 1669–1679, 2014.
17. Knapp, S. P., Kern, C. C. & Webster, C. R., Harvested opening size affects cohort development and failures in a second-growth northern hardwood forest, *For. Ecol. Manag.* 482, 118804, 2021.
18. Knapp, S. P., Webster, C. R. & Kern, C. C., The Composition and Height of Saplings Capturing Silvicultural Gaps at Two Long-Term Experiments in Managed Northern Hardwood Forests, 10(10), 22, 2019.
19. Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S.C., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Pastur, G.M., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J., Wayne, A., & Gustafsson, L., A major shift to the retention approach for forestry can help resolve some

global forest sustainability issues: Retention forestry for sustainable forests. *Conserv. Lett.*, 5(6), 421–431, 2012.

20. Wikle, J., Duguid, M. & Ashton, M. S., Legacy forest structures in irregular shelterwoods differentially affect regeneration in a temperate hardwood forest. *For. Ecol. Manag.*, 454, 117650, 2019.
21. Lefèvre, F., Boivin, T., Bontemps, A., Courbet, F., Davi, H., Durand-Gillmann, M., Fady, B., Gauzere, J., Gidoin, C., Karam, M.-J., Lalagüe, H., Oddou-Muratorio, S., & Pichot, C., Considering evolutionary processes in adaptive forestry. *Ann. For. Sci.,* 71(7), 723–739, 2014.
22. Agel, L.M., Palik, B.J., Battaglia, M.A., D'Amato, A.W., Guldin, J.M., Swanston, C.W., Janowiak, M.K., Powers, M.P., Joyce, L.A., Millar, C.I., Peterson, D.L., Ganio, L.M., Kirschbaum, C., & Roske, M.R., Adaptive Silviculture for Climate Change: A National Experiment in Manager-Scientist Partnerships to Apply an Adaptation Framework. *J. For.,* 115(3), 167–178, 2017.
23. Bowditch, E., Santopuoli, G., Binder, F., del Río, M., La Porta, N., Kluvankova, T., Lesinski, J., Motta, R., Pach, M., Panzacchi, P., Pretzsch, H., Temperli, C., Tonon, G., Smith, M., Velikova, V., Weatherall, A., & Tognetti, R., What is Climate-Smart Forestry? A definition from a multinational collaborative process focused on mountain regions of Europe. *Ecosyst. Serv.,* 43, 101113,2020.
24. Tognetti, R., Smith, M., & Panzacchi, P. (Eds.), *Climate-Smart Forestry in Mountain Regions*, pp. 574, Springer International Publishing, Cham, 2022.
25. Abuurs, G.-J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., & Lindner, M., By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry. *Forests*, 8(12), 484, 2017.
26. D'Amato, A. W., Palik, B. J., Franklin, J. F. & Foster, D. R., Exploring the Origins of Ecological Forestry in North America. *J. For.,* 115, 126–127, 2017.
27. D'Amato, A. W. & Palik, B. J., Building on the last "new" thing: exploring the compatibility of ecological and adaptation silviculture. *Can. J. For. Res.,* 51, 172–180, 2021.
28. Franklin, R. T., The "new forestry", *J. Soil Water Conserv.,* 44, 549, 1989.
29. Pinkerton, E., Integrated management of a temperate montane forest ecosystem through holistic forestry: a British Columbia example, in: *Linking social and ecological systems: management practices and social mechanisms for building resilience*, F. Berkes & C. Folke, pp. 363–389, Cambridge University Press, New York, 1998.
30. Ciancio, O. & Nocentini, S., Biodiversity conservation and systemic silviculture: Concepts and applications. *Plant Biosyst.,* 145, 411–418, 2011.
31. Ciancio, O. & Nocentini, S., La gestione forestale sistemica: una i potesi per la conservazione della biodiversità, in: 14th Meeting of the Italian Society of Ecology, p. 7, Italian Society of Ecology, Siena, 2004.
32. Nocentini, S., Buttoud, G., Ciancio, O. & Corona, P., Managing forests in a changing world: the need for a systemic approach. A review. *For. Syst.,* 26, eR01,2017.

33. Boncina, A., History, current status and future prospects of uneven-aged forest management in the Dinaric region: an overview. *Forestry*, 84, 467–478, 2011.
34. Schütz, J. Ph., Opportunities and strategies of transforming regular forests to irregular forests. *For. Ecol. Manag.,* 151, 87–94, 2001.
35. Gonçalves, A. C., Influence of Stand Structure on Forest Biomass Sustainability, in *Natural Resources Conservation and Advances for Sustainability*, M. K. Jhariya, R. S. Meena, A. Banerjee & S. N. Meena, pp. 327–352 Elsevier, Cambridge, United States, 2022.
36. Grossnickle, S., Seedling establishment on a forest restoration site – An ecophysiological perspective. *REFORESTA*, 6, 110–139, 2018.
37. Löf, M., Castro, J., Engman, M., Leverkus, A.B., Madsen, P., Reque, J.A., Villalobos, A., & Gardiner, E.S., Tamm Review: Direct seeding to restore oak (*Quercus* spp.) forests and woodlands. *For. Ecol. Manag.,* 448, 474–489, 2019.
38. Malcolm, D. C., Mason, W. L. & Clarke, G. C., The transformation of conifer forests in Britain Ð regeneration, gap size and silvicultural systems. *For. Ecol. Manag.,*151, 7–23, 2001.
39. McMahon, P., Sarshar, D. & Purser, P. Investing in Continuous Cover Forestry, pp. 24, SLM Partners, http://slmpartners.com/wp-content/uploads/2016/09/SLM-PartnersInvesting-in-Continuous-Cover-Forestry-Sept-2016.pdf, 2016.
40. Kremer, K. N. & Bauhus, J., Drivers of native species regeneration in the process of restoring natural forests from mono-specific, even-aged tree plantations: a quantitative review. *Restor. Ecol.*, 28, 1074–1086, 2020.
41. Schütz, J. Ph., *Sylviculture 2. La Gestion des ForêtsIrrégulières et Mélangées*, p. 178, Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland, 1997.
42. Ferreira, A. G., Gonçalves, A. C. & Dias, S. S., Avaliação da Sustentabilidade dos Sistemas Florestaisem Função da Erosão, Silva Lusit., mº especial, 55–67, 2008.
43. Nyland, R. D., *Silviculture. Concepts and appli*cations, 3rd edition, pp. 680, Waveland Press, Inc., Long Grove, 2016.
44. Biber, P., Borges, J., Moshammer, R., Barreiro, S., Botequim, B., Brodrechtová, Y., Brukas, V., Chirici, G., Cordero-Debets, R., Corrigan, E., Eriksson, L., Favero, M., Galev, E., Garcia-Gonzalo, J., Hengeveld, G., Kavaliauskas, M., Marchetti, M., Marques, S., Mozgeris, G., Navrátil, R., Nieuwenhuis, M., Orazio, C., Paligorov, I., Pettenella, D., Sedmák, R., Smreček, R., Stanislovaitis, A., Tomé, M., Trubins, R., Tuček, J., Vizzarri, M., Wallin, I., Pretzsch, H., & Sallnäs, O., How Sensitive Are Ecosystem Services in European Forest Landscapes to Silvicultural Treatment? *Forests*, 6, 1666–1695, 2015.
45. Brang, P., Spathelf, P., Larsen, J.B., Bauhus, J., Bonc ina, A., Chauvin, C., Drossler, L., Garcia-Guemes, C., Heiri, C., Kerr, G., Lexer, M.J., Mason, B., Mohren, F., Muhlethaler, U., Nocentini, S., and Svoboda, M., Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. *Forestry*, 87, 492–503, 2014.

46. Davies, O., Haufe, J. & Pommerening, A., Silvicultural principles of continuous cover forestry: A guide to best practice, p. 111, Bangor University, Bangor, UK, 2008.
47. Mason, B. & Kerr, G., Transforming Even-aged Conifer Stands to Continuous Cover Management, Information Note, p. 8, Forestry Commission, 2004.
48. Gonçalves, A. C., Thinning: An Overview, in: *Silviculture*, A. C. Gonçalves (Ed.), pp. 41–58, IntechOpen, London, 2021. doi:10.5772/intechopen.93436
49. Johann, E., Historical development of nature-based forestry in Central Europe, in: *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation*, J. Diaci (Ed.), pp. 1–17, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
50. Piussi, P., Close to nature forestry criteria and coppice management, in: *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation,* J. Diaci (Ed.), pp. 27–37, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
51. Moravcik, M., Sarvaov, Z., Mergani, J. & Kovalk, M., Close to Nature Management in High-Mountain Forests of Norway Spruce Vegetation Zone in Slovakia, in: *Forest Ecosystems - More than Just Trees*, J. A. Blanco & Y.-H. Lo (Eds.), pp. 375–414, 2012.
52. Larsen, J. B., Close-to-Nature Forest Management: The Danish Approach to Sustainable Forestry, in: *Sustainable Forest Management*, J. M. Garcia & J. J. D. Casero (Eds.), pp. 199–218, InTech, Rijeka, Croatia, 2012.
53. O'Hara, K. L., Ina, A. B., Diaci, J., Anić, I., Boydak, M., Curovic, M., Govedar, Z., Grigoriadis, N., Ivojevic, S., Keren, S., Kola, H., Kostov, G., Medarević, M., Metaj, M., Nicolescu, N. V., Raifailov, G., Stancioiu, P. T., & Velkovski, N., Culture and silviculture: origins and evolution of silviculture in Southeast Europe. *Int. For. Rev.,* 20, 130–143, 2018.
54. Janowiak, M. K., Nagel, L. M. & Webster, C. R., Spatial Scale and Stand Structure in Northern Hardwood Forests: Implications for Quantifying Diameter Distributions, *Forest Science*, 54(5), 497–506, 2008.
55. O'Hara, K. L., *Multiaged Silviculture Managing for Complex Forest Stand Structures*, pp. 213, Oxford University Press, Oxford, 2014.
56. Borderieux, J., Paillet, Y., Dalmasso, M., Mårell, A., Perot, T., & Vallet, P., The presence of shade-intolerant conifers facilitates the regeneration of *Quercus petraea* in mixed stands. *For. Ecol. Manag.*, 491, 119189,2021.
57. Klopčič, M., Simončič, T. & Bončina, A., Comparison of regeneration and recruitment of shade-tolerant and light-demanding tree species in mixed uneven-aged forests: experiences from the Dinaric region. *Forestry*, 88, 552–563, 2015.
58. Scherrer, D., Hiltebrand, F., Dengler, J. & Wohlgemuth, T., Mind the gaps: Comparison of representative vs opportunistic assessment of tree regeneration in Central European beech forests. *For. Ecol. Manag.,* 491, 119179, 2021.
59. O'Hara, K. L., What is close-to-nature silviculture in a changing world? *Forestry*, 89, 1–6, 2016.

60. Bogdziewicz, M., Ascoli, D., Hacket-Pain, A., Koenig, W.D., Pearse, I., Pesendorfer, M., Satake, A., Thomas, P., Vacchiano, G., Wohlgemuth, T., & Tanentzap, A., From theory to experiments for testing the proximate mechanisms of mast seeding: an agenda for an experimental ecology. *Ecol. Lett.*, 23, 210–220, 2020.
61. Tinya, F., Márialigeti, S., Bidló, A. & Ódor, P., Environmental drivers of the forest regeneration in temperate mixed forests. *For. Ecol. Manag.*, 433, 720–728, 2019.
62. Kerr, G. & Haufe, J. Successful underplanting, Forestry Commission, 2016.
63. Bolibok, L., Andrzejczyk, T., Szeligowski, H. & Liziniewicz, M., New methods of oak planting require modification of tending prescriptions under high browsing pressure – A case study from north-eastern Poland. *For. Ecol. Manag.,* 497, 119449, 2021.
64. Dey, D. C., Knapp, B. O., Battaglia, M. A., Deal, R. L., Hart, J. L., O'Hara, K. L., Schweitzer, C. J., and Schuler, T. M., Barriers to natural regeneration in temperate forests across the USA. *New For.,* 50, 11–40, 2019.
65. Löf, M., Barrere, J., Engman, M., Petersson, L. K. & Villalobos, A., The influence of fencing on seedling establishment during reforestation of oak stands: a comparison of artificial and natural regeneration techniques including costs. *Eur. J. For. Res.*, 140, 807–817, 2021.
66. Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V. P., Pilbeam, D.J., Pisanelli, A., & Dupraz, C., Silvoarable Systems in Europe – Past, Present and Future Prospects. *Agrofor. Syst.*, 67, 29–50, 2006.
67. Gonçalves, A. C., Sousa, A. M. O. & Mesquita, P., Functions for aboveground biomass estimation derived from satellite images data in Mediterranean agroforestry systems. *Agrofor. Syst.*, 93, 1485–1500, 2019.
68. Nerlich, K., Graeff-Hönninger, S. & Claupein, W., Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. *Agrofor. Syst.,* 87, 475–492, 2013.
69. Gonçalves, A. C., Effects of Forest Stand Structure in Biomass and Carbon, in: *Forest Biomass and Carbon*, G. Shukla & S. Chakravarty (Eds.), pp. 1–21, InTech, Rijeka, Croatia, 2018.
70. Gonçalves, A. C., Multi-Species Stand Classification: Definition and Perspectives, in: *Forest Ecology and Conservation*, Shukla & S. Chakravarty (Eds.), pp. 3–23, InTech, Rijeka, Croatia, 2017
71. Gonçalves, A. C., Models of silviculture for Mediterranean species: old and new challenges, submitted.
72. Natividade, J. V., Subericultura, p. 387, Ministério da Agricultura, Pescas e Alimentação. Direção Geral das Florestas, Lisboa, 1950.
73. Bugalho, M. N., Dias, F. S., Briñas, B. & Cerdeira, J. O., Using the high conservation value forest concept and Pareto optimization to identify areas maximizing biodiversity and ecosystem services in cork oak landscapes. *Agrofor. Syst.,* 90, 35–44, 2016.

74. Löf, M., Madsen, P., Metslaid, M., Witzell, J. & Jacobs, D. F., Restoring forests: regeneration and ecosystem function for the future. *New For.,* 50, 139–151, 2019.
75. Petersson, L. K., Milberg, P., Bergstedt, J., Dahlgren, J., Felton, A. M., Götmark, F., Salk, C., and Löf, M., Changing land use and increasing abundance of deer cause natural regeneration failure of oaks: Six decades of landscape-scale evidence. *For. Ecol. Manag.,* 444, 299–307, 2019.
76. Pommerening, A. & Grabarnik, P., *Individual-based Methods in Forest Ecology and Management*, p. 411, Springer Nature, Cham, 2019.
77. Gonçalves, A. C., Afonso, A., Pereira, D. G. & Pinheiro, A., Influence of umbrella pine (*Pinus pinea* L.) stand type and tree characteristics on cone production. *Agrofor. Syst.* 91, 1019–1030, 2017.
78. Gonçalves, A. C. & Pommerening, A., Spatial dynamics of cone production in Mediterranean climates: A case study of *Pinus pinea* L. in Portugal. *For. Ecol. Manag.*, 266, 83–93, 2012.
79. Hupperts, S. F., Webster, C. R., Froese, R. E. & Dickinson, Y. L., Seedling and sapling recruitment following novel silvicultural treatments in Great Lakes northern hardwoods. *For. Ecol. Manag.,* 462, 117983, 2020.
80. Kolo, H., Ankerst, D. & Knoke, T., Predicting natural forest regeneration: a statistical model based on inventory data. *Eur. J. For. Res.,* 136, 923–938, 2017.
81. Leonardsson, J., Löf, M. & Götmark, F., Exclosures can favour natural regeneration of oak after conservation-oriented thinning in mixed forests in Sweden: A 10-year study. *For. Ecol. Manag.,* 354, 1–9, 2015.
82. VanderMolen, M. S., Knapp, S. P., Webster, C. R., Kern, C. C. & Dickinson, Y. L., Spatial patterning of regeneration failure in experimental canopy gaps 15–24 years post-harvest. *For. Ecol. Manag.,* 499, 119577, 2021.
83. Bianchi, S., Huuskonen, S., Siipilehto, J. & Hynynen, J., Differences in tree growth of Norway spruce under rotation forestry and continuous cover forestry. *For. Ecol. Manag.*, 458, 117689, 2020.
84. Kerr, G., Snellgrove, M., Hale, S. & Stokes, V., The Bradford–Hutt system for transforming young even-aged stands to continuous cover management. *For. Int. J. For. Res.*, 90, 581–593, 2017.
85. Macdonald, E., Gardiner, B. & Mason, W., The effects of transformation of even-aged stands to continuous cover forestry on conifer log quality and wood properties in the UK, *Forestry,* 83, 1–16, 2010.
86. Schütz, J.-P. & Zingg, A., Improving estimations of maximal stand density by combining Reineke's size-density rule and the yield level, using the example of spruce (*Piceaabies* (L.) Karst.) and European Beech (*Fagussylvatica* L.). *Ann. For. Sci.,* 67, 507–507, 2010.
87. Spiecker, H. Minority tree species - a challenge for multi-purpose forestry, in: *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation*, J. Diaci (Ed.), pp. 47–59, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.

88. Oliver, C. D. & Larson, B. C., *Forest Stand Dynamics*, p. 544, John Wiley & Sons, Inc, New York, 1996.
89. Mason, B., Encouraging Greater Use of Continuous Cover Forestry. Part 1. Stand and site considerations. *Q. J. For.,* 114, 251–259, 2020.
90. Hale, S., Managing Light to Enable Natural Regeneration in British Conifer Forests, p. 6, Forestry Commission Information Note, 2004.
91. Hale, S. E., The effect of thinning intensity on the below-canopy light environment in a Sitka spruce plantation. *For. Ecol. Manag.,* 179, 341–349, 2003.
92. Cameron, A. & Prentice, L., Determining the sustainable irregular condition: an analysis of an irregular mixed-species selection stand in Scotland based on recurrent inventories at 6-year intervals over 24 years. *Forestry*, 89, 208–214, 2016.
93. Davies, O. & Kerr, G., Comparing the Costs and Revenues of Transformation to Continuous Cover Forestry for Sitka Spruce in Great Britain. *Forests,* 6, 2424–2449, 2015.
94. Peura, M., Burgas, D., Eyvindson, K., Repo, A. & Mönkkönen, M., Continuous cover forestry is a cost-efficient tool to increase multifunctionality of boreal production forests in Fennoscandia. *Biol. Conserv.,* 217, 104–112, 2018.
95. Pukkala, T., Assessing the externalities of timber production. *For. Policy Econ.,* 135, 102646, 2022.
96. Duncker, P. S., Barreiro, S. M., Hengeveld, G. M., Lind, T., Mason, W. L., Ambrozy, S. & Spiecker, H., Classification of Forest Management Approaches: A New Conceptual Framework and Its Applicability to European Forestry. *Ecol. Soc.,* 17, art51, 2012.
97. Schall, P. & Ammer, C., How to quantify forest management intensity in Central European forests. *Eur. J. For. Res.,* 132, 379–396, 2013.
98. Hertog, I. M., Brogaard, S. & Krause, T., Barriers to expanding continuous cover forestry in Sweden for delivering multiple ecosystem services. *Ecosyst. Serv.,* 53, 101392, 2022.
99. Tahvonen, O. & Rämö, J., Optimality of continuous cover vs. clear-cut regimes in managing forest resources. *Can. J. For. Res.*, 46, 891–901, 2016.
100. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India, in *Landscape and Ecological Engineering*, Springer Nature, 17(1), 1–13, 2021. https://doi.org/10.1007/s11355-021-00450-1
101. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, p. 112829, Elsevier, 2021. https://doi.org/10.1016/j.jenvman.2021.112829
102. Raj, A., Jhariya, M.K., Yadav, D. K. & Banerjee, A., Forest for Resource Management and Environmental Protection. In: Banerjee, A., Jhariya, M.K., Yadav, D. K. and Raj, A. (Eds.), *Environmental and Sustainable Development through Forestry and Other Resources.* AAP: CRC Press, pp. 1–24, 2020.

103. Banerjee, A., Jhariya, M.K., Khan, N., Raj, A., & Meena, R.S., Ecomodelling towards Natural Resource Management and Sustainability. In: M.K. Jhariya *et al.* (Eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*, Springer, pp. 491–519, 2021. https://doi.org/10.1007/978-981-33-4203-3_14
104. Raj, A., Jhariya, M.K. & Khan, N.*, Forest for soil, food and climate security in Asia.* In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservatiwon and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, p. 33–52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
105. Pommerening, A., Maleki, K. & Haufe, J., Tamm Review: Individual-based forest management or Seeing the trees for the forest. *For. Ecol. Manag.,* 501, 119677, 2021.
106. Pommerening, A., Brill, M., Schmidt-Kraepelin, U. & Haufe, J., Democratising forest management: Applying multiwinner approval voting to tree selection. *For. Ecol. Manag.*, 478, 118509, 2020.
107. Pommerening, A., Pallarés Ramos, C., Kędziora, W., Haufe, J. & Stoyan, D., Rating experiments in forestry: How much agreement is there in tree marking? *PLOS ONE*, 13, e0194747, 2018.
108. Vítková, L., NíDhubháin, Á. & Pommerening, A., Agreement in Tree Marking: What Is the Uncertainty of Human Tree Selection in Selective Forest Management? *For. Sci.,* 62, 288–296, 2016.
109. Hočevar, M. & Hladnik, D., Development of forest monitoring methods for sustainable forest management in Slovenia, in: *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation*, J. Diaci (Ed.), pp. 133–145, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
110. Kotar, M., Sustainable and multipurpose forest management with production of high quality timber, in: *Nature-based forestry in Central Europe alternatives to industrial forestry and strict preservation*, J. Diaci (Ed.), pp. 153–167, Univ. Ljubljane, Biotech. Faculty, Dept. of Forestry and Renewable Forest Resources, Ljubljana, 2006.
111. Spazzi, J., Tuama, P. O., Wilson, E. R. & Short, I., Comparison of three inventory protocols for use in privately-owned plantations under transformation to Continuous Cover Forestry. *Irish Forestry*, 76, 8–28, 2019.

7

Forest Landscape Restoration for Environmental Management

Nur Nadiah Md Yusof[1]*, Siti Khairiyah Mohd Hatta[1], Siti Hasnah Kamarudin[1], Norashirene Mohamad Jamil[1], Siti Nurbaya Supardan[1] and Mohd Nazip Suratman[1,2]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia*
[2]*Institute of Biodiversity and Sustainable Development, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia*

Abstract
Forest resources around the world have been under immense pressure mainly due to anthropogenic activities. Land use changes have taken place caused by an increase in commercial agricultural as well as an intensified development for human settlements and infrastructure advancement, leading to the decline in forest cover. In addition, a substantial amount of forest loss is also contributed by natural phenomena such as drought and tree diseases which are different in magnitude between countries. The dwindling forest area has negatively affected our ecosystem by decreasing the biodiversity as a direct result of habitat loss and depletion in food source. This could bring about a cascade of environmental issues including reduction in plant production, increase in soil erosion, water and air pollution, as well as reducing the efficiency of carbon sequestration. In order to moderate the negative impacts, an implementation of forest landscape restoration (FLR) could improve the health and productivity of forests. FLR involves various stakeholders coming together and reinstating the forest landscape at any scale using appropriate approaches. Through careful planning of FLR operations, forest restoration can be executed which will be beneficial not only to the forests, but also to the whole ecosystem by enhancing food security, air and water quality as well as reducing the adverse impact of climate change to our planet. This chapter aims at introducing the roles of FLR in restoring ecological functionality of degraded forest landscapes. The various tools used in conducting FLR to support human

**Corresponding author*: nurnadiah@uitm.edu.my

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (161–200) © 2023 Scrivener Publishing LLC

well-being and biodiversity will be highlighted. Finally, the implementation of FLR in meeting the present and future needs of mankind will also be discussed.

***Keywords*:** Forest landscape restoration, biodiversity conservation, ecological restoration, sustainable development goals

7.1 Introduction

Forests supply various ecological services which are crucial for the preservation of endangered and indigenous species [1]. Forests cover 31% of all global surface area, with more than 50% of the world's forests found in the United States, Canada, Brazil, China, and the Russian Federation [2]. Since the turn of the century, the globe has lost 420 million hectares of tree cover, although the rate of deforestation has reduced during the last three decades [3]. In recent years, tree cover loss has increased, growing from 13.4 million hectares in 2001 to 25.8 million hectares in 2020 [4]. Forests all over the world have been under threat due to increasing demand in agriculture (including farming and cattle ranching), logging and mining industrial projects [5]. These factors are also correlated with economic development and urbanization [6]. Other natural or human-related activities that cause considerable forest loss include wildfires, droughts, floods, diseases, and climate change [7–9]. Agriculture causes more tree cover loss in tropical regions, but forestry and wildfires cause more loss in boreal and temperate regions [10]. In 2019, an unprecedented number of fires burned in Brazil, peaking in August with more than 80,000 fires reported, which is the highest number it has ever seen. When compared to the same time in 2018, the number of fires across the country increased by approximately 80% [11, 12]. Forest loss is typically an irreversible process, posing environmental stress on ecosystems and causing a global loss of biodiversity, as well as deterioration in the quality of ecological life in both aquatic and terrestrial environments [13]. Recent studies have also linked deforestation with an increased number of vector-borne and zoonotic diseases outbreaks over the period 1990 to 2016, majorly in tropical countries [14, 15].

One of the major contributors to deforestation is agricultural activity [6, 10] which is responsible for approximately 80% of global deforestation [16]. As demands for meat, biofuel (palm oil), textile (cotton) and crops (such as soybeans, rice, cocoa and coffee) increase, more uncultivated lands are being cleared to accommodate space to grow food and for livestock farming [16, 17]. Palm oil output has quadrupled since the turn of the century, owing to its numerous applications in food, cosmetics, cleaning products and fuels [18]. Widespread deforestation observed in the Southeast Asian countries Malaysia and Indonesia for large-scale commercial oil palm plantations [19, 20]. In contrast, cattle ranching and farming, particularly soy crops, are the main culprits causing the decline in forest cover of Amazon [21]. Habitat loss, greenhouse gas amplification, water cycle disruption, increased soil erosion, and excessive flooding are all consequences of this extreme land clearing [6].

Mining is also a relevant driver behind deforestation. Mineral demand creates substantial risks particularly in areas where mineral resources and biodiverse primary forests coexist. It tends to be concentrated in developing countries and linked to certain commodities supply networks. For example, 165 million hectares of Brazil's land is permitted for mining leases and exploration, of which 60% is part of the Amazon tropical forest [22]. Based on a focus study by [23], both legal and illegal mining activities contribute to the growing percentages of deforestation in Colombia involving 400,000 hectares of national land [23]. Forest clearing and the development of mining infrastructure and roadways can result in severe deforestation in large-scale mining operations, particularly those utilising open-cast mining methods. Therefore, reclamation plans are crucial for reforestation and to repair damages caused by mining activities. To do that, it is critical to comprehend deforestation in both the spatial and temporal domains, as well as to support reclamation efforts from a geospatial standpoint.

The emphasis on economic growth that came with modernization fostered the rapid exploitation of forests for timber extraction and logging. According to studies on global patterns of forest degradation, the highest proportion of overall forest loss in Latin America and subtropical Asia is due to wood exploitation and logging activities [21]. Loggers also construct roads to get access to more remote forests, resulting in fragmentation. Many species are vulnerable to logging, and research which has been conducted throughout various species of flora and fauna has demonstrated an increase in adverse effects depending on the severity of logging as well as the amount of time a particular forest has been logged [24, 25]. A current worldwide survey of over 20,000 vertebrate species, for example, found that the occurrence of minor degradation within an intact landscape has damaging effects on vertebrate biodiversity in a specific area, thus highlighting the significance of intact forests in reducing extinction risk [26]. Diverse communities are vital because they are more productive since they comprise key species that have a substantial impact on productivity, and variations in functional traits across organisms that boost overall resource acquisition [27]. Although some degraded areas may recover on their own, degradation must be controlled to minimize anthropogenic effects on tropical forests and environmental resources, which are essential to human well-being [28, 29].

7.2 Forest Landscape Restoration

The conventional methods to restore a degraded forest ecosystem are through rehabilitation and restoration process [30]. However, to maintain the sustainability of flows, linkages, and interconnections with adjacent ecosystems, all ecosystem restoration activities must be addressed from a spatially distributed landscape perspective [31]. Forest landscape restoration (FLR) is often recommended as a solution to global forest loss and degradation, with the aim to enhance human well-being and ecological integrity in deforested and degraded landscapes [32]. Within a landscape, this phrase refers to the restoration of forest function in terms of biodiversity, ecological, economic, and social advantages [33]. A landscape is a diverse patchwork of multiple ecosystems that spans a wide amount of land or a watershed [34]. Instead of relying on a single ecosystem, many ecological restorations require the reintegration of dispersed ecosystems and landscapes [31]. FLR covers some basic components such as topography, soils, vegetation, biodiversity, erosion, hydrology and wildlife [35]. FLR involves collaborative approaches to align the goals and decisions of multiple stakeholders to meet the specific requirements of the site, together with its biophysical conditions [36]. This FLR integrates the natural science perspective, the social sciences perspective and the integrated perspective [37]. The natural sciences include connecting the landscapes through hydrologic [38], riparian zones [39] and spatial modelling [40]. The social part of this FLR involves the decision making and conflict management [41], the economic restoration [42] and cultural landscape [43].

The development of governance structures that allow restoration proponents to create incentives for restoration efforts and improved conditions while providing constraints to stop deterioration is an important component toward the successful implementation of ecosystem and landscape restoration actions [44]. Integrated landscape management has the ability to maximise the positive effects of restoration efforts on a variety of Sustainable Development Goals (SDGs) [45]. In the Malaysian state of Sabah, the restoration effort in Bukit Piton was started in 2007 to sustain the critically endangered Bornean orangutan through the protection of key areas [46]. FLR employs a variety of additional restorative measures across landscapes to enable this initiative, which focuses on combining several goals and sustainable land use types to overcome the causes and effects that lead to landscape deterioration in the first place [47]. Despite many challenges in the development of FLR, people nowadays are enlightened about FLR as well as its value, and a number of countries are attempting to establish their FLR measures in response to the SDG objectives [48].

7.3 Types of FLR

The landscapes to be restored are generally categorised into three types: i) forest land, ii) agricultural land, and iii) protective lands and buffer. These three different types of land incorporate different strategies and techniques in their restoration processes. Brief explanations on each type of land are as follows.

7.3.1 Forest Land

Forest land is an area where forests are, or will be, the most prominent land feature. It might consist of both protected and productive forestry. Planting of trees for various purposes or natural regeneration is needed on the land without the trees. The trees to be planted can be native or introduced species [49]. Natural regenerations comprising self-sown seed, root sucker and coppice shoots induce new forest formations and its sustenance [50]. Passive forest restoration from seedlings or sprouting keeps wild or domestic herbivores in their natural landscapes. Assisted natural regeneration is much more work demanding, generally including weed removal to limit competition for desirable seedlings [32]. In Japan, 40% of its existing forests are planted, with 90% of them developed after World War II due to a need to raise national income while also ensuring a steady supply of wood for domestic and international trades [51]. Due to rising labour and equipment expenses, the Russian Federation's taiga forests, for example, are primarily naturally regenerated, while in Ukraine, natural regeneration is prominent in regions with a sufficient number of seedlings of the required tree type [52]. Rehabilitation and silvicultural treatment are conducted on the degraded forests which enhance the existing forests and woodlands such as by reducing fire and grazing [32]. Silviculture comprises thinning, harvesting, planting, pruning, planned burning, and site preparation, whereas rehabilitation focuses on the restoration of ecosystem processes, production, and services [31, 53]. For example, the Trusan Sugut Forest Reserve in Sabah is putting into practice a silvicultural treatment that attempts to remove specified trees from climber and bamboo disturbances so that they can develop at their optimal pace. Throughout 2017, up to 625 acres of forest were improved with Silviculture treatment [54].

7.3.2 Agricultural Land

Agricultural land is designated as the landscape that is operated for food production. The restoration of an agricultural land can be accomplished by either agroforestry or improved fallow. The latter is usually implemented if the land is not permanently under any management, which is the primary requirement for agroforestry restoration. By planting and managing the trees on fallow agricultural lands, the productivity of the lands can be enhanced, eventually returning the area to active agriculture [32]. When stakeholders in a particular landscape have different restoration goals, agroforestry initiatives may potentially be a good option in reducing climate change, restoring landscape functionality, and enhancing smallholder livelihoods, though the benefits might take longer to achieve [55, 56]. Agroforestry in Canada contributed to the country's climate change mitigation goals by increasing carbon sequestration within the agricultural landscape [57]. A study on bird biodiversity in Peninsular Malaysia showed that agroforestry orchards had much higher species richness and abundance than the other two agricultural habitats [58]. On the other hand, short-term fallows would boost soil fertility and future crop yield, while lowering fertiliser expenses and enhancing soil fertility through soil treatment and nutrient addition. By including quick growing N-fixing legumes in between the major vegetation period, green manure integration may be accomplished with minimal land opportunity cost [59]. While in the central Peruvian Andes, research on managed fallow among smallholder farmers revealed a rise in forage production with the greater quality compared to unseeded fallows, as well as an increase in legume abundances in the year of implementation [60].

Restoration of protective lands and buffers through FLR is also important to mitigate climatic or other phenomena. Mangrove restoration option will be chosen when the target land is a degraded mangrove, where mangroves will be established or restored along coastal areas in estuaries. Environmental purification, carbon fixation, and shoreline stabilization significantly represent mangroves as the coastal guard [61–63]. Mangroves have experienced drastic reduction across the world, limiting their ability to provide coastal protection. That loss is much due to human activities, aquaculture, or resource exploitation [64, 65]. In the next decade, it is predicted that about half of the current artificial coastal defence facilities in Victoria, Australia, will need to be repaired and updated to preserve coastal regions from floods and erosion [66]. In addition, if there is other protected land and buffer, watershed protection and erosion management will be implemented. Forest restoration and its establishment on steep slopes, in flooded areas and along the water channel, etc., are among these approaches [32]. Source watershed restoration is vital to maintain the quality and quantity of fresh water, thus increasing interest around the world to invest in its restoration programme [67]. It is expected that the soil erosion by water may rise by 30% to 66% by 2070 worldwide, mainly in the Global South [68]. Erosion is believed to eliminate the valuable topsoil, which contains the majority of nutrients and organic substances [69]. In the Czech Republic, it is critical to reduce the steepness of slopes to allow for the cultivation of maize and root crop, or possibly an obligation to switch from arable to grassland use. These authorities should recommend that the agricultural enterprise alter the plot's land use from arable land to grassland if three or more erosion incidences occur on the same plot [70].

7.4 Benefits of FLR on the Environment/Ecosystem

The number of environmental issues that have arisen recently, such as extreme climate change, rising population, depleting natural resources, and altered land-use patterns, is concerning, and the consequences have surfaced from time to time [71–73]. FLR aims to improve and restore landscapes on a large scale while considering ecological prospects, human well-being, and community livelihood [72, 74, 75]. FLR has the potential to provide long-term benefits, either indirect or direct on-the-ground benefits, in a variety of areas, including societal, economic, and, most importantly, environmental benefits [74–76]. FLR initiatives aimed at restoring degraded lands and forests and making them resilient to an ever-changing environment [48, 77, 78]. FLR initiatives also aim to accomplish the Sustainable Development Goals (SDGs) by 2030, which entails delivering SDGs concurrently: SDG1, 2, 3, 5, 6, 7, 8, 12, 13, 15 and 17 [72, 76] which is further depicted in Figure 7.1 [80]. FLR initiatives are intertwined with many SDGs because they share a common vision of securing the rights and future of people all over the world, as well as an emphasis on healthy, sustainable ecosystems [79]. The following are the primary environmental benefits of FLR initiatives and previous restoration projects that demonstrated significant positive outcomes for both people and nature.

Figure 7.1 Sustainable Goals development (SDG), Source from UNESCO [80].

7.4.1 Healthy, Resilient and Productive Ecosystems

Restoration aids in the transformation of deforested and degraded areas into healthy ones. To live up to the name FLR, trees or forests are the focal component of FLR that must be protected and restored [73]. However, restoring degraded landscapes is more than just planting or replanting trees [75, 81]; it also entails determining how to create healthy, resilient, and productive landscapes [53, 72, 74]. Restoring the landscapes may reduce the risk of disasters or catastrophic events such as floods, landslides, drought, storms, and tsunamis [74, 79, 82] as well as pest outbreaks [75]. For example, Indonesia is prone to natural calamities such as tsunamis, forest fires, and landslides. Degraded mangrove forests are blamed for the tsunami that struck Aceh and Nias in North Sumatra in 2004 [74]. Degraded forests make Indonesia more vulnerable to natural disasters and cause it to lose 20% to 30% of its biodiversity each year. Various agencies collaborated to carry out restoration and rehabilitation programmes. Among the most important bodies that implement FLR in Indonesia are the Forest Management Unit (FMU) or Kesatuan Pengelolaan Hutan (KPH) by WWF Indonesia [83]. The goal of restoration and rehabilitation was to restore and maintain healthy forest landscapes to combat disaster surges, with a focus on ecosystem and productivity improvement. The restoration, for example, aided *Acacia mangium*, the intensively used, fast-growing exotic species [74]. In degraded and deforested ecosystems, FLR programmes can also improve geological resilience, soil composition and fertility, water quality, and natural resources [53, 75].

7.4.2 Improved Sustainable Provision of Ecosystem Services

FLR aims to improve the supply of forest-based products and landscape goods, as well as ecosystem services through restoring ecosystems and their functionality [53, 72]. One of the most important factors in restoration is ensuring continuous supply [75]. Natural resources such as food, water, timber [84, 75] construction materials, herbs, traditional medicine [72], and biomedicines [53] are examples of landscape goods. A significant proportion of forests have been degraded and altered, primarily for agricultural purposes such as cocoa [81], oil palm, rubber, and timber [72, 78], and fisheries [74]. This is due to the fact that these provisions have the potential to generate income and earnings. As a result, FLR provides communities with opportunities for income generation and long-term livelihoods by promoting sustainable forest/land management [72]. This strategy is consistent with SDGs 1, 8, and 15. Local people's livelihoods are improved by improving and optimising forest products. Furthermore, more job opportunities are created, ultimately reducing poverty [72].

7.4.3 Biodiversity Conservation

Biodiversity conservation is the process of conserving, enhancing, and maintaining a diverse range of species, ecosystems, habitats, ecological communities, and genetic diversity in a sustainable manner for the benefit of current and future generations. Restoration is critical for biodiversity conservation, particularly for threatened forest-dependent species, which inevitably suffer as their niches and habitats are reduced as a result of deforestation and human intervention [78]. Restoring old-growth plants, reforestation, and improving forest cover are all part of successful conservation strategies for these species and their habitats [75, 78]. The restoration initiative helps to conserve biota, whether they are rare, endangered, or widely distributed, and protects them from extinction [85, 86]. Conserving genetic diversity is crucial for species survival and preventing them from becoming endangered or extinct. The IUCN Red List of Threatened Species has listed a total of 20,334 tree species since around 2019, with approximately 8,056 of them classified as Critically Endangered, Endangered, or Vulnerable. Of these, a total of 1,400 tree species were noted as critically endangered and in need of protection [81].

Increasing landscape connectivity is one method of conserving species by restoring natural habitats or facilitating species migration to more hospitable environments within human-modified landscapes [75, 87]. In Sabah, Malaysia, for example, continuous forest corridors were restored along the 560-kilometer Kinabatangan River in 2000. The entire ecosystem near the river had been altered and fragmented for agricultural or urban development. Large areas had been actively used to grow oil palms, which is now economically important for both locals and Malaysia, the world's largest producer. In Sabah, Malaysia, landscape restoration efforts have reconnected fragmented ecological corridors, restored lands, and protected endangered species [85]. Restoration for biodiversity conservation prioritises connectivity between buffer zones in fragmented forest, and the viability among the remaining species [74].

7.4.4 Global and Local Climate Resilience

The growing interest in FLR as an SDG goal 13 is one of the factors driving the increased interest and concern regarding climate change mitigation and adaptation. Climate change has a catastrophic impact worldwide through food and water depletion, poverty, economics, pandemics, human rights, and other areas. SDG 13 conservation efforts necessitated ongoing concern and effort. Reforestation and sustainable management of terrestrial ecosystems may be able to withstand climate change because increased forest cover reduces heat effects [72], reduces the effect of forest fires, and stabilises carbon storage [71].

The Bonn Challenge, a pledge made by the German government in collaboration with the IUCN and GPFLR, is an ongoing large-scale effort and seeks to restore 350 million hectares of forest landscapes by 2030 [29]. One of the goals of this approach is to enhance the carbon sequestration process and storage. Restoring the targeted 350 million hectares of land might sequester approximately 1.7 gigatonnes of carbon dioxide (CO_2) [81] and reduce the annual carbon emissions gap by 11% to 20% [79], potentially contributing to climate resilience evolving environments [87].

7.5 FLR Partnerships

In the year 2000, the World Wildlife Fund (WWF) and the International Union for Conservation of Nature (IUCN) began introducing and promoting FLR efforts, as well as the framework, methodology, and objectives [74]. FLR initiatives address a variety of issues, including environmental, socioeconomic, and governance concerns, all while operating within multifunctional landscapes. As a result, FLR partnerships have emerged at all levels, as cooperation is required in carrying out restoration efforts [72, 74]. FLR involves the government, practitioners, research institutions, non-governmental organisations (NGOs), and other stakeholders nationally and regionally, as well as local community organisations, with the intention to increase reforestation efforts and the restoration of deforested and degraded lands for multiple benefits [85]. Since its inception, the WWF and IUCN have frequently worked together rather than independently. FLR objectives, which were aligned with many global conservation efforts to rehabilitate deforested and degraded land by involving governments, organisations, research institutions, including universities, communities, and individuals in a holistic manner (GPFLR, n.d). GPFLR is a platform that encourages multi-organization collaboration in large-scale FLR projects (e.g., IUFRO, UNEP, RECOFTC) [48]. The Bonn Challenge which was established in 2011 in Bonn has a global goal which aims to restore degraded and deforested land [29]. Currently, more than 60 nations, eight states and five associations have engaged the Bonn Challenge, joining the global effort with a total of 170.6 million hectares under restoration commitment such as the United Nations Decade on Ecosystem Restoration, which runs from 2021 to 2030, that aims to accelerate global restoration efforts. However, development has been gradual [81]. Only 18% of the 150 million hectares (commitment to be met by 2020) have been met [88].

Another FLR partnership is the Collaborative Partnership on Forests (CPF), which was founded in April 2001 and is chaired by FAO. It is a multi-sectoral coalition that focuses on forest-related initiatives. The collaborations include over 15 international organisations, institutions, and secretariats [89]. CPF provides advice, assistance, and methodology development to improve the execution of the 2030 Agenda (especially SDG 15, Life on Land) and the 2017–2030 United Nations Strategic Plan for Forests [81].

The Collaborative Partnership on Sustainable Wildlife Management (CPW), founded in 2013, is a voluntary collaboration similar to CPF [90]. The bond currently includes 15 international organisations from all over the world. It provided a platform for dealing with wildlife issues at all levels, including illegal wildlife trade. CPW also provides programmes that encourage the responsible use and conservation of wildlife resources [81].

7.6 Techniques and Tools in FLR

Unlike the traditional site-based approach in restoring ecological function, FLR adopts a larger-scale perspective to forest restoration which not only focuses on enhancing the ecological integrity of the forest but also on improving the livelihoods and well-being of the local people within the landscape [44, 91]. It is included as "Nature-based Solutions" in order to solve complex socio-environmental problems which can be achieved through a healthy ecosystem [92]. Globally, FLR process has been initiated across two billion hectares of forest together with savannah biomes all over the world, employing a variety of techniques and tools in FLR [93]. In other words, FLR tools are categorised as live procedure where people join together to recognise, compromise, and execute strategies that reestablish a pre-agreed balance of the environmental, social, and economic advantages of forests and trees within a landscape. For a long time, the thoroughness, acceptability, applicability, productivity, and adaptability theories serve as a theoretically beneficial foundation for sustainable and systematic landscape restoration (SLR) planning.

FLR tools aim to restore tree-rich landscapes and forests in a sustainable way. More than just trees are involved in forest landscape restoration. It enhances overall livelihoods by expanding beyond afforestation, replanting, and ecological restoration as well as environmental integrity. There are several tools available; however, choosing appropriate tools has become increasingly difficult. The solution is far more complex than simply planting new trees. To succeed, all stakeholders need to come together to collectively develop a plan that can be agreed upon by all parties. Everybody needs to recognise and understand the benefit of bringing back trees to the landscape [94, 95]. For many people, foods, nuts and mushrooms from the forests are sources of food and income. Farmers benefits when trees protect their fields while livestock is more likely to thrive with the presence of trees to provide them with shelter. In addition to these, bringing back trees to the landscape means more firewood which can be harvested in a sustainable way.

To plan these well, existing land must first be analysed. What did a region look like before it was deforested? Where would it make more sense to grow trees and forests? Issues of land ownership of 10 years must also be resolved [96, 97]. One successful case of FLR implementation in Nigeria was awarded the alternative Nobel Prize in 2018. Germany is a strong supporter of FLR measures. The world is aiming to help restore 100 million of ha of forest landscape in sub-Saharan Africa by 2030 to give millions of people long-term prospects for the future [98, 99]. In order to achieve this goal, people need to fully understand and support all the pillars of United Nations Sustainable Development Goals by 2030.

One of the 2030 United Nations sustainable development goals is to reduce trade-offs between sectoral policies and increase consistency [100]. SDG of policy and climate change actions must be strongly affected by relationships with certain other SDGs and institutions, putting them into practise to ensure that the SDGs are implemented holistically as shown in Figure 7.1 [80]. Climate change affects food systems, which has consequences for scarcity, health, economy, infrastructure, equity, and gender equality. The inappropriate usage and production of energy from the food systems can amplify climate change, most of which contribute to feedback effects. Success in several other SDG aspects is also important for development, such as achieving sustainability (12), food security (2), scarcity alleviation (1), energy (7), education (4), gender equity (5), water cleanliness (6), and life on land (15). This development creates agricultural efficiency in terms of energy, water, and nutrient inputs. Similarly, a synergy of SDG element 13 with other SDGs for 2030 Agenda's goals is depicted in Figure 7.2 [101].

Figure 7.2 Synergy of SDG element 13 with other SDGs for 2030 Agenda's goals [Adapted from Campbell *et al.* [101].

There are a variety of techniques available to estimate the trade-offs in ecosystem services related with forest restoration and SDG. The following are key characteristics of SLR: 1. Stakeholders in the community are actively involved in selection choices, participation, and execution. 2. Not only individual sites, but entire landscapes are restored; therefore, trade-offs between competing interests can be formed and minimised in a larger condition. 3. Landscapes are maintained and administered in order to give an agreed-upon level of service, a well-balanced mix of ecological services and goods, not only a larger forest cover. 4. There are numerous restoration strategies available, ranging from handled revegetation to tree planting. 5. The importance of continuous monitoring, learning, and adaptation cannot be overstated [102]. There are several FLR tools which are frequently being used for assessment and ecosystem services mapping for systematic restoration planning (SLR) around the world, which is depicted in Table 7.1.

Moreover, to deal with big issues such as food security, climate change, disaster risk reduction, biodiversity and local economic development, IUCN, which has committed to environmental protection and sustainable natural resource management, has made the decision to engage in Nature-based Solutions (NbS) tools and techniques. This initiative works to maintain and create a sustainable competitive advantage while also striving to preserve the natural and modified ecosystems. This could efficiently and adaptively solve societal concerns which could enhance social well-being and increase biodiversity benefits. a) Water Infrastructure Solutions from Ecosystem Services; b) Ecosystems Protecting Infrastructure and Communities (EPIC); c) Bonn Challenge Barometer; d) Land Degradation Neutrality; and e) Nature-based Solutions for resilient societies in the Western Balkans (ADAPT) are just among the few examples of the efforts by IUCN in promoting nature as a solution (Table 7.2) [115].

NbS can be classified as a general idea that encompasses a variety of techniques based on ecosystems that address one or more socioeconomic issues while concurrently promoting improvements for biodiversity and human well-being [121]. Despite the fact that NbS is not a perfect umbrella concept for other methods, it has expanded its concepts from other approaches by including social and economic components rather than conservation alone. As a result, NbS can serve as a tool to incorporate environmental concern within the procedure and policy [121].

In order to achieve a successful FLR, stakeholder needs to be forward-thinking and dynamic, striving to improve landscape resilience and developing future possibilities for adjusting and further optimising environmental goods and services. It incorporates seven bases: 1) Concentrate

Table 7.1 Several types of common FLR tools being used for the purpose of analysing and mapping ecosystem services for systematic restoration planning (SLR).

Type of tool	Description	Advantages	References
Social Values for Ecosystem Services (SolVES)	The social (non-market) value related to the services offered by a particular ecosystem, is mapped and quantified.	Facilitate in assessing, mapping and quantifying the social value of ecosystem services by calculating a non-monetary Value Index from public opinion and preference survey findings.	[103, 104]
Artificial Intelligence for Ecosystem Services (ARIES)	An interconnected ecological services modelling paradigm that respects dynamic complexity and unpredictability while emphasising service generation, flow, and usage by society.	Assist in the discovery, understanding, and quantification of environmental assets, as well as the factors that determine their worth, based on specified goals and priorities.	[105]
Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)	A set of models to assess and value the products and services from nature which may be beneficial in the sustainability of human life. This is an effective tool to balance between the environmental and economic goals.	The InVEST model is based on gridded maps and is part of a collection of models that may be divided into three classifications: support services, final services, and tools for ecosystem service study. Because these are straightforward models and require less particulars, they can be employed everywhere and by non-experts.	[106, 107]

(*Continued*)

Table 7.1 Several types of common FLR tools being used for the purpose of analysing and mapping ecosystem services for systematic restoration planning (SLR). (*Continued*)

Type of tool	Description	Advantages	References
Toolkit for Ecosystem Service Site-based Assessment (TESSA)	A set of useful tools for assessing and monitoring ecosystems service at the site level, and comparing the quantity of advantages individuals already receive from them to those projected under alternative land uses.	Enables non-experts in a reasonably quick and low-cost manner to analyse the volume, economic values, and distribution of ecosystem services offered by a particular landscape, to better comprehend the effects of prospective changes in land management on the ecosystem service provided, as well as considering the impartial implications of decisions, which are sometimes missed in previous evaluations.	[108, 109]
Multi-scale Integrated Models of Ecosystem Services (MIMES)	A multi-scale, integrated set of models for evaluating the value of ecosystem services and allowing stakeholders to make timely decisions comprehend ecosystem service processes, how environmental effects are connected with human welfare, and how the value of ecosystem services may alter under different management situations.	Evaluates the qualitative evaluation of community perceptions of environmental services by incorporating all societal stakeholders. It follows step-by-step instructions for completing an evaluation, disseminating findings, and implementing findings into multiple situations, starting with describing the problem that necessitated an assessment and carrying out all scientific, analytical, and management tasks necessary to complete an assessment, reporting results, and incorporating results into diverse situations.	[110]

(*Continued*)

Table 7.1 Several types of common FLR tools being used for the purpose of analysing and mapping ecosystem services for systematic restoration planning (SLR). (*Continued*)

Type of tool	Description	Advantages	References
Costing Nature	A web-based application that maps the generation and conservation of bundled ecological services.	Commonly used method in landscape restoration economic analysis although its usage appears to be restricted and variable. Demonstrate the economic viability of landscape restoration by calculating the baseline of the current provision of various ecosystem services. In the long run, the benefits of restoration can surpass the large investment costs.	[111, 112]
Restoration Opportunities Optimization Tool (ROOT)	Identifies significant regions for ecosystem service supply by combining information on the potential outcomes of a particular restoration process with spatial prioritising maps.	Non-expert users can use the Diversity for Restoration tool to decide on the tree species to be planted as well as the seed supplies that best match the condition of the restoration site and its goals. For this, researchers combined species characteristics, environmental data, and climate change models.	[113]
Land Degradation Surveillance Framework (LDSF)	Indicators of an ecosystem's health, by the assessment of floristic composition, vegetation cover and structure as well as history of land usage, evidence of soil deterioration, and soil physical parameters.	Meant to offer a biophysical baseline on a landscape scale, as well as assessing and reporting framework for evaluating the degradation of a particular landscape and the efficacy of rehabilitation initiatives in the long run.	[114]

Table 7.2 Types of Nature-Based Solutions proposed by IUCN.

Type of NbS	Description	Advantages	References
Water Infrastructure Solutions from Ecosystem Services	Thorough discussion with decision makers to identify and agree on trade-offs, with optimal portfolios of built and natural infrastructure being applied.	Combining and engaging with basin stakeholders to develop products or outputs that are approachable, practical, and directly applicable (e.g., dams, levees, irrigation channels).	[116]
Ecosystems Protecting Infrastructure and Communities (EPIC)	EPIC is adopting ecological system ways to safeguard populations from catastrophes and climate change-related consequences. It is a five-year effort that promotes ecosystem-based disaster risk reduction in Burkina Faso, Chile, China, Nepal, Senegal, and Thailand through five case studies.	Demonstrate the efficacy and economic worth of environmental management in sustainable development and climate change adaptation while bringing a broader audience into the fold of livelihood benefits to communities	[117]
Bonn Challenge Barometer	A systematic approach for identifying and analysing action on worldwide restoration pledges that is universally applicable.	- Hectares brought under restoration - Reduce population vulnerability to climate change-related dangers. - Advantages of biodiversity	[118]

(*Continued*)

Table 7.2 Types of Nature-Based Solutions proposed by IUCN. (*Continued*)

Type of NbS	Description	Advantages	References
Land Degradation Neutrality (LDN)	The LDN idea was created to encourage the implementation of an optimal mix of policies aimed at preventing, reducing, and/or reversing land degradation and achieving a condition without significant deficit of healthy and productive land.	- mitigation and adaptation to climate interchange - increasing the vulnerability of rural communities to climate shocks	[119]
Nature-based Solutions for resilient societies in the Western Balkans (ADAPT)	ADAPT is a three-year funded regional project implemented by IUCN through the Regional Office for Eastern Europe and Central Asia (ECARO). The project is to enhance ecosystem and community resilience towards climate change and environmental degradation in the Western Balkans.	- Increase understanding and awareness of disaster risk reduction strategies based on nature - Integrate NbS and equitable climate-smart goal into adjustment and disaster-prevention policies.	[120]

on Landscape, 2) Preserve Natural Ecosystems, 3) Restore Functionality, 4) Involve Stakeholders, 5) Tailor to Local Conditions, 6) Allow for Numerous Advantages and 7) Long-Term Resilience Strategy [115]. Despite the fact that FLR application is common throughout all continents (with the obvious exclusion of Antarctica and the Arctic), the majority of the literature publications were originated from industrialised countries in North America, Oceania, and Europe. The body of knowledge created by FLR programmes has successfully contributed to the FLR implementations that has already taken place in selected countries (Table 7.3).

7.7 Implementation of FLR

Achieving a successful implementation of FLR is not a one-size-fits-all solution. It is also not a simple and linear process, but needs to consider various circumstances involving socioeconomic, biophysical and political hindrance in order to attain the balance between biodiversity conservation and the livelihood of people living in and around the protected areas [29, 73]. To commence the implementation of an FLR project, Stanturf *et al.* [29] have established a systematic framework comprising four phases within its project cycle management (PCM) starting with visioning, conceptualizing, implementing and sustaining. These phases start with a more general approach and moving forward, it progresses toward a greater specificity [127]. It is also important to understand that FLR in general is not merely a project, but it is a process, with a flexible timeframe.

7.7.1 Visioning

Visioning, which is also a preparation phase, requires various stakeholders to come together to identify the goals and purpose needed to start off the implementation of FLR. Decisions need to be made on where and how to restore the forests across the selected landscape while highly considering national priorities as well as local concerns [128]. As the whole process of FLR is flexible in timing, the goals usually described expected long-term outcomes which are generally centred by what might be inadequate, degraded or both in a particular landscape based on discussion and consultation among multi-stakeholders [29]. However, each stakeholder may have different understandings and priorities related to forest degradation and restoration process. Failure in reaching common understanding may impede the progress of FLR [129]. From a survey conducted to identify the issues related to the failed implementation of FLR projects on a global scale, there were

Table 7.3 Successful FLR tools implementations for systematic restoration planning in selected countries and areas.

Type of FLR tools	Country	Description	References
ARIES	Europe (Danube River Basin)	Demonstrate a general model-coupling framework to conserve and manage freshwater ecosystems utilizing three elements: biodiversity, ecosystem services (ESS), and a spatial prioritisation.	[122]
SolVES	Asia (Shanghai China)	Evaluate several environmental services with societal values, including beauty, biodiversity, culture, and recreation in Wusong Paotaiwan Wetland Forest Park in Shanghai.	[123]
InVEST	Asia (Southwest China & Thailand)	Establish an approach to include several categories of biodiversity into models so that ecosystem functions and services can be evaluated together.	[124]
InVEST	Asia (China)	Evaluate the outcomes of changing landscape patterns on the quality of habitat and offer a scientific foundation for ecological conservation policy and land resource sustainability in the region.	[125]
InVEST, AIRES, MIMES, SolVES & etc.	American (Ecuador)	Using existing modelling methods to estimate promising properties of forest ecosystem services (e.g., InVEST, AIRES, MIMES, SolVES, etc.) and synthesis of research.	[126]

three major problems faced by the respondents: i) not enough participation by local stakeholders, ii) divergence in priorities and interest between local communities and restoration managers, and iii) environmental, anthropogenic and technical issues affecting tree regeneration [130]. Involvement of local stakeholders in planning and management decisions for a restoration project is one of the most crucial elements in FLR as it could shed more light on the local needs as well as ensuring equal and widespread benefits distribution [131]. In Pakistan, dispute over land and forest resources is one of the main factors that hindered local farmers' participation in a restoration project [132]. In a region of Northern Argentina, the land use is mainly for transhumant cattle farming and therefore, restoration of forest does not contribute much to the community [131]. Both of the mentioned scenarios highlight the difficulties for FLR to be realized in practice and for this reason, policymakers and project designers should implement an adaptive management approach that emphasize empowerment, equity, trust and learning to increase the involvement of local communities [133].

7.7.2 Conceptualizing

The conceptualizing or planning phase involves setting up measurable and tangible objectives which are linked to the goals that have been identified that could be carried out [29]. In this phase, priority landscape and specific ecological functions to be restored are determined by assessing the biophysical and social criteria of the particular landscape [134]. Then, particular restoration interventions can be assigned to the specific criteria and opportunities that have been identified according to their suitability focussing on a range of social and environmental needs [135]. The interventions and techniques to achieve the agreed FLR objectives can be determined by carrying out cost-benefit analysis involving experts and all stakeholders [128]. The interventions selected to execute FLR need to be realistic, achievable and effective in both social and ecological context as well as sustainable in time [136]. To increase the participation of community members, approaches selected to conduct FLR should provide initial financing, economic incentives and education for the local communities to adopt wildlife-friendly agricultural practices and use more technologically advanced agricultural systems [137, 138]. Employment opportunity could also be generated which could increase revenues [139, 140]. It is estimated that every $1 used in the restoration of degraded forest can yield between $7 to $30 in economic benefits [141]. If all of these benefits can be sustained throughout a particular FLR project, the advantages of a restoration and conservation process may outweigh the costs [29].

As mentioned in the first part of this chapter, there are typically three categories of landscape where the restoration process can be conducted: i) forest land, ii) agricultural land, and iii) protective land and buffer, all of which require different strategies in their restoration process. However, the specific tools or techniques to be utilized are not straightforward as the level of degradation of each land may be varied. The composition of the landscape such as the proportion and spatial distribution of remaining natural forest is one of the factors influencing the intervention and restoration outcomes [142]. For example, if a certain landscape has less than 30% of remaining native forest, restoration by sparing schemes is more suitable to be utilized as opposed to sharing schemes which are more appropriate to be applied to fragmented landscapes where some proportion of forest cover is still retained [142, 143]. Therefore, in this conceptualization phase, a thorough analysis and discussion among experts and stakeholders should be conducted to choose the most appropriate as well as effective strategies for the target landscape according to the national, regional or local goals that have been identified.

7.7.3 Acting

The acting or implementation phase is where the objectives are accomplished by creating a list which includes what should be done, where, when, and by whom as well as the cost involved in the restoration work. As the restoration take place locally, the decision-making process that should be made at local levels is comprised of site selection, FLR intervention to be utilized, pace and schedule in carrying out the restoration works, costs, and the monitoring process related to expenses and evaluation [32]. All of these components enable the implementers to determine whether the restoration outcomes are going to be successful or not [144]. In this phase, it is recommended to start implementing the plan on a small scale, for example through pilot projects where everyone could learn the pros and cons that could be implemented in the next bigger project [145]. During site selection process, more often than not, the landscape selected has diverse and complex physical as well as ecological characteristics. The works can be simplified by separating the target landscape into more or less similar units, which can be achieved using GIS mapping [29]. Depending on the landscape, one can choose to use passive restoration, active restoration or the combination of both active and passive restoration process. Passive restoration involves natural colonization or secondary succession by removing environmental stressors such as grazing animals and agricultural plots which is in contrast to direct seeding or out planting suitable species of plant in active restoration [146]. The restoration method may differ subject to several factors such as the extent of soil and vegetation degradation. In addition, restoration may also involve removing invasive plant species which contribute to the extinction of natural vegetation and reduced biodiversity [147]. The selection of appropriate species to be planted is also one of the important elements to achieve a successful implementation of FLR project. Another major obstacle is in obtaining quality seeds and seedlings to be planted. By correctly planting high-quality seeds at the proper time the survival of the plants can be maximized which will eventually accelerate forest restoration [147, 148]. As FLR is a dynamic and ongoing process involving people as well as landscape, it is impossible to accomplish everything at once [149]. The route to a successful FLR is not simple and has no clear starting or endpoint. It can begin as an ecological conservation project, local food security project or even a watershed management project. Regardless of how it begins, it is important to ensure that the common goals can be achieved by regularly assessing and evaluating progress as well as readily adapting to the challenges and opportunities that come up throughout the process [149]. It should also be ensured that the intervention plans are acceptable to local stakeholders which may require compromises with the national agenda on certain issues [150].

7.7.4 Sustaining

The sustaining phase involves a combination of management planning with monitoring and evaluation to ensure the initial restoration phases that have taken place are leading to the social and environmental outcomes as outlined in the planning phase, as well as taking necessary corrective actions from the gained feedbacks [29, 151]. There has been unanimous agreement on the role of monitoring as one of the most essential stages in the success of a particular forest restoration project [152, 153]. However, it is very common to allocate insufficient funds for the monitoring process which could adversely affecting restoration works. Effective monitoring can be achieved by using new tools and technology such as utilizing applications on a mobile phone that can immediately transmit the data to the forestry department or observing the restoration progress via remote sensing imaging [152, 154].

As FLR is a long-term process, success might only be seen years after the commencement of the first restoration process, and therefore maintaining the momentum and sustaining interest on FLR over the long period of time are extremely necessary. Collaborative or participatory monitoring which involves various stakeholders including local communities can be cost-effective and should be conducted along with appropriate quality control mechanism [155]. Investment in providing necessary training should also be provided to equip the local people and the staffs of FLR organization with skills needed to monitor and evaluate the outcome of the restoration process [156]. It is worth checking whether the locals are still motivated to participate and if they are not, solutions should be developed to ensure that they continue to be involved throughout the life cycle of the FLR project [157]. If the monitoring phase is conducted comprehensively, it becomes an important tool for problem solving, leading to improved project management.

7.8 Forest Landscape Assessment

In order for restoration work to take place, the chosen landscape needs to be assessed to identify opportunity and challenges before choosing the best intervention method for a successful FLR project. In recent years, various assessment tools have been developed which facilitate in setting up the foundation for a long-term process in transforming the landscape that could benefit the environment and stakeholder groups. One of the tools is Restoration Diagnostic which was developed by World Resources Institute (WRI) in 2015 and is used to determine the key success factors that are present or might be absent from a particular landscape or country where restoration work is taking place [158]. There is also Forest Landscape Assessment Tool (FLAT) developed by the Green Cities Research Alliance in the United States which was primarily designed to be used on landscape scale. FLAT can be used to determine the overall health and ecological condition of the landscape as well as to recognize possible threats that might affect the restoration process [159]. However, the most used tool with extensive application is the Restoration Opportunity and Assessment Methodology (ROAM) developed by IUCN and WRI [144, 160]. This tool is used to facilitate in the identification of a suitable landscape to be prioritized for restoration within a national or sub-national context. ROAM can provide relevant and detail analytical input related to scope and availability of land, economic cost and benefit of potential restoration interventions as well as legal and policy frameworks [144]. ROAM has also been through a lot of improvement to allow for a more accurate analysis by including gender focussed elements [161], biodiversity components [162], food security [163] and governance [164]. The ROAM process has resulted in a number of suggestions and comprehensive plans, but many resources are needed to execute the restoration work such as funding, investment plans, and impartial incentives for landowners as well as local communities. Therefore, forest assessment helps in understanding biomass and carbon pools which ensure soil, food and climate security [165–169]. Assessing the forest landscape and its management through sustainable intensification promise resource conservation, amplify ecosystem services and mitigate carbon, land and energy footprint for environmental security [170–176].

7.9 Conclusion

Forest landscape restoration offers a promising future on environmental sustainability as it aims to restore forest ecosystem function and improve the livelihood of local communities. Many tools have been developed through significant research which can be implemented extensively across different forest and landscape restoration projects. Nevertheless, implementing restoration is not a straightforward process and poses difficulties due to ecological and socioeconomic complexities in many regions. This is further exacerbated by the nature of FLR itself which is dynamic and requires a long-term effort. Regardless of the challenges and obstacles, successful restoration can still be achieved with continuous engagement from local stakeholders and fair benefits distribution. Enhanced communication and collaboration among stakeholders at local, national and global levels as well as utilizing a more comprehensive monitoring system could also increase the effectiveness of FLR implementation.

References

1. Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., Peres, C. A., Bradshaw, C.J.A., Laurance, W. F., Lovejoy, T. E. & Sodhi, N. S., Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378-381, 2011.
2. FAO and UNEP., *The State of the World's Forests 2020. Forests, Biodiversity and People*. Rome, 2020.
3. Rodney, J.K., Gregory, A. R., Frédéric, A., Joberto, V., Alan, G. & Erik, L., Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, 352, 9-20, 2015.
4. "Indicators of Forest Extent: Forest Loss" Global Forest Review, update 3. Washington, DC: World Resources Institute. Available online at https://research.wri.org/gfr/global-forest-review, 2022.

5. Lewis, S.L., Edwards, D. P. & Galbraith, D., Increasing human dominance of tropical forests. *Science*, 349(6250), 827-832, 2015.
6. Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S. & Wood, R., Agricultural and forestry trade drives large share of tropical deforestation emissions. *Global Environmental Change*, *56*, 1-10, 2019.
7. Negrón-Juárez, R.I., Holm, J.A., Marra, D.M., Rifai, S.W., Riley, W.J., Chambers, J.Q., Koven, C.D., Knox, R.G., McGroddy, M.E., Di Vittorio, A.V., Urquiza-Muñoz, J., Tello-Espinoza, R., Muñoz, W.A., Ribeiro, G.H.P.M. & Higuchi, N., Vulnerability of Amazon forests to storm-driven tree mortality. *Environmental Research Letters*, 13(5), 054021, 2018.
8. Van Wees, D., van der Werf, G.R., Randerson, J. T., Andela, N., Chen, Y. & Morton, D. C., The role of fire in global forest loss dynamics. *Global Change Biology*, 27(11), 2377-2391, 2021.
9. Zemp, D.C., Schleussner, C.-F., Barbosa, H.M.J., Hirota, M., Montade, V., Sampaio, G., Staal, A., Wang-Erlandsson, L. & Rammig, A., Self-amplified Amazon forest loss due to vegetation-atmosphere feedbacks. *Nature Communications*, 8(1), 14681, 2017.
10. Curtis, P.G., Slay, C.M., Harris, NL., Tyukavina, A. & Hansen, M.C., Classifying drivers of global forest loss. *Science*, 361(6407), 1108-1111, 2018.
11. Barlow, J., Berenguer, E., Carmenta, R. & França, F., Clarifying Amazonia's burning crisis. *Global Change Biology*, 26(2), 319-321, 2020.
12. Brando, P., Macedo, M., Silvério, D., Rattis, L., Paolucci, L., Alencar, A., Coe, M. & Amorim, C., Amazon wildfires: Scenes from a foreseeable disaster. *Flora, 268*, 151609, 2020.
13. Brondizio, E.S., Settele, J., Díaz, S. & Ngo, H.T., *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES secretariat, Bonn, Germany, 2019.
14. Morand, S. & Lajaunie, C., Outbreaks of Vector-Borne and Zoonotic Diseases Are Associated with Changes in Forest Cover and Oil Palm Expansion at Global Scale [Original Research]. *Frontiers in Veterinary Science*, 8, 2021.
15. Serge, M., Emerging diseases, livestock expansion and biodiversity loss are positively related at global scale. *Biological Conservation*, 248, 108707. 2020.
16. Hosonuma, N., Herold, M., De Sy, V., De Fries, R.S., Brockhaus, M., Verchot, L., Angelsen, A. & Romijn, E., An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, 7(4), 044009, 2012.
17. Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N., & Foley, J.A., Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences of the United States of America*, 107(38), 16732-16737, 2010.

18. Foong, S.Z.Y., Goh, C.K.M., Supramaniam, C.V. & Ng, D.K.S., Input–output optimisation model for sustainable oil palm plantation development. *Sustainable Production and Consumption*,17, 31-46, 2019.
19. Austin, K.G., Mosnier, A., Pirker, J., McCallum, I., Fritz, S. & Kasibhatla, P.S., Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. *Land Use Policy*, 69, 41-48,2017.
20. Haijon, G., Dg Siti Noor Saufidah Ag Mohd, S., Zuraidah, Z. & May Siaw-Mei, L., Where Have All the Forests Gone? Deforestation in Land Below the Wind. *Procedia - Social and Behavioral Sciences*, 153, 363-369, 2014.
21. Skidmore, M.E., Moffette, F., Rausch, L., Christie, M., Munger, J. & Gibbs, H.K., Cattle ranchers and deforestation in the Brazilian Amazon: Production, location, and policies. *Global Environmental Change*, 68, 102280, 2021.
22. Sonter, L.J., Herrera, D., Barrett, D.J., Galford, G.L., Moran, C. J. & Soares-Filho, B.S., Mining drives extensive deforestation in the Brazilian Amazon. *Nature Communications*, 8(1), 1013, 2017.
23. González-González, A., Clerici, N. & Quesada, B., Growing mining contribution to Colombian deforestation. *Environmental Research Letters*, 16(6), 064046, 2021.
24. Edwards, D.P., Tobias, J.A., Sheil, D., Meijaard, E. & Laurance, W.F., Maintaining ecosystem function and services in logged tropical forests. *Trends EcolEvol*, 29(9), 511-520, 2014.
25. Venier, L.A., Thompson, I.D., Fleming, R., Malcolm, J., Aubin, I., Trofymow, J.A., Langor, D., Sturrock, R., Patry, C., Outerbridge, R.O., Holmes, S.B., Haeussler, S., De Grandpré, L., Chen, H.Y.H., Bayne, E., Arsenault, A. & Brandt, J.P., Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. *Environmental Reviews*, 22(4), 457-490, 2014.
26. Betts, M.G., Wolf, C., Ripple, W.J., Phalan, B., Millers, K.A., Duarte, A., Butchart, S. H.M. & Levi, T., Global forest loss disproportionately erodes biodiversity in intact landscapes. *Nature*, 547(7664), 441-444, 2017.
27. Cardinale, B., Duffy, J., Gonzalez, A., Hooper, D., Perrings, C., Venail, P., Narwani, A., Tilman, D., Wardle, D., Kinzig, A., Daily, G., Loreau, M., Grace, J., Larigauderie, A., Srivastava, D. & Naeem, S., Biodiversity loss and its impact on humanity. *Nature*, 486, 59-67, 2012.
28. Lamb, D. & Gilmour, D., Rehabilitation and Restoration of Degraded Forests. IUCN, Gland, Switzerland and Cambridge, UK and WWF, Gland, Switzerland. x +110 pp, 2003.
29. Stanturf, J., Kleine, M., Mansourian, S., Parrotta, J., Madsen, P., Kant, P., Burns, J. & Bolte, A., Implementing forest landscape restoration under the Bonn Challenge: a systematic approach. *Annals of Forest Science*, 76, 2019.
30. Indrajaya,Y., Yuwati, T.W., Lestari, S., Winarno, B., Narendra, B.H., Nugroho, H.Y.S.D., Rachmanadi, D., Pratiwi., Turjaman, M, Adi, R.N., Savitri, E., Putra, P.B., Santosa, P.B., Nugroho, N.P., Cahyono, S.A., Wahyuningtyas, R.S., Prayudyaningsih, R., Halwany, W., Siarudin, M., Widiyanto, A/, Utomo,

M.M.B., Sumardi., Winara, A., Wahyuni, T. & Mendham, D., Tropical Forest Landscape Restoration in Indonesia: A Review. *Land*. 11, 328, 2022.

31. *SER*., The SER international primer on ecological restoration. Tucson: Society for Ecological Restoration International, 2004.
32. Stanturf, J., Mansourian, S. & Kleine, M., Implementing forest landscape restoration, a practitioner's guide. *International Union of Forest Research Organizations*, 1-128, 2017.
33. Van Oosten, C., Gunarso, P., Koesoetjahjo, I. & Wiersum, F., Governing Forest Landscape Restoration: Cases from Indonesia. *Forests*, 5, 1143, 2014.
34. GLF., *Global Landscapes forum website*. http://www.landscapes.org/glf-2014/about/, 2014.
35. Lamb, D., Stanturf, J. & Madsen, P., What is forest landscape restoration? In *Forest Landscape Restoration*; Springer: Berlin/Heidelberg, Germany; pp 3-23, 2012.
36. Van Oosten, C., Forest Landscape Restoration: Who Decides? A Governance Approach to Forest Landscape Restoration. *Natureza & Conservação*, 11, 119-126, 2013.
37. Stanturf, J., David, L. & Palle, M., *Forest Landscape Restoration*; Springer: Berlin/Heidelberg, 2012.
38. Nagy, R.C. & Lockbaby, B.G., Hydrological connectivity of landscapes. *In Forest Landscape Restoration;* Springer: Berlin/Heidelberg, Germany; pp. 69-92, 2012.
39. Bentrup, G., Dosskey, M., Wells, G. & Schoeneberger, M., Connecting landscapes fragments through riparian zones. In *Forest Landscape Restoration*; Springer: Berlin/Heidelberg, Germany; pp. 93-110, 2012.
40. Wimberly, M.C., Boyte, S.P. & Gustafson, E.J., Understanding landscapes through spatial modelling. *In Forest Landscape Restoration; Springer:* Berlin/Heidelberg, Germany; pp. 111-130, 2012.
41. Emborg, J., Walker, G. & Daniels, S., Forest landscape restoration Decision-making and conflict management: applying discourse-based approaches. In *Forest Landscape Restoration; Springer:* Berlin/Heidelberg, Germany; pp. 131-154, 2012.
42. Wilson, K.A., Lulow, M., Burger, J., Convery, I. & McBride, F., The economics of restoration. In *Forest Landscape Restoration;* Springer: Berlin/Heidelberg, Germany; pp 69-92, 2012.
43. Convey, I. & Dutson, T., Wild ennerdale: A cultural landscape. In *Forest Landscape Restoration*; Springer: Berlin/Heidelberg, Germany; pp. 233-252, 2012.
44. Sabogal, C., Christophe, B. & McGuire, D., Forest and landscape restoration: Concepts, approaches and challenges for implementation. *Unasylva*, *245*, 3-10, 2015.
45. Sarkar, P., Fennessy, S. & Edrisi, S., *Land Restoration for Achieving the Sustainable Development Goals: An International Resource Panel Think Piece*, 2019.

46. Mansourian, S., Fung, M., Lobinsiu, F. & Vallauri, D., *Lessons Learnt from 12 Years Restoring the Orangutan's Habitat: the Bukit Piton Forest Reserve in the Malaysian State of Sabah*, 2020.
47. Beatty, C.R., Cox, N.A. & Kuzee, M.E., *Biodiversity guidelines for forest landscape restoration opportunities assessments* (p. 10). Gland, Switzerland: IUCN, 2018.
48. Mansourian, S., Berrahmouni, N., Blaser, J., Dudley, N., Maginnis, S., Mumba, M.& Vallauri, D., Reflecting on Twenty years of Forest Landscape Restoration. *Restoration Ecology*, 29, 2021.
49. IUCN., *Assessing forest landscape restoration opportunities at the national level: A guide to the Restoration Opportunities Assessment Methodology (ROAM)* (Road-test ed.). Gland, Switzerland, IUCN. https://infoflr.org/what-flr, 2014.
50. Nieuwenhuis, M., *Terminology of forest management, terms and definitions in English* (2nd revised ed., Vol. 9). International Union of Forest Research Organizations. Austria, Vienna, 2010.
51. Fujiwara, M., Silviculture in Japan. In Iwai, Yoshiya. *Forestry and the forest industry in Japan* (1-23). Vancouver: UBC Press, 2002.
52. Krott, M., Tikkanen, I., Petrov, A., Tunytsya, Y., Zheliba, B., Sasse, V., Rykounina, I. & Tunytsya, T., *Policies for sustainable forestry in Belarus, Russia, and Ukraine. European Forest Institute Research Report 9*. Koninklijke Brill NV, Leiden, The Netherlands, 2000.
53. Maginnis, S., Rietbergen-McCracken, J. & Jackson, W., Restoring forest landscapes: an introduction to the art and science of forest landscape restoration. In. http://www.itto.or.jp/live/LiveServer/1064/ts23e.pdf, 2005.
54. SCA. (n.d.). *Introduction*. http://www.forest.sabah.gov.my/sugut/, 2021.
55. Coulibaly, J., Chiputwa, B., Nakelse, T. & Kundhlande, G., Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agricultural Systems*, 155, 52-69, 2017.
56. Julia Ihli, H., Chiputwa, B., Winter, E. & Gassner, A., Risk and time preferences for participating in forest landscape restoration: The case of coffee farmers in Uganda. *World Development*,150, 105713, 2022.
57. Ma, Z., Bork, E.W., Carlyle, C.N., Tieu, J., Gross, C.D. & Chang, S.X., Carbon stocks differ among land-uses in agroforestry systems in western Canada. *Agricultural and Forest Meteorology*, 313, 108756, 2022.
58. Yahya, M.S., Atikah, S.N., Mukri, I., Sanusi, R., Norhisham, A.R. & Azhar, B., Agroforestry orchards support greater avian biodiversity than monoculture oil palm and rubber tree plantations. *Forest Ecology and Management*, 513, 120177, 2022.
59. Amede, T., Legesse, G., Agegnehu, G., Gashaw, T., Degefu, T., Desta, G., Mekonnen, K., Schulz, S. & Thorne, P., Short term fallow and partitioning effects of green manures on wheat systems in East African highlands. *Field Crops Research*, 269, 108175, 2021.

60. Vanek, S.J., Meza, K., Ccanto, R., Olivera, E., Scurrah, M. & Fonte, S.J., Participatory design of improved forage/fallow options across soil gradients with farmers of the Central Peruvian Andes. *Agriculture, Ecosystems & Environment*, 300, 106933, 2020.
61. Atwood, T.B. & Hammill, E., The importance of marine predators in the provisioning of ecosystem services by coastal plant communities. *Frontiers in Plant Science*, 1289, 2018.
62. Duan, J., Han, J., Cheung, S.G., Chong, R.K.Y., Lo, C.-M., Lee, F. W.-F., Xu, S.J.-L., Yang, Y., Tam, N. F.-y. & Zhou, H.-C., How mangrove plants affect microplastic distribution in sediments of coastal wetlands: Case study in Shenzhen Bay, South China. *Science of the Total Environment*, 767, 144695, 2021.
63. Xiong, Y., Liao, B., Proffitt, E., Guan, W., Sun, Y., Wang, F.& Liu, X., Soil carbon storage in mangroves is primarily controlled by soil properties: A study at Dongzhai Bay, China. *Science of the Total Environment*, 619, 1226-1235, 2018.
64. Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N. C., Ellison, A. M., Ellison, J. C., Farnsworth, E. J., Fernando, E. S., Kathiresan, K. & Koedam, N. E., The loss of species: mangrove extinction risk and geographic areas of global concern. *PloS one*, 5(4), e10095, 2010.
65. Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A. & Simard, M., Distribution and drivers of global mangrove forest change, 1996–2010. *PloS one*,12(6), e0179302, 2017.
66. *DELWP*, Department of Environment Land, Water and Planning. Melbourne, Australia. In https://www.marineandcoasts.vic.gov.au/__data/assets/pdf_file/0027/456534/Marine-and-Coastal-Policy_Full.pdf, 2020.
67. Vogl, A.L., Bryant, B.P., Hunink, J.E., Wolny, S., Apse, C. & Droogers, P., Valuing investments in sustainable land management in the Upper Tana River basin, Kenya. *Journal of Environmental Management*, 195, 78-91, 2017.
68. Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E., Alewell, C., Wuepper, D., Montanarella, L. & Ballabio, C., Land use and climate change impacts on global soil erosion by water (2015-2070). *Proceedings of the National Academy of Sciences*,117(36), 21994-22001, 2020.
69. Zheng, F.-L., Effects of accelerated soil erosion on soil nutrient loss after deforestation on the Loess Plateau. *Pedosphere*,15(6), 707-715, 2005.
70. Sklenicka, P., Efthimiou, N., Zouhar, J., van den Brink, A., Kottova, B., Vopravil, J., Zastera, V., Gebhart, M., Bohnet, I.C., Molnarova, K.J. & Azadi, H., Impact of sustainable land management practices on controlling water erosion events: The case of hillslopes in the Czech Republic. *Journal of Cleaner Production*, 337, 130416, 2022.
71. Liang, S., Hurteau. M.D. & Westerling, A.L., Large-scale restoration increases carbon stability under projected climate and wildfire regimes. *Frontiers in Ecology and the Environment,* 16, 207–212, 2018.

72. Herrick, J.E., Abrahamse, T., Abhilash, P.C., Ali, S.H., Álvarez-Torres, P., Barau, A. S. & Zeleke, G., *Land restoration for achieving the sustainable development goals: An international resource panel think piece*, 2019.
73. Noulèkoun, F., Mensah, S., Birhane, E., Son, Y. & Khamzina, A., Forest Landscape Restoration under Global Environmental Change: Challenges and a Future Roadmap. *Forests*, 12(3), 276, 2021.
74. FAO., Forest landscape restoration in Asia-Pacific forests, by Appanah, S. (ed.). Bangkok, Thailand. // Nawir, A.A., Gunarso, P., Santoso, H., Julmansyah, & Hakim, M.R. (2016). Forest landscape restoration for Asia-Pacific forests, 2016.
75. César, R.G., Belei, L., Badari, C.G., Viani, R.A.G., Gutierrez, V., Chazdon, R.L., Brancalion, P.H.S. & Morsello, C., Forest and Landscape Restoration: A Review Emphasizing Principles, Concepts, and Practices. *Land*, 10(1), 28, 2020.
76. RECOFTC., *Introduction to forest landscape restoration.* Retrieved April 17, 2022, from https://www.recoftc.org/publications/0000384, 2020.
77. Dumroese, R.K., Williams, M.I., Stanturf, J.A. & Clair, J.B., Considerations for restoring temperate forests of tomorrow: forest restoration, assisted migration, and bioengineering. *New Forests,* 46, 947-964, 2015.
78. Brancalion, P.H.S. & Chazdon, R.L., Beyond hectares: Four principles to guide reforestation in the context of tropical forest and landscape restoration. *Restor. Ecol.*, 25*,* 491–496, 2017.
79. Freiberg, H., Liu, J.D. & Jagger, B., Forest Landscape Restoration Potential and Impacts. Arborvitae The IUCN Forest Conservation Magazine (45), 2014.
80. UNESCO, n.d. UNESCO and Sustainable Development Goals. https://en.unesco.org/sustainabledevelopmentgoals. Retrieved April 2022.
81. United Nations Environment Programme., *The State of the World's Forests 2020: Forests, Biodiversity and People.* https://wedocs.unep.org/20.500.11822/32472, 2020.
82. International Union for Conservation of Nature ((IUCN))., *Forest Landscape Restoration – Pathways to Achieving the SDGs.* Global Landscapes Forum. https://www.globallandscapesforum.org/publication/forest-landscape-restoration-pathways-to-achieving-the-sdgs, 2020.
83. Nawir, A.A., Gunarso, P., Santoso, H. & Julmansyah dan Hakim, M.R., Experiences, lessons and future directions for forest landscape restoration in Indonesia *in FAO/RECOFTC. Forest landscape restoration in Asia-Pacific forests,* Appanah, S. (ed.). Bangkok, Thailand, 2016.
84. Stanturf, J.A., Future landscapes: opportunities and challenges. *New Forests,* 46, 615-644, 2015.
85. Dudley, N. & Aldrich, M. (Eds.)., *Five years of implementing forest landscape restoration. Lessons to date.* WWF International, Gland, Switzerland, 2007.
86. Luther, D., Beatty, C.R., Cooper, J., Cox, N., Farinelli, S., Foster, M. & Brooks, T.M., Global assessment of critical forest and landscape restoration needs for threatened terrestrial vertebrate species. *Global Ecology and Conservation*, 24, e01359, 2020.

87. Morán-Ordóñez, A., Hermoso, V. & Martínez-Salinas, A., Multi-objective forest restoration planning in Costa Rica: Balancing landscape connectivity and ecosystem service provisioning with sustainable development. *Journal of Environmental Management*, 310, 114717, 2022.
88. NYDF., *Protecting and restoring forests: A story of large commitments yet limited progress. New York Declaration on Forests Five-year assessment report.* Amsterdam, Climate Focus, 2019.
89. Schultz, C.A., Jedd, T. & Beam, R.D., The Collaborative Forest Landscape Restoration Program: A History and Overview of the First Projects, *Journal of Forestry*, 110(7), 381-391, 2012.
90. Vizina, Y. & Kobei, D., Indigenous peoples and sustainable wildlife management in the global era. *Unasylva*, 68(249), 27, 2017.
91. Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J. & Dixon, K.W., International principles and standards for the practice of ecological restoration. *Restoration Ecology.*, 27(S1), S1-S46, 2019.
92. International Union for Conservation of Nature (IUCN). Nature Based Solutions. Available online: https://www.iucn.org/theme/nature-based-solutions/our-work (accessed on 19 April 2022).
93. Laestadius, L., Saint-Laurent, C., Minnemeyer, S. & Potapov, P., A world of opportunity: the world's forests from a restoration perspective. The global partnership on forest landscape restoration, World Resources Institute, South Dakota State University and the International Union for the Conservation of Nature. http://pdf.wri.org/world_of_opportunity_brochure_2011-09.pdf, 2011.
94. Urgenson, L.S., Ryan, C.M., Halpern, C.B., Bakker, J.D., Belote, R.T., Franklin, J.F. & Waltz, A.E., Visions of restoration in fire-adapted forest landscapes: lessons from the Collaborative Forest Landscape Restoration Program. *Environmental Management*, 59(2), 338-353, 2017.
95. Maginnis, S., Rietbergen-McCracken, J. & Sarre, A. (Eds.)., *The forest landscape restoration handbook*. Routledge, 2012.
96. Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A. & Turner, B., Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, 375(1794), 20190120, 2020.
97. Bustamante, M., Silva, J.S., Scariot, A., Sampaio, A.B., Mascia, D.L., Garcia, E. & Nobre, C., Ecological restoration as a strategy for mitigating and adapting to climate change: lessons and challenges from Brazil. *Mitigation and Adaptation Strategies for Global Change*, 24(7), 1249-1270, 2019.
98. Mansourian, S. & Berrahmouni, N., *Review of forest and landscape restoration in Africa 2021*. Food & Agriculture Organisation.
99. Brack, D. (2018, May). Sustainable consumption and production of forest products. In *Proceedings of the Thirteenth Session of the United Nations Forum on Forests, New York, NY, USA* (pp. 7-11), 2021.
100. Nilsson, M., Griggs, D. & Visbeck, M., Policy: map the interactions between Sustainable Development Goals. *Nature*, *534*(7607), 320-322, 2016.

101. Campbell, B.M., Hansen, J., Rioux, J., Stirling, C.M. & Twomlow, S., Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. *Current opinion in environmental sustainability*, 34, 13-20, 2018.
102. Mansourian, S. & Vallauri, D., Restoringforest landscapes: important lessons learnt. *Environmental Management*, 53(2), 241-251, 2014.
103. Sun, F., Xiang, J., Tao, Y., Tong, C. & Che, Y., Mapping the social values for ecosystem services in urban green spaces: Integrating a visitor-employed photography method into SolVES. *Urban Forestry & Urban Greening*, 38, 105-113, 2019.
104. Sherrouse, B.C., Semmens, D.J. & Clement, J.M., An application of Social Values for Ecosystem Services (SolVES) to three national forests in Colorado and Wyoming. *Ecological Indicators*, 36, 68-79, 2014.
105. Villa, F., Bagstad, K.J., Voigt, B., Johnson, G.W., Portela, R., Honzák, M. & Batker, D., A methodology for adaptable and robust ecosystem services assessment. *PloS one*, 9(3), e91001, 2014.
106. Cong, W., Sun, X., Guo, H. & Shan, R., Comparison of the SWAT and InVEST models to determine hydrological ecosystem service spatial patterns, priorities and trade-offs in a complex basin. *Ecological Indicators*, 112, 106089, 2020.
107. Tallis, H. & Polasky, S., Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences*, 1162(1), 265-283, 2009.
108. Birch, J.C., Thapa, I., Balmford, A., Bradbury, R.B., Brown, C., Butchart, S.H. & Thomas, D.H., What benefits do community forests provide, and to whom? A rapid assessment of ecosystem services from a Himalayan forest, Nepal. *Ecosystem Services*, 8, 118-127, 2014.
109. Peh, K.S.H., Balmford, A., Bradbury, R.B., Brown, C., Butchart, S.H., Hughes, F.M. & Birch, J.C., TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. *Ecosystem Services*, 5, 51-57, 2013.
110. Boumans, R., Roman, J., Altman, I. & Kaufman, L., The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems. *Ecosystem services*, 12, 30-41, 2015.
111. Wainaina, P., Minang, P.A., Gituku, E. & Duguma, L., Cost-benefit analysis of landscape restoration: a stocktake. *Land*, 9(11), 465, 2020.
112. Mulligan, M., Trading off Agriculture with Nature's Other Benefits, Spatially. In *Impact of climate change on water resources in agriculture* (pp. 192-212). CRC Press, 2015.
113. Fremout, T., Thomas, E., Taedoumg, H., Briers, S., Gutiérrez-Miranda, C. E., Alcázar-Caicedo, C. & Muys, B., Diversity for Restoration (D4R): Guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. *Journal of Applied Ecology*, 59(3), 664-679, 2022.
114. Vâgen, T.G., Winowiecki, L.A., Walsh, M.G., Tamene, L. & Tondoh, J.E., Land Degradation Surveillance Framework (LSDF): field guide, 2010.

115. International Union for Conservation of Nature (IUCN). Forest Landscape Restoration. Available online: https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration (accessed on 20 April 2022).
116. Baker, T., McCartney, M.P. & Mul, M.L., Concept note on ecosystem services mapping and linkages to models. Project report submitted to IUCN under the project "Water Infrastructure Solutions from Ecosystem Services Underpinning Climate Resilient Policies and Programmes (WISE-UP to Climate)" Gland, Switzerland: International Union for Conservation of Nature (IUCN). (4), 2014.
117. Monty, F., Murti, R., Miththapala, S. & Buyck, C. (eds)., Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation. Gland, Switzerland: IUCN. 108, 2017.
118. Dave, R., Saint-Laurent, C., Moraes, M., Simonit, S., Raes, L. & Karangwa, C., Bonn Challenge Barometer of Progress: Spotlight Report 2017. Gland, Switzerland: IUCN, 36, 2017.
119. Gilbey, B., A review of the Land Degradation Neutrality Process. IUCN, 2018.
120. Schuh, B. & Pesic, M., ADAPT: Nature-based Solutions for Resilient Societies in the Western Balkans. Mid Term Review - Final Report, ECARO and IUCN, 2021.
121. Cohen-Shacham, E., Walters, G., Janzen, C. & Maginnis, S., Nature-based solutions to address global societal challenges. *IUCN: Gland, Switzerland*, 97, 2016-036, 2016.
122. Domisch, S., Kakouei, K., Martínez-López, J., Bagstad, K.J., Magrach, A., Balbi, S., & Langhans, S.D., Social equity shapes zone-selection: Balancing aquatic biodiversity conservation and ecosystem services delivery in the transboundary Danube River Basin. *Science of the Total Environment*, 656, 797-807, 2019.
123. Wang, Y., Fu, B.T., Lyu, Y.P., Yang, K. & Che, Y., Assessment of the social values of ecosystem services based on SolVES model: A case study of Wusong Paotaiwan Wetland Forest Park, Shanghai, China. *Ying Yong Sheng tai xue bao= Journal of Applied Ecology*, 27(6), 1767-1774, 2016.
124. Cotter, M., Häuser, I., Harich, FK., He, P., Sauerborn, J., Treydte, A.C. & Cadisch, G., Biodiversity and ecosystem services– A case study for the assessment of multiple species and functional diversity levels in a cultural landscape. *Ecological Indicators*, 75, 111-117, 2017.
125. Liu, S., Liao, Q., Xiao, M., Zhao, D. & Huang, C., Spatial and Temporal Variations of Habitat Quality and Its Response of Landscape Dynamic in the Three Gorges Reservoir Area, China. *International Journal of Environmental Research and Public Health*, 19(6), 3594, 2022.
126. Burgess, P., Li, X. & Qin, S., Mangroves in Ecuador: An application and comparison of ecosystem service models. Master's project, Duke University, 2015.
127. ITTO, Guidelines for forest landscape restoration in the tropics. Yokohama, Japan: International Tropical Timber Organization, 2020.

128. Boedhihartono, A.K. & Sayer, J., Forest landscape restoration: restoring what and for whom? In *Forest landscape restoration* (pp. 309-323). Springer, Dordrecht, 2012.
129. Mansourian, S., Parrotta, J., Balaji, P., Bellwood-Howard, I., Bhasme, S., Bixler, R. P. & Yang, A., Putting the pieces together: integration for forest landscape restoration implementation. *Land Degradation & Development*, 31(4), 419-429, 2020.
130. Höhl, M., Ahimbisibwe, V., Stanturf, J.A., Elsasser, P., Kleine, M. & Bolte, A., Forest landscape restoration—what generates failure and success? *Forests*, 11(9), 938, 2020.
131. Newton, A.C., Del Castillo, R.F., Echeverría, C., Geneletti, D., González-Espinosa, M., Malizia, L.R. & Williams-Linera, G., Forest landscape restoration in the drylands of Latin America. *Ecology and Society*, 17(1), 2012.
132. Ullah, A., Sam, A.S., Sathyan, A.R., Mahmood, N., Zeb, A. & Kächele, H., Role of local communities in forest landscape restoration: Key lessons from the Billion Trees Afforestation Project, Pakistan. *Science of the Total Environment*, 772, 145613, 2021.
133. Reed, M., Stakeholder participation for environmental management: a literature review. *Biological Conservation*, 14110, 2417-2431. http://dx.doi.org/10.1016/j.biocon.2008.07.014, 2008.
134. Chazdon, R.L. & Guariguata, M.R., *Decision support tools for forest landscape restoration: Current status and future outlook* (Vol. 183). CIFOR, (2018).
135. Orsi, F., Geneletti, D. & Newton, A.C., Towards a common set of criteria and indicators to identify restoration priorities: An expert panel-based approach. *Ecological Indicators*, 11, 337–47, 2011.
136. Brancalion, P.H., Schweizer, D., Gaudare, U., Mangueira, J.R., Lamonato, F., Farah, F.T. & Rodrigues, R.R., Balancing economic costs and ecological outcomes of passive and active restoration in agricultural landscapes: the case of Brazil. *Biotropica*, 48(6), 856-867, 2016.
137. Brancalion, P.H., Viani, R.A., Strassburg, B.B.N. & Rodrigues, R.R., Finding the money for tropical forest restoration. *Unasylva*, 63(1), 25-34, 2012.
138. Rey Benayas, J.M., Altamirano, A., Miranda, A., Catalán, G., Prado, M., Lisón, F. & Bullock, J.M., Landscape restoration in a mixed agricultural-forest catchment: Planning a buffer strip and hedgerow network in a Chilean biodiversity hotspot. *Ambio*, 49(1), 310-323, 2020.
139. Dave, R., Saint-Laurent, C., Murray, L., Antunes Daldegan, G., Brouwer, R., de Mattos Scaramuzza, C.A. & Pearson, T., Second Bonn challenge progress report. *Application of the Barometer in2019*, 2018.
140. Mansuy, N. & MacAfee, K., More than planting trees: career opportunities in ecological restoration. *Frontiers in Ecology and the Environment*, 17(6), 355-356, 2019.
141. Verdone, M. & Seidl, A., Time, space, place, and the Bonn Challenge global forest restoration target. *Restoration Ecology*, 25(6), 903-911, 2017.

142. Meli, P., Rey-Benayas, J.M. & Brancalion, P.H., Balancing land sharing and sparing approaches to promote forest and landscape restoration in agricultural landscapes: Land approaches for forest landscape restoration. *Perspectives in Ecology and Conservation*, 17(4), 201-205, 2019.
143. Banks-Leite, C., Pardini, R., Tambosi, L.R., Pearse, W.D., Bueno, A.A., Bruscagin, R.T. & Metzger, J.P., Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science*, 345(6200), 1041-1045, 2014.
144. Stanturf, J.A. & Mansourian, S., Forest landscape restoration: state of play. *Royal Society open science*, 7(12), 201218, 2020.
145. Vallauri, D., Aronson, J., Dudley, N. & Vallejo, R., Monitoring and evaluating forest restoration success. In *Forest restoration in landscapes*: *beyond planting trees* (eds. S Mansourian, D Vallauri, N Dudley), pp. 150-158. Berlin, Germany: Springer, 2005.
146. Morrison, E.B. & Lindell, C.A., Active or passive forest restoration? Assessing restoration alternatives with avian foraging behavior. *Restoration Ecology*, 19(201), 170-177, 2011.
147. Stanturf, J.A., Palik, B.J. & Dumroese, R.K., Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management*, 331, 292-323, 2014.
148. Dumroese, K.R., Landis, T.D., Pinto, J.R., Haase, D.L., Wilkinson, K.W. & Davis, A.S., Meeting forest restoration challenges: using the target plant concept. *Reforesta*, 1(1), 37-52, 2016.
149. Chazdon, R.L., Herbohn, J., Mukul, S.A., Gregorio, N., Ota, L., Harrison, R.D. & Gutierrez, V., Manila declaration on forest and landscape restoration: making it happen. *Forests*, 11(6), 685, 2020.
150. Reinecke, S. & Blum, M., Discourses across scales on forest landscape restoration. *Sustainability*, 10(3), 613, 2018.
151. Harvey, C.A. & Guariguata, M.R., Raising the profile of woodfuels in the forest landscape restoration agenda. *Conservation Science and Practice*, 3(2), e342, 2021.
152. Stanturf, J.A., Forest landscape restoration: building on the past for future success. *Restoration Ecology*, 29(4), e13349, 2021.
153. Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E. & Buck, L.E., Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences*, 110(21), 8349-8356, 2013.
154. Kusters, K., Buck, L., de Graaf, M., Minang, P., van Oosten, C. & Zagt, R., Participatory planning, monitoring and evaluation of multi-stakeholder platforms in integrated landscape initiatives. *Environmental Management*, 62(1), 170-181, 2018.
155. Evans, K., Guariguata, M.R. & Brancalion, P. H., Participatory monitoring to connect local and global priorities for forest restoration. *Conservation Biology*, 32(3), 525-534, 2018.

156. Sayer, J., Margules, C., Boedhihartono, A.K., Sunderland, T., Langston, J.D., Reed, J., Riggs, R., Buck, L.E., Campbell, B.M. & Kusters, K., Measuring the effectiveness of landscape approaches to conservation and development. *Sustainability Science*, 12, 465-476, 2017.
157. Guariguata, M.R. & Evans, K., A diagnostic for collaborative monitoring in forest landscape restoration. *Restoration Ecology*, 28(4), 742-749, 2020.
158. Hanson, C., Buckingham, K., DeWitt, S. & Laestadius, L., The restoration diagnostic: A Method for Developing Forest Landscape Restoration Strategies by Rapidly Assessing the Status of Key Success Factors. Version 1.0. World Resources Institute, Washington D.C., 2015.
159. Ciecko, L., Kimmett, D., Saunders, J., Katz, R., Wolf, K.L., Bazinet, O. & Blahna, D. J., Forest Landscape Assessment Tool (FLAT): rapid assessment for land management. *Gen. Tech. Rep. PNW-GTR-941. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.* 51 p., 941, 2016.
160. IUCN and WRI., "A Guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing Forest Landscape Restoration Opportunities at the National or Sub-National Level. Working Paper (Road-Test Edition)." Gland, Switzerland: International Union for Conservation of Nature, 2014.
161. IUCN, Gender-Responsive Restoration Guidelines: A Closer Look at Gender in the Restoration Opportunities Assessment Methodology. International Union for Conservation of Nature, Gland, Switzerland, 2017.
162. Beatty, C.R., Vidal, A., Devesa, T. & Kuzee, M., Accelerating Biodiversity Commitments through Forest Landscape Restoration; Evidence from Assessments in 26 Countries Using the Restoration Opportunities Assessment Methodology (ROAM). Gland, Switzerland: International Union for Conservation of Nature, 2020.
163. Kumar, C., Begeladze, S., Calmon, M. & Saint-Laurent, C. (eds.), Enhancing food security through forest landscape restoration: Lessons from Burkina Faso, Brazil, Guatemala, Viet Nam, Ghana, Ethiopia and Philippines. Gland, Switzerland: IUCN. pp. 5-217, 2015.
164. Campese, J., Mansourian, S., Walters, G., Hamzah, A., Brown, B., Nuesiri, E.O. & Bugembe, N., Advancing Landscape Governance: An Analysis and Recommendations to Strengthen Governance in Restoration Opportunities Assessment Methodology. Gland, Switzerland: International Union for Conservation of Nature & Commission Environmental, Social, and Economic Policy, 2021.
165. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
166. Jhariya, M.K., Yadav, D.K. & Banerjee, A., Agroforestry and Climate Change: Issues and Challenges. Apple Academic Press Inc., CRC Press - a Taylor and

Francis Group. ISBN:978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book), pp. 335, 2019b. https://doi.org/10.1201/9780429057274

167. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, 112829, 2021a. Elsevier. https://doi.org/10.1016/j.jenvman.2021.112829
168. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1): 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
169. Raj, A., Jhariya, M.K. & Khan, N., *Forest for soil, food and climate security in Asia*. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
170. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888110, pp. 400, 2020. https://doi.org/10.1201/9780429276026
171. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019a. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
172. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management*. Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
173. Jhariya, M.K., Meena, R.S. & Banerjee, A., *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore. eISBN: 978-981-334-203-3, Hardcover ISBN: 978-981-334-206-6, pp. 655, 2021. Doi: 10.1007/978-981-33-4203-3.
174. Jhariya, M.K., Meena, R.S., Banerjee, A. & Meena, S.N., *Natural Resources Conservation and Advances for Sustainability*. Elsevier, Academic Press. ISBN: 9780128229767, pp. 650, 2022. https://doi.org/10.1016/C2019-0-03763-6
175. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021a, ISBN 978-981-15-9495-3, pp. 221-246, 2021a. https://doi.org/10.1007/978-981-15-9496-0_7
176. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al*. (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021b, ISBN 978-981-15-9495-3. Pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-0_14

8

Ecological Restoration of Degraded Land through Afforestation Activities

P. R. Oraon[1]*, Vidya Sagar[1] and Kumari Beauty[2]

[1]*Department of Silviculture & Agroforestry, Faculty of Forestry, Birsa Agricultural University, Ranchi, Jharkhand, India*
[2]*Forest Research Centre for Eco-Rehabilitation, Prayagraj, U.P., India*

Abstract

Land degradation is a global challenge for the environmentalist. The continuous degradation of land destroys soil quality, ecological stability, ecosystem functioning and environmental health. Land degradation deteriorates natural resources including forest, soil, and agriculture, which further affects soil, food and climate security. Deforestation, intensive agriculture, mining activities and various problematic soils affect ecosystem health and environmental sustainability. In this context, afforestation activities not only reverse land quality but also help in ecological restoration and climate change mitigation for the long term. Eco-restoration of degraded land through afforestation and sustainable forest management (SFM) practices ensure greater ecological stability and sustainability in the climate change era. Thus, afforestation activities must be employed in degraded and wasteland including problematic soils such as saline, waterlogged, marshy, coastal and sandy land. Problematic soil can be restored through better scientific practices of afforestation which are further strengthened by SFM practices. Furthermore, an effective policy and governance catalyze afforestation activities in degraded land which further meet global timber, fuelwood, food and fodder demands along with greater greenery forest covers on the earth.

***Keywords*:** Afforestation, land degradation, problematic soil, SFM, deforestation, ecological restoration

**Corresponding author*: prabhat.ranjan.oraon@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (201–216) © 2023 Scrivener Publishing LLC

8.1 Introduction

Land degradation is known as the greatest threat causing severe environmental issues around the globe [1]. Decline in the productive capacity and of an ecosystem is known as land degradation [2]. There is a global increment in the area and severity of land degradation, particularly in the Northern Hemispheric dry land [3]. Additionally, land degradation also alters the soil structure and its potential to retain and supply nutrients and water [4, 5]. LDN alleviates land degradation mainly through land management and ecological restoration to eventually improve and maintain the contribution of land to sustain the ecosystem [6]. To counter the widespread and ever-increasing cases of land deterioration, the International Decade of Deserts and Desertification program was launched. It began its sectional evaluation of land degradation to draw the attention of people worldwide. The Sustainable Development Goals (SDGs) identified the land degradation problem as the most severe environmental problem and suggested that LDN should be provided some special priority to resolve the issue [7, 8].

Ecological restoration is an activity that escalates the improvement of an ecosphere that has been degraded, damaged or destroyed. Ecosystems are potent communities of animals, plants, and microorganisms continuously interacting among themselves and their surroundings and environment as a structural and functional unit. These communities can be degraded, damaged, or destroyed by various anthropogenic activities. Degradation can be identified as chronic human interference resulting in the disbalance of an ecosystem's function and structure and the loss of biodiversity and composition. Examples include long-term hunting or overfishing pressure, long-term grazing effects and regular invasions by exotic species. Ecological restoration generally initiates and accelerates the recovery process of the ecosystem against degradation, damage, or destruction. The objective of ecological restoration is to restore a degraded ecosystem to its historical trajectory. Ecological restoration aims to reorganise a self-organising and self-sustaining ecosystem on a path towards full recovery. Restoration activities can sometimes provide quick initial recovery for the degraded ecosystem. Still, complete recovery of the ecosystem is a relatively slow process that can often take years, decades or even centuries.

Afforestation is known as activities related to establishing and maintaining a forest or plantation site or stands of trees in an area or a degraded land where there was either no previous tree cover or damaged forest covers due to natural calamities and harmful human activities. Afforestation assists in stabilising the climate of a specified region and helps transform semi-arid and arid areas into comparatively more productive areas. The tree species planted during the afforestation help minimise the greenhouse gas effect, which further helps prevent global issues such as global warming. Afforestation activities help lower and maintain the CO_2 and other harmful GHGs (greenhouse gases) to improve the ecological conditions that arise, primarily due to land degradation and deforestation like anthropogenic activities. Degraded lands can be restored for their potential services by applying various afforestation activities based on edaphic and climatic factors of the specified site and the species that most suit a particular region to enhance its ecological conditions. This chapter discusses the extent and severity of land degradation, its global impact and ecological restoration through afforestation activities.

8.2 Concept of Ecological Restoration

Ecological restoration is restoring natural sites whose interacting groups of biological communities and ecosystems have been destroyed or degraded. It mainly focuses on restoring the natural areas at their most possible earlier native conditions, which were impaired due to various human activities, including deforestation, pollution, and the burning of fossil fuels. Ecological restoration is relatively different from conservation practices as the latter is generally concerned with preventing further degradation of the ecosystem. In contrast, the former is concerned with the restoration of degraded ecosystems. To restore ecosystems to their full potential, restoring specialists apply ecological concepts. Ecological succession may be known as the long-term evolutionary change in an ecosystem's structure and biological community. This succession process also plays a crucial role in restoring any degraded ecosystem. Soil rehabilitation and land stabilisation are among the components of active restoration. This component generally includes restoring the original physical, chemical and biological properties of the water or soil.

8.3 Global Scenario of Land Degradation

The global initiation and spread of the land degradation problem have been closely associated with the introduction, growth and spread of human populations and their increasing demands for naturally available resources. The primary reason is that inappropriate land utilization is influenced by economic, political, social, and technological factors. Another reason is the unavailability of authentic global maps related to the severity and extent of land degradation [9, 10], despite the significant issue of land degradation around the globe [11]. The possible causes are both methodological – that is, how it can be quantified [12] and conceptual – how land degradation is identified, using what criterion [13] or around what period. The first reasonably carefully documented illustration of land degradation comes from ancient Mesopotamia, the irrigated lands in the Euphrates River systems and Tigris. Secondary waterlogging, salinization, and severe soil fertility decline were the primary problems [14]. Pressure on the universal land resource is continuously increasing due to the following factors:

1. Competition for available fertile land resources for urban expansion, biofuel and other non-productive uses;
2. Incapacitate resilience of forest and agricultural production systems as a consequence of associated ecosystem services and the depleted biodiversity;
3. Deficiency of growth in productivity due to a decrease in soil health which is generally indicated by lower available nutrient status and other soil degradation processes;
4. Natural factors such as extreme weather events and climate variability;
5. Growing demand for forest and agricultural commodities regarding both quantity and quality for an ever-increasing and more prosperous world population;
6. Climate change exacerbates vegetative yield and livelihood variations, alarming the ecosystem's resilience and stability of food production systems.

8.4 Perspective of Land Degradation

"Land" includes the soil resource and the landscape, vegetation, water and micro-climatic components of an ecosphere. "Land degradation" suggests a short-term or permanent reduction in the land's productive capacity or its capacity for sustainable environmental management. "Degradation" is also known as a process of transformation over the course of time. From a policy approach, it is crucial to differentiate those presently undergoing degradation lands to estimate the need for action to balance or reverse the operation. Many decades or centuries ago, some lands may have been in a degenerating state compared to "natural" conditions but are currently in an improving situation. Forest degradation is known as the degradation of remaining forest stands. In contrast, deforestation is converting forests for non-forest purposes that involve an alteration in land use and a loss of tree cover. The essential smallholding effects of land degradation are diminishing potential yields. The probable threat of degradation can also be seen in the need to use more significant inputs to sustain profits. Severe degradation in some cases results in temporary or permanent evacuation of some plots. Sometimes, degradation prompts farmers to transform the land into less desirable utilities; for example, low-valued cassava may be replaced for maize, non-cultivating periods may be stretched and croplands may be transformed into grazing lands or forests. For some farmers, land degradation can cause economic problems on a specific plot: they keep fallow that plot for some duration or use the eroded soil from the field to build up surface soil on a relatively flatter down slope of the plot. Furthermore, degradation processes such as soil erosion are not certainly linked with decrease in biomass yield; the threshold of productivity response to a change in land quality can occur according to different criteria, depending on soil type or depth and the species or variety of crop. Moreover, an interaction exists between environment (E) and human (H) of a land system that ensures a key linkage among ecosystem services and decision-making capabilities (Figure 8.1) [15, 16].

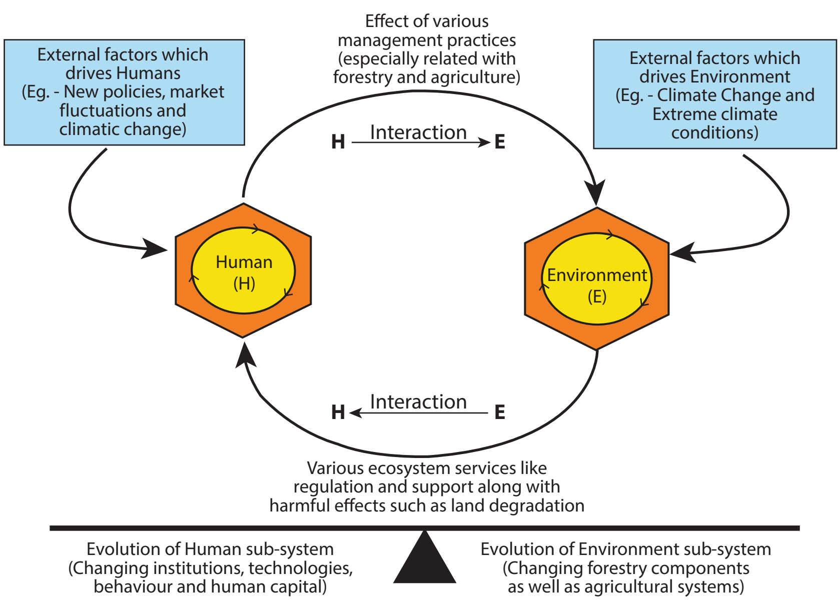

Figure 8.1 Diagrammatic representation of interaction between Environment (E) and Human (H) of a land system key linkage among ecosystem services and decision-making capabilities [15, 16].

8.5 Land Degradation under Changing Climate

Anthropogenic activities induce land degradation that cause emission of GHGs into the atmosphere, which leads to C footprint and climate change issues. A suitable land management practice and sustainable land use system including agroforestry check GHGs (CO_2) emissions and enhance C sequestration potential in vegetation and soils. These activities not only minimize climate change impacts but also restore soil fertility and land quality [17, 18]. However, afforestation activities including leguminous trees enhance biomass, carbon and nitrogen status into the vegetation and soils [19–23]. Forests improve biomass and carbon status into the vegetation and soils that suppress the climate change consequences [24–26]. Applying sustainable intensification in any land use practices ensures agroecosystem-based soil, food and climate security [27, 28]. Similarly, a sustainable or degraded outcome can be determined by the interaction of climate change with land management practices, which is depicted in Figure 8.2 [29, 30]. However, there is a connection between land management, climate change and socio-economic conditions represented in Figure 8.3 [31, 30].

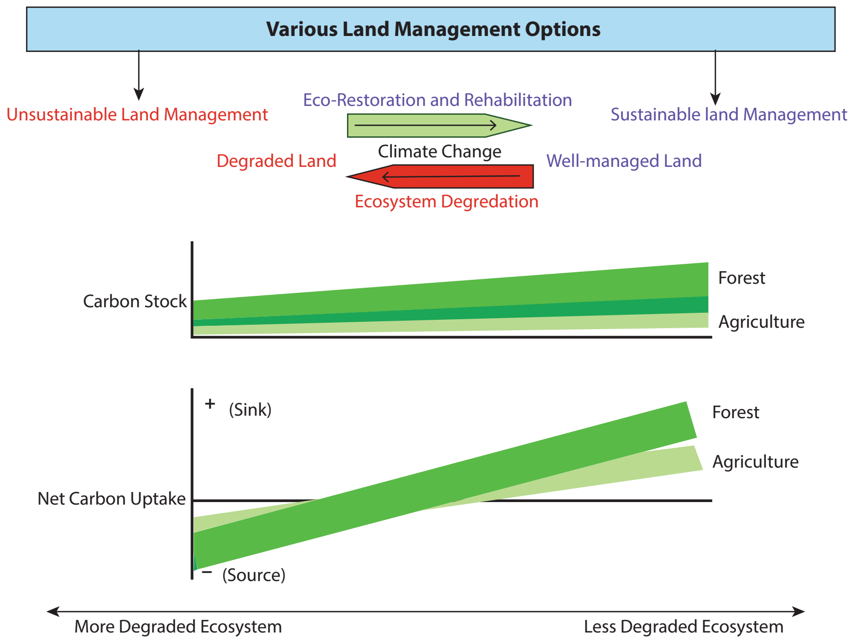

Figure 8.2 Conceptual figures indicating that sustainable or degraded outcomes can be determined by the interaction of climate change with land management practices [29, 30].

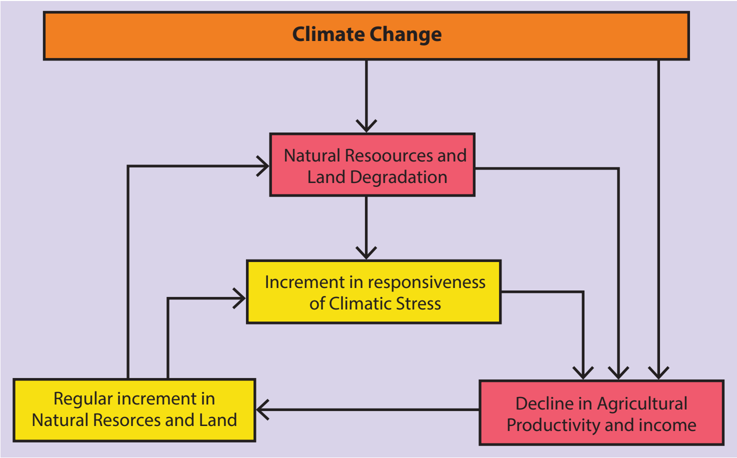

Figure 8.3 Diagrammatic representations of connections between land management, climate change and socioeconomic conditions [31, 30].

8.6 Afforestation for Climate Change Mitigation

Afforestation refers to establishing a forest, particularly on land that did not contain the forest previously. It serves as one of the most effective measures of tackling climate change, especially when designed to depend on green energy. This natural climate solution can reduce the impact of desertification by this natural climate solution to support ecosystems and removing CO_2 from the atmosphere. It is a shift against deforestation, which has contributed mainly to climate change dramatically for the last few centuries. The Intergovernmental Panel on Climate Change (IPCC) clarifies that deforestation is a direct cause of the enhanced presence of CO_2 in the atmosphere over the past few decades. This rise is not equivalent to any other period in the past two million years. Forests cycle damaging carbon out of the atmosphere, can act as a carbon sink, and transform light into bioenergy and carbon into biomass by photosynthesis. Afforestation can reduce or slow down the impact of climate change while also directing other environmental issues, such as soil erosion and barren land. Research from Crowther Lab indicated that one trillion new trees could absorb about one-third of CO_2 emitted into the atmosphere by human activities. In reality, an additional 25% of the forested area could soak up 25% of atmospheric carbon, making a critical impact on ever-increasing temperatures around the globe.

8.7 Afforestation for Problematic Soil and Land Management

Soil health is frequently evaluated in isolation, without reference to interconnected soil functions, and is also based on a few parameters soil test. In soil health management, the soil's physico-chemical condition and biological fertility are disregarded, necessitating a revisit by soil users. Agriculture is a significant issue in India, the world's second-most populous country. It is estimated that 173.65 million hectares of India's entire geographical area are degraded, yielding less than 20% of its potential output. The variable nature of crop production patterns is due to soil heterogeneity. Soil heterogeneity occurs when the texture, topography, fertility, drainage, moisture content, and other soil characteristics in a small region vary substantially. The problem of soil appropriateness for agriculture emerges if it exists on a wide scale due to human actions. Soil comprises a solid phase (organic materials and minerals) and a porous phase (gases and water). As a result, soils are frequently thought of as a three-state system. In terms of agriculture, the soil should be able to sustain all of the functions. Problem soils have features that make it uneconomical to cultivate crops without implementing suitable reclamation methods. We frequently use chemical methods of reclamation, which compromise ecosystem functioning. Natural and integrative techniques will fix the problem and prevent irreversible damage. Agroforestry systems like agri-silviculture, silvopasture, etc., can modify the Physico-chemical properties of the soil on a long-term basis. Some grasses like *Cynodondactylon* (Bermuda grass) and *Brachariamutica* (Para grass) have produced a 50% yield. The most suitable tree species are *Acacia nilotica, A. auriculiformis* and *Terminalia arjuna*, *Pithecellobium dulce*, *Pongamia pinnata*, *Azadirachta indica*, *Cassia siamea, C. equisetifolia, Acacia nilotica, Prosopis alba, Eucalyptus tereticornis*, etc.

8.7.1 Saline-Alkaline Soils

In the afforestation of such soils, the proper method of soil manipulation is critical. Varying soil works, such as pits, auger holes, and trenches of diverse sizes and forms, are utilized in various regions to meet these requirements. Mounds, on the other hand, are built-in waterlogged environments. Some soil amendments, such as Gypsum, farm yard manure, or molasses, should be utilized for long-term soil improvement.

The best tree species to plant depends on the local agro-climate, land availability, planting purpose, tolerance to salinity/alkalinity, and drought stress. Plantations for fuelwood are generally rated higher for salty salts than timber wood tree species. Tolerances of forest tree species vary with growth phases and inter- and intragenic variability in salt tolerance. It should also be illustrated that, in addition to salt tolerance, societal and economic situations and the beneficial role of trees should be considered when selecting tree species for afforestation schemes. Some species have been scored higher than others among the main species of arid and semi-arid environments. Some of the species are *Acacia nilofica, Butea monosperma, Casuarina equisetifolia, Prosopjsjuljflora, Aegle marmelos, Albizzia lebbeck Carissa carandua, Cassia siamea, Eucalyptus fereticornis, Dalbergia sissoo, Feronia Jimonia, Pongamiapinnala, Terminaiia arjuna, Zizyphusmaurtiana, Azardirachta indica,* etc.

8.7.2 Afforestation in Waterlogged/Marshy Land

One of the primary abiotic stressors impacting crop growth is waterlogging [32, 33]. Waterlogging events are becoming increasingly common, severe, and unexpected due to global climate change [34–36]. Locations that are already wet will get even wetter, and protracted waterlogging will become more common [37]. Appropriate soil and crop management strategies increase soil quality and crop productivity while being more environmentally friendly and cost-effective. By decreasing the requirement for new agricultural land, flexibility is gained [38–40]. Improved soil management can promote infiltration, reduce surface run-off and improve water and nutrient availability for plants [41–44]. Crop management can help increase yields [45].

8.7.3 Afforestation in Mined-Out Areas

The creation of many mining spoil dumps has a significant impact on the landscape. The dump material requires a secure location for disposal. Due to environmental restrictions, forest land, and agricultural land, obtaining land around the mine is especially difficult. Environmental deterioration such as land, water, air, and ecological changes are linked to dumping failure [46]. The amount of available area is restricted, making it difficult to manage the dump on the defined property. Optimizing the slope for improved dump material adjustment is the best solution [47]. With billions of tonnes produced annually, mine dumps account for the largest share of waste created by industrial activities [48]. They are among the most popular methods for controlling soil erosion and stabilization of dump slopes and, as a result, maintaining ecological stability of the area is re-vegetation with trees and grasses [49–52].

Plants to be grown in a specific place are chosen based on the type of soil, the climate of the area, and the intended purpose of the land. Furthermore, there may be certain special local factors in plant material selection. Insect resistance, disease resistance, landscape planting, growth habits and compatibility with other plants, and availability of seeds or root stock of the particular species are all examples of local conditions. Generally, native species of plants are most commonly used for re-vegetation. The native species easily adapt to the local climate. Moreover, the rehabilitated site is in harmony with the local landscape and encourages recolonization by the wildlife. Some of the tree species suitable for the afforestation of the mined-out areas are *Prosopis cineraria, Zizyphus mauritiana, Acacia Senegal, Acacia nilotica, Butea monosperma, Leucaena leucocephala, Eucalyptus tereticornis, Terminalia arjuna, Tamarindus indica, Salix*, *Dalbergia sissoo, Pinus roxburghii, Cassia fistula, Delonix regia*, etc.

8.7.4 Afforestation in Coastal and Sandy Areas

Large amounts of sand accumulate along the sea coast due to tides. Afforestation of coastal sands has been undertaken in all states with a sea coast to mobilize sands driven inland by high winds and put these sandy wastes to productive uses to meet the ever-increasing need for firewood. For most of the sea coast, *Casuarina equisetifolia* is the best species. It is quick growing, hardy and easy to raise. Other species which can be successfully raised are *Eucalyptus hybrid, Pongamia pinnata, Acacia auriculaeformis, Prosopis juliflora and Calophylluminophyllum*.

8.8 Policy Initiative in Land Degradation and Afforestation

A successful response to land degradation and afforestation calls for enhancing farmers' motivations to supervise their land and upgrading their approach to the knowledge needed for suitable care. The ten recommendations are based on the workshop discussions learned from previous achievements and failures in supervising land degradation.

There is a demand to increase consciousness about land degradation and developmental issues among the broader social and political leaders. These land issues in farming need to be consolidated broadly into rural extension services and educational programs. High priorities are given to encourage public funding in research to visualize land degradation and development and improve yield-enhancing and resource-conserving technology. A more effective practice is required to survey and inventory land degradation which further improves valuable ecological services. While national and international governments have a clear role in information transfer, coordination and research in several countries, the prominent role in promoting land-improving funding will account for local governmental organizations. While current efforts at government broadcast should, in the long term, improve the quality and level of public concern for land degradation problems, in the meantime, there are severe shortfalls in the capacity of local government and investment to be overcome.

Greater dependency on local communities to direct land-use management proceedings has many suggestions for public policy reforms. First, it requires that complicated permit systems and restrictions for local communities/organizations be lifted to decrease the organization prices. Second, local organizations may require support to modify their management role. Public agencies and local organizations frequently need to work simultaneously to attain land management objectives, and institutions need to be redesigned to play this pivotal role. New arrangements for association between NGOs, local public organizations, and research institutions need to effectively develop and adopt resource-conserving, yield-improving technologies.

8.9 Conclusion

Land degradation could be a conceivably serious threat to rural livelihoods and livelihood production by 2030, especially in highly populated pockets of countryside poverty. Further enlargement of cultivable land for agriculture into areas of delicate soils or assigned as critical habitats for ecological diversity conservation practices can lead to significant land degradation and environmental degradation unless carefully supervised. Several ways of land degradation can certainly be reversed, but the practice needs long-term dedication and responsibilities. Land-modifying investments and improved land management practices can be motivated through suitable working policies. Enhanced information technologies and improved regular research and development are required to grow and spread information on technically sound options. Public funding, training programs, co-financing and helpful property rights can encourage farmer and industrial investment in ecology and land improvement programs. Institutional revolutions in land use planning, particularly assistance for local organizations and farmers, should be explored. The larger policy context should also provide assistance for rural development, develop marketing infrastructure, encourage rural economic growth, correct disturbed price incentives and diversification, and reduce inequity against marginal areas in public stake. Thus, policymakers must evaluate the kinds of degradation problems that will be crucial for their countries in 2022 and initiate serious action now. The international group can play a stimulant role in encouraging such planning, developing information systems, supporting research, and comparing experiences of diverse countries with different policy approaches and tools.

References

1. Chi, W., Zhao, Y., Kuang, W. & He, H., Impacts of anthropogenic land use/cover changes on soil wind erosion in China. *Sci. Total Environ*. 668, 204-215, 2019.
2. United Nations Convention to Combat Desertification (UNCCD), Land in Balance. The Scientific Conceptual Framework for Land Degradation Neutrality (LDN). Science-Policy Brief 02. September 2016. Science-Policy Interface, Bonn, Germany, 2016.
3. Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schuett, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L. & Panagos, P., An assessment of the global impact of 21st century land use change on soil erosion. *Nat. Commun.* 8, 1-13, 2017.
4. Wei, S., Zhang, X., McLaughlin, N., Chen, X., Jia, S. & Liang, A., Impact of soil water erosion processes on catchment export of soil aggregates and associated SOC. *Geoderma*, 294, 63-69, 2017.
5. Duan, X., Bai, Z., Li, R., Li, Y., Ding, J., Tao, Y., Li, J. & Wang, W., Investigation method for regional soil erosion based on the Chinese Soil Loss Equation and high-resolution spatial data: a case study on the mountainous Yunnan Province, China. *Catena* 184, 104237, 2020.
6. Akhtar-Schuster, M., Stringer, L.C., Erlewein, A., Metternicht, G., Minelli, S., Safriel, U. & Sommer, S., Unpacking the concept of land degradation neutrality and addressing its operation through the Rio conventions. *J. Environ. Manag.,* 195, 1-15, 2017.
7. Orr, B.J., Cowie, A.L., Castillo-Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G.I., Minelli, S., Tengberg, A.E., Walter, S. & Welton, S., Scientific conceptual framework for land degradation neutrality. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, 2017.

8. Shen, Y., Zhang, C., Wang, X., Zou, X. & Kang, L., Statistical characteristics of wind erosion events in the erosion area of Northern China. *Catena*, 167, 399-410, 2018.
9. Gibbs, H.K. & Salmon, J.M., Mapping the world's degraded lands. *Appl. Geogr.,* 57, 12-21, doi: 10.1016/J.APGEOG.2014.11.024, 2015.
10. Van der Laan, C., Wicke, B., Verweij, P.A. & Faaij, A.P.C., Mitigation of unwanted direct and indirect land-use change – an integrated approach illustrated for palm oil, pulpwood, rubber and rice production in North and East Kalimantan, Indonesia. *GCB Bioenergy*, 9, 429-444, 2017.
11. Turner, K.G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., Dominati, E., Kubiszewski, I., Ogilvy, S., Porfirio, L. & Ratna, N., A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. *Ecological Modelling*, 319, 190-207, 2016.
12. Prince, S., Von Maltitz, G., Zhang, F., Byrne, K., Driscoll, C., Eshel, G., Kust, G., Martínez-Garza, C., Metzger, J.P., Midgley, G. & Moreno-Mateos, D., Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem functions. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2018.
13. Herrick, J.E., Shaver, P., Pyke, D.A., Pellant, M., Toledo, D. & Lepak, N., A strategy for defining the reference for land health and degradation assessments. *Ecological Indicators*, 97, 225-230, 2019.
14. Boyden, S., *Western Civilization in Biological Perspective: Patterns in History*. Oxford University Press, Oxford, 1987.
15. Liu, M., Wei, H., Dong, X., Wang, X.C., Zhao, B. & Zhang, Y., Integrating Land Use, Ecosystem Service, and Human Well-Being: A Systematic Review. *Sustainability*, 14(11), 6926, 2022.
16. Bennett, E.M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B.N., Geijzendorffer, I.R., Krug, C.B., Lavorel, S., Lazos, E. & Lebel, L., Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability*, 14, 76-85, 2015.
17. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
18. Raj, A., Jhariya, M.K., Yadav, D.K., Banerjee, A. & Meena, R. S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (Eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore Pte Ltd. 2019. ISBN ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4
19. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of*

Environmental Management, 293, 112829, 2021a. https://doi.org/10.1016/j.jenvman.2021.112829

20. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1), 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
21. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
22. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
23. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
24. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
25. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888110, pp. 400, 2020. https://doi.org/10.1201/9780429276026
26. Raj, A., Jhariya, M.K. & Khan, N., Forest for soil, food and climate security in Asia. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
27. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management*. Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
28. Jhariya, M.K., Meena, R.S., Banerjee, A. & Meena, S.N., *Natural Resources Conservation and Advances for Sustainability*. 2022. Elsevier, Academic Press. ISBN: 9780128229767. https://doi.org/10.1016/C2019-0-03763-6
29. Sivakumar, M.V. & Stefanski, R., Climate and land degradation—an overview. *Climate and Land Degradation*, 105-135, 2007.
30. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.),

Agroecological Footprints Management for Sustainable Food System, Springer Nature Singapore Pte Ltd. 2021, ISBN 978-981-15-9495-3, pp. 221-246. https://doi.org/10.1007/978-981-15-9496-0_7
31. Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M. & Hasegawa, T., Land-use futures in the shared socio-economic pathways. *Global Environmental Change*, 42, 331-345, 2017.
32. Linkemer, G., Board, J.E. & Musgrave, M.E., Waterlogging effects on growth and yield components in late-planted soybean. *Crop Sci.,* 38, 1576-1584, 1998.
33. Lone, A.A., Khan, M.H., Dar, Z.A. & Wani, S.H., Breeding strategies for improving growth and yield under waterlogging conditions in maize: a review. *Maydica*, 61, 11, 2018.
34. Jackson, M. & Colmer, T., Response and adaptation by plants to flooding stress. *Ann. Bot.* 96, 501-505, 2005.
35. Setter, T. & Waters, I., Review of prospects for germplasm improvement for waterlogging tolerance in wheat, barley and oats. *Plant Soil*, 253, 1-34, 2003.
36. Intergovernmental Panel on Climate Change [IPCC], Climate Change 2014: Synthesis Report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2014.
37. Dore, M.H., Climate change and changes in global precipitation patterns: what do we know? *Environ. Int.* 31, 1167-1181, 2005. doi: 10.1016/j.envint.2005.03.004,
38. Setter, T. & Belford, B., Waterlogging: how it reduces plant growth and how plants can overcome its effects. *J. Dep. Agric. West. Aust. Ser.*, 4, 51-55, 1990.
39. Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S., Agricultural sustainability and intensive production practices. *Nature*, 418, 671-677. doi: 10.1038/nature01014, 2002.
40. Shaxson, F. & Barber, R., Optimizing Soil Moisture for Plant Production: The Significance Of Soil Porosity. Rome: UN-FAO, 2003.
41. Amare, T., Terefe, A., Selassie, Y.G., Yitaferu, B., Wolfgramm, B. & Hurni, H., Soil properties and crop yields along the terraces and toposequece of Anjeni Watershed, Central Highlands of Ethiopia. *J. Agric. Sci.,* 5, 134, 2013.
42. Negusse, T., Yazew, E. & Tadesse, N., Quantification of the impact of integrated soil and water conservation measures on groundwater availability in Mendae Catchment, Abraha We-Atsebaha, eastern Tigray, Ethiopia. *Momona Ethiopian J. Sci.,* 5, 117-136, 2013.
43. Schmidt, E. & Zemadim, B., Expanding sustainable land management in Ethiopia: scenarios for improved agricultural water management in the Blue Nile. *Agric. Water Manag.,* 158, 166-178, 2015.
44. Masunaga, T. & Marques Fong, J.D., "Chapter 11 - strategies for increasing micronutrient availability in soil for plant uptake," in *Plant Micronutrient Use Efficiency*, eds. M, 2018.

45. Soomro, U.A., Rahman, M.U., Odhano, E.A., Gul, S. & Tareen, A.Q., Effects of sowing method and seed rate on growth and yield of wheat (*Triticum aestivum*). *World J. Agric. Sci.*, 5, 159-162, 2009.
46. Singh, T.N., Barde, K.S., Purwar, N., Gupta, S. & Sarkar, K., Effects of heightening on overburden spoil dump stability. *Min Eng J.,* 9(2), 16-23, 2007.
47. Vishal, V., Pradhan, S.P. & Singh, T.N., Mine sustainable development vis-a-vis dump stability for a large open castmine. In: Proceedings of an international conference on earth sciences and engineering, pp 1-7, 2010.
48. Bell, F.G., *Environmental Geology. Principles and Practice*. Cambridge University Press, Cambridge, 1998.
49. Singh, J.S., Singh, K.P. & Jha, A.K., An integrated ecological study on the re-vegetation of mine spoil. Final Technical Report submitted to the Ministry of Coal. Government of India, New Delhi, 1996.
50. Chaulya, S.K., Singh, R.S., Chakraborty, M.K. & Tewary, B.K., Bioreclamation of coalmine overburden dumps in India. *Land Contam Reclam*., 8(3), 189-199, 2000.
51. Singh, T.N., Assessment of coal mine waste dump behaviour using numerical modeling. In: Fuenkajorn K, Rock mechanics. pp 25-36, 2011. ISBN 978 974 533 636 0.
52. Jorgensen, S.E., Models as instruments for the combination of ecological theory and environmental practice. *Ecological Model*., 75/76, 5-20, 1994.

9

Sustaino-Resilient Agroforestry for Climate Resilience, Food Security and Land Degradation Neutrality

Dinesha S.[1]*, Suraj R. Hosur[2], Toushif P. K.[3], Divya Bodiga[4], Deepthi Dechamma N. L.[5], Ashwath M. N.[6] and Devbratha Pradhan[7]

[1]Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India
[2]University of Agricultural Sciences, Dharwad, Karnataka, India
[3]Mizoram University, Mizoram, India
[4]Sam Higginbottom University of Agricultural, Technology and Sciences, Uttar Pradesh, India
[5]KSN University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India
[6]Kerala Agricultural University, Thrissur, Kerala, India
[7]Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal, India

Abstract
"Anthropocene epoch" is an unofficial unit of geological time which resulted due to insignificant effects of human activities on the climate and ecosystems. The term alone is not enough and it is most important to develop or manage Sustaino-resilient Agroforestry (SRAF) models locally or globally. Some researchers are keeping sustainability science and resilience theory separate and focusing on further exploring their distinctiveness while others are using them in combination. Most of the common agroforestry (AF) practices are either sustainable or resilient and normally facing some challenges related to species selection and composition, labor, natural resource conservation, productivity, erratic climate and ecological concern. These challenges can be effectively tackled by SRAF practices by using principles and practices of climate-smart farming, integrated farming, organic farming, native plant farming, natural farming, permaculture and precision farming. SRAF systems are helpful in diversifying livelihood, increasing food security, conservation and efficient utilization of natural resources, providing various

**Corresponding author*: dineshasid100@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (217–246) © 2023 Scrivener Publishing LLC

ecosystem services as well as reducing pressure on forest. Most of the agricultural space can adopt AF because of the adoption and availability of fast-growing, economic and climate resilient trees along with the livestock that thrive well under limited space. These SRAF practices also contribute to various countries' commitment on land degradation neutrality (LDN) and United Nations sustainable development goals (SDGs) of climate action, zero hunger, no poverty, good health and well-being in addition to increasing food security by 2030. In summary, this chapter covers most of the AF aspects and is expected to be a guiding principle for practitioners to integrate SRAF practices and for policymakers to develop scientific and sustainable policies to achieve food security and ecological balance.

***Keywords*:** Anthropocene, food security, ecosystem restoration, perennials, sustainable development goals

9.1 Introduction

In ancient times, local species and natural resource–based traditional cultivation was practiced in collaboration with indigenous knowledge and experience of the practitioners. Agroforestry (AF), crop rotation, mixed cropping and natural farming are the best examples which help to safeguard the nation of less population with food security and ecological balance. The green revolution, industrialization, increasing population and urbanization made ancient agriculture suffer from climate change and ecological imbalance. Although the green revolution has had a marked influence on the agricultural sector in some countries by initial boosting crop productivity, later it began to lose its promise. Introduction of hybrids and GM crops, overuse of fertilizers, pesticides and many other synthetic substances have deliberately led to stagnation in productivity, ecological imbalance, extinction of local landraces and long-term soil health deterioration [1].

Although many countries are blessed with the environment and natural resources for farming practices, climate change, degradation and fragmentation of land, ecological imbalance, the green revolution effect, population and urbanization results in farmers' reluctance to farm [1]. AF is a land use practice (sustainable and/or resilient) that integrates perennial plant and tree species with crops and livestock systems. In changing climate scenario, this sustainable practice is recouping its importance and has a great potential to address global challenges. As compared to monocropping, diverse, mixed and well-established cropping systems of AF are well known for climate change mitigation, enhancing food security and achieving land degradation neutrality (LDN). These results and success stories are renewing farmers' willingness to farm by integrating AF practices that provide various ecosystem services. In addition, policy makers and researcher are now considering AF for building climate resilient communities [2].

Some organizations associated with AF like Food and Agriculture Organization (FAO), World Agroforestry Centre (ICRAF), etc., are fulfilling policy space, conducting scientific studies, providing best practices and publishing guidelines. There is an increase of interest in AF as an important component of sustainable land use and development. For instance, the government of India initiated "Green India Mission", which includes AF as a solution for different challenges including problems in Indian agriculture [3]. Hence, AF as a sustainable land-use system [4–7] as well as resilient to climate change [2, 8–10] is being acknowledged globally for its active role in climate change mitigation, food security and ecological balance. Most of the agricultural space can adopt AF because of the adoption and availability of fast-growing, economic and climate resilient trees along with the livestock that thrive well under limited space. To date, many researchers have studied the effects of climate change on agricultural and horticultural crops; however, they have been less focused on perennial trees and shrubs including livestock. This chapter provides detailed information and implications of SRAF in climate change, food security and LDN.

9.2 Is Agroforestry a Sustaino-Resilient Model?

"Anthropocene epoch" is an unofficial unit of geological time which resulted due to insignificant effects of human activities on the climate and ecosystems [11]. The term resilience denotes the capacity to withstand adversity and recover quickly from difficult events such as climate change and ecological imbalance. In the current scenario, the world is facing food insecurity and ecological imbalance. Hence, maintaining sustainability alone is not enough and it is most important to develop or manage Sustaino-resilient Agroforestry (SRAF) models locally or globally. Some researchers are keeping sustainability science and resilience theory separate and focusing on further exploring their distinctiveness while others are using them in combination [12]. Most of the common AF practices are either sustainable or resilient and normally facing some challenges related to species selection and composition, labor, natural resource conservation, productivity, sustainability, erratic climate and ecological concern. These challenges can be effectively tackled by SRAF practices by using principles and practices of climate-smart farming, integrated farming, organic farming, native plant farming, natural farming, permaculture and precision

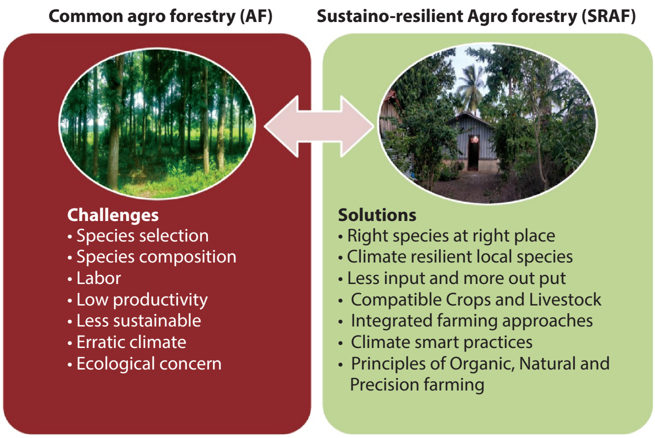

Figure 9.1 Sustaino-resilient Agroforestry solutions to deal with challenges of common AF [4].

farming (Figure 9.1) [4]. SRAF systems are helpful in diversifying food and livelihood, conservation and efficient utilization of natural resources, and providing various ecosystem services as well as reducing pressure on forest.

9.2.1 Components of AF

Incorporating diverse plant and animal components into monocropping will significantly improve food security, climate resilience and ecological balance [9, 13]. Local species and natural resource–based traditional cultivation, crop rotation, mixed cropping and natural farming practices are helpful. Integrating leguminous species in AF system ensure soil fertility by enhancing C and N status which promise soil, food and climate security [14–16].

9.2.1.1 Perennials

Perennials like trees, shrubs, herbs and lianas are the important components and provide various ecosystem services. For instance, among trees, *Gliricidia sepium* and *Pongamia pinnata* as manure trees supplement nutrients which can improve the crop yield by twofold in degraded and denuded lands, *Leucaena leucocephala* and *Harwikia binata* as fodder trees substitute commercial feeds, *Artocarpus lachocha* and *Pithocelobium dulce* as an underutilized fruit species can supplement household nutrition and livelihood and *Aegle marmelos* and *Saraca asoka* as medicinal trees can supplement synthetic medicines. Similarly, shrubs like *Paracalyx scariosus, Salacia chinensis* and *Woodfordia fruticosa,* herbs such as *Lasia spinosa*, *Momordica dioica* and *Musa balbisiana,* and liana, namely *Haematocarpus validus, Tinospora cordifolia* and *Hugonia mystax* are providing various ecosystem services.

9.2.1.2 Crops

AF is also referred to as sustainable evergreen agriculture [9]. Rice-wheat cropping system is more predominant in many parts of the world. The important cash crops such as sugarcane, potato tobacco, etc., fruit crops like mango, litchi, banana, etc., and vegetable crops like brinjal, onion, tomato, etc., are grown along with the perennial components and livestock. The main reasons for incorporating crops with trees and livestock include assured and diverse food, increased production, improved livelihood and added income. *Allanblackia,* Calliandra *and Faidherbia* based AF systems provide nutrients to crops at a useful time and have high compatibility with other commonly growing crops. High compatibility among trees, crops and livestock can enhance farm productivity, resource use efficiency and agro ecological balance [17].

9.2.1.3 Livestock

AF definition clearly includes at least one animal component or livestock such as cow, goat, pig, sheep, chicken, etc., along with perennials and crop component. An earlier study in sub-Saharan Africa reported that livestock provides roughly one-fifth of the energy requirement of the households [13]. A clear shift in livestock over different farms (known as livestock ladder) was observed, i.e., poor farmers depend on poultry while rearing cattle shows farm holds with improved food security [13].

9.2.2 Sustaino-Resilient Agroforestry Practices

SRAF practices are the farming practices which include principles and practices of climate-smart farming, integrated farming, organic farming, native plant farming, natural farming, permaculture and precision farming. Many studies reported on the sustainability and/or resilience of AF systems [5]. Study in the Mediterranean region reported that sustaino-resilient traditional AF systems can help to preserve diverse habitat and soil health along with counteracting land degradation events. Problems like greenhouse gas emissions, plantation and peat fire, and biodiversity loss faced by several countries can be effectively managed by using SRAF practices like climate-smart AF, organic AF, native plant farming, permaculture, precision AF, etc. Already several studies have recommended AF systems, namely agrosilviculture, agrosilvipasture and agrofisheries that were successfully adopted by the village community [18–20]. AF systems have relatively high species richness and cover diverse food components like food crops, vegetables, fruits, nuts, seeds, spices, tubers and livestock [18]. For example, potentiality of AF systems for providing food security was already assessed in Kalampangan, Indonesia [18]. Furthermore, SRAF practices should be concerned about agricultural and allied problems such as dependency on monocropping, biomass and residue burning, less resource use efficiency, infertility of soil, resistance to change and limited support of institutions and policies.

9.2.2.1 Integrated Agroforestry Systems

Since time immemorial, AF systems have been recognized as important integrated farming practices followed under different names, and they have been highly helpful in the tropical and subtropical regions of the world. Some of the Integrated AF systems that are practiced in different regions of the world are Alley farming in Nigeria, Inga alley cropping in Costa Rica, Pekarangan home garden in Indonesia, Chagga home garden in Tanzania and *Faidherbia albida*–based integrated farming in Mali [21]. Similarly in India, some indigenous tree–based integrated farming systems are Alder-cardamom system in Sikkim, Alder-based AF system in Mizoram, Apatani system in Arunachal Pradesh, Bun in Meghalaya, Zabo system in Nagaland, Agri-Silvi-horti system with Cattle and Silvi-horti-pastoral system with goats in central Karnataka (Figure 9.2).

An integrated AF system is a holistic combination of perennials, crops and livestock. Along with AF components, this system comprises apiculture, biogas generation, crops husbandry, poultry, duckery, rabbitry, horticulture, pisciculture, sericulture and piggery. This system helps to overcome problems involved in agriculture and livestock farming such as poor income, food insecurity, input unavailability and labor scarcity by increasing additional and diverse income, productivity, and resource use efficiency along with diverse ecosystem services [20].

In some countries, the government promotes this system due to its role in better economic return, year-round employment and income, C sequestration, enhancement in soil-health and nutrient cycling, and high resource use efficiency. It promotes synergic blending of perennials

Figure 9.2 Sustaino-resilient Agroforestry practices in different states of India; (a) Zabo system in Nagaland; (b) Alder-based AF system in Mizoram; (c) Alder-cardamom-based AF system in Sikkim; (d) Home garden in Bihar; (e) Integrated farming system in Bihar; (f) Home garden in West Bengal; (g) Home garden in Kerala; (h) Integrated farming system in Kerala; (i) Agri-silvi-horti system in Kerala; (j) Home garden in Karnataka; (k) Agri-Silvi-horti system with Cattle in Karnataka; (l) Silvi-horti-pastoral system with goats in Karnataka.

comprising trees, shrubs, herbs and climbers, agricultural and horticultural crops, rearing livestock like dairy, fisheries, piggery, poultry, etc. This system is a viable option for smallholders because it creates multiple sources of income, regular employment, less cultivation cost and providing sustaino-resilience for the changing climate change scenario. Studies reported that home gardens are more sustainable and/or resilient AF systems which enhance soil fertility and resource use efficiency [22]. Meta-analysis in Kaduna state, Nigeria, showed that most of the agricultural area can adopt AF because of the adoption and availability of fast-growing, economic and climate resilient trees along with the livestock that thrive well under limited space [23]. Integrated farming is a dynamic approach; it can be applied to any farming practice around the world to reduce degradation of land, loss of nutrient, water and other resources, and environmental footprint of human and livestock. Recently, global policies are integrating livestock with regular crops and perennials through initiatives like "Adapting African Agriculture" started in Marrakech as well as "4 Per 1,000" in Paris [24].

9.2.2.2 Organic-Agroforestry

Organic-AF is a practice that integrates principles and practices of organic farming in AF and vice versa. Combination of organic farming and AF has the potential to develop sustaino-resilient agro ecosystems. Many studies recommended adoption of AF practices to increase the sustainability of organic farming [25, 26] and vice versa [27, 28]. A study on Organic-AF recommended redesigning AF systems that incorporate improved management practices and technology requirements to achieve sustainable growth along with ecological balance [25]. Results showed higher cumulative yields in the Organic-AF system as compared to the monocultures in Bolivia [29]. A similar study reported higher yield in organic production of sweet potato in a poplar-based AF system in India [28]. Organic yerba mate (*Ilex paraguariensis*) grown under AF system with native trees improved soil fertility while providing additional income in Argentina [27]. Native trees like *Anadenanthera macrocarpa. Balfourodendron riedelianum*, *Cordia trichotoma, Jacaranda micrantha, Peltophorum dubium,* etc., are grown with yerba mate to promote organic production and diversify income [27]. Similarly, in a study on the African continent, trees like *Aeschynomene afraspera, Gliricidia sepium, Gmelina arborea* and *Sesbania rostrata* combined with rice enhanced yield with providing various ecosystem services [26].

One study compared microbial diversity in soils of organic cocoa AF system and monoculture cocoa [30]. Indicator species of fungi coupled with organic cocoa AF were highly diverse compared to monoculture cocoa. A study in Suhum, Ghana, concluded that organic management of cocoa AF systems ensures nutrients return, enhanced overall soil quality and high yield as compared to conventional management [31]. Another study evaluated the effects of long-term organic farming on two AF systems, namely Poplar- and Robinia-based alley cropping systems [32]. Organic farming with Robinia-based alley cropping system generally increased total N and soil C than organic farming with Poplar-based alley cropping [32].

A study compared energy and economic efficiency of the cocoa AF under traditional and organic management in the province of Guayas, Ecuador [33]. Four types of management were identified: traditional, semi-intensive, intensive, and organic. Among these, organic and traditional forms of management systems were found to be the best for energy and economic efficiency of the cocoa AF [33].

9.2.2.3 Natural Farming–Assisted Agroforestry

Natural Farming (NF) is a chemical-free, diversified and nature-based traditional farming method which incorporates crops, tree species and livestock. It helps to increase production, improve soil health, improve efficiency in nutrients and water use, and sustainability of agro ecosystem. This cost-effective farming practice has wide scope for sustainable production, food security, employment and socioeconomic development of the dependent community. To tackle the global issues, many countries including India are initiating nature-based farming practices. It promotes indigenous and traditional farming practices, which reduces external inputs and is largely based on on-farm inputs and biomass recycling with use of mulching, cow dung and urine formulations and proper soil aeration. The government of India is implementing Bharatiya Prakrutik Krishi Padhati through Paramparagat Krishi Vikas Yojana scheme to promote NF. NF is our ancient heritage and traditional cultivation practice which is gaining momentum nowadays and may be suitable mainly to animal and perennial species component–based AF systems as compared to sole agriculture. In AF, animal component supplies inputs required for the preparation of jeevamrut and beejamrut, in addition perennials such as neem, custard apple, etc., supplement byproducts required for preparation of plant protection formulations [1].

9.2.2.4 Perma-Agroforestry

Permaculture or Permanent culture (PC) is a philosophy of working with nature or the farming approach that imitates the way of nature and is completely self-sustained. There are a few similarities among OF, NF and PC, like the farming methods that are chemical and poison-free, work in accordance with nature's biodiversity and allow the diverse living species that create a sustaino-resilient ecosystem. The fundamental theme of PC is that humans can reduce or replace intensive agriculture and promote habitat and species diversity involving diverse living species [34]. It revalidated indigenous or traditional knowledge where it was previously devalued through the unsustainable nature of Western industrialized intensive agriculture. Agriculture intensification has caused many problems over recent decades. In this context, Perma-AF system is crucial to enhance agricultural production, C sequestration, soil health, sustainability and self-sufficiency of the ecosystem [35]. Talun-Kebun is a typical Perma-AF system normally practiced in Indonesia. It is an artificial forest where the bottom layer is covered by profitable annual plant species which provide financial benefits to the community, and the upper layer covers tree species which provide various ecosystem services [7]. Similarly Perma-AF system helps in restoration of temperate two quarries in Germany [36]. Trees, shrubs and annual plants are grown to afford diverse food and various other ecosystem services [36].

9.2.2.5 Precision-Agroforestry

The precision farming principles and practices as well as tools and technologies have gained more importance equally in silviculture and AF in the previous two decades. Intervention of precision farming in silviculture is known as precision silviculture [37] while its integration in AF is known as precision AF [38]. Precision AF is undergoing enormous change due to technologies like artificial intelligence, drone and remote sensing, etc., assistance in various operations of AF, particularly in developed countries. It aims to make decisions for site-specific management, improve productivity, protect the environment, reduce waste and increase profit. It can be used in all phases of AF, such as planning, site operations, planting, monitoring, harvesting, processing, and marketing. A study proposed precision AF policy for Mexico to promote climate resilient economy through the implementation of precision AF technologies in the Mexican AF sector [38]. AF systems are very diverse with tree-crop characteristics and distribution; require improved methodologies and technologies that have ability to adapt to difficult and diverse area, and multi-strata. Further research on resource use efficiency and natural resource conservation, policy support and technological advancement are vital concerns for precision AF promotion.

9.2.2.6 Horticulture Intervention in Agroforestry

Intervention of nutritious fruit and other horticultural crops in AF through agri-horticulture, silvi-horticulture or agri-silvi-horticulture systems helps to improve the health and nutrition of the people. Fruit plants are the most valuable component in Horticulture-based AF and serve as a rich source of macro- and micro-minerals, vitamins, fibers, alkaloids, antioxidants, polyphenols and many more. It can play an important role in reducing hunger and malnutrition, and poverty eradication. These AF systems are also helpful in conservation and utilization of indigenous or underutilized fruit resources; thus, pressures on remaining forests will be abated and forests resource overexploitation will be effectively addressed. Some of the important native underutilized edible fruit species are *Artocarpus lacucha, Baccaurea ramiflora, Cordia myxa, Diospyros melanoxylon, Elaeagnus latifolia, Ficus palmata* and *Glycosmis pentaphylla*. These are rare minor wild fruits which are native and unique and mostly eaten by the locals and benefit the poor people by supplying nutritional diet and also generate additional livelihood [39, 40]. Horticultural crops are becoming important components in the AF systems; apart from food security, it also supports timber and fuel availability in the region [40]. There are many indigenous fruits such as *Adansonia digitata* and *Citrullus lanatus* in Africa and *Parkia timoriana* and *Pithocelobium dulce* in India that have high nutraceuticals but very poorly organized value chains. Hence, there is a need to strengthen market systems along with institutional and policy support.

9.2.2.7 Bamboo-Based Agroforestry

Bamboo-based AF systems are praised for climate change mitigation, degraded land restoration and providing various ecosystem services [41, 42]. Integration of bamboo in AF significantly improves C sequestration, overall soil health, and produces renewable biomass energy [43]. Its fast growth, adaptive nature and ability to grow on varied soils and climate helps to restore the degraded lands, enhances soil property and diversifies food and livelihood [41, 43]. Thus, in the changing climate, integrating bamboo with crops, trees and livestock could give various benefits in a sustaino-resilient way. Many countries, as a part of the Bonn Challenge, incorporated bamboo in high-priority species list for restoration and sustainable land management programs [44]. Organization of African Bamboo in Africa and The Eco Planet Bamboo in Latin America are active in restoring degraded lands through bamboo-based AF systems [45].

9.2.2.8 Medicinal Perennials Intervention in Agroforestry

There is a huge scope in a growing market for medicinal plants around the world and export of raw materials may help to improve income and livelihood of the medicinal plants' grower [46]. One of the main constraints faced by the medicinal plant sector is depletion of the resources by large dependency and unsustainable harvesting from the wild. Intervention of medicinal crops in AF helps to provide manifold advantages including various ecosystem services. Practice of intercropping is as old as taungya and shifting cultivation [47]. Many studies reported successful intervention of medicinal plants in AF systems [47, 48]. For instance, improved growth and yield was recorded in medicinal plants grown under Poplar-based AF in Tarai region of India [47]. Integration of medicinal plants through intercropping or multistoried cropping under plantation crops is a suitable suggestion for ex situ conservation of shade-adapted medicinal plants [48]. Intercropping of medicinal plants in AF can be a sustainable approach for medicinal plant conservation, management and ecorestoration along with potential food and livelihood source for practitioners.

9.2.2.9 Industrialized Agroforestry

Due to policy and legal restrictions in many countries around the world including India, the supply of wood from forests has been almost prohibited or reduced. In this backdrop, a study in Tamil Nadu of India has envisioned and started a value chain model on industrial AF to overcome constraints of quality wood production, harvesting, marketing and consumption [49]. Multifunctional and profitable AF models were developed by using precision silviculture and fast-growing, high-yielding genotypes suitable for varied industrial utility and acclimatized to varied ecogeographic conditions. Marketing and consumption segments were strengthened by assurance of a price supportive system and establishment of value addition technology. With the increased productivity and profitability this model has attracted farmers towards industrialized AF. This model may help to fulfill the gap between demand and supply of raw materials required for the development of the country while achieving sustaino-resilience [49].

9.2.3 Improved vs. Traditional Agroforestry Practices

Generally, AF practices are classified into two forms, i.e., traditional AF practice and improved AF practice. In the traditional AF system, farmers were engaged in different forms of tree-based farming and they were also well aware of the benefits of different forms of AF practices. Later, it was diluted and devalued through unsustainable agriculture practices. Some progressive farmers are showing interest in modifying and improving their present AF practices with mechanization and sustainable and/or resilient management practices for satisfying household requirements along with added profits. Some studies compared the adaptation and benefits of these two forms of AF practices [50, 51]. Traditional farming practitioners are facing some problems such as biomass and residue burning, bare and long fallow phase, injudicious cultivation, mining of soil fertility, careless cropping and irrigation practices [50]. These problems can be overcome by following recommended management practices such as conservation tillage, cover and nurse cropping, crop rotation, integrating climate resilient trees and crops with livestock, efficient cropping and irrigation practices, mulching, proper use of resources, sensible use of off-farm inputs and use of management practices [50]. Studies reported a nearly threefold increase in annual income and diverse benefits from improved AF practices as compared to traditional AF practices [51]. In addition, improved AF practitioners are self-sustained in meeting demand of various forest products. In conclusion, it is important to maintain harmony with nature in the changing climate scenario by adopting best recommended management practices, and modifications are needed for faulty ongoing practices to enhance food security and ecological balance.

9.3 Agroforestry for Climate Resilience

Generally, climate change is recognized as one of the greatest challenges in today's world. Hence, there is a need to improve policies and practices and develop strategies that integrate the objectives of adaptation and mitigation of climate change along with ecological concern [52]. Among the greenhouse gases, carbon dioxide (CO_2) is a dominating element that increases the earth's temperature, resulting in global warming [53] and climate change. The climate calamities such as floods, droughts, etc., are degrading the environmental quality [54] that leading soil destruction and lower crop yields. Anthropogenic activities in agriculture are also depleting the status of productive soils [55]. Thus, atmospheric carbon sequestration would be an effective solution in order to ensure improved soil quality [56], yield sustainability and environmental security. AF practices are helpful in strengthening climate change resilience, while contributing diversified food and nutritional security, livelihood and other ecosystem services to the dependent communities. Realizing the importance of AF practices, policy makers and conservation practitioners are now considering agroforestry for building climate resilient communities [57–59]. Moreover, climate resilient AF practices minimize energy, land and carbon footprint that ensure environmental sustainability and ecological stability [60]. SRAF interventions provide effective measures to vulnerable communities to adapt and become resilient to the impacts of climate change. The AF role in climate change mitigation includes improving microclimate through tree canopies, protection and allied benefits through permanent cover, farm diversification, improving soil health, water and climatic resources, increasing C sequestration and reducing emissions. It has capability to curtail climate extremes and intra-annual climatic fluctuations. Some of the case studies on AF role in climate change mitigation were documented briefly in Table 9.1.

9.3.1 World Context

Smallholder farmers and their farming systems are adversely affected by climate change. Crop failure is most common due to dependence on rain-fed agriculture in most parts of the world. In this scenario, AF mitigates these ill effects by enhancing adaptation, resilience and reducing vulnerability in smallholder farming systems [10]. A study conducted in Cameroon, Central Africa, showed that smallholding farmers adopted four different AF practices dominated by coffee, cocoa, apiculture and plantation crops [10]. These four AF practices provided diverse ecosystem services and were important in enhancing resilience, reducing vulnerability and mitigating climate change [10]. High plant diversity and density has been correlated to enhanced soil physico-chemical properties in home gardens of Bangladesh [61]. Higher soil C stock in AF systems as compared to adjacent croplands and nurseries was obtained in eastern China [62]. AF systems like agro-silvicultural system and shelterbelts are effective practices to increase soil carbon stock in China [63]. A study in the humid and sub-humid tropical regions demonstrated that AF can decrease soil erosion rates by half as compared to monocropping systems [64].

9.3.2 Indian Context

Currently, AF is gaining importance in a changing climate context as it captures and stores a significant amount of C and synergies among climate change mitigation, food security and ecological concern [6]. Tree species in agriculture and other ecosystems can improve soil productivity, conserve natural resources, reduce the soil erosion and runoff, and enhance soil nutrient cycling [65]. N fixing perennials can enhance productivity of agricultural crops by improving moisture, N availability and organic matter [66]. In addition, incorporation of soil fertility management practices can increase soil organic matter, physical and chemical properties and nutrient cycling with minimal cash inputs [67]. The litter and debris of AF species are rich in allelochemicals which impart species resistance to insects and pathogens [68]. In addition, AF has diverse components which act as biological barriers for insects and pests. Some AF multipurpose tree species are used in bio-pesticides and they also help in biodiversity conservation and harboring beneficial insects, which helps in pollination. Ill effects such as climate change–induced sudden outbreak of pest and diseases, erratic rainfall and temperature, floods and dry spells are causing severe food insecurity by reducing yield of crops. Integration of climate-resilient native species in AF can mitigate the problems raised by climate change by acting as a biological barrier to insect and pests, insurance for the failure crop, incorporating nutrients into the soil and proving diverse food from diversified crop.

9.4 Agroforestry for Food Security

Food insecurity is a complex global issue impacted and influenced by climate change, demography, human activity and resource use patterns [69]. Availability of safe, steady and sufficient food that fulfills dietary requirements of people is a vital concern [70]. Intervention of well-planned AF is viewed as a cost-effective means to improve food, health, livelihood and other ecosystem services [5]. An earlier study suggested that there is a need for government interventions through various schemes to attain food security and ecological balance [71]. Some of the case studies on the AF role in food security were documented briefly in Table 9.1.

9.4.1 World Context

AF helps to achieve food security as cash source for all surveyed households in sub-Saharan Africa [9] and as a food source for nearly three-fourths of surveyed households [13]. One-fifth of households that practiced AF were food secure while non-AF practiced households were insecure in the Isingiro, southwestern Uganda [71]. The values of AF and food security include socioeconomic and environmental value, and the main reasons for following AF practices include an increase in food production, livelihood and income. *Faidherbia*-based AF systems in Malawi reported that *Faidherbia*, an indigenous African acacia provides nutrients to crops at a useful time and is highly compatible with other commonly growing crops. In addition, a study has found enhanced maize yields and soil physicochemical and biological properties of *Faidherbia albida*-maize inter-cropping in Malawi [17]. *Allanblackia,* Calliandra and *Faidherbia*–based AF

Table 9.1 Studies documenting the role of AF in climate resilience, food security and LDN.

Study area	AF type and species	Key findings	References
AF for Climate resilience			
Cameroon	Coffee, Cocoa and Apiculture-based AF systems	AF mitigates ill effects of climate change by enhancing resilience and reducing vulnerability in various farming systems	[10]
Bangladesh	Homestead AF systems	High plant diversity and density enhanced soil physico-chemical properties in homesteads	[61]
South Africa	Different AF systems	AF in the humid and sub-humid tropical regions can decrease soil erosion rates by halfas compared to monocropping system	[64]
China	Different AF system	AF systems had higher SOC stocks in the whole soil profile compared to croplands	[62]
India	Different AF systems	N fixing trees enhanced productivity of associated agricultural crops	[66]
India	Different AF systems	Trees act as a biological barrier and allelo chemicals of trees often imparts species resistance to insect and pests	[68]

(*Continued*)

Table 9.1 Studies documenting the role of AF in climate resilience, food security and LDN. (*Continued*)

Study area	AF type and species	Key findings	References
AF for Food security			
Isingiro, Uganda	Different AF systems	One-fifth of households that practiced AF were food secure	[71]
Nepal	Compared traditional and improved AF practices	Nearly threefold increase in annual income was recorded in improved AF system than traditional AF system	[51]
Africa	General account on different AF systems	AF is a cost-effective means to enhance food, health, livelihood and other ecosystem services	[5]
Sub Saharan Africa	Agricultural crops, AF perennial species and livestock	Agriculture and AF with livestock as a food source for nearly three-fourths of surveyed households	[13]
Malawi, East Africa	Different Agroforestry System	AF Species of Allanblackia, *Calliandra*, Faidherbia and *Leucaena* deliver relatively quick payoffs to farmers	[17]
India	Different AF systems	AF intervention to achieve food security is well documented	[3]
India	Different Agroforestry System	49% of the fuel wood and 48% of timber are provided by Agroforestry	[72]

(*Continued*)

Table 9.1 Studies documenting the role of AF in climate resilience, food security and LDN. (*Continued*)

Study area	**AF type and species**	**Key findings**	**References**
AF for LDN			
Iowa, USA	*Castanea mollisima* and *Asiminatriloba* AF with corn-soyabean rotation	AF increases soil health and C sequestration relative to corn-soyabean agriculture	[86]
Gedeo, Ethiopia	Home garden, Parkland and Ficha system	Home garden had higher soil physico-chemical attributes	[22]
Bangladesh	Homestead AF system	Mixed and diverse species under AF can enhance soil C and other nutrients	[61]
Cameroon, Africa	Agrosilvopastoral and other two AF systems	Agrosilvipastoral system is more efficient in soil fertility improvement	[19]
Colombian Amazon	Cocoa AF system	Soil fertility improved by 42%.	[81]
Eastern Himalaya, India	Teak, Eucalyptus, Sissoo, Neem with Pineapple	28 yrs AF system with pineapple on degraded lands increased soil quality and C	[20]
Northwest India	*Punica granatum* and *Salvadora persica* AF with rice-wheat	Soil pH significantly reduced with optimum production from all components	[83]
Haryana, India	Different AF systems	Salt tolerant trees, namely *Casuarina equisetifolia, Leptochloa fusca, Tamarix articulate,* etc., were found best	[84]

are known to deliver early returns for their multifaceted use [17, 71]. To strengthen food security and livelihood, understanding households' psychological and behavioral issues, government intervention and policy support are vital [71].

9.4.2 Indian Context

The most important AF systems like Agri-silviculture, silvi-pastoral, agri-silvi-pastoral play an important role in food security of the country [3]. AF is normally considered as a cost-effective way to improve farming systems for attaining food security. AF can enhance food production through their various benefits like resource conservation, soil amelioration and insects, pathogens, and weed control. In India, AF systems are fulfilling half of the annual fuel wood and timber requirement of the country [72]. Hence, production of food along with fuel wood and other products is a vital concern. Some tree species including babul (*Acacia nilotica*) in AF system provide valuable edible gum which has popularly become a source of income and strengthens livelihood and biodiversity too [73, 74]. AF systems can contribute to the production of bio-energy, food, fodder, fruits, fuel wood, timber and many more [75].

9.5 Agroforestry for Land Degradation Neutrality

There is strong nexus among climate change food insecurity and land degradation (Figure 9.3) [18, 23], posing serious global problems. Roughly, out of the total world population, one-sixth lives in degraded areas and one-third is affected by land degradation and denudation [76]. In addition, the worst effects of land degradation are malnutrition, disease, forced migration, increased conflicts, cultural damage and poverty. Hence, it is an alarming sign and underlines the importance of conserving biodiversity and maintaining ecological balance. Restoration of these degraded lands by using various measures is a major concern. To prevent further degradation and desertification, LDN is an important concept. For restoring or further reducing degradation and denudation of land, AF has some typical advantages, especially in a place where food shortage and high population were noticed [77]. Some of the case studies on the AF role in LDN were documented briefly in Table 9.1.

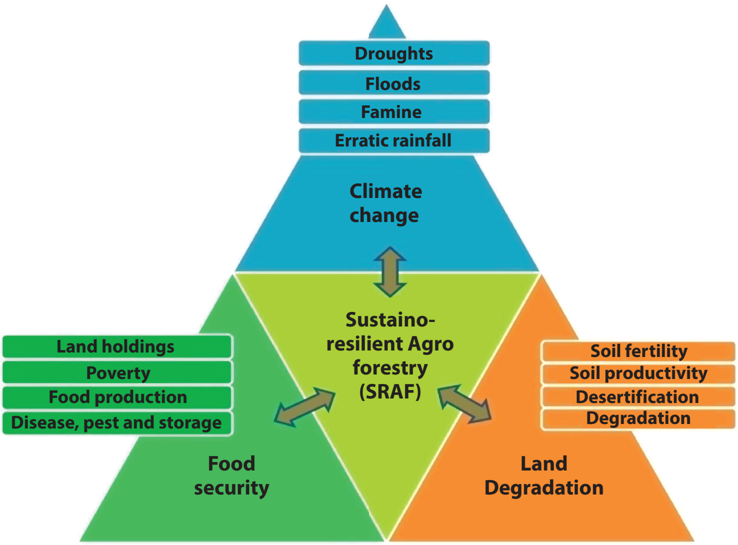

Figure 9.3 Sustaino-resilient Agroforestry for climate change mitigation, food security and LDN [18, 23].

9.5.1 World Context

Species having good adaptive capability, nutrient and water use efficiency and fast-growing with dense foliage, stand first in neutralization of degraded lands [78]. AF has greater contribution global soil C by sequestering additional C of 5.3 × 109 Mg in 944 million ha globally [79]. A study in Xishuangbanna, China, compared three AF systems such as intercropping with tea, coffee or cocoa and one rubber monoculture [80]. The Agrosilvopastoral system is more effective in enhancing soil fertility as compared to agrisilvicultural and silvopastoral systems in Mbelenka, Cameroon [19]. The establishment of a cacao-based AF system on degraded pasture can improve the capacity to maintain soil ecological functions along with restoration of soil quality [81]. Dwindling ground water tables due to faulty irrigation and drainage in irrigated lowlands and in an arid climate, evaporative loss and enhanced capillary rise are pressing environmental challenges. Species selection for the bio-drainage and the right species at the right place are key features in the resilient AF systems [8].

9.5.2 Indian Context

Practice of AF helps in restoring the degraded lands [82]. In semiarid and arid regions of India, a vast amount of land is remaining barren due to salinity and sodicity. *Salvadora persica, Punica granatum* and *berseem*-kallar grass combined AF practices with site-specific nursery technique is recommended for reclamation of problematic soil [83]. A similar study recommended incorporating salt tolerant trees, namely *Casuarina equisetifolia, Leptochloa fusca, Populus deltoids, Tamarix articulate* and *Tectona grandis* in AF system for restoration of salt-affected sites [84]. In India, the INBAR encouraged Bamboo-Based AF for improving diverse ecosystem services from degraded and mining lands [85]. Integration of diverse perennials in AF systems enhanced soil health and soil C sequestration [86]. For instance, AF systems with multipurpose trees like Eucalyptus, Neem, Sissoo and Teak in combination with Pineapple enhanced soil C dynamics in Eastern Himalayas [20]. The Integrated Watershed Management Program (IWMP) which is operational in India has incorporated and promoting tree-based farming systems.

9.6 The Way Forward

- There is a great need of scientific revalidation of available ancient knowledge in the Grantas, Vedas, Vrikshayurvedas and Upanishads.
- Further research on crop compatibility and crop interaction in agroforestry is a vital concern.
- Development of successful regional models which integrate local cultivars, livestock and native perennials along with their regular, successful and sustainable cropping systems.
- Constraint that discourages AF adoption such as long juvenile phase, small and insecure land holding, lacking agronomic and recommended management practices for AF systems, agricultural crops are as important as woody perennials, absence of crop varieties and cultivars suitable for adverse conditions. To overcome these issues, certain fast-growing trees, successful varieties, planting techniques, scientific interventions and recommended management practices are critical.
- Encouraging farmer through payment for environmental services (PES) especially in developing countries is a vital concern and already some countries like Costa Rica are successfully practicing these services.
- Research in the adaptation and management of SRAF practices like Organic-AF, bamboo-based AF, Perma-AF system and integrated AF systems is required.

9.7 Conclusion

Since time immemorial, AF has been widely practiced for achieving sustaino-subsistance farming with the objectives of agricultural sustainability, food security, soil health management and reducing degradation and desertification. Later, it was diluted and devalued through unsustainable agriculture practices. Some progressive farmers are showing interest in modifying and improving their present AF practices with mechanization and sustainable and/or resilient management practices for satisfying household requirements along with added profits. This study has demonstrated that some SRAF practices can provide options for reducing poverty, improving food and livelihood security, and sustaining ecological balance. Plantations, intensive agriculture areas, peat and grass lands and other farms are the potential SRAF intervention areas in the future. Production-linked incentives, agronomic practices, institutional and policy support, long-term management strategies and market access are essential to encourage farmers to invest in perennial trees through SRAF practices. In conclusion, this chapter has covered most of the AF aspects and is expected to be a guiding principle for practitioners to integrate SRAF practices and for policymakers to develop scientific and sustainable policies to achieve food security and ecological balance.

Acknowledgement

The authors are thankful to Ms. Shridevi, B. Teli and Dr. S. Rakesh, for the relevant corrections to a first draft of the manuscript.

References

1. Biswas, S., Zero budget natural farming in India: aiming back to the basics. *Int. J. Environ. Climate Change.*, 10, 38-52, 2020.
2. Aryal, K., Thapa, P.S. & Lamichhan, D., Revisiting Agroforestry for Building Climate Resilient Communities: A Case of Package-Based Integrated Agroforestry Practices in Nepal. *Emerg. Sci.,* 3, 303-311, 2019. https://doi.org/10.28991/esj-2019-01193
3. Sarvade, S. & Singh, R., Role of agroforestry in food security. *Popular Kheti.,* 2, 25-29,2014.
4. Kiyani, P., Andoh, J., Lee, Y. and Lee, D.K., Benefits and challenges of agroforestry adoption: a case of Musebeya sector, Nyamagabe District in southern

province of Rwanda. *Forest Science and Technology*, 13(4), 174-180, 2017. https://doi.org/10.1080/21580103.2017.1392367

5. Nair, P.K.R. & Toth, G. G., Measuring agricultural sustainability in agroforestry systems. In *Climate change and multi-dimensional sustainability in African agriculture*, pp. 365-394. Springer, Cham, 2016.
6. Prasad, Rajendra, S. K., Dhyani, R., Kumar, N.S. & Tripathi. V. D., Contribution of advanced agroforestry research in sustaining soil quality for increased food production and food security. *J. Soil Water Conserv.,* 15, 31-39, 2016.
7. Kurniawan, T. & Kuriawan, E., Policy on Utilizing Indigenous Knowledge in Critical Land Rehabilitation and Fulfillment of Sustainable Food Security in Indonesia: Regrowing "Talun-Kebun" as Part of the Local Permaculture Model in West Java". *Environ. Sci. Proc.,* 1, 15-18, 2022. https://doi.org/10.3390/environsciproc2022015002
8. Maharjan, S. & Khamzina, A., Assessment of tree water use for development of resilient agroforestry systems in salinized areas of Uzbekistan. Conference on International Research on Food Security, Natural Resource Management and Rural Development, Gottingen, Germany. 2012.
9. Mulugeta, G., Evergreen agriculture: Agroforestry for food security and climate change resilience. *J. Nat. Sci. Res.* 4, 80-90, 2014.
10. Awazi, N.P., Agroforestry for Climate Change Adaptation, Resilience Enhancement and Vulnerability Attenuation in Smallholder Farming Systems in Cameroon. *J. Atmos. Sci.*, 5, 25-33, 2022. https://doi.org/10.30564/jasr.v5i1.4303
11. Smith, B.D. & Zeder, M.A., The onset of the Anthropocene. *Anthropocene,* 4, 8-13, 2013. https://doi.org/10.1016/j.ancene.2013.05.001.
12. Redman, C.L., Should sustainability and resilience be combined or remain distinct pursuits? *Ecology and Society*, 19(2), 37, 2014. http://dx.doi.org/10.5751/ES-06390-190237
13. Frelat, R., Lopez-Ridaura, S., Giller, K.E., Herrero, M., Douxchamps, S., Djurfeldt, A.A., Erenstein, O., Henderson, B., Kassie, M., Paul, B.K. & Rigolot, C., Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proceedings of the National Academy of Sciences*, 113(2), 458-463, 2015. https://doi.org/10.1073/pnas.1518384112
14. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.). *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
15. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X

16. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
17. Saka, A.R., Bunderson, W.T., Itimu, O.A., Phombeya, H.S.K. & Mbekeani, Y., The effects of Acacia albida on soils and maize grain yields under smallholder farm conditions in Malawi. *For. Ecol. Manag.*, 64, 217-230, 1994. https://doi.org/10.1016/0378-1127(94)90296-8
18. Indrayanti, L., Rotinsulu,J., Hidayat,N. & Sianipar, J., The potential of agroforestry in supporting food security for peatland community–a case study in the Kalampangan village, Central Kalimantan. *Ecol. Eng.* 22, 8-13, 2021. https://doi.org/10.12911/22998993/140260
19. Tsufac, A.R., Awazi, N. P. & Yerima, B. P., Characterization of agroforestry systems and their effectiveness in soil fertility enhancement in the southwest region of Cameroon. *Curr. Res. Environ. Sustain.*, 3, 1-7, 2021. https://doi.org/10.1016/j.crsust.2020.100024
20. Yadav, G.C., Kandpa, B.K., Das, A., Babu, S., Mohapatra, K.P., Devi, G., Devi, H.L., Chandra, P., Singh, R. & Barman, K.K., Impact of 28 year old agroforestry systems on soil carbon dynamics in Eastern Himalayas. *J. Environ. Manag.*, 283, 1-11, 2021. https://doi.org/10.1016/j.jenvman.2021.111978
21. Nair, P.K.R., *An introduction to agroforestry*. Springer Science & Business Media, 1993.
22. Dori, T., Asefaw, Z. & Kippie., T., Soil characteristics under dominant agroforestry systems along toposequence of Gedeo, Southeastern Ethiopia. *Environ. Sustain. Indicators*. 191, 6-28, 2022. https://doi.org/10.1016/j.indic.2022.100191
23. To, A. & Ea, O., Mitigation of Land Degradation for Agricultural Space Using Agroforestry System in Chikum Local Government Area, Kaduna State, Nigeria. *J. Appl. Sci. Environ. Manage.* 22, 743-748, 2018. https://doi.org/10.4314/jasem.v22i5.26
24. Lal, R., Food security impacts of the "4 per Thousand" initiative. *Geoderma,* 374, 114427, 2020. https://doi.org/10.1016/j.geoderma.2020.114427
25. Rosati, A., Borek, R. & Canali, S., Agroforestry and organic agriculture. *Agrofor. Syst.*, 4(1), 1-17, 2021. https://doi.org/10.1007/s10457-020-00559-6
26. Rodenburg, J., Mollee, E., Coe, R. & Sinclair, F., Global analysis of yield benefits and risks from integrating trees with rice and implications for agroforestry research in Africa. *Field crops research.* 281, 1-18, 2022. https://doi.org/10.1016/j.fcr.2022.108504
27. Montagnini, F., Eibl, B.I. & Barth, S.R., Organic yerba mate: an environmentally, socially and financially suitable agroforestry system. *Bios et forest des tropiques,* 308(2), 59-74, 2011.

28. Pawar, S. & Wani, A.M., Effect of Organic production on growth and productivity of Sweet Potato (*Ipomoea batatas* L.) under Poplar based Agroforestry system. *International Journal of Advanced Research,* 2(12), 229-232, 2014.
29. Schneider, M., Andres, C.,Trujillo, G., Alcon, F., Amurrio, P., Perez, E., Weibel, F. & Milz, J., Cocoa And Total System Yields Of Organic And Conventional Agroforestry Vs. Monoculture Systems In A Long-Term Field Trial In Bolivia. *Experimental agriculture.* 53(3), 351-374, 2017.
30. Lori, M., Armengot, L., Schneider, M., Schneidewind, U., Bodenhausen, N., Mader, P. & Krause, H.M., Organic management enhances soil quality and drives microbial community diversity in cocoa production systems. *Sci. Total Environ.,* 834, 1-11, 2022. https://doi.org/10.1016/j.scitotenv.2022.155223
31. Asigbaase, M., Dawoe, E., Lomax, B.H. & Sjogersten, S., Temporal changes in litterfall and potential nutrient return in cocoa agroforestry systems under organic and conventional management, Ghana. *Heliyon,* 7, 1-11, 2021. https://doi.org/10.1016/j.heliyon. 2021.e08051
32. Sun, H.Y., Koal, P., Gerl, G., Schroll, R., Joergensen, R.G. & Munch, J.C., Response of water extractable organic matter and its fluorescence fractions to organic farming and tree species in poplar and robinia-based alley cropping agroforestry systems. *Geoderma,* 290, 83-90, 2017. https://doi.org/10.1016/j.geoderma.2016.12.014
33. Neira, D.P., Energy efficiency of cacao agroforestry under traditional and organic management. *Agron. Sustain. Dev*. 2, 36-49, 2016.
34. Fath, B., *Encyclopedia of ecology*, Elsevier. 1, 347-353, 2019.
35. Nath, M.K., Potentialities of Permaculture to Emerge as an Alternative for Intensive Agriculture - A Review. *Org. Agric*., 1, 16-24, 2022.
36. Cossel, M., Ludwig, H., Cichocki, J., Fesani, S., Guenther, R., Thormaehlen, M., Angenendt, J., Braunstein, I., Buck, M., Kunle, M., Bihlmeier, M., Cutura, D., Bernhard, A., Wachendorf, F., Erpenbach, F., Melder, S., Boob, M. & Winkler, B., Adapting Syntropic Permaculture for Renaturation of a Former Quarry Area in the Temperate Zone. *Agricultuture.* 10, 1-14, 2020. https://doi.org/10.3390/agriculture10120603
37. Hegde, R., Amanulla, B.K.M., Singh, A. & Manasa, P.C., Precision silviculture: status in Karnataka. In: *Advances in Tree Seed Science and Silviculture*, pp. 173-184, 2015.
38. Montes, O., Miguel, U., Rogelio, C., Clemente, V., Mario, P. & Alejandro, L., Policy forum: proposal of a Mexican precision agroforestry policy. *For. Policy Econ.,* 119, 2020. https://doi.org/10.1016/j.forpol.2020.102292
39. Suresh, C.P., Bhutia, K.D., Shukla, G., Pradhan, K. & Chakravarty, S., Wild edible tree fruits of Sikkim Himalayas. *J. Tree Sci*. 33, 43-8, 2014.
40. Chakravarty, S., Bhutia, K.D., Suresh, C.P., Shukla, G. & Pala, N.A., A review on diversity, conservation and nutrition of wild edible fruits. *J. Appl. Nat. Sci.,* 8, 46-53, 2016.

41. Mohit, G. & Neelu, G., Bamboos: importance for mitigation and adaptation to climate change. The fifth assessment report of IPCC.2012.
42. Yuen, J.Q., Fung, T. & Ziegler, A.D., Carbon stocks in bamboo ecosystems worldwide: estimates and uncertainties. *For. Ecol. Manag.,* 393, 113-138, 2017. https://doi.org/10.1016/j.foreco.2017.01.017
43. Lobovikov, M., Schoene, D. & Yping, L., Bamboo in climate change and rural livelihoods. *Mitig. Adapt. Strateg. Glob. Change* 17**,** 261–276, 2012. https://doi.org/10.1007/s11027-011-9324-8
44. FAO & INBAR, Bamboo for land restoration. INBAR policy synthesis report 4. INBAR, Beijing, China, 2018.
45. Eco Planet Bamboo. "Commercial bamboo plantations as a tool for restoring landscapes". 2014.
46. Dinesha, S., Vineeta, Shukla. G., Mondal, H.A. & Chakravarty, S., Macro-proliferation Cup Technique for Mass Multiplication of *Woodfordiafruticosa* (L.) Kurz (Dhawai) in Sub-humid Foothills of Eastern Himalaya. *Ind. J. Ecol.*, 48(5), 1305-1312, 2021.
47. Jha, K.K. & Gupta, A.C., Intercropping of medicinal plants with Poplar and their phenology. *Indian Forester*, 117(7), 535-544, 1991.
48. Neerakkal, I., Medicinal plants for intercropping in plantations. *Int. J. Bot. Stud.,* 6(2), 249-251, 2021.
49. Parthiban, K.T. & Fernandaz, C. C., Industrial agroforestry-status and developments in Tamil Nadu. *Indian J. of Agroforestry*, 19, 1-11, 2017.
50. Patle, G.T., Kharpude, S.N., Dabral, P.P. & Kumar, V., Impact of organic farming on sustainable agriculture system and marketing potential: A review. *Int. J. Env. Clim.*, 10(11), 100-120, 2020. https://doi.org/10.9734/IJECC/2020/v10i1130270
51. Paudel, D., Tiwari, K.R., Raut, N., Sitaula, B.K., Bhattarai, S., Timilsina, Y.P. & Thapa, S., Which agroforestry practice is beneficial? A comparative assessment of the traditional and the improved agroforestry techniques in the midhills of Nepal. *Advances in Agriculture*, 2021, 1-8, 2021. https://doi.org/10.1155/2021/2918410
52. Bodegom, A.J, Savenije, H. & Wit, M., Forests and climate change: adaptation and mitigation. *Tropenbos International.*, 50, 2009. ISBN: 978-90-5113-100-0
53. Rakesh, S., Sinha, A.K., Juttu R., Sarkar, D., Jogula, K., Reddy, S.B., Raju, B., Danish, S. & Datta, R., Does the accretion of carbon fractions and their stratification vary widely with soil orders? A case study in Alfisol and Entisol of sub-tropical eastern India. *Land Degrad Dev.*, 1-11, 2022a. https://doi.org/10.1002/ldr.4291
54. Rakesh, S., Ranjith Kumar, G., Anil, D., Ravinder, J., Kamalakar, J., Sharan, B.R., Jogarao P. & Umarajashekar, A., Technology and Policy Options: Opportunities for Smallholder Farmers to Achieve Sustainable Agriculture. In: *Innovation in Small-Farm Agriculture: Improving Livelihoods and Sustainability*. CRC Press, Taylor & Francis Group. 2022b. p. 65-73. ISBN: 9780367759766

55. Srinivasarao, C.H., Rakesh, S., Kumar, G.R., Manasa, R., Somashekar, G., Lakshmi, C.S. & Kundu, S. Soil degradation challenges for sustainable agriculture in tropical India. *Cur Sci.*, 120(3), 492, 2021. https://doi.org/10.18520/cs/v120/i3/492-500
56. Rakesh, S., Sarkar, D., Sankar, A., Sinha, A.K., Mukhopadhyay, P. & Rakshit, A., Protocols for determination and evaluation of organic carbon pools in soils developed under contrasting pedogenic processes and subjected to varying management situations. In: *Soil Analysis: Recent Trends and Applications*. Springer, Singapore., 87-105, 2020. https://doi.org/10.1007/978-981-15-2039-6_6
57. Raj, A. & Jhariya, M.K., Sustainable agriculture with agroforestry: adoption to climate change. In: P. Suresh Kumar, Manish Kanwat, P.D. Meena, Vinod Kumar and Rajesh A. Alone, editors. *Climate Change and Sustainable Agriculture*. New India Publishing Agency (NIPA), New Delhi, 2017. ISBN No. 9789-3855-1672-6, pp. 287-294.
58. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
59. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
60. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al.* (eds.), editors. *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021b, ISBN 978-981-15-9495-3, pp. 415-443, 2021. https://doi.org/10.1007/978-981-15-9496-0_14
61. Jaman, M.S., Taofeek, O., Muraina, T.O., Dam, Q., Zhang, X., Jamil, M., Bhattarai, S. & Islam, F., Effects of single and mixed plant types on soil carbon and nitrogen dynamics in homestead agroforestry systems in Northern Bangladesh. *Agric. Ecosyst. Environ.*, 315, 1-11, 2021. https://doi.org/10.1016/j.agee.2021.107434
62. Jing, X. J., Liu, W., Wu, J., Wang, P., Liu, C. & Yuan, Z., Land degradation controlled and mitigated by rubber–based agroforestry systems through optimizing soil physical conditions and water supply mechanisms: A case study in Xishuangbanna, China. *Land Degrad Dev*. 28, 2277-2289, 2019.
63. Hubner, R., Kühnel, A., Lu, J., Dettmann, H., Wang, W. & Wiesmeier, M., Soil carbon sequestration by agroforestry systems in China: A meta-analysis. *Agric. Ecosyst. Environ*. 315, 437-448, 2021. https://doi.org/10.1016/j.agee.2021.107437
64. Muchane, M.N., Sileshic, G.W., Gripenberge, S., Jonsson, M., Pumariño, L. & Barriosa, E., Agroforestry boosts soil health in the humid and sub-humid

tropics: A meta-analysis. *Agric. Ecosyst. Environ*., 295, 899-902, 2020. https://doi.org/10.1016/j.forpol.2020.102292
65. Dinesha, S., Dey, A.N., Deb, S. & Debnath, M.K., Litter Pattern and Nutrient Dynamics of *Switeniamacrophylla* (King) Plantation in Terai Region, West Bengal, India. *Indian Forester*, 146(1), 7-12, 2020. http://dx.doi.org/10.36808/if%2F2020%2Fv146i1 %2F144390
66. Singh, R.K., Murthy, H.R. & Dikshit, A.K., An overview of sustainability assessment methodologies. *Ecological Indicators*. 9, 189-212, 2009. https://doi.org/10.1016/j.ecolind.2011.01.007
67. Rao, M.R., Nair, P.K.R. & Ong, C.K., Biophysical interactions in tropical systems. *Agrofor. Sys*. 38, 3-50, 1998. https://doi.org/10.1023/A:1005971525590
68. Rizvi, A.J.H., Tahir, M., Rizvi, V., Kohli, R. K. & Ansari, A., Allelopathic Interactions in Agroforestry Systems. *Crit. Rev. Plant Sci*., 18, 773-796, 1999. http://dx.doi.org/10.1007/978-94-011-4173-4_13
69. Wheeler, T. & Braun, J.V., Climate change impacts on global food security. *Science*, 341, 508-513, 2013. https://doi.org/10.1126/science.1239402
70. FAO, *World food summit: Rome declaration on world food security and world food summit plan of action*. 1996.
71. Kamugisha, M., Mutembei, H. & Thenya, Assessing the value of agroforestry and food security among households in Isingiro District, South-western Uganda. *Int. J. Sustain. Dev.,* 1-15, 2022. https://doi.org/10.1080/13504509.2022.2048118
72. Pandey, D. N., Multifunctional agroforestry systems in India. *Curr. Sci*. 92, 455-463, 2007.
73. Raj, A. & Singh, L., Effects of girth class, injury and seasons on Ethephon induced gum exudation in *Acacia nilotica* in Chhattisgarh. *Indian Journal of Agroforestry*, 19(1), 36-41, 2017.
74. Raj, A. & Jhariya, M.K., Effect of environmental variables on *Acacia* gum production in the tropics of Chhattisgarh, India. *Environment, Development & Sustainability*, 24(5), 6435-6448, 2021. https://doi.org/10.1007/s10668-021-01709-1
75. Dhyani, D., Maikhuri, R. K., Rao, K. S., Kumar, L., Purohit, V. K., Sundriyal, M. & Saxena, K. G., Basic nutritional attributes of *Hippophaerh amnoides* (Seabuckthorn) populations from Uttarakhand Himalaya, India. *Curr. Sci.* 92, 1148-1152, 2007.
76. FAO, "Assessing forest degradation. Towards the development of globally applicable guidelines". Forest resources assessment working paper no. 177. FAO, Rome, 2011.
77. Lamb, D. & Gilmour, D., Rehabilitation and restoration of degraded forests. IUCN, WWF, Gland. Switcher land, 2003.
78. Mishra, G., Giri, K., Panday, S., Kumar, R. & Bisht, N.S., Bamboo: potential resource for eco-restoration of degraded lands. *J. Biol. Earth Sci.,* 4, 130–136, 2014.

79. Shi, L., Feng, W., Xu, J. & Kuzyakov, Y., Agroforestry systems: Meta-analysis of soil carbon stocks, sequestration processes, and future potentials. *Land Degrad. Dev.* 29, 11, 3886-3897, 2018. https://doi.org/10.1002/ldr.3136
80. Li, X., Ge, T., Chen, Z., Wang, S., Ou, X., Wu, Y., Chen, H. & Wu, J., Enhancement of soil carbon and nitrogen stocks by abiotic and microbial pathways in three rubber-based agroforestry systems in Southwest China. *Land. Degrad. Dev.,* 16, 2507-2015, 2020. https://doi.org/10.1002/ldr.3625
81. Suarez, L.R., Salazar, J.C. & Casanoves, F., Cacao agroforestry systems improve soil fertility: Comparison of soil properties between forest, cacao agroforestry systems, and pasture in the Colombian Amazon. *Agric. Ecosyst. Environ*., 314, 1-15, 2021. https://doi.org/10.1016/j.agee.2021.107349
82. Rakesh, S., Sarkar, D.R, Sinha, A.K, Abhilash, P.C. & Rakshit, A. Climate Change and Agricultural Policy Options: Indian Story. *Clim. Ch. Env. Sustainability*, 7(2), 208-211, 2019. https://doi.org/10.5958/2320642X.2019.00027.9
83. Dagar, J.C., Sharma, H.B. & Shukla, Y.K., Raised and sunken bed technique for agroforestry on alkali soils of Northwest India. *Land Degrad. Dev.,* 12, 107-118, 2001. https://doi.org/10.1002/ldr.442
84. Singh, G., Singh, N.T. & Abrol, I.P., Agroforestry techniques for the rehabilitation of degraded salt affected lands in India. *Land Degrad Dev*., 5, 223-242, 1994. https://doi.org/10.1002/ldr.3400050306
85. Benton, A., Greening red earth: restoring landscapes, rebuilding lives. *INBAR* Working Paper, 76, 16-17, 2014.
86. Eddy, W.C. & Yang, W.H., Improvements in soil health and soil carbon sequestration by an agroforestry for food production system. *Agric. Ecosyst. Environ*. 333, 22-27, 2022. https://doi.org/10.1016/j.agee.2022.107945

10

Land and Environmental Management through Agriculture, Forestry and Other Land Use (AFOLU) System

Kamlesh Verma[1], Prashant Sharma[2*], D.R. Bhardwaj[2], Raj Kumar[1], Nasam Midhun Kumar[2] and Alok Kumar Singh[2]

[1]ICAR-Central Soil Salinity Research Institute, Zarifa farm, Karnal, India
[2]Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India

Abstract
Agriculture, Forestry, and Other Land Use (AFOLU) is one of the most important sectors for the food and livelihood security, as well as being among the leading greenhouse gases (GHG) emitters, especially from the developing countries. (AFOLU is responsible for about a quarter of human-induced GHG emissions.) Among the different AFOLU activities, deforestation and agriculture are leading drivers of growing emission. In order to reduce GHG from the AFOLU sector, it is necessary to develop cost-effective mitigation strategies and adaptation measures via investment for adequate land and environment management. Investments should be made in food security efforts, boosting carbon sinks, modernizing old technologies, and introducing new technical innovation in order to minimize AFOLU emissions. The AFOLU mitigation measure can also give a co-benefit in the form of ecosystem service, but the adverse effects of the mitigation strategies, implementation problems and barriers should not be overlooked. Nevertheless, there are ample potential and perspectives to minimize GHG emission from the AFOLU sector. Therefore, in this chapter, the different sub-sectors of AFOLU are explored in terms of their emission status along with proper land and environment management including cost-effective mitigation measures, challenges and opportunities for making the AFOLU sector net zero or negative emitter of GHG.

**Corresponding author*: prashantsharma92749@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (247–272) © 2023 Scrivener Publishing LLC

Keywords: AFOLU, adaptation, GHG, challenges, opportunities, mitigation strategies, investment

10.1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) report on climate change and land, the average air temperature has risen 1.53 °C since the pre-industrial era [1]. The repercussions of this increasing temperature are being felt by natural and human ecosystems. Specifically, the greenhouse gases (GHGs) [2], most notably carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), which account for about 76, 6, and 16 percent of global warming, respectively, are major contributors to the increasing temperature [3]. Due to this changing climate, which leads to rising temperatures and changes in precipitation, the crop and animal output is anticipated to suffer throughout the globe with repercussions for profitability, food and livelihood security, health, and government finances [4]. In addition to increasing pressure from pests, weeds, and diseases, there are mounting evidences that an increase in temperature will have a detrimental effect even on the perennial crops such as trees [5]. Although this changing climate has some benefits, the negative consequences of climate change on agricultural production have outnumbered the positive ones [4].

Agriculture, Forestry, and Other Land Use (AFOLU) is a sector that includes a range of practices, from agriculture to land use changes, and it plays a crucial role in sustainable development for the advancement of social and economic growth [6]. Simultaneously, it provides food and fodder to feed the world's seven billion people, as well as fiber and fuel for a variety of applications; it is a source of income for billions of people and a plethora of products and ecosystem services that are critical to human prosperity [7]. Agriculture is typically crucial to the lives of a wide range of socioeconomic groups, especially in developing economies where it accounts for a large share of outputs, and forestry helps to maintain the regular flow of the ecosystem services and management of the environment for proper production from agriculture. However, the AFOLU sector is unquestionably affected by climate change, particularly rising temperatures, but it is also one of the biggest causes of rising GHG emissions. AFOLU plays an important part in the global carbon cycle due to its potential to offer emission reduction options and ability to function as a carbon sink [8]. Historically, AFOLU was first used in the IPCC Guidelines of 2006 to characterize the human-induced greenhouse gases (GHG) emissions from two different sectors: LULUCF (Land Use, Land Use Change, and Forestry) and agriculture, which were formerly classified independently [9].

10.2 AFOLU and Climate Change

AFOLU is accountable for over a quarter of human-induced GHG emissions [9], making it a crucial sector for countries to reach their emission objectives, as outlined in their intended national determined contributions (INDCs) [10]. Specifically, in 2019, about 7.2 Gt CO_2eq of worldwide GHG emissions came from the AFOLU segment [11], accounting for 23 percent with 11 percent coming from agriculture and 12 percent from the other AFOLU activities [1]. However, there is a strong connection between these land use sectors, and in many regions, agriculture is the key cause of deforestation [12], making deforestation and agriculture emissions primary causes of rising emissions from the AFOLU sector [9]. There is a wide variety in GHG emission around the globe, with about 28 nations having negative GHG emission while 14 countries have zero GHG emission from the AFOLU sector. The Russian Federation had the biggest forest sink (0.45 Gt CO_2eq) whereas Indonesia (1.15 Gt CO_2eq), Brazil (0.92 Gt CO_2eq) and India (0.72 Gt CO_2eq) were the top contributors in the GHG emission from the AFOLU segment. Similarly, Asia was the leading source of GHG emissions (3.05 Gt CO_2eq) from the AFOLU sector, while Europe had the greatest carbon sink (0.23 Gt CO_2eq) [11].

10.2.1 Trend of GHGs Emission from Agriculture

The agriculture sector is mainly responsible for non-CO_2 gases, especially methane (CH_4) and nitrous oxide (N_2O), which are created through biological processes associated with bacterial breakdown in agricultural and pasture soils as well as cattle digestive system. The CO_2 emissions from the agricultural farm are considered neutral because they are linked to annual photosynthetic carbon fixing and oxidation cycles [6]. Different processes such as enteric fermentation from the livestock, manure management including the use of the organic and synthetic fertilizers, rice cultivation, crop residue degradation, regulated savannah and crop residue burning from field all contribute to emissions of GHG. Sources of GHG emission from the agriculture sector with their specific emission potential is depicted in Figure 10.1 [11]. Among these practices, agricultural GHG emissions are growing from all sources, with some sources increasing faster than others.

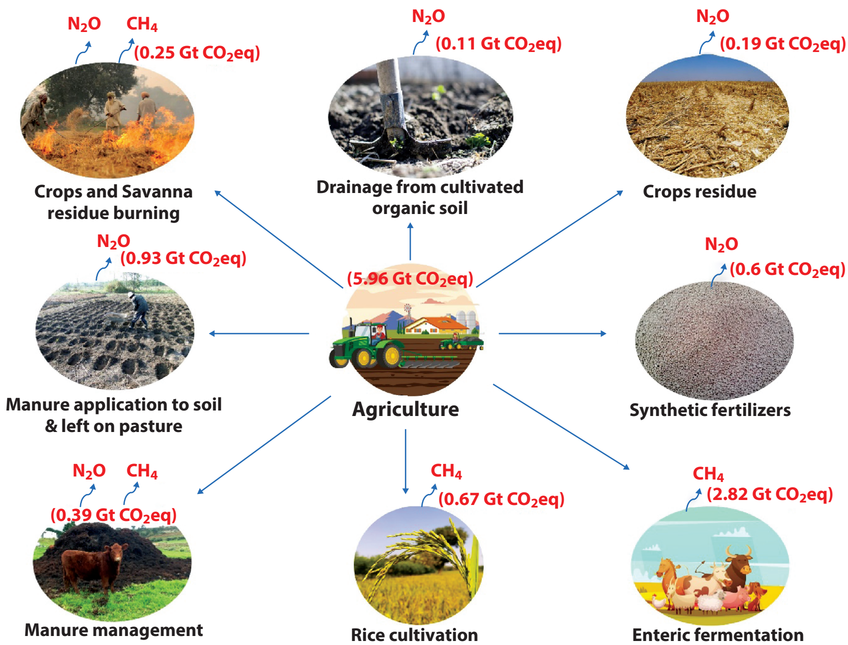

Figure 10.1 Sources of GHG emission from agriculture sector with their specific emission potential (data adapted from [11]).

In 2019, global emissions from agriculture amounted to nearly 5.96 Gt CO_2eq [11] which accounts for between 10 and 12 percent of CO_2eq [6], a figure that has remained relatively stable over the past three decades as a result of a balance between rising emissions from the agricultural sector and declining emissions from change of land use. The major contributor to the GHG emission from the agricultural sector includes CH_4 emitted from enteric fermentation of livestock's digestive tracts (2.8 Gt CO_2eq), followed by N_2Oemissions from fertilizer application (1.5 Gt CO_2eq), including both livestock manure (0.9 Gt CO_2eq) and synthetic fertilizers (0.6 Gt CO_2eq) [11, 13]. The draining of organic soils and peat lands generated 0.8 Gt CO_2eq in 2019, primarily in the form of CO_2 gas [14]. These emissions were preceded by CH_4 (0.6 Gt CO_2eq) from rice cultivation and CO_2 (0.5 Gt CO_2eq) from agricultural fossil fuel energy use [11, 13]. Agricultural soils, in particular, serve as both sources and sinks; they contribute 60-80 percent to the anthropogenic sources [15] and make up around 60 and 50 percent of the world's N_2O and CH_4 emissions, respectively [16]. Worldwide, in 2019, agricultural emissions per capita averaged 1.4 t CO_2eq per person, a decrease of roughly 35 percent from 1990 levels of 2.1 t CO_2eq per person with substantial regional differences in per capita emissions although they reduced steadily over time. Simultaneously, Brazil, Indonesia, and China are the major GHG emitters, accounting for over half of global agricultural emissions [13]. Moreover, fossil fuels are extensively used to power agricultural equipment, irrigation systems and fishing boats which on combustion produce the CO_2 and trace quantities of other GHGs, although still are not quantified by the different agencies. Aquaculture is also one of the significant emitters of the global N_2O (43 CO_2eq in 2009) which is expected to climb to 178 Mt CO_2eq by 2030 [6, 17].

10.2.2 Trend of GHGs Emission from Forestry and Other Land Use System

Forestry and other land use systems (LULUCF) contribute much less emission compared to the agricultural sector. The foremost contributor to GHG emission from this sector includes removal of harvestable material including timber and organic carbon from the soil [18]. Moreover, GHG from net forest conversion are CO_2 created through C oxidation in vegetative biomass lost as a result of deforestation for the sake of other land use such as agriculture. Sources of GHG emission from Forestry and other land use systems (LULUCF) with their specific emission potential is depicted in Figure 10.2 [11]. CH_4 and N_2O from the combustion of biomass in forest regions and CH_4, N_2O and CO_2 gas from the combustion of organic soils make up the emissions from the burning of biomass [6].

Worldwide, during the period 2016–2020, forest conversion (deforestation) was responsible for yearly emissions of around 2.9 Gt CO_2eq.

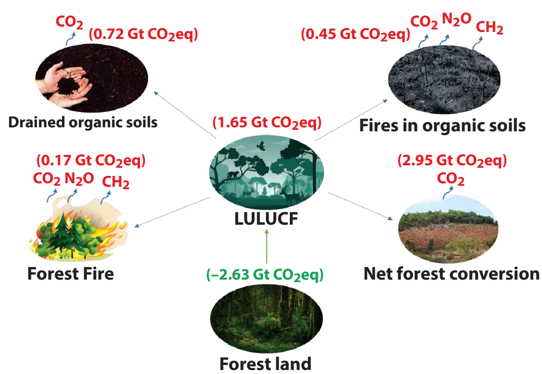

Figure 10.2 Sources of GHG emission from Forestry and other land use systems (LULUCF) sector with their specific emission potential (data adapted from [11]).

Simultaneously, remaining forests absorbed around 2.5 Gt CO_2eq, resulting in annual net emissions of approximately 0.5 Gt CO_2eq from forest land to the atmosphere [19]. Fires are a subset of draining and net forest conversion's cycle the second-largest emitter of the GHG from land use change (0.4 Gt CO_2eq); however, they contribute negligible non-CO_2 emissions (0.2 Gt CO_2eq) [11, 19]. Moreover, South America and Africa had the highest deforestation emissions in 2020, with around 1 Gt CO_2eq emission, whereas Europe had the biggest forest sink (1 Gt CO_2eq removed per year), followed by Asia and the Americas. Similarly, China, Russia, and the USA were the top C sinks (each removing around 0.5 Gt CO_2eq year), while Brazil, Congo, and Indonesia were the leading nations for C source through deforestation and forest conversion (each removing approximately 0.5 Gt CO_2eq annually) [19].

10.3 Role of AFOLU in Land and Environment Management

The GHG emission from the AFOLU sector can be reduced through the proper management of the land and environment. It is vital to pursue strategies to increase and improve the AFOLU sector's performance in order for it to realize its full mitigation potential, which would help toward any successful climate change management goal [20]. However, the policies that govern this sector's operations must take both mitigation and adaptation into account. This can assist in orienting AFOLU activities toward the global dissemination of breakthrough technology for efficient land use [10]. During the implementation of NDCs, it also provides the possibility to pursue mitigation and adaptation concurrently through AFOLU [20] as mitigation and adaptation are complementary to each other [21, 22]. The AFOLU mitigation includes, but is not limited to, afforestation and reforestation, sustainable forest management and reductions in emissions by restricting deforestation, better management of farmlands, woodlands, rangelands, pastures, fisheries, restoring organic soils, and rehabilitation of wetlands as well as peat lands [4, 9]. Overall, there are two options for achieving mitigation in the AFOLU sector, viz., supply-side or demand-side measures which are depicted in Figure 10.3 [6]. Supply-side solutions include improved livestock, land as well as land use shift management, and increased afforestation, whereas changes in eating patterns and reduced food waste are examples of demand-side initiatives, although quantifiable criterions for demand-side measures are less definite [6]. However,

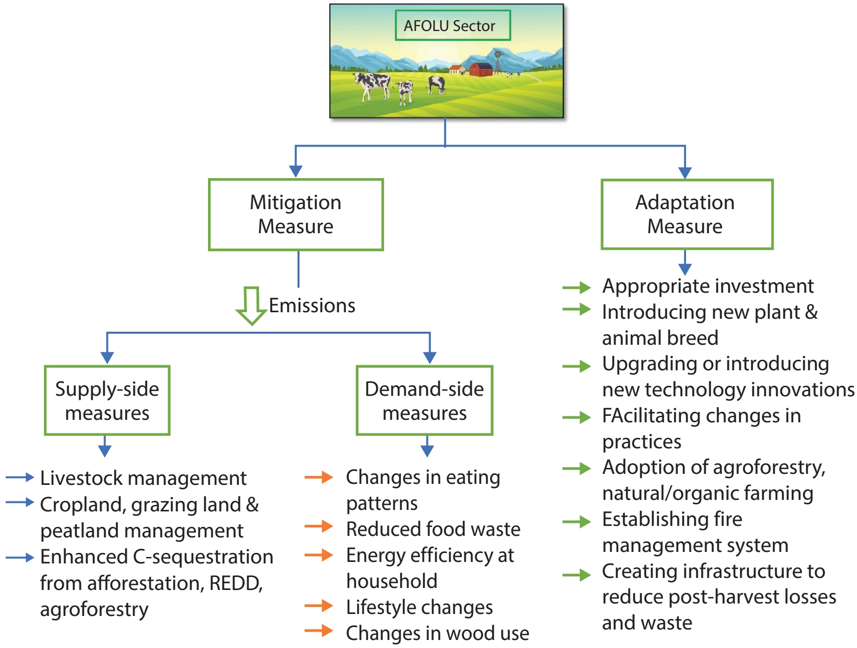

Figure 10.3 Mitigation and adaptation strategies to combat the GHG emission from AFOLU sector [6].

the different mitigation measures can be related to the costs. According to estimates of Smith *et al.* [6], in 2030 with C pricing of around USD 100 per t CO_2eq, the mitigation from the supply-side strategies in AFOLU will be 7.18-10.60 Gt CO_2eq yr^{-1} of which 33 percent can be done for less than USD 20 per tCO_2eq. Moreover, in the developing countries, the cost of the C-sequestration ranges 0.5-7.0 per tCO_2eq, while in developed countries, the costs are comparably higher (USD 1.4-22 per tCO_2eq) [23–25]. Graham *et al.* [26] assessed the economics of reducing carbon emissions using several REDD+ initiatives in Southeast Asia; the expenditure per prevented tonne carbon emission ranges from $9 to $75. Similarly, in Thailand, the potential for CO_2 sequestration in 2050 would be 23.6 MtCO_2eq at $5 per t$CO_2$eq, 28.7 t$CO_2$eq at $10 per t$CO_2$eq [9].

Simultaneously, the right investment in AFOLU is needed to help people adapt to climate change and make socioeconomic and environmental systems which are more resilient to climate change and underpin the production of diversified products [4]. This investment should be directed towards food security initiatives, increasing carbon sinks, upgrading the established technologies and introduction of new technological innovation so that emission from the AFOLU can be reduced to a greater extent. The adaptation measure includes adoption to the sustainable land use system such as organic and natural farming, agroforestry [22, 27, 28] and introduction of innovative farming practices to rehabilitate wetlands in order to maintain their productivity while conserving carbon stocks, proper management regarding forest fire through early warning systems and equipments, development of the improved plant varieties for higher productivity and stress tolerant. Similarly, there is a need to introduce new animal breeds that are less vulnerable to diseases that are projected to increase due to climate change [8]. However, for AFOLU mitigation initiatives to be effective, it is vital to ensure that (a) communities are actively involved in the execution of mitigation methods, (b) any new approach is compatible with existing policies or programs, and (c) smallholder approval is secured in advance. Gender, barriers, and opportunity are all issues that need extra work to address [29].

10.3.1 Agriculture Sector

Agriculture is indeed a substantial contributor to changing climate and one of the most vulnerable economic sectors to its effects [11]. Feeding a growing global population while simultaneously decreasing environmental impact and protecting natural resources for future generations is a major problem for the agricultural sector [30]. Food is necessary for human survival; hence the agriculture sector is critical in the aspect of sustainable development and climate change. Therefore, it would not be in opposition to the United Nations Framework Convention on Climate Change (UNFCCC) goal of food security. As a result, agricultural mitigation measures should be based on a win–win scenario [9, 31]. Agriculture may have substantial environmental effects which may be positive, such as carbon sinks by sequestering carbon in biomass products and soil organic matter [30] and reducing flood risks via the adoption of specific agricultural methods while negative environmental effects include pollution and deterioration of land, water, and air [6].

At the farm level, the GHG emission from the agriculture sector can be managed more effectively by controlling carbon and nitrogen fluxes [32]. For instance, it is feasible to minimize CH_4 emissions from cattle by enhancing the feed use efficiency, using improved breeds with higher productivity and manipulation of bedding and storage conditions. Simultaneously, the N_2O emissions can be reduced from crop production by implementing measures that boost nitrogen use efficiency by crops at the low rate of manure or synthetic fertilizer use, drainage management, manipulation of diets and grazing management [6, 32]. However, increase in the yield of the crops and livestock can reduce the land competition to a greater extend and thus the GHG [6]. For instance, the addition of biochar to the soil may result in greater carbon abatement than conventional bioenergy solutions including increased biomass and crop yield [33].

Moreover, in the aquaculture system, "Aquaponic aquaculture" and "Bioflocs Technology" are two promising strategies to reduce N_2O release. When compared to Aquaponic aquaculture, which uses fish tanks and hydroponically grown plants (Bioflocs Technology), the latter relies on the cultivation of nitrogen-fixing heterotrophic bacteria in flocs inside the fish culture component wherein heterotrophic bacterial growth is fostered, resulting in nitrogen absorption [6, 17].

Several countries are concerned about and working to improve their agricultural systems in light of the effects of climate change, particularly emerging nations [20]. The adaptation measures include adoption and implementation of the sustainable land use system/climate smart agriculture such as organic and natural farming, agroforestry which has the potential to net sink since trees trap carbon [34] compared to other monocropping systems which are generally carbon source [22, 27, 28]. Concurrently, agroforestry can contribute to create a management system that is based on an ecosystem approach and provides novel and beneficial remedies to many of the negative repercussions of human land usage including improved agricultural production, diversity, crop and livestock yields [35, 36], non-point source pollution reduction, and rural development [37–40]. Agroforestry systems are expected to sequester 12 - 228 Mg ha^{-1} $yr^{-1}$of CO_2, with a mean of 95 Mg ha^{-1} yr^{-1} [41]. Adaptation and mitigation initiatives may benefit greatly from agroforestry, which has a technical C reduction capacity of 1.1-2.2 Pg C in terrestrial ecosystems during next 50 years [42]. In their study, Kim *et al.* [27] documented that the shift from monocropping to agroforestry can help to mitigate 27.2 ± 13.5 t CO_2 eq ha^{-1} y^{-1} at least up to the initial growth phase, i.e., 14 years due to the higher C-sequestration rate in vegetative biomass and soil component (26.4 ± 10.3 t CO_2 eq ha^{-1} y^{-1}) and negative net CH_4 and N_2O emission (-0.8 ± 3.2 t CO_2 eq ha^{-1} y^{-1}). In light of the above finding, agroforestry can be seen as a strategy that combats the degradation of the environment, especially the soil, while boosting crop diversification and raising the land's productivity [43]. Simultaneously, agroforestry is also recognized for its contribution to conventional employment creation; therefore, it has the potential to provide dual advantages, i.e., revenue creation for impoverished farmers and environmental and ecological stability including desertification and deforestation control [28, 43].

Simultaneously, with the adoption of advancement in the technology, indirect emission from farms can be reduced to a greater extend through the adaptation of measures. In some instances, fossil fuel energy may be substituted by bioenergy derived from wood, agricultural feedstocks, and wastes, or the energy efficiency of the agriculture sector can be increased [32]. Biofuel is a flexible fuel that may be utilized to generate power, liquified fuel, gasoline, hydrogen, or be straight burned. In addition, bioenergy produces fewer CO_2 emission compared to traditional fuels such as fossil fuels; its C was just taken from the atmosphere [44]. If crop residues and savanna residue can be exploited for bioenergy instead of being burned, this would serve the twin objective of simultaneously reducing GHG emissions from burning agricultural residues and substituting bioenergy for fossil fuel. However, use of bioenergy carries considerable risks if forests are removed to cultivate bioenergy [45, 46]. Moreover, due to large-scale awareness programs, farmers have made significant strides in adopting ecologically friendly methods such as organic farming, natural farming, conservation tillage, better manure storage and soil nutrient testing including improving usage and management of fertilizers, pesticides, energy, and water, employing fewer inputs per acre [47]. Moreover, cultivating transgenic crops has enabled the adoption of no- or reduced-tillage systems that employ weed control instead of ploughing. In addition to conserving fuel and decreasing emissions, this improves soil health and water retention by reducing runoff and preventing soil compaction, so allowing moisture to be retained, thus allowing soil to store carbon more efficiently [48]. The use of weedicides can be further reduced using the estimation of weed seed bank at the farm level, so that future weed menace can be predicted and suitable measures can be adapted at an early stage, i.e., even before planting the crop [49].

10.3.2 Forestry and Other Land Use

Forests serve a critical role in upholding the local people's livelihoods in most of the developing countries. Forests encompass around one-third of the surface area of earth, which are vital to the health of our ecosystem. For instance, trees and forests absorb and store a significant amount of the CO_2 that would otherwise contribute to global warming. Forests have a major function in exchange of CO_2 between the atmosphere and biosphere [50]. Forests, particularly primary ones, are actively involved in the global C cycle because photosynthesis and respiration store the majority of C in vegetation and its underlying soil [51–53]. Globally, 1.09 to 1.74 billion people are dependent on forests to varying degrees for meeting their daily requirements, and around 0.2 billion indigenous communities are nearly entirely reliant on forests [54]. The human increase in food demand increases the strain on forest areas and forest resources, resulting in an unsustainable use of the nation's environmental assets and a substantial loss of global carbon stores [55]; it becomes the primary driver for decimation of natural forest biodiversity and contributes significantly to the global GHG emission [56].

Risk management through adoption of a sustainable land use system such as agroforestry on the agricultural ecosystem can help to reduce the emission from deforestation and degradation of forest as it encourages sustainable forest management (SFM) and environmental protection as well as sustainability [57]. Simultaneously, the presence of the perennial component, i.e., the trees to be specific multi-purpose tree species [58, 59] which have abilities to supply diversified products such as food, fiber, fruit, timber, fiber, fuel wood with enhanced crop yield, helps people with a means of subsistence even during drought years [34]. Therefore, it decreases the dependence of the local people on the nearby forest and simultaneously helps to expand the forest proportion of the landscape [28]. The strongest effect of mitigation strategies to reduce the GHG emission includes reducing the deforestation, introducing afforestation/reforestation, proper forest management and restoration [6, 60]. Potential intervention and strategies for the management and reduction of GHG emission from AFOLU is depicted in Figure 10.4 [8].

In particular, preventing or reducing deforestation, safeguarding natural and secondary forests, peat lands, wetlands, and mangroves, as well as other human-induced disturbances like forest fires, insect infestations, and shifting cultivation, will help conserve the prevailing C pools in forest biomass and soil. The restriction on deforestation and afforestation are strategies of preventing or reversing the reduction in terrestrial carbon stock via increasing forest cover [44]. Forest fires should be appropriately managed through the prescribed burning or early warning system. Simultaneously, the planting of trees on the non-forested lands such agricultures (i.e., agroforestry), degraded and wastelands, enables these areas to also act as carbon sinks [6]. Moreover, forest ecosystems, being an economically viable choice for C-sequestration, require a high degree of management to retain their carbon stores [61] through proper implementation of the SFM practices, especially the certification of forest products and practices [8, 62]. The timber production from the forest should be managed sustainably through prolonging rotation periods, decreasing harm to surviving trees, introducing soil and water conservation methods, logging waste reduction, fertilizing, and making more effective use of wood; sustainable exploitation of wood energy [6]. Simultaneously, more focus should be directed towards the plantation initiatives, like joint forest management (at regional level)

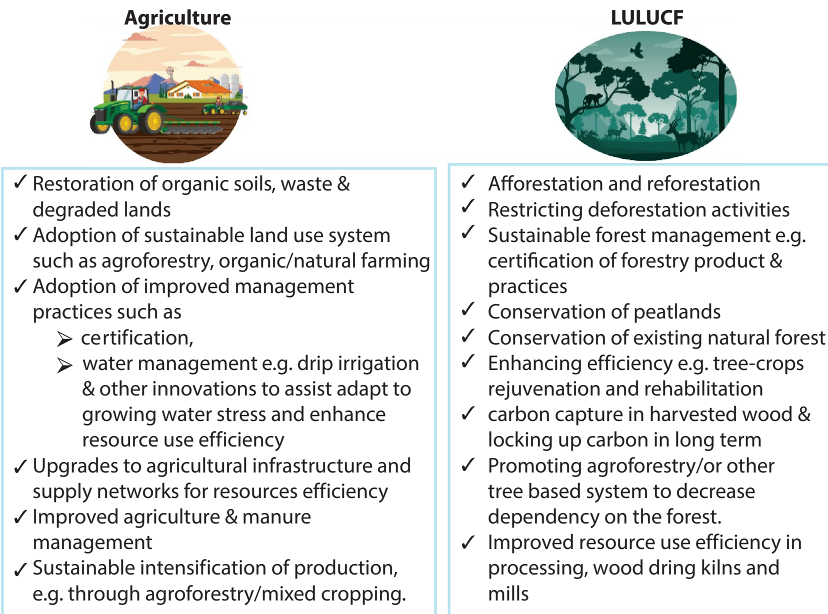

Figure 10.4 Potential intervention and strategies for the management and reduction of GHG emission from AFOLU (adopted from [8]).

and REDD (reducing emissions from deforestation in developing countries) or REDD+ (reduce emissions from deforestation and forest degradation in developing countries) to satisfying climate change targets, as being effective for encouraging afforestation and replanting and implementing a framework for forestry development [52, 53].

10.4 Co-Benefit from AFOLU

In addition to changes in GHG balances, the implementation of AFOLU mitigation measures has a number of institutional, socioeconomic, and environmental effects which can have a beneficial or adverse effect on the ecosystem. Potential co-benefits from the AFOLU mitigation strategies are depicted in Figure 10.5 [6, 10]. However, co-benefits or adverse effects from different strategies depend on various factors including geographical region [6]. Specifically, AFOLU mitigation strategies may influence tenure and rights to land for socioeconomic groups that depend on natural resources [63] and thus help in clarification and harmonization of land tenure as well as rights and preparation of the sectoral policies through

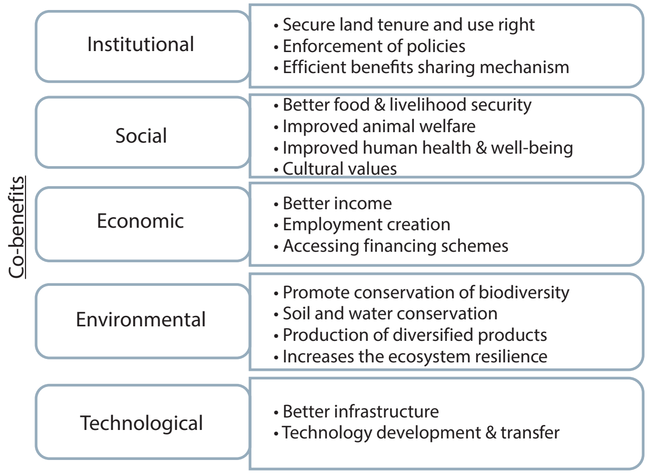

Figure 10.5 Potential co-benefits from the AFOLU mitigation strategies (adapted from [6, 10]).

participative mechanism and decision-making process [6]. Some AFOLU, such as agroforestry, organic/natural farming can boost food production and employment generation and also produce higher income and diversified products, thus securing livelihood security and improving human well-being while increasing ecosystem resilience and providing ecosystem services including conservation of soil water resources and cultural values and traditional knowledge. However, some AFOLU mitigation strategies only provide tangible benefits such as food while decreasing other environmental services [64, 65]. AFOLU mitigation strategies can have a variety of effects on soil and water resources. Increasing soil organic carbon can help to reduce climate change and enhance soil health. Although the quantity of organic C that could be retained in soil is limited, several management strategies that increase soil organic carbon also improve farmland and rangeland yields [66]. Reforestation and afforestation may potentially offer co-benefits for climate change adaptation by protecting [67-69] and restoring biodiversity ecologically varied ecosystems on previously developed cropland [70, 71] and ecosystem services [72].

10.5 Challenges

The foremost and major challenge is the lack of statistics about the GHGs emissions from AFOLU activities, especially for recent years; this is mainly due to the absence of international institutional publishing AFOLU emissions at regular intervals, which prevents a more exact characterization of recent overall anthropogenic forcing [73]. However, this challenge is somehow solved by the FAOSTAT which provides the yearly emission data from the AFOLU at the country level. Another major challenge is that it is impossible to precisely predict the quantity and spatial distribution of future mitigation potentials due to a variety of intrinsically unknown elements such as population increase, and economic and technological advancement [6]. Simultaneously, there are a number of obstacles to scaling up mitigating policy measures in AFOLU, including the need to assess the effects of complex interconnections between diverse land use activities on policy effectiveness. Adapting to concerns about food security and farmers' livelihoods provides policymakers with extra obstacles, particularly in the least developed nations. It also demonstrates the difficulties in identifying successful objectives and tactics for varied AFOLU programs with intricate land use connections [74]. Moreover, FAO indicates that AFOLU GHG emissions have roughly doubled in the last half-century and are expected to rise by an additional 30 percent by 2050 due to the increased demand for food production and land conversion, if greater reduction efforts are not undertaken [75]. It is also anticipated that the contribution of developing nations to future GHG emissions would fluctuate greatly owing to predicted increases in production for food by 2030, which will drive rapid land use change [6].

Around the globe, INDCs and national plans have taken various AFOLU initiatives for socioeconomic and sector-specific development, combating global warming and climate change, and sustainable growth approaches and tactics. However, these projects come in a number of forms and are not always necessarily explicitly focused on lowering emissions. The majority are intended to meet developmental and adaptation goals while also providing mitigation advantages [76]. Moreover, measurable targets are far more prominent in the forestry sector compared to the agricultural sector in the INDC tactics of nations. There are worries that food and AFOLU outcomes will compete with each other. This could be because biofuel plantations are taking up more land [77, 78], afforestation and reforestation are taking up farmland [79, 80], or there are not enough options and flexibility for agricultural development because of measures to stop or reverse land conversion [79, 80]. Moreover, there are still socioeconomic, technical, ecological, institutional, and other impediments and challenges to implementing mitigation and adaptation initiatives [6]. Further emission reductions are hampered by the difficulty of tracking and verifying emissions from the LULUCF sector. Also, some ways to reduce GHG emissions elevate the concern of non-permanence as well as leakage, which can lead to the transfer of activities to non-protected areas and put conservation areas in countries with few resources at risk [81, 82]. Other difficulties linked with additionality, permeability, and permanency have sparked discussions and constitute the most significant obstacles [9, 32, 83]. Technical and institutional frameworks and market access may also impede the implementation of mitigation solutions, as well as the ability to accurately report emission levels and emission components based on activity data [29, 84].

10.6 Opportunities: the Way Forward and Future Perspective

AFOLU emissions are substantial and in future the proportion of total emission is likely to expand [9] although not as quickly as fossil fuels emissions, indicating that AFOLU emissions are dropping in proportion to total emissions from all human activities [85]. Therefore, there is a need to develop cost-effective strategies and policies controlling the AFOLU sector's operations which must account for both mitigation and adaptation. Simultaneously, there is an urgent need to expedite investments via encouraging innovation and technologies with a high probability of economic success and widespread adoption, even beyond what nations have sought in their INDCs [20] that can boost agricultural and forestry productivity [86]. Thus, there should be enough finance possibilities for the AFOLU sector in the smallholders as well as large farmers [87, 88]. Modularity, like the Clean Development Mechanism and the Joint Implementation, may be effective in the implementation of mitigation initiatives [9, 88]. This can assist in orienting AFOLU activities toward the global dissemination of breakthrough technology for efficient land use [10].

Moreover, regular revisions of AFOLU emission estimations are crucial for scientific and political purposes. Better scientific assessments of anthropogenic forcing and related trends are needed to accurately predict the medium- and long-term climate consequences and to find effective ways to reduce them [89, 90]. Simultaneously, all sub-sectors under the AFOLU sector have an immediate need to address climate change. In order to accomplish outcomes in a well-organized and operative manner, it is crucial to eliminate sector-specific obstacles in AFOLU via an integrated and robust strategy [20]. A thorough evaluation of forests' total carbon stores and fluxes must be augmented by an investigation of the impacts of changing climate on forest structure, composition and productivity [91]. Evaluating forest biomass and carbon storage and its management through

SFM encourage soil, food and climate security in tropical forest ecosystems [92–94]. Also, it ensures healthy land by minimizing land/soil degradation and delivers uncountable ecosystem services [95]. SFM including leguminous plants also enhance nitrogen and carbon status into the vegetation and soils that ensure a healthy environment and ecosystem [96–99]. Applying sustainable intensification in the AFOLU sector enhances a climate-resilient agro ecosystem which helps in achieving environmental sustainability [100–103]. In future, the reporting of the GHG emission from AFOLU sector should be made compulsory for all nations within the framework of the UNFCCC [18].

10.7 Conclusion

There is no doubt AFOLU is one of the largest emitters of the GHG, particularly in developing countries. Without the AFOLU, however, it would be impossible to sustain food and livelihood security. Therefore, greater emphasis should be placed on sustaining the AFOLU system through effective application of the land and environment management plans. While mitigation and adaptation strategies and plans should be given equal consideration, it is important to prioritize those that have the potential for both. Simultaneously, sustainable land use system and climate smart landscape such as agroforestry are the need of the hour for maximizing and sustaining the land's benefits while minimizing emissions from AFOLU. However, the execution of mitigation measures is not simple, since they are always accompanied by a number of negative impacts. Specifically, it is challenging to achieve a balance among the goals of reducing emissions and adapting to climate change and promoting development and reducing poverty, or to design solutions which are effective on both fronts. Therefore, in addition to mandating the inclusion of GHG reduction and adaptation strategies from AFOLU in all national and INDCs, major investments and technical innovation should be undertaken so that all nations work toward GHG reduction.

References

1. IPCC, Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte,

H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. 2019. https://www.ipcc.ch/srccl/

2. Datta, A., Smith, P. & Lal, R., Effects of long-term tillage and drainage treatments on greenhouse gas fluxes from a corn field during the fallow period. *Agriculture, Ecosystems & Environment*, 171, 112-123, 2013. https://doi.org/10.1016/j.agee.2013.03.014
3. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Environmental Protection Agency, USA, Washington DC, 2017. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.
4. Gitz, V., Meybeck, A., Lipper, L., Young, C.D. & Braatz, S., Climate change and food security: risks and responses. Food and Agriculture Organization of the United Nations (FAO) Report, 110, 2-4, 2016. Available at http://www.fao.org/3/a-i5188e.pdf
5. Hatfield, J.L. & Prueger, J.H., Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, 10, 4-10, 2015. https://doi.org/10.1016/j.wace.2015.08.001
6. Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N.H., Rice, C.W., Abad, C.R., Romanovskaya, A., Sperling, F. & Tubiello, F.N., Agriculture, Forestry and Other Land Use (AFOLU), In: Edenhofer O, Pichs-Madruga R, Sokona Y, *et al*., editors. *Climate change 2014: mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, and New York: Cambridge University Press; pp. 811-922, 2014.
7. MEA, Millennium Ecosystem Assessment. United National Environment Program, New York, Nairobi, 155 pp. 2005.
8. Havemann, T., Negra, C., Agriculture, Forestry and Other Land Uses (AFOLU) and Climate bond standard. AFOLU Technical Working Group Climate Bonds Initiative, 2012. https://www.climatebonds.net/standard/land-use
9. Pradhan, B.B., Chaichaloempreecha, A. & Limmeechokchai, B., GHG mitigation in agriculture, forestry and other land use (AFOLU) sector in Thailand. *Carbon Balance and Management*, *14*(1), 1-17, 2019. https://doi.org/10.1186/s13021-019-0119-7.
10. Bustamante, M., Robledo-Abad, C., Harper, R., Mbow, C., Ravindranat, N. H., Sperling, F., & Smith, P., Co-benefits, trade-offs, barriers and policies for greenhouse gas mitigation in the agriculture, forestry and other land use (AFOLU) sector. *Global Change Biology*, *20*(10), 3270-3290, 2014. https://doi.org/10.1111/gcb.12591
11. Food and Agriculture Organization of the United Nations. FAOSTAT statistical database. [Rome]: FAO 2022. https://www.fao.org/faostat/en/#data

12. Glantz, M.H., Gommes, R. & Ramasamy, S., Coping with a changing climate: considerations for adaptation and mitigation in agriculture. *Environment and Natural Resources Management Series, Monitoring and Assessment-Food and Agriculture Organization of the United Nations*, No. 15, 100 pp. Rome, Italy, 2009.
13. FAO. Emissions from agriculture and forest land. Global, regional and country trends 1990–2019. FAOSTAT Analytical Brief Series No. 25. Rome, 2020a. https://www.fao.org/3/cb5293en/cb5293en.pdf
14. Conchedda, G. & Tubiello, F.N., Drainage of organic soils and GHG emissions: Validation with country data. *Earth System Science Data Discussions*, 1-47, 2020. https://doi.org/10.5194/essd-2020202
15. Syakila, A. & Kroeze, C., The global nitrous oxide budget revisited. *Greenhouse gas Measurement and Management*, 1(1), 17-26, 2011. https://doi.org/10.3763/ghgmm.2010.0007
16. Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H.H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, R.J., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Rose, S., Schneider, U. & Towprayoon S., Agriculture. In: Chapter 8 of *Climate change 2007: Mitigation. Contribution of Working group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer, (eds.), Cambridge University Press, Cambridge, UK and New York, USA, pp. 497-540, 2007.
17. Hu Z., Lee, J.W., Chandran, K., Kim, S. & Khanal S.K., Nitrous Oxide (N_2O) Emission from Aquaculture: A Review. *Environmental Science & Technology,* 46, 6470–6480, 2012. doi: https://doi.org/10.1021/es300110x ISSN: 0013-936X, 1520–5851.
18. Petrescu, A.M.R., Peters, G.P., Janssens-Maenhout, G., Ciais, P., Tubiello, F.N., Grassi, G. & Dolman, A.J., European anthropogenic AFOLU greenhouse gas emissions: a review and benchmark data. *Earth System Science Data*, *12*(2), 961-1001, 2020. https://doi.org/10.5194/essd-12-961-2020
19. FAO, Forest land emissions and removals. Global, regional and country trends 1990–2020. FAOSTAT Analytical Brief Series No. 12. Rome, 2020b. http://www.fao.org/3/cb1578en/cb1578en.pdf
20. Fobissie, K., Chia, E., Enongene, K. & Oeba, V. O., Agriculture, forestry and other land uses in Nationally Determined Contributions: the outlook for Africa. *International Forestry Review*, *21*(1), 1-11, 2019. https://doi.org/10.1505/146554819827167484
21. Locatelli, B., Synergies between adaptation and mitigation in a nutshell. 2011. https://www.cifor.org/fileadmin/fileupload/cobam/ENGLISHDefinitions%26ConceptualFramework.pdf
22. Verma, K., Sharma, P., Kumar, D., Vishwakarma, S.P. & Meena, N.K., Strategies Sustainable Management of Agroforestry in Climate Change Mitigation and Adaptation. *Int. J. Curr. Microbiol. App. Sci*, *10*(01), 2439-2449. 2021. https://doi.org/10.20546/ijcmas.2021.1001.182

23. Cacho, O.J., Hean, R.L. & Wise, R.M., Carbon-accounting methods and reforestation incentives. *Australian Journal of Agricultural and Resource Economics*, *47*(2), 153-179, 2003. https://doi.org/10.1111/1467-8489.00208
24. Richards, K.R. & Stokes, C., A review of forest carbon sequestration cost studies: a dozen years of research. *Climatic change*, *63*(1), 1-48, 2004. https://doi.org/10.1023/B:CLIM.0000018503.10080.89
25. Nabuurs, G.J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, O., Krankina, W., Kurz, A., Matsumoto, M., Oyhantcabal, W., Ravindranath, N.H., Sanchez, M.J.S. & Zhang X., Forestry. In: *Climate Change 2007: Contribution of Working Group III to the Fourth Assessment Report of the Intergovenmental Panel on Climate Change*. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer, (eds.), Cambridge University Press, Cambridge, UK and New York, USA, pp. 541-584, 2007.
26. Graham, V., Laurance, S.G., Grech, A., McGregor, A., Venter, O., A comparative assessment of the financial costs and carbon benefts of REDD+ strategies in Southeast Asia. *Environ Res Lett.,* 11(11), 114022, 2016.
27. Kim, D.G., Kirschbaum, M.U. & Beedy, T.L., Carbon sequestration and net emissions of CH4 and N2O under agroforestry: Synthesizing available data and suggestions for future studies. *Agriculture, Ecosystems & Environment*, *226*, 65-78, 2016. https://doi.org/10.1016/j.agee.2016.04.011
28. Sharma, P., Singh, M.K., Tiwari, P. & Verma, K., Agroforestry systems: Opportunities and challenges in India. *Journal of Pharmacognosy and Phytochemistry*, *1*(sp), 953-957, 2017.
29. Mbow, C., Skole, D., Dieng, M., Justice, C., Kwesha, D., Mane, L., Gamri, M., Vordzogbe, V., & Virji, H., Challenges and Prospects for REDD+ in Africa: Desk Review Of REDD+ Implementation in Africa. GLP-IPO, Copenhagen, 70 pp. 2012.
30. Johnson, J.M.F., Franzluebbers, A.J., Weyers, S.L. & Reicosky, D.C., Agricultural opportunities to mitigate greenhouse gas emissions. *Environmental Pollution*, *150*(1), 107-124, 2007. https://doi.org/10.1016/j.envpol.2007.06.030
31. Office of Natural Resources and Environmental Policy and Planning (ONEP), Thailand's Second National Communication under the United Nations Framework convention on climate change. Bangkok: Ministry of Natural Resources and Environment, 2010.
32. Grassi, G., House, J., Dentener, F., Federici, S., den Elzen, M. & Penman, J., The key role of forests in meeting climate targets requires science for credible mitigation. *Nature Climate Change*, *7*(3), 220-226, 2017. https://doi.org/10.1038/nclimate3227
33. Woolf D., Amonette, J.E., Street-Perrott, F.A., Lehmann, J. & Joseph S., Sustainable biochar to mitigate global climate change. *Nature Communications*, 1, 1-9, 2010 https://doi.org/10.1038/ncomms1053
34. Mbow, C., Smith, P., Skole, D., Duguma, L. & Bustamante, M., Achieving mitigation and adaptation to climate change through sustainable agroforestry

practices in Africa. *Current Opinion in Environmental Sustainability*, *6*, 8-14, 2014. https://doi.org/10.1016/j.cosust.2013.09.002

35. Dey, S., Prasad, S., Tiwari, P., & Sharma, P., Effect of urea, KCl, zinc placement and spray on growth of cowpea. *Journal of Pharmacognosy and Phytochemistry, SPI*, 971-973, 2017.
36. Garima, Bhardwaj, D.R., Thakur, C.L., Kaushal, R., Sharma, P., Kumar, D. & Kumari, Y., Bamboo-based agroforestry system effects on soil fertility: Ginger performance in the bamboo subcanopy in the Himalayas (India). *Agronomy Journal*, *113*(3), 2832-2845, 2021. https://doi.org/10.1002/agj2.20684
37. Adedire, M.O., Environment protection. The Agroforestry option. *Nig. J. Forestry*, 34(1), 16, 2004.
38. Adekunle, V.A.J., Trends in Forest Reservation and Biodiversity Conservation in Nigeria. In: *Environmental Sustainability and Conservation in Nigeria*, Okoko, E., Adekunle, V.A.J. & Adeduntan, S.A. (Eds), Environmental conservation and Research Team, Federal University of Technology, Akure Nigeria, pp. 82-9. 2005.
39. Oke D.O. & Odebiyi K.A., Traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria. Agriculture, Ecosystems & Environment 122, 305–311, 2007. Available at: http: //www.sciencedirect.com/science/article/pii/S0167880907000540. https://doi.org/10.1016/j.agee.2007.01.022
40. Sharma, P., Bhardwaj, D.R., Singh, M.K., Nigam, R., Pala, N.A., Kumar, A. & Thakur, P., Geospatial technology in agroforestry: status, prospects, and constraints. *Environmental Science and Pollution Research*, 1-29, 2022. https://doi.org/10.1007/s11356-022-20305-y
41. Murthy, I.K., Gupta, M., Tomar. S., Munsi, M., Tiwari, R., Hegde, G.T. & Ravindranath, N.H., Carbon sequestration potential of agroforestry Systems in Indian. *Journal of Earth Science Climate Change,* 4, 131, 2013. https://doi.org/10.4172/2157-7617.1000131
42. IPCC (Intergovernmental Panel on Climate Change), *Climate change 2000: the scientific basis*. Oxford University Press, Oxford, 2007.
43. Sharma, P., Singh, M.K. & Tiwari, P., Agroforestry: a land degradation control and mitigation approach. *Bulletin of Environment, Pharmacology and Life Sciences, 6*(5), 312-317, 2017.
44. Calvin, K. V., Beach, R., Gurgel, A., Labriet, M. & Rodriguez, A.M.L., Agriculture, forestry, and other land-use emissions in Latin America. *Energy Economics*, *56*, 615-624, 2016. https://doi.org/10.1016/j.eneco.2015.03.020
45. Reilly, J., Mellilo, J., Cai, Y., Kicklighter, D., Gurgel, A., Paltsev, S., Cronin, T., Sokolov, A. & Schlosser, A., Using land to mitigate climate change: Hitting the target, recognizing the trade-offs. *Environ. Sci. Technol.* 46 (11), 5672-5679, 2012. https://doi.org/10.1021/es2034729
46. Calvin, K., Wise, M., Kyle, P., Patel, P., Clarke, L. & Edmonds, J., Trade-offs of different land and bioenergy policies on the path to achieving climate

targets. *Clim. Chang.*, 123 (3-4), 691-704, 2014. https://doi.org/10.1007/s10584-013-0897-y

47. Smith P. & Wollenberg E., Achieving mitigation through synergies with adaptation. In: *Climate Change Mitigation and Agriculture*. E. Wollenberg, A. Nihart, M. Tapio-Biström, M. Grieg-Gran, (eds.), Earthscan, London, UK, pp. 50-57, 2012.
48. Sood, K.K. & Mitchell C.P., Household level domestic fuel consumption and forest resource in relation to agroforestry adoption: Evidence against need-based approach. *Biomass and Bioenergy*, 35, 337-345, 2011. https://doi.org/10.1016/j.biombioe.2010.08.045
49. Sharma, P., Singh, M.K., Verma, K. & Prasad, S.K. Changes in the weed seed bank in long-term establishment methods trials under rice-wheat cropping system. *Agronomy*, *10*(2), 292. 2020. https://doi.org/10.3390/agronomy10020292
50. Sandrine, L., Claude, N.Y.S., Christian, W., Françoise, F., Sandrine, H., Paula, R. & Stéphane, F., Estimation of carbon stocks in a beech forest (Fougères Forest - W. France): extrapolation from the plots to the whole forest. *Ann. For. Sci.63*, 139-148, 2006. https://doi.org/10.1051/forest:2005 106.
51. McMahon, S.M., Parker, G.G., Miller, D.R., Evidence for a recent increase in forest growth. *Proc. Natl. Acad. Sci. USA, 107*, 3611-3615, 2010. https://doi.org/10.1073/pnas.0912376107
52. Bhardwaj, D.R., Tahiry, H., Sharma, P., Pala, N.A., Kumar, D. & Kumar, A., Influence of Aspect and Elevational Gradient on Vegetation Pattern, Tree Characteristics and Ecosystem Carbon Density in Northwestern Himalayas. *Land*, *10*(11), 1109, 2021. https://doi.org/10.3390/land10111109.
53. Bhardwaj, D.R., Kumar, A., Pala, N.A., Sharma, P., Kumar, D., Kumar, A. & Zahoor, S., Carbon density and C-sequestration by tree plantation ecosystems in mid-hill of NW-Himalayas: Implications for climate change mitigation. *Land Degradation & Development*. https://doi.org/10.1002/ldr.4307
54. Langat. D.K., Maranga, E.K., Aboud, A.A., Cheboiwo, J.K., Role of forest resources to local livelihoods: the case of east mau forest ecosystem, Kenya. *International Journal of Forestry Research*, 10p, 2016. https://doi.org/10.1155/2016/4537354
55. Hoque, M.Z., Cui, S., Islam, I., Xu, L. & Ding, S., Dynamics of plantation forest development and ecosystem carbon storage change in coastal Bangladesh. *Ecological Indicators*, *130*, 107954, 2021. https://doi.org/10.1016/j.ecolind.2021.107954
56. Khan, I.A., Khan, M.R., Baig, M.H.A., Hussain, Z., Hameed, N. & Khan, J.A., Assessment of forest cover and carbon stock changes in sub-tropical pine forest of Azad Jammu & Kashmir, Pakistan using multi-temporal landsat satellite data and field inventory. *PLoS One*, 15,19, 2020. https://doi.org/10.1371/journal.pone.0226341

57. Strassburg B., Turner, R.K., Fisher, B., Schaeffer, R. & Lovett A., Reducing emissions from deforestation — The "combined incentives" mechanism and empirical simulations. Global Environmental Change 19, 265-278, 2009. https://doi.org/10.1016 / j.gloenvcha.2008.11.004, ISSN: 09593780.
58. Panda, S., Bhardwaj, D.R., Sharma, P., Handa, A.K. & Kumar, D., Impact of climatic patterns on phenophase and growth of multi-purpose trees of north-western mid-Himalayan ecosystem. *Trees, Forests and People*, *6*, 100143, 2021. https://doi.org/10.1016/j.tfp.2021.100143
59. Panda, S., Bhardwaj, D.R., Thakur, C.L., Sharma, P. & Kumar, D., Growth response of seven multipurpose tree species to climatic factors: A case study from northwestern Himalayas, India. *Journal of Forest Science*, *68*(3), 83-95, 2022. https://doi.org/10.17221/159/2021-JFS
60. Canadell, J.G. & Raupach, M.R., Managing forests for climate change mitigation. *Science* 320, 1456-1457, 2008. https://doi.org/10.1126/science.1155458
61. Lorenz, K. & Lal, R., *Carbon sequestration in forest ecosystems*. Springer Science & Business Media, 2010. https://doi.org/10.1007/978-90-481-3266-9
62. Kumar, D., Thakur, C.L., Bhardwaj, D.R., Sharma, N., Sharma, H. & Sharma, P., Sustainable Forest Management a Global Review. *Int. J. Curr. Microbiol. App. Sci*, *10*(01), 2521-2528, 2021. https://doi.org/10.20546/ijcmas.2021.1001.292
63. Bryant, J.R., Snow, V.O., Cichota, R. & Jolly, B.H., The effect of situational variability in climate and soil, choice of animal type and N fertilisation level on nitrogen leaching from pastoral farming systems around Lake Taupo, New Zealand. *Agricultural Systems*, *104*(3), 271-280, 2011. https://doi.org/10.1016/j.agsy.2010.11.001
64. Cotula L., The international political economy of the global land rush: A critical appraisal of trends, scale, geography and drivers. *Journal of Peasant Studies,* 39, 649-680, 2012. doi: 10.1080/03066150.2012.674940, ISSN: 0306-6150.
65. Haberl H., Mbow, C., Deng, X., Irwin, E.G., Kerr, S., Kuemmerle, T., Mertz, O., Meyfroidt, P. & Turner B.L., Finite Land Resources and Competition. Strungmann Forum Reports. In: *Rethinking global land use in an urban era*, edited by Karen C. Setoand Anette Reenberg. MIT Press, Cambridge, MA, pp. 33-67, 2013a. ISBN: 9780262026901.
66. Lal, R., Sequestering carbon in soils of agro-ecosystems. *Food Policy*, *36*, S33-S39, 2011. https://doi.org/10.1016/j.foodpol.2010.12.001
67. Chhatre, A., Lakhanpal, S., Larson, A.M., Nelson, F., Ojha, H. & Rao, J., Social safeguards and co-benefits in REDD+: a review of the adjacent possible. *Current Opinion in Environmental Sustainability*, *4*(6), 654-660, 2012. https://doi.org/10.1016/j.cosust.2012.08.006
68. Visseren-Hamakers, I.J., McDermott, C., Vijge, M.J. & Cashore, B., Trade-offs, co-benefits and safeguards: current debates on the breadth of REDD+. *Current Opinion in Environmental Sustainability*, *4*(6), 646-653, 2012. https://doi.org/10.1016/j.cosust.2012.10.005

69. Smith P., Ashmore, M.R., Black, H.I.J., Burgess, P.J., Evans, C.D., Quine, T.A., Thomson, A.M., Hicks, K. & Orr H.G., The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology,* 50, 812- 829. 2013. https://doi.org/10.1111/1365-2664.12016, ISSN:00218901
70. Harper, R.J., Beck, A.C., Ritson, P., Hill, M.J., Mitchell, C.D., Barrett, D.J. & Mann, S.S., The potential of greenhouse sinks to underwrite improved land management. *Ecological Engineering*, *29*(4), 329-341, 2007. https://doi.org/10.1016/j.ecoleng.2006.09.025
71. Galatowitsch, S.M., Carbon offsets as ecological restorations. *Restoration Ecology*, *17*(5), 563-570, 2009. https://doi.org/10.1111/j.1526-100X.2009.00587.x
72. Giam, X., Global biodiversity loss from tropical deforestation. *Proceedings of the National Academy of Sciences*, *114*(23), 5775-5777, 2017. https://doi.org/10.1073/pnas.1706264114
73. FAO, Energy-Smart Food for People and Climate. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 66 pp. 2011. Available at: www.fao.org/docrep/014/i2454e/i2454e00.pdf.
74. Henderson, B., Frank, S., Havlik, P. & Valin, H. "Policy strategies and challenges for climate change mitigation in the Agriculture, Forestry and Other Land Use (AFOLU) sector", OECD Food, Agriculture and Fisheries Papers, No. 149, OECD Publishing, Paris, 2021. http://dx.doi.org/10.1787/47b3493b-en
75. Tubiello, F.N., Salvatore, M., Cóndor Golec, R.D., Ferrara, A., Rossi, S., Biancalani, R. & Flammini, A., Agriculture, forestry and other land use emissions by sources and removals by sinks. Rome, Italy, 2014.
76. Zeleke, A., Phung, T., Tulyasuwan, N., O'Sullivan, R., Lawry, S. & Gnych, S., Role of agriculture, forestry and other land use mitigation in INDCs and national policy in Asia. *LEDS, Agric., Forestry and Other Land Use (AFOLU) Working Group*, 2016.
77. Fargione, J., Hill, J., Tilman, D., Polasky, S. & Hawthorne, P., Land clearing and the biofuel carbon debt. *Science*, *319*(5867), 1235-1238, 2008. https://doi.org/10.1126/science.1152747
78. Alves Finco M. V. & Doppler W., Bioenergy and sustainable development: The dilemma of food security in the Brazilian savannah. *Energy for Sustainable Development*, 14, 194 – 199, 2010. https://doi.org/10.1016/j.esd.2010.04.006
79. Mitchell, C.D., Harper, R.J. & Keenan, R.J., Current status and future prospects for carbon forestry in Australia. *Australian Forestry*, *75*(3), 200-212, 2012. https://doi.org/10.1080/00049158.2012.10676402
80. Harvey, M. & Pilgrim, S., The new competition for land: Food, energy, and climate change. *Food Policy*, *36*, S40-S51, 2011. https://doi.org/10.1016/j.foodpol.2010.11.009
81. Lippke, B., Garcia, J.P. & Manrique, C., The Impact of Forests and Forest Management on Carbon Storage. Rural Technology Initiative, College of Forest Resources, University of Washington, Seattle, 7 pp. 2003.

82. Jackson R.B. & Baker J. S., Opportunities and Constraints for Forest Climate Mitigation. *BioScience*, 60, 698 – 707, 2010. doi: 10.1525/bio.2010.60.9.7, ISSN: 0006-3568, 1525–3244. https://doi.org/10.1525/bio.2010.60.9.7
83. Siikamaki, J., Ferris, J. & Munnings, C., Land Use, Land-Use Change, and Forestry Ofsets Resources for the future. Washington DC, 2012.
84. Corbera E. & Schroeder H., Governing and implementing REDD+. *Environmental Science & Policy*, 14, 89 – 99, 2011. https://doi.org/10.1016/j.envsci.2010.11.002, ISSN: 1462-9011.
85. OECD (Organisation for Economic Co-operation and Development), *Enhancing Climate Change Mitigation Through Agriculture*, 2019.
86. Smith, P., Haberl, H., Popp, A., Erb, K. H., Lauk, C., Harper, R. & Rose, S., How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*, *19*(8), 2285-2302, 2013. https://doi.org/10.1111/gcb.12160
87. Seeberg-Elverfeldt, C., *Carbon finance possibilities for agriculture, forestry and other land use projects in a smallholder context*. Rome: FAO, 2010.
88. Sharma, P., Bhardwaj, D.R, Singh, M.K., Verma, K., Viswakarm, S.P., Kumar D. & Thakur, P. Carbon trading in agroforestry: potential, prospects and constraints In Yadav Luxmi and Yadav K Sohan (Ed.), *Climate Change: Adaptation, Loss and Damage* (pp.185-197). Neel Kamal Prakashan (ISBN: 978-93-93248-05-3), 2021.
89. Houghton, R.A., House, J.I., Pongratz, J., Van Der Werf, G.R., Defries, R.S., Hansen, M.C. & Ramankutty, N., Carbon emissions from land use and land-cover change. *Biogeosciences*, *9*(12), 5125-5142, 2012. https://doi.org/10.5194/bg-9-5125-2012
90. Hansen, J., Sato, M. & Ruedy, R., Perception of climate change. *Proceedings of the National Academy of Sciences*, *109*(37), E2415-E2423, 2012. https://doi.org/10.1073/pnas.1205276109
91. Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., van der Maaten, E., Schelhaas, M.J., Lasch, P., Eggers, J., van der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., & Hanewinkel, M., Climate change and European forests: What do we know, what are the uncertainties, and what are the implications for forest management? *J. Environ. Manage*, 146, 69-83, 2015. https://doi.org/10.1016/j.jenvman.2014.07.030.
92. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, p. 112829, Elsevier, 2021a. https://doi.org/10.1016/j.jenvman.2021.112829
93. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, Springer Nature, 17(1), 1-13, 2021b. https://doi.org/10.1007/s11355-021-00450-1
94. Raj, A., Jhariya, M.K. & Khan, N., Forest for soil, food and climate security in Asia. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D.

and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3

95. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer, ISBN 978-981-15-9495-3, pp. 221-246, 2021. https://doi.org/10.1007/978-981-15-9496-0_7
96. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
97. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
98. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
99. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
100. Jhariya, M.K., Yadav, D.K. & Banerjee, A., Agroforestry and Climate Change: Issues and Challenges. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book), pp. 335. 2019. https://doi.org/10.1201/9780429057274
101. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383. 2020. https://doi.org/10.1201/9780429286759
102. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., Sustainable Intensification for Agroecosystem Services and Management. Springer Singapore, pp. 748. eBook ISBN: 978-981-16-3207-5. 2021. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
103. Jhariya, M.K., Meena, R.S., Banerjee, A. and Meena, S.N. (2022). Natural Resources Conservation and Advances for Sustainability. Elsevier, Academic Press. ISBN: 9780128229767. https://doi.org/10.1016/C2019-0-03763-6.

11

Eco-Restoration of Degraded Forest Ecosystems for Sustainable Development

Bhimappa Honnappa Kittur[1], Abhishek Raj[2*], Anup P. Upadhyay[1], Manoj Kumar Jhariya[3] and Arnab Banerjee[4]

[1]*Indian Institute of Forest Management (IIFM), Bhopal (M.P.), India*
[2]*Pt. Deendayal Upadhyay College of Horticulture & Forestry, Dr. Rajendra Prasad Central Agriculture University, Pusa, Samastipur, Bihar, India*
[3]*Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India*
[4]*Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India*

Abstract

Forest is one of the largest natural resources that provides many ecosystem services and maintains environmental sustainability. Though forests provide a large number of services, their health is steadily decreasing. The causes of the decrease in the health of the forest is attributed to deforestation, illegal cutting of timbers, extensive agriculture practices, mining and developmental activities that are degrading the forest ecosystem at an alarming rate. This process can be minimized carefully by framing afforestation and restoration management plans. Adopting people-centric sustainable forest management (SFM) including social forestry and forest protection programs that can ensure soil, food and climate security in a more sustainable way is a good start. Particularly silvicultural practices, such as fire protection, pest and disease control, soil and water conservation techniques, improve forest productivity and health. Attempts of eco-restoration through natural (NR) or assisted (AR) for regaining the forest regeneration and composition is the best solution, because site-specific restoration is believed to be the fastest and surest technique. Further, the social transformation in terms of a concrete policy, governance and institutional reformations are also equally needed for promoting forest management and its conservation.

***Keywords*:** Afforestation, ecosystem services, land quality, forest degradation, natural resources, ecological stability, restoration

**Corresponding author*: ranger0392@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (273–292) © 2023 Scrivener Publishing LLC

11.1 Introduction

Ecosystems are the structural and functional units where living organisms interact with each other and the surrounding environment. There are many types of ecosystems such as forest, grassland, agriculture, desert, ocean, riverine, etc. The forest ecosystems have unique biotic and abiotic components among all these ecosystems. Forest shows great diversity by harbouring plants, amphibians, and mammals [1]. Forest also helps in maintaining climatic changes by sequestrating -15.6 ± 49 gigatonnes/year of atmospheric carbon during the years 2001 to 2009 [2, 3]. Forests provide various forms of ecosystem services (e.g., food and fodder, preventing soil erosion, mitigating climate change, etc). Though this ecosystem provides comprehensive services, due to high dependency on resource use, the ecosystem is slowly losing its stability due to forest destruction, fragmentation, and the replacement of native forest species with exotics [4]. The underlying drivers of threats are the result of interaction of political, socioeconomic, and technological processes that catalyses the proximate drivers. The global net loss of forests was accounted to be 4.7 million hectares per year since 2010 [2]. However, deforestation rates were significantly higher. It was estimated by UN FAO that each year about 10 million hectares of forest were cut down.

Understanding the role of restoration of degraded forests, many frameworks are committed towards achieving fixed targets in the conventions. Bonn Challenge and the New York Declaration on Forests have targeted the restoration and rehabilitation of the 350 m ha of degraded land through an afforestation program by the year 2030 [5, 6]. The Convention on Biological Diversity (CBD) has also committed to restoring 15% of degraded forests which is further strengthened by active ecological restoration of degraded forests [7, 8]. This chapter discusses the status of forest degradation, its indicators and the criteria for assessment. Restoration techniques at the ecological and social context are also included. The pillars of sustainable forest management (SFM) and afforestation techniques are discussed, which help in improving land quality and ecosystem management. Ecosystem restoration through forest management ensures soil, food and climate security which is greatly employed in this chapter.

11.2 Forest Cover and Degradation

Assessment of global forest cover helps in the understanding of the magnitude of management and its sustainability. Country-wise forest cover (m ha) are reported in the order of Russian Federation (815)>, Brazil

(497)>, Canada (347)>, USA (310)>, China (220)>, Australia (134)>, Democratic Republic of the Congo (126)>, Indonesia (92)>, Peru, and India (72 in each), respectively. In this context, world forest cover and its distributions are depicted in Figure 11.1 [2]. However, its degradation is also reported which is based on the extent and severity. The extent and severity of land degradation is now becoming a global challenge. Land degradation and its percentage are depicted in Figure 11.2 [9]. As per the figure, various parameters such as unaffected and stable land, high land degradation, moderately land degradation, bare land, water and improving land have contributed 37%, 25%, 8%, 18%, 2% and 10% of degradation, respectively. Approximately 10.0 m ha/year of forest areas have been lost globally from 2015 to 2020 [2]. This rate of loss reduces the global canopy which will shrink by 223 m ha by 2050 [10]. However, clearance of natural forests has increased >1/2 of the new arable land in tropical countries from 1980 to 2000 [11]. Fire, flood, drought and emergence of infectious pests and disease affect approximately 122 m ha of forest every year [12]. Mostly, 1.70 billion people who reside in or around the forest areas are directly or indirectly affected by deforestation and forest degradation. Declining forests increase the chances of flood and human-animal conflicts [13, 14]. Furthermore, forest degradation also induced various vectors and animal-based infectious disease which affects environmental health and the ecosystem [15, 16]. Moreover, deforestation and forest degradation also affect environmental health by inducing climate change and C footprint issues due to emissions of 8.1 ±2.5 Gt CO_2e yr^{-1} which was reported during the period 2001-2009 [3]. But forest restoration ensures biomass production, carbon management and ecosystem stability in a sustainable way [17, 18].

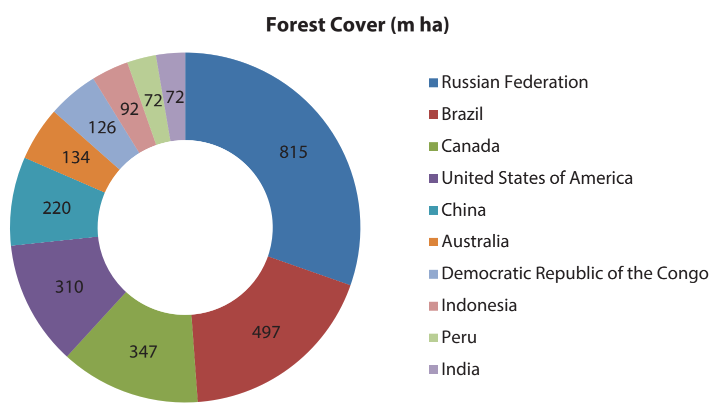

Figure 11.1 Country-wise forest covers in the world [2].

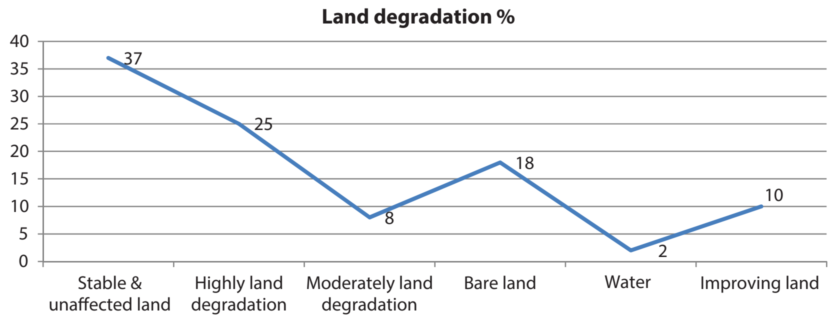

Figure 11.2 Percentage of global land degradation [9].

Forest degradation is a contemporary issue, and the consequences of forest degradation are complex and will remain for a longer time. Degradation can cause a decrease in niche areas and in their diversity; it can also cause pests and disease outbreaks and limit the regeneration of species by changing seed dispersal, deposition and recruitment. The process of degradation occurs in many ways predominantly by endogenous (e.g., landslides, tree fall, wild animal grazing, erosion) and exogenous (anthropogenic activities like forest fires, grazing, construction of the dams, roads, etc.) pressures. These ways of degradation depend on the place where the process takes place, the intensity of the cause, and the temporal and spatial scales. The causes of degradation can be predictable and measurable in many ways (satellite imaginaries, ground-truthing, baseline survey, etc.). Generally, ITTO has classified three types of degradation in the forest:

1. Degraded primary forest (resulting from extreme timber exploitation).
2. Secondary forest (spontaneously regrowing on areas that had been largely cleared).
3. Degraded forest land (degraded forest mostly occupied by grasses and shrubs).

11.3 Indicators of Forest Degradation

In a natural forest unscientific logging practice, over-harvesting of minor produces and development activities are often the precursors of degradation [19]. Landslide, tree-fall, and erosion are the effects of degradation that is dynamic and spontaneous across time and space, and the intensity of the process is directly related to the threat that occurs by anthropogenic and natural factors [20]. Measuring these degradation processes through succession, species distribution, abundance, etc., can provide baseline information and may be considered to be easy and practicable. But care has to be taken while assessing the process and it should not be over-emphasized because properly logged forest stands may not necessarily contain a complete balance of biodiversity.

11.4 Criteria for Assessment of Forest Degradation

The disturbance in forests is recognized as the driver of forest degradation such as species-specific harvest, biological infestation, regeneration failures, conversion to monoculture, and other forms of disturbances. These drivers not only destroy the flora but also affect the faunal diversity; the process of assessing the threshold of degradation is complex and has rarely been attempted [21]. However, the study of these drivers largely is attributed to the availability of time, intensity, funds, etc., and the primary variables used for the study are species density and richness, plant vigour, the species height and diameter variables [22]. In addition, the soil is the most commonly used functional indicator and must be checked prior to the start of restoration [23]. However, the process for adopting these norms including other technical skills must be explicit, readily adaptable, provide quantitative information over time and also permit flexibility of scaling up in other localities [24].

11.5 Forest Ecosystem Restoration

Forest provides various ecological functions that maintain environmental health and sustainability [25–27]. Biodiversity conservation, multifarious productions, soil and water conservation and several other functions are delivered by the forest ecosystem. These functions ensure soil, food and climate security along with maintaining ecological stability for the long term during the time of framing restoration plans (Figure 11.3) [9, 28, 29]. The strategy of taking forest ecosystem restoration natural or assisted is generally determined by its effectiveness and sustainability [30]. However, the long-term strategy must integrate the prevention and mitigation measures of deforestation [31] by facilitating the transition towards a sustainable future through restoration [32]. Recently, efforts are consistently being made to achieve the targets set in the conventions for expanding

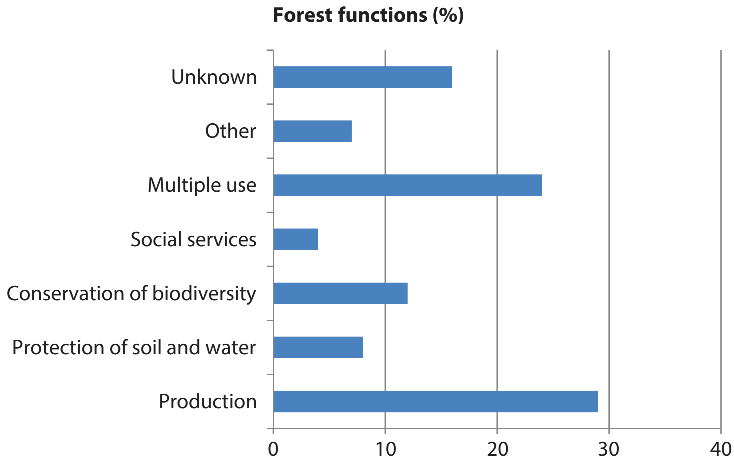

Figure 11.3 Ecosystem stability and sustainability through forest functions [9, 28, 29].

reforestation regionally and globally [33, 34]. The Bonn Challenge and Initiative 20x20 have committed to 350 and 20 m ha of degraded forest restoration in the world and Latin America and the Caribbean by 2020 [35, 36], but these targets have rarely been achieved. The aim was to meet restoration enhancement, ecosystem health and services in sustainable ways. Thus, restoration of ecosystem structure, its services and biodiversity health can be possible only through better restoration actions [37].

Many restoration projects are initiated which help in recovering ecosystem services and attracting various financial supports [38, 39]. However, the biggest challenge is the managing of degraded forests; success entirely relies on technical, financial, and social inputs. The other challenges involved in the restoration would be the site-specific conditions, the scale of restoration, time, and funds are the prerequisites [40]. Presently, management tactics for forests lack agreed common institutional monitoring and legal frameworks, therefore hindering restoration efforts [41]. In general, the cost of restoration varies from lower (natural or passive approaches) to higher (artificial or active approaches) [20, 40] and wise consideration should be made depending on the availability of funds and feasibility of extrapolation of work. Generally natural restoration is the surest method of restoration due to the fact that it is possible through the colonization of native tree species in disturbed and degraded areas. This process can be further initiated by human intervention that also helps in protecting regeneration from overgrazing, animal intervention, biotic pressures, weeds and frequent fire occurrence. Similarly, direct seeding process, nursery-based seedling plantation, thinning and tending operations are active restorations that speed up ecosystem restoration and accelerate ecological succession.

11.6 The Restoration Indicators

The indicators for restoration must rely on the production potential of the site. These indicators can be divided into different categories, such as biodiversity, ecological complexity, social implications, etc., based on relevance with different restoration trajectories. These categories may be made while connecting different contexts (sustainability, monetary benefits, adaptation, etc.) and each context has its attributes and importance in the restoration process. In addition to previous tactics, a technical encrustation is also equally important. For instance, competition between two species leads to the suppression of one species. Therefore, asymmetric competition if observed during the recruitment process hinders the restored sites due to heavy competition in the later stages [42]. Similarly, both asymmetric competition and low mortality can support high density at the initial stages after the planting. However, higher density and biomass of neighbours also affect target plants due to greater competition for resources [43].

11.6.1 Social and Economic Context

Social context refers to the cultural, economic, environmental, social and political dimensions which characterise a society. Restoration ensuring the improvement of economic and social outcomes through the local communities residing in the forest is a vital, triple-bottom-line approach. Success in the restoration of the forest lies in assessing social and economic benefits, costs, procedural guidelines, and their applicability [44]. The social indicators of forest restoration must consider the local community's well-being and involve them in the decision-making for site selection and monitoring. The primary users of the benefits that arise from the restoration are the local communities and the values of the degraded forests may be influenced by their desire to harvest forest products for household consumption. In addition, the ecosystem services such as the hydrological functions, religious and other cultural values attached to the forest are also important. The restoration goals must be developed for monitoring a plan of operations to enhance community sustainability and capacity building of workers and staff that would improve the quality of life in the fringe areas and adjacent villages.

11.6.2 Ecological Context

The biggest challenge in restoration is the ecological perspectives of management, such as habitat improvement and biodiversity enhancement while considering species which are most suitable to the site. However, other factors such as unstable hydrology, nutrient-deficient soils, introduction of exotics, etc., induce forest degradation. Forest successions also would be prevented by physical, chemical and biological barriers that affect ecosystem structure and ecological services. Poor seed and rootstocks availability, higher seed predation, low soil fertility, inadequate beneficial organisms (bacteria, fungi, etc.), invasive weeds, drought, fires, etc., are key barriers to regeneration by natural means. However, these factors totally depend on the ecosystem type and species distribution patterns. Poor seed dispersal and its germination hinder regeneration which directly affects composition of the forest to a greater extent. The degradation beyond threshold makes its recovery impossible in these areas. In this context, restoration may be achieved in these sites after a successful understanding of ecological conditions. Also, sustainable land use (SLM) practices including agroforestry in fringe areas where land is owned privately can ensure eco-restoration and maintain ecological stability [45, 46].

11.6.3 Silvicultural Context

The natural succession in degraded forests is intended to restore most forests, which can rarely be possible without silvicultural interventions. However, silviculture-based vegetation management are key techniques that minimize competition and enhance regeneration for greater ecosystem restoration. These measures include mechanical site preparation, species selection, and weeding, followed by a prescribed fire technique. Seedling survival and plant growth are higher under the concepts of stress gradient hypothesis. However, the intensity of stress can be judged by organic matter, soil moisture condition [47] and plant competition. Similarly, silviculture management including tending operation also minimizes undesirable plants and enhances proper growth and development of forest species by greater regeneration and ecosystem restoration.

11.7 Restoration through SFM and Afforestation

Forest provides both direct and indirect benefits which maintain soil-food-climate security and degradation of this ecosystem is the greatest environmental challenge which affects many aspects of ecosystem health and services. Deforestation and forest degradation affect these services and influence ecosystem health and productivity. Eco-restoration of degraded forests is an urgent need for environmental health and sustainability. Restoration of the forest ecosystem through the application of sustainable forest management (SFM) is a viable tool that enhances productivity and environmental health. SFM not only restores the forest ecosystem but also enhances biodiversity which intensifies ecosystem services for a better sustainable world. Enhancing forest cover through afforestation helps in maintaining soil fertility, land quality, food-nutritional security and ecosystem health. Adopting SFM and afforestation techniques sustains 1.60 billion forest fringe people by providing timber, fuel wood, and NTFPs including nutritious fruits, etc., and also provides employment opportunities to them on a long-term basis [48]. However, degraded land can also be restored through plantation of leguminous trees that promote carbon and nitrogen availability and ensure soil and climate security [49–52]. Therefore, a successful implementation of SFM techniques including better research and technological intervention help in eco-restoration of degraded land which ensure many environmental services in a sustainable way.

11.8 Forest Resilience

Forest ecosystem is self-sustaining; it recovers itself from many disturbances based on its persistent ability and functions. Understanding of various effects is important for forest management and its conservation goals which are being discussed under the ongoing series of deforestation changes in the world. Quantifying forest recovery and resilience needs significant workability, technically and financially. Assessment of disturbance patterns and the process of recovery depend on topography, landscape size, time, staff availability, etc. [53]. Further, the ecosystem resilience and its sustainability generally depend on reestablishing attributes such as vegetation structure, successional stage, and the choice of the species in assisted regeneration and existing regeneration is a good indicator of restoration practice [54]. This can explicitly exemplify the self-regenerating of *Nothofagus* production in Chile forests explaining that harvesting trees below a specific basal area relative to site type. This causes a reduction in the resilience of the forest ecosystem and an unpredictable shift in the succession stages. On the other hand, forest productivity, resilience and sustainability are also affected by over-harvesting practices.

11.9 Forest Recovery

Existing forests and woodlands can deliver a variety of ecosystem services that depends on their extent of distribution and their global coverage (Figure 11.4) [33]. However, case studies of forest degradation and its recovery in the world are depicted in Table 11.1.

The recovery of the ecosystem also depends on disturbance frequency, climate, and vegetation type [55]. The recovery of an ecosystem from the disturbance can be described in terms of resilience, "the persistence of interactions within a system" and a measure of the ability to absorb changes. The forest ecosystem normally resists disturbances and then recovers from disturbances [56]. However, the threshold of resilience and recovery are two important phenomena in determining forest health [57], and therefore understanding the pattern of recovery is a key challenge to pursue post-disturbance management.

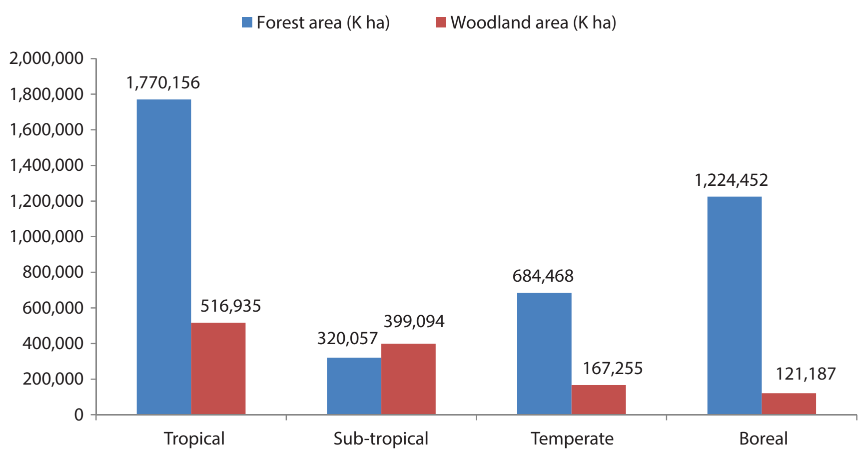

Figure 11.4 Assessment of forest and woodland areas in the world [33].

Table 11.1 Case study of forest degradation and its recovery in different regions of the world.

Name	Description	Problems	Initiatives	References
Land use policy changes for natural regeneration (NR) in the region of Tanzania	This is open woodlands type which exists in the Shinyangan region of Tanzania. Pasture-based traditional agroforestry system is practiced in this region.	Deforestation and woodland clearance exposed the soil health and fertility. Soil erosion problem existed in this region due to land degradation.	Reforestation has been promoted in this area. Biodiversity and ecosystem restoration achieved. Soil quality and fertility enhanced. Fodder is utilized for animals for feeding purposes in dry period. Overall, land quality and forest-based ecosystem services enhanced.	[58]
Natural regeneration (NR) in the region of Puerto Rico	Demographic change occurred in this region	Deforestation and woodland cleared for agricultural expansion. A scanty forest exists in steep mountain region. Soil erosion, landslide, land degradation, etc., are reported extensively.	Forest plantation and woodlands have been promoted in these affected regions. This ensures higher land quality, soil fertility, food and environmental security at sustainable basis.	[59]

(*Continued*)

Table 11.1 Case study of forest degradation and its recovery in different regions of the world. (*Continued*)

Name	Description	Problems	Initiatives	References
Direct seeding of rainforest species in the wet-tropics region of Australia	The region was degraded continuously	Rainforest ecosystem has been lost due to heavy felling and deforestation activity which also initiated land degradation problem extensively. Degradation also affected biodiversity including flora and fauna species.	Diversified forest recreated through forest plantation based on the principle of "Maximum Diversity Method" that helps in maintaining eco-restoration and its sustainability in the rainforests.	[60]
Acacia and Eucalyptus based monoculture system in the region of Vietnam	Tropical and sub-tropical forests existed in this region	Exotic species like Acacia and Eucalyptus were cleared extensively. Deforestation and woodland clearance decreased the soil health and fertility. Soil erosion problem was prevalent in this region due to land degradation.	Reforestation program initiated which helps in maintaining forest covers and deliver variety of ecosystem services for soil, food and climate security. Exotic species like *Acacia* and *Eucalyptus* were introduced under reforestation program. Some private nurseries have developed for raising Eucalyptus and Acacia seedlings.	[61]

(*Continued*)

Table 11.1 Case study of forest degradation and its recovery in different regions of the world. (*Continued*)

Name	Description	Problems	Initiatives	References
Mt. Popa Forest Reserve in the region of Burma	Mt. Popa Forest Reserve established in the central Burma region which protects surrounding Buddhist monastery	Deforestation and woodland clearance have been observed clearly during Second World War. Illicit timber felling for firewood and biodiversity losses have been reported. Deforestation caused drying of natural springs due to denudation of mountains.	*Eucalyptus camaldulensis* tree species were planted extensively in denuded and degraded areas under the supervision of forest department. The plantation enhanced biodiversity and intensifies ecosystem services for promoting land and environmental quality. Eco-tourism projects are also initiated in this region.	[62]

11.10 Policy and Future Roadmap

Eco-restoration of degraded forests is rigorously discussed by policy makers, researchers, and other stakeholders in many national and international platforms. Land degradation is continuously rising which affects overall ecosystem health and services. A degrading forest ecosystem not only affects productivity but also minimizes many important forest-based benefits. However, recent policies have stressed combating of forest degradations and its restoration strategies but it is not applied up to the mark. Existing policies must be revised and reframed in favour of adopting SFM and afforestation technologies which helps in restoring land, soil fertility and forest ecosystem productivity in sustainable ways. Policy must be reframed in the context of biodiversity conservation, C footprint and climate change mitigation to enhance forest restoration through sustainable forest management (SFM). However, degraded land must be targeted for afforestation and forest plantation which enhance forest covers and help in ecosystem restoration for the long term [63, 64]. Therefore, an effective policy and good governance are needed to restore forest landscapes which promise soil-food-climate security for a sustainable world.

11.11 Conclusion

Forest degradation and its restoration is raising concern due to its severity. Anthropogenic activities including deforestation, intensive farming practices, mining and developmental projects affect forest species, its diversity and ecosystem services. Deforestation and degradation of forest ecosystems also enhance C footprint and climate change by releasing GHGs into the environment. This must be regulated through people-centric forest management and conservation techniques. In this context, adopting SFM and other afforestation techniques not only improves land quality and ecosystem health but also enhances forest covers throughout the world. Eco-restoration can be possible through better management and conservation techniques that rely on forests. Policy and good governance must be formed for enhancing forest health and productivity for eco-restoration, which is the basis of sustainable development.

References

1. Vié, J-C., Hilton-Taylor, C. & Stuart, S.N., Wildlife In A changing world: An analysis of the 2008 IUCN Red List of Threatened Species. Gland: IUCN, 2009.

2. FAO. 2020. Global Forest Resources Assessment 2020 – Key findings. Rome. https://doi.org/10.4060/ca8753en
3. Harris, N.L., Gibbs, D.A., Baccini, A., Birdsey, R.A., de Bruin, S., Farina, M., Fatoyinbo, L., Hansen, M.C., Herold, M., Houghton, R.A., Potapov, P.V., Suarez, D.R. & Roman-Cuesta, R.M., Saatchi, S.S., Slay, C.M., Turubanova, S.A. & Tyukavina, A., Global maps of twenty-first century forest carbon fluxes. *Nature Climate Change*, 11(3), 234-240, 2021. https://doi.org/10.1038/s41558-020-00976-6
4. Philipson, C.D., Cutler, M.E., Brodrick, P.G., Asner, G.P., Boyd, D.S., Moura Costa, P. & Burslem, D.F., Active restoration accelerates the carbon recovery of human-modified tropical forests. *Science*, *369*(6505), 838-841, 2020.
5. Conway, D., Keenylside, P., Roe, S., Streck, C., Vargas-Victoria, G. & Varns, T., Progress on the New York declaration on forests – An assessment framework and initial report, 2015.
6. Saint-Laurent, C., Begeladze, S., Vidal, A. & Hingorani, S., The Bonn Challenge: building momentum on restoration. Restoring the Earth - The next decade: *Unasylva* No. *252, 252*(1), 82, 2020.
7. CBD, Aichi biodiversity targets. 15. Ecosystems restored and resilience enhanced [Online]. Montreal: Secretariat of the convention on biological diversity, 2010. Available: https://www.cbd.int/decision/cop/?id=12268
8. EU, EU biodiversity strategy to 2020. European Union, Luxembourg. 2011. http://dx.doi.10.2779/39229
9. FAO, Food and Agriculture Organization of the United Nations, The State of the World's Land and Water Resources for Food and Agriculture. Rome. 2010.
10. Bastin, J.F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M. & Routh, D., The global tree restoration potential. *Science*, 365 (6448), 76-79, 2019. https://doi.org/10.1126/science.aax0848
11. Lambin, E.F. & Meyfroidt, P., Global land use change, economic globalization, and the looming land scarcity. *Proc Natl Acad Sci* USA, 108(9), 3465-3472, 2011.
12. International Union of Forest Research Organizations [IUFRO], Global fire challenges in a warming world. Robinne F.-N., Burns J., Kant P., de Groot B., Flannigan M.D., Kleine M., Wotton D. M. (eds.). Occasional Paper No. 32. Vienna: IUFRO, 2018.
13. High Level Panel of Experts on Food Security and Nutrition [HLPE], Sustainable Forestry for Food Security and Nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HPLE, 2017. http://www.fao.org/3/i7395e/i7395e.pdf
14. Gibb, R., Redding, D.W., Chin, K.Q., Donnelly C.A., Blackburn, T.M., Newbold, T. & Jones, K.E., Zoonotic host diversity increases in human dominated ecosystems. *Nature* 584, 398-402, 2020. https://doi.org/10.1038/s41586- 020-2562-8
15. UNEP & ILRI, Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. Nairobi: UNEP and International

Livestock Research Institute. 2020. https://www.unep.org/resources/report/preventing-future-zoonotic-disease-outbreaks-protecting-environmentanimals-and
16. Morand, S. & Lajaunie, C., Outbreaks of vector-borne and zoonotic diseases are associated with changes in forest cover and oil palm expansion at global scale. *Frontiers in Veterinary Science,* 8, 230, 2021. https://doi.org/10.3389/fvets.2021.661063
17. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, 112829, 2021a. https://doi.org/10.1016/j.jenvman.2021.112829
18. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1), 1-13, 2021b.https://doi.org/10.1007/s11355-021-00450-1
19. Asner, G.P., Broadbent, E.N., Oliveira, P.J.C., Keller, M., Knapp, D.E. & Silva, J.N.M., Condition and fate of logged forests in the Brazilian Amazon. *Proceedings of the National Academy of Sciences,* 103(34), 12947-12950, 2006. http://dx.doi.org/10.1073/pnas.0604093103
20. Chazdon, R.L., Beyond deforestation: Restoring forests and ecosystem services on degraded lands. *Science* 320, 1458–1460, 2008.
21. Van Nes, E.H., Hirota, M., Holmgren, M.A. & Scheffer, M., Tipping points in tropical tree cover: linking theory to data. *Global Change Biol.*, 20, 1016-1021, 2014.
22. Harrison, R.D., Emptying the forest: hunting and the extirpation of wildlife from tropical nature reserves. *BioScience,* 61(11), 919-924, 2011. http://dx.doi.org/10.1525/bio.2011.61.11.11
23. Gatica-Saavedra, P., Echeverría, C. & Nelson, C.R., Ecological indicators for assessing ecological success of forest restoration: a world review. *Restoration Ecology*, *25*(6), 850-857, 2017.
24. Gardner, T.A., Barlow, J., Sodhi, N.S. & Peres, C.A., A multi-region assessment of tropical forest biodiversity in a human-modified world. *Biological Conservation*, *143*(10), 2293-2300, 2010.
25. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
26. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management*. Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
27. Banerjee, A., Jhariya, M.K., Yadav, D.K. & Raj, A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc.,

CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888110, pp. 400, 2020. https://doi.org/10.1201/9780429276026
28. Fuhrer, E., Forest functions, ecosystem stability and management. *Forest Ecology and Management*, 132, 29-38, 2000.
29. Raj, A., Jhariya, M.K. & Khan, N., *Forest for soil, food and climate security in Asia*. In: M. Öztürk, Khan, S.M., Altay, V., Efe, R., Egamberdieva, D. and Khassanov, F.O. (Eds.). *Biodiversity, Conservation and Sustainability in Asia, Vol. 2; South and Middle Asia*. Springer, pp. 33-52, 2022. https://doi.org/10.1007/978-3-030-73943-0_3
30. Higgs, E., Harris, J., Murphy, S., Bowers, K., Hobbs, R., Jenkins, W., Kidwell, J., Lopoukhine, N., Sollereder, B., Suding, K & Thompson, A., On principles and standards in ecological restoration. *Restor. Ecol.*, 26, 399-403, 2018. 10.1111/rec.12691
31. Muscio, A. & Sisto, R., Are agri-food systems really switching to a circular economy model? implications for European research and innovation policy, *Sustaina*. 12(14), 2020. 5554, 10.3390/su12145554
32. Priyadarshini, P. & Abhilash, P.C., Fostering sustainable land restoration through circular economy governed transitions. *Restor. Ecol.*, 28, 719-723, 2020. 10.1111/rec.13181
33. FAO, Global Forest Resources Assessment 2015: How are the world's forests changing? Second Edition. Rome. (Available at http:// www.fao.org/3/a-i4793e.pdf).
34. Poorter, L., Bongers, F., Aide, T.M., Zambrano, A.M.A., Balvanera, P. & Becknell, J.M., Biomass resilience of Neotropical secondary forests. *Nature,* 1-18, 2016.
35. IUCN, Bonn Challenge [Internet]. 2011 [cited 2017 Nov 20]. Available from: http://www.bonnchallenge.org/
36. WRI. Initiative 20x20 [Internet]. 2016 [cited 2017 Nov 20]. Available from: http://www.wri.org/our-work/project/initiative-20x20
37. Lamb, D., Erskine, P.D. & Parrotta, J.A., Restoration of Degraded Tropical Forest Landscapes. *Science*, 310(5754), 1628-32, 2015. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1111773
38. Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A. &Coomes, D., Biodiversity Conservation: Challenges Beyond. *Science*, 329, 1298-1303, 2010.
39. Bullock, J.M., Aronson, J., Newton, A.C., Pywell, R.F. & Rey-Benayas, J.M., Restoration of ecosystem services and biodiversity: Conflicts and opportunities. *Trends EcolEvol.*, 26(10), 541-9, 2011.
40. Holl, K.D. & Aide, T.M., When and where to actively restore ecosystems? *For. Ecol. Manag.*, 261, 1558-1563, 2011.
41. Sasaki, N. & Putz, F.E., Critical need for new definitions of "forest" and "forest degradation" in global climate change agreements. *Conservation Letters*, 2, 226-232, 2009.

42. Weiner, J., Asymmetric competition in plant populations. *Trends in ecology & evolution*, *5*(11), 360-364, 1990.
43. Zhang, K., Artati, Y., Putzel, L., Xie, C., Hogarth, N.J., Wang, J.N. & Wang, J., The 'Conversion of Cropland to Forest Program' (CCFP) as a national 'Payment for Ecosystem Services' (PES) scheme in China: Institutional structure and roles, ensuring voluntarism and conditionality of subsidy payments. *International Forestry Review, Special Issue: Forest landscape restoration and upland land use* 19(S4), 24-36, 2017.
44. Iftekhar, M.S., Polyakov, M., Ansell, D., Gibson, F. & Kay, G.M., How economics can further the success of ecological restoration. *Conserv Biol.* 31(2), 261-268, 2017. doi: 10.1111/cobi.12778. Epub 2016 Sep 29. PMID: 27302753
45. Raj, A., Jhariya, M.K.,Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
46. Raj, **A.,** Jhariya, M.K., Yadav, D.K., Banerjee, A. & Meena, R. S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (Eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore Pte Ltd. 2019. ISBN ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4
47. He, Q., Bertness, M.D. & Altieri, A.W., Global shifts towards positive species interactions with increasing environmental stress. *Ecol Lett*, 16, 695-706, 2013.
48. DeFries, R.S., Rudel, T., Uriarte, M. & Hansen, M., Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geosci*, 3(3), 178-181, 2010.
49. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10
50. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
51. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
52. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition,

Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7

53. DeRose, R.J. & Long, J.N., Resistance and Resilience: A Conceptual Framework for Silviculture. *Forest Science*, 60(6), 1205-12, 2014.
54. Wortley, L., Hero, J.M. & Howes, M., Evaluating ecological restoration success: a review of the literature. *Restor. Ecol.,* 21, 537-543, 2013. 10.1111/rec.12028
55. Yang, J., Pan, S., Dangal, S., Zhang, B., Wang, S. & Tian, H., Continental-scale quantification of post-fire vegetation greenness recovery in temperate and boreal North America. *Remote Sensing of Environment*, 199, 277-290, 2017. https:// doi.org/10.1016/j.rse.2017.07.022
56. Philip, J.B., Anke, J. & Lawrence, R.W., The Ecology of Disturbance Interactions. *BioScience,* 70(10), 854-870, 2020. https://doi.org/10.1093/biosci/biaa088
57. Hanna, L., Kissick, A.L., McCroskey, E. & Holland, J.D., Resilience to disturbance is a cross-scale phenomenon offering a solution to the disturbance paradox. *Ecosph*, 10, e02682, 2019.
58. Barrow, E. & Mlenge, W., Trees as key to pastoralist risk management in semi-arid landscapes in Shinyanga, Tanzania and Turkana, Kenya. In *International Conference on Rural Livelihoods, Forests and Biodiversity* (pp. 19-23), 2003.
59. Aide, T.M., Zimmerman, J.K., Pascarella, J.B., Rivera, L. & Marcano-Vega H., Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. *Restoration Ecology*, 8, 328, 2000.
60. Doust, S., Seed and Seedling Ecology in the Early Stages of Rainforest Restoration. PhD Thesis, University of Queensland, Brisbane, Australia, 2005.
61. Huynh Duc Nhan, The ecology of mixed species plantations of rainforest tree species. PhD thesis, University of Queensland, Brisbane, 2001.
62. Htun, N.Z., Mizoue, N., Kajisa, T. & Yoshida, S., Deforestation and forest degradation as measures of Popa Mountain Park (Myanmar) effectiveness. *Environmental Conservation*, 36(3), 218-224, 2009.
63. Löf, M., Madsen, P., Metslaid, M., Witzell, J. & Jacobs, D.F., Restoring forests: regeneration and ecosystem function for the future. *New Forests*, 50, 139-151, 2019. https://doi.org/10.1007/s11056-019-09713-0
64. Lindenmayer, D.B., Integrating forest biodiversity conservation and restoration ecology principles to recover natural forest ecosystems. *New Forests* 50, 169-181, 2019. https://doi.org/10.1007/s11056-018-9633-9

12

Forest for Sustainable Development

Abhishek Raj[1], Manoj Kumar Jhariya[2*], Arnab Banerjee[3], Bharat Lal[4], Taher Mechergui[5], Annpurna Devi[2] and Ghanshyam[2]

[1]Pt. Deendayal Upadhyay College of Horticulture & Forestry, Dr. Rajendra Prasad Central Agriculture University, Pusa, Samastipur, Bihar, India
[2]Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[3]Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[4]College of Agriculture, Rani Lakshmi Bai Central Agricultural University, Jhansi (U.P.), India
[5]Faculté des Sciences de Bizerte, Laboratoire des Ressources Sylvo-Pastorales de Tabarka, Tabarka, Tunisie

Abstract
The productivity, health and sustainability of the world's forests are declining due to various natural and anthropogenic or human-made deleterious activities. Deforestation, overexploitation of timbers, overuse of natural resources, mining activities, forest fragmentations and various unsustainable land-use practices destroy the health and productivity of forest ecosystems. These deleterious activities affect not only vegetational structure and diversity but also regeneration and soil quality. Forest plays an important role in atmospheric carbon balance, improving soil fertility and health, rhizosphere biology, efficient nutrient cycling, and maintaining food and climate security at a global scale. These tangible and intangible services of forests can ensure that the goal of sustainability is achieved. The delivery of ecosystem services through forestry promises various multifarious and uncountable benefits to humankind. Climate change mitigation through forestry is another important dimension which can be possible through carbon sequestration process. This process can add carbon into vegetation and soils as biomass and soil organic carbon (SOC) pools which indirectly affect fertility and productivity. Healthy soil is a basis for quality and nutritive food that offers health

**Corresponding author*: manu9589@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (293–312) © 2023 Scrivener Publishing LLC

benefit, human prosperity and sustainable development. Therefore, judicious utilization and management of these resources is key concern for sustainability and social development. Therefore, sustainable forest management (SFM) is viewed as an integrated approach which maintains soil-food-climate security along with environmental sustainability and ecological stability. A policy and future roadmap must be framed in accordance to maintain forest, soil and climate health that fulfils the goal of sustainable development at the global level.

Keywords: Forest, environment, ecosystem services, land degradation, sustainability

12.1 Introduction

Forests are recognized as the largest natural resources that harbor a variety of flora and fauna and deliver uncountable ecosystem services in both tangible and intangible ways [1]. It has multifarious approaches for sustaining entire human civilization by maintaining social, economic, culture and environmental dimensions on a sustainable basis [2–4]. Forest is a life-sustaining natural resource that manages and conserves other resources; its uptake and proper utilization maintains overall ecosystem structure and related services [5]. It regulates water and soil quality which are very important natural resources that add a better growth and development of varying life forms in the forest ecosystem. Likewise, Mediterranean forests deliver key soil-based ecosystem services due to its greater ecological and biological diversity along with maintaining the heterogenous nature of the forest ecosystem [6, 7].

Climate change mitigation is another prospect of forest treasure that can be possible through the process of carbon sequestration in which tree species capture atmospheric carbon and fix into varying parts of vegetations [8, 9]. This process will add biomass in the form of timber, fuelwood, firewood, fodder (for animals) and NTFPs (non-timber forest products). Moreover, accumulation of biomass and productivity run in parallel to climate change mitigations which entirely link with land, energy and climate footprints in tropical forest ecosystem [10, 11]. However, these biomass accumulation processes are affected by site quality and nutrient load which entirely affects whole vegetational attributes [12]. These forest products are a viable income source for forest fringe peoples and strengthen farmers' livelihoods prior to achieving the goal of sustainable development.

The term sustainability reflects the judicious use of resources at present and in the future without disturbing environmental health. Eco-designing of natural resources can ensure environmental sustainability and ecological stability [13]. A better and scientific management of forest would be helpful in enhancing diversifying products that intensify ecosystem services and maintain overall soil-food-climate security, which is a prerequisite for fulfilling the dream of sustainable development at a global scale [3, 14, 15]. Forest adds leaf litter and other residues into the soil which undergoes decay and decomposition by soil inhabiting microorganisms that add organic matter as SOC pool and maintains overall soil fertility. However, SOC is a good indicator of soil fertility that helps in maintaining soil health, and healthy soil is directly linked with better forest ecosystems and overall sustainable development [16].

Today, deforestation and other anthropogenic activities such as mining, illicit felling of timbers, encroachments, industrialization, forest fires, etc., affect a forest ecosystem by disturbing its health and productivity and causing degradations [17–19]. Similarly, unsustainable land use systems definitely destroy the land quality and its fertility that overall affects the soil quality, food productions and climate security by releasing greenhouse gases (GHGs) into the atmosphere [20, 21]. These changing climate conditions, unsustainable land use and related footprints affect Mediterranean forests and related ecosystem services (ES) [22]. All these activities will affect environmental sustainability, ecological stability and overall sustainable development at local scale. Therefore, a synthetic approach is required for achieving the goal of sustainability which not only maintains the health of a forest ecosystem but also intensifies the ecosystem services for maintenance of ecological stability [23, 24]. In this context, SFM is a good strategy and represents a hope for achieving the goal of sustainable development at the social, economic and environmental levels.

In view of the above, this paper comprehensively discusses forest ecosystems, including a global overview and the forest's role in ecosystem services such as soil-food-climate security for maintaining environmental and ecological stability which helps in achieving the goal of sustainable development.

12.2 World Forest: An Overview

There was a time when forests were distributed over the whole landscape of the earth, but now the area has shrunk and is being reduced day by day due to deforestation and other anthropogenic activities. These deleterious activities affect not only an area coverage, ecosystem services and economic security but also overall sustainability. Forest ranked second after agriculture land use system as the largest natural resource which takes part in farmers' socioeconomic development and livelihood security [25]. Trees are a principal component of human well-being and play an important role in improving the livelihood of 2.5 billion people that are dependent upon agriculture and engaged in varying forms of farming practices [26, 27]. As per one estimate, globally around 820 million poor people lived in the savannah regions that are directly or indirectly connected with nearby forest areas and depended on them for sustaining their lives [28]. This figure represents the people's dependency on forests for their livelihood, so restoring forest ecosystems would be helpful in strengthening the socioeconomic status of farmers and food security which could help to achieve the goal of sustainable development in a global context.

12.3 Forest under Changing Climate

A rigorous discussion has been conducted on climate change by policy makers, stakeholders, academics and scientists and has become the most common topic of discussion at national and international platforms. There are two schools of thought; first, degradation of forest through deforestation and other anthropogenic activities leads to GHGs emissions being released into the atmosphere, which cause the climate change phenomenon. Second, climate change is affecting our forest ecosystem in terms of yield, productivity, phenology, reproductive biology and morphology, which in turn diminishes overall health, farmers' wealth and environmental sustainability. In India, as per one researcher's estimate, climate change threatens half of the total forest area within the geographical limit. These threatened forest areas include the dense forests of Central India, Eastern and Western Ghats, and the upper Himalaya regions [29]. These findings have been modified and synthesized by Chaturvedi *et al.* [30] and according to them, approximately 77% of changes occurred in forest types of the Indian subcontinent.

The impacts of climate change are very dramatic in most parts of Asia, Africa, Europe and other Mediterranean regions. Extreme weather has created severe effects by disturbing morphology, phenology, growth rate, timber quality, species compositions, distribution, diversity and overall dry matter productivity of tropical forest. Vegetation shifting, its diversions and mortality are other impacts that were observed as a result of the changing climate and global warming. Similarly, climate variability affects tree species nature, distributions and shifting from one to other places [31–33]. The tree species of boreal biomes is becoming the invasive alien for the biome of arctic regions, whereas conifers vegetations shifted towards deciduous characteristics of larch forest ecosystem. Likewise, coastal vegetations comprising mangroves ecosystem are also affected by extreme weather events by intrusion of salty water that threatens the marshy and swampy vegetations. Meanwhile the coral reefs are also vulnerable due to this extreme climate variability [34]. Further, the expansion of shrubby areas in the arctic tundra biomes is another impact that was observed due to the climate change phenomenon [35]. Various research was conducted on changing climate impact and on varying tree species in the world, which is depicted in Table 12.1.

These climatic impacts on forest resources not only minimized the forest covers but also deprived the other resources, biodiversity, related ecosystem services and overall vegetation structure, composition and its diversity [45, 46]. In this context, a question appears, "How does climate change affect forest sustainability at a global scale?" Climate change becomes a major hurdle behind the dreams of sustainable development by affecting overall forest productivity and health. Forest regulates climate but due to extreme weather conditions the overall species composition, diversity and productivity are disturbed, which affects the overall forest ecosystem. These disturbances directly affect biodiversity and related ecosystem services and lead to unsustainable and degraded quality of the environment [47, 48]. Thus, it is now clear that a great synergy exists among healthy climate and forest that leads to sustainable development. Moreover, the SFM practices will help in mitigating climate change and global warming by minimizing the excessive GHGs emission through the carbon sequestration process. Thus, SFM helps in maintaining soil-food-climate security and promotes the environmental sustainability and ecological stability at global scale [45, 47, 48].

12.4 Forest for Ecosystem Services

The forest sustains lives of every organism by delivering ecosystem services in both tangible (direct) and intangible (indirect) ways. Tangible services include timber products, fuelwood, firewood, fodder (for animals), nutritive fruits, medicinal and aromatic plants, spices and other NTFPs. It can be utilized by people residing near the forest and improves social, economic and cultural values by strengthening the livelihood security [49, 50]. Soil fertility enhancement, higher microbial population, better rhizosphere biology, efficient nutrient cycling, higher SOC pools, water availability and its conservations are key advantages promised by sustainable forest practices. Additionally, enhancement in nutrient use efficiency, resources

Table 12.1 Extreme weather and its impacts on forest tree species in different regions of the world.

Forest tree species in different regions of the world	Extreme weather and its impacts	References
Oak tree (*Quercus* species) based forest ecosystem in the regions of U.S.A.	Region experienced a heavy drought condition that resulted in declined population of Oak tree in forest	[36]
Ash tree (*Fraxinus* species) based forest ecosystem in the regions of Pennsylvania (USA)	Region experienced a drought and freezing condition that promoted insect outbreak conditions which caused dieback disease that led to higher mortality of tree species	[37]
Scots pine (botanically known as *Pinus sylvestris*) based forest ecosystem mostly prevalent in the European region	Region experienced freezing and cold temperatures that resulted in dieback disease and loss of the needles	[38]
Cotton tree (botanically known as *Ceiba pentandra*) based forest prevalent in the USA	Experienced higher temperature that caused emergence of pink bollworm pest and resulted in heavy tree mortality	[39]
Citrus (comes under Rutaceae family) based forest prevailed in Australia	Experienced higher temperature, which caused emergence of leafroller moth	[40]
Apple pear (botanically known as *Pyruspyrifolia*) based forest prevalent in the regions of Himanchal Pradesh, India	Experienced higher temperature & resulted global warming has shifted *Pyrus* species to peach forest through vegetational shifting	[41]

(*Continued*)

Table 12.1 Extreme weather and its impacts on forest tree species in different regions of the world. (*Continued*)

Forest tree species in different regions of the world	Extreme weather and its impacts	References
Apple tree (botanically known as *Malus pumila*) mostly prevalent in the regions of Himanchal Pradesh (India)	Experienced higher temperature & resulting global warming that has shifted apple tree to Kiwi plant	[42]
Apple tree (botanically known as *Malus pumila*) mostly prevalent in the regions of Asian continent	Experienced extreme temperature	[43]
Sal and Gurjan tree (*Dipterocarpus* species) based forest ecosystem in the region of North and western Ghats in Indian subcontinent	Experienced wide extreme temperature that threatened the overall tree species	[44]

conservation, food and nutritional security, climate security, environmental sustainability and overall ecological stability are other recognized intangible services provided by a forest ecosystem [51]. Better management practices, i.e., sustainable and ecology-oriented forest management and conservation will strengthen the ecosystem services at a satisfactory level that will be a recognized pillar for sustainable development [52].

12.5 Forest for Soil Management

Soil is another of the largest natural resources that support other natural resources such as forest, agriculture, agroforestry, animals, etc. There is a great link between soil quality and vegetation structure. Topography, land forms, soil physico-chemical properties, nutrient loads, etc., affect the vegetation types, structure, compositions and diversity [9, 12]. Forests add litter and other residues that decay and get decomposed by soil inhabiting microorganisms to release essential nutrients that in turn are taken up by the extensive root system of higher plants and utilized for better growth and development. In parallel, forest is a good sink of carbon in which vegetation absorbs atmospheric carbon and fixes it into different parts of tree species (stem, branch, roots and leafs) which add biomass and carbon into the vegetation and soils [17, 53]. Therefore, soil carbon sequestration is a viable strategy that not only maintains the carbon balance but also improves fertility and productivity of soil through better SOC pools and other nutrients. In this context, nitrogen fixing leguminous MPTs (multi-purpose trees) would be helpful in promoting soil nitrogen content and its mobilizations into the plants for better metabolic activities. Thus, we can say there is a great connection between forest and soil ecosystem.

Presently, land degradations are becoming major problems that not only affect overall land use pattern but also disturb food-soil-climate security. In this context, Figure 12.1 represents the extent and status of land degradations worldwide. An unaffected and stable land contributed maximum percentage (37%) followed by high and moderate land degradation as 25% and 8%, respectively, whereas bare land contributed 18% but only 10% of land system was observed under improvement [54]. People across the globe are aware of the importance of forest and its role in managing soil and other resources, its conservation and overall sustainable development. In this context, several countries have managed the existing forest areas for improving the clean water system, ameliorating desertification areas, controlling soil erosion, and maximizing the coastal stabilizations, as is represented in Figures 12.2, 12.3, 12.4 and 12.5, respectively [55]. Thus, forest has the greatest potential to restore soil fertility, regulate water and nutrient cycling, and maintain climate and food security at global level. Similarly, adopting plantations and scientific-based farming systems can improve degraded and wasteland for better yield and productivity.

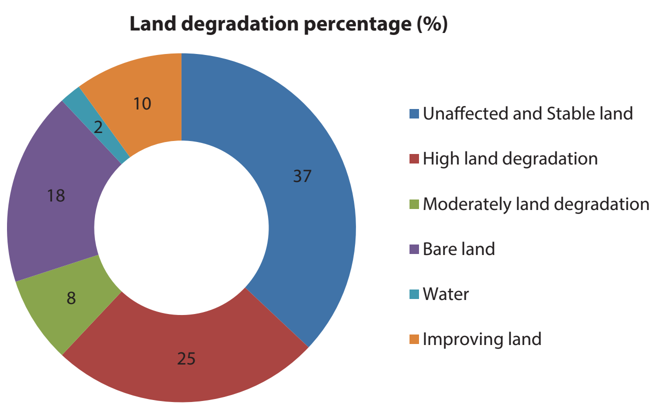

Figure 12.1 Status of land degradation in the world [54].

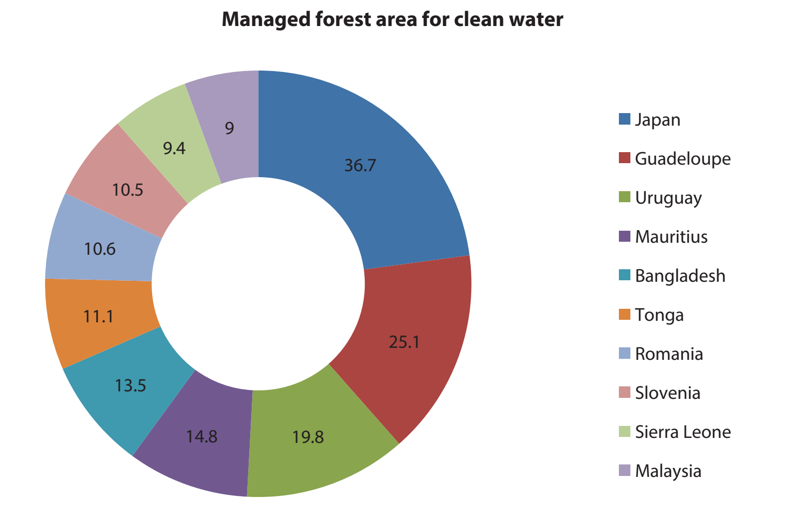

Figure 12.2 Managed forest area for availability of clean water [55].

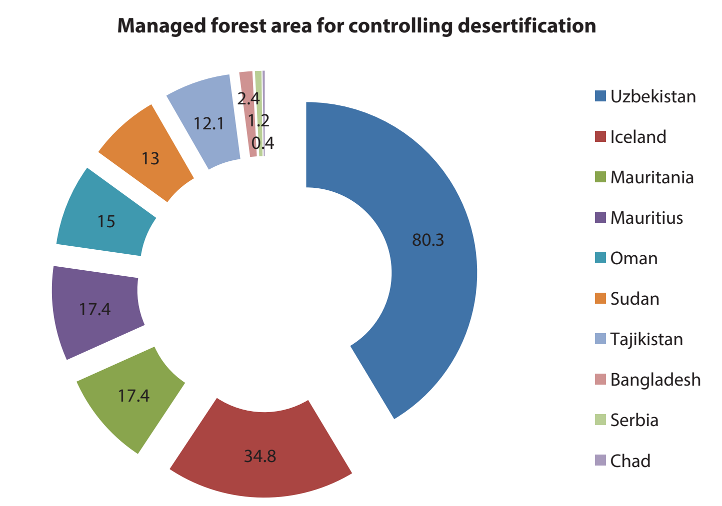

Figure 12.3 Managed forest areas for controlling desertification [55].

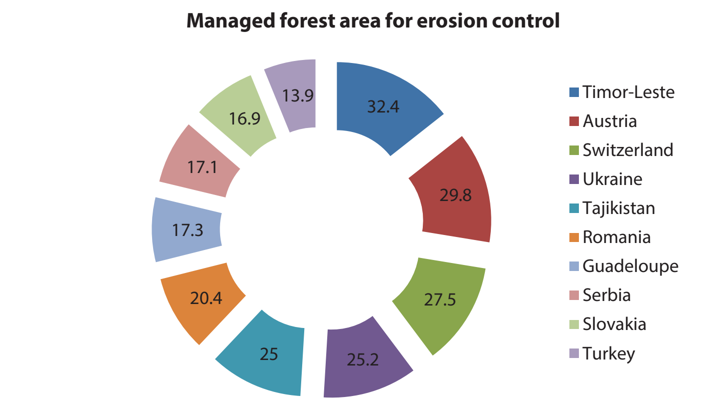

Figure 12.4 Managed forest areas for erosion control [55].

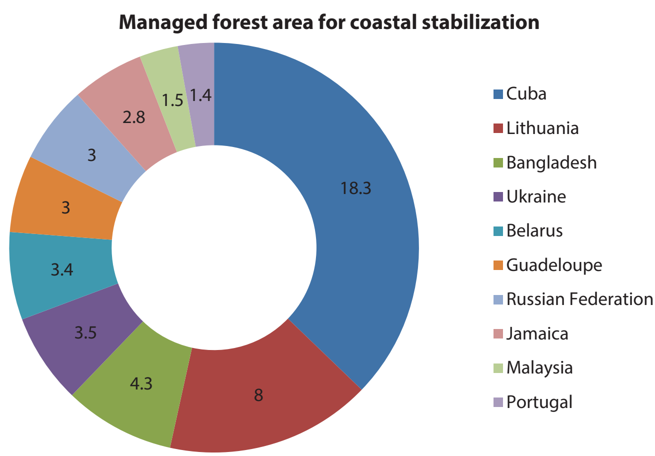

Figure 12.5 Managed forest area for the coastal stabilization [55].

12.6 Forest for Food and Nutritional Security

Healthy forest will produce quality food and nutritive fruits that could potentially fulfill the food requirement of a rising population. A single forest ecosystem can sustain millions of people by providing diverse forms of food, fodder, edible fruits, flowers and other NTFPs. That will not only fulfil the demand, but also surplus production will be economically viable for the forest fringe people and strengthen their livelihood. There is a great nexus between forest and food that drives nation development in sustainable ways. Forest makes quality and nutritious fruits available to people that improve their health, wealth and livelihood security [3, 56, 57]. Gum productions are important NTFPs that add extra income for the farmers due to its efficient utilizations in various forms [58]. Beside timber, the productions of gum, katha, catechu, dye, resin, sal leaves, etc., are the other important NTFPs that sustain the lives of people and maintain food-income-climate security at a global scale. However, degradation of land and deforestation activity affects regeneration and important trees which directly or indirectly affect yield and productivity. But better management and protection of forest by applying SFM activities will surely help in strengthening farmers' livelihoods through ample production on a sustainable basis which is a prerequisite for sustainable development [3, 5, 59].

12.7 Sustainable Development: A Wake-Up Call

The term "sustainable" is widely used at national and international platforms due to its importance for betterment of our Mother Nature. The management and conservation of natural resources without destroying the present and future environment are the basic principles of sustainable development [46]. Applying an ecology-oriented system in forests and any farming systems is the key for achieving the goal of sustainability [60]. Land degradation, resource depletion, depriving soil fertility arise as bottleneck problems which are the major hurdles to sustainable development [61]. Forest and other resource conservation are the prerequisite for maintaining environmental sustainability and ecological stability. Unsustainable land use practices, unscientific farming technology, higher synthetic inputs, illicit felling of timbers, overexploitation of natural resources, etc., are the major hurdles to be overcome in order to create sustainable development. That is why it is necessary to focus on resource conservation through ecological-oriented systems that enhance biodiversity which intensifies ecosystem services and overall ecological sustainability. The term sustainability offers a perfect ecosystem through better social, economic and environmental development [62, 63]. Therefore, both ecological and sustainable intensification in land use systems are viable strategies which add higher yield and productivity, maintain soil-food-climate security and improve the economy of poor farmers. This eco-intensification helps in achieving the goal of sustainability for better human civilizations [64, 65].

12.8 A Journey from Forest to Sustainable Forest Management

A synthetic approach is needed for exploring a journey that begins from forest and leads to SFM practices that not only maximize the yield, productions and biodiversity but also intensify ecosystem services. The old and unscientific forest management practices are poorly recognized and have been replaced by new ecological and sustainable-oriented practices. These sustainable practices maintain forest health and productivity and promote ecosystem services by diversifying vegetation composition and structure. Poor land management, deforestation, unscientific way of farming system, and other anthropogenic activities resulted in degradation of forest ecosystem. In this context, adopting SFM promises better protection and higher productivity of forest vegetations along with overall environmental sustainability at global scale. Sustainable harvesting of timber and forest products (fodder and NTFPs, etc.) and their efficient utilizations are also helpful in maintaining socioeconomic status of farmers that strengthen the farmers' livelihood. Moreover, SFM is potentially certified for better carbon sink that adds organic matter and carbon content into the soil as SOC pools and balances the carbon in the atmosphere [9, 66]. Similarly, climate smart agriculture, conservation agriculture, agroforestry, farm forestry, extension forestry, urban forestry and community forestry can enhance socioeconomic status of farmers and ensure soil-food-climate security at global scale [67, 68]. Thus, SFM is an integrated approach for maintaining environmental sustainability and ecological stability which is a pillar for sustainable development and betterment of human civilization.

12.9 Policy and Future Roadmap

A good governance and policy are needed for promoting SFM, which is the pillar for achieving the goal of sustainable development. Sustainability is not possible without efficient utilization of resources including maintenance of environmental health. Policymakers must take an effective decision for promoting SFM which maintains soil-food-climate security from local to global level. Land, energy and carbon footprint are another important dimension which is strongly linked with forest ecosystem that must be added to strengthen an effective policy. Further, policy should be aimed towards controlling forest degradation, checking illicit felling of timber and NTFPs, solving the problems of encroachment, enhancing livelihood security and also looking into climate change mitigation at global scale. However, a wide gap of knowledge exists in addressing climate change impacts on changing forest biomes across the globe. Thus, a future roadmap must be undertaken to explore the impact of climate variability on forest biomes, its attributes, vegetational shifting, and mortality due to insect infestation [69, 70] that would make it easier to achieve the goal of sustainable development for better human civilization.

12.10 Conclusions

Deforestation and other anthropogenic activities decrease forest health and productivity by affecting new regeneration, vegetation composition and its diversity. Loss of biodiversity, poor ecosystem services, unhealthy soils and GHGs emissions are the common outcome of forest degradations that seriously affect our natural ecosystem and environment sustainability. In this context, SFM becomes a good strategy that not only maintains soil-food-climate security but also enhances farmers' livelihoods and builds a better human civilization which is the pillar of sustainable development. Thus, governance and policy must be reformed for better adoptability of SFM through which we can achieve the goal of sustainability in social, economic and environmental dimensions.

References

1. FAO, World's food systems rely on biodiversity. Food and Agriculture Organization, Rome, 2020. http://www.fao.org/news/story/en/item/1263301/icode/
2. FAO, Global Forest Resources Assessment - Progress towards sustainable forest management. FAO Forestry Paper 147, 2006. Food and Agriculture Organisation of the United Nations, Rome.
3. Jhariya, M. K., Banerjee, A., Meena, R. S. & Yadav, D. K., *Sustainable agriculture, forest and environmental management.* Springer Nature Singapore, pp. 606, 2019a. https://doi.org/10.1007/978-981-13-6830-1.
4. Jhariya, M. K., Yadav, D. K. & Banerjee, A., *Agroforestry and Climate Change: Issues and Challenges.* Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, pp. 335, 2019b. https://doi.org/10.1201/9780429057274.
5. Jhariya, M. K., Meena, R. S., Banerjee, A. & Meena, S. N., Natural Resources Conservation and Advances for Sustainability. Elsevier, Academic Press. ISBN: 9780128229767, 2022. https://doi.org/10.1016/C2019-0-03763-6.

6. Masiero, M., Pettenella, D. M. & Secco, L., From failure to value: economic valuation for a selected set of products and services from Mediterranean forests. *For Syst*, 25(1), e051, 2016. https://doi.org/10.5424/fs/2016251-08160.
7. Martinez de Araño, I., Muys, B., Corrado, T., Pettenella, D., Feliciano, D., *et al.*, *A forest-based circular bioeconomy for southern Europe: visions, opportunities and challenges. Reflections on the bioeconomy.* European Forest Institute (EFI), Joensuu, Finland, 117p, 2018.
8. Yadav, V. S., Gupta, S. R., Yadav, S. S., Meena, R. S., Lal, R., Sheoran, N. S. & Jhariya, M. K., Carbon Sequestration Potential and CO_2 Fluxes in a Tropical Forest Ecosystem. *Ecological Engineering,* 176, 106541, 2022.https://doi.org/10.1016/j.ecoleng.2022.106541.
9. Raj, A. & Jhariya, M. K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *J Environ Manage*, 293(1), 112829, 2021a.https://doi.org/10.1016/j.jenvman.2021.112829.
10. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N.& Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore, pp. 221-246, 2021a. https://doi.org/10.1007/978-981-15-9496-0_7.
11. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore, pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-014.
12. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1), 1-13, 2021b.https://doi.org/10.1007/s11355-021-00450-1.
13. Khan, N., Jhariya, M.K., Raj, A., Banerjee, A.& Meena, R.S., Eco-Designing for Sustainability. In: M.K. Jhariya *et al.* (eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*, Springer Nature Singapore, pp. 565-595, 2021a. https://doi.org/10.1007/978-981-33-4203-3_16
14. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, pp. 1-383, 2020.https://doi.org/10.1201/9780429286759.
15. Banerjee A., Jhariya M.K., Yadav D.K. & Raj A., *Environmental and Sustainable Development through Forestry and Other Resources*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, pp. 1-400, 2020.https://doi.org/10.1201/9780429276026.
16. Khan, N., Jhariya, M. K., Raj, A., Banerjee, A. & Meena, R. S., Soil carbon stock and sequestration: implications for climate change adaptation and mitigation. In: *Ecological Intensification of Natural Resources for Sustainable Agriculture*. MK Jhariya, RS Meena, A Banerjee (Eds.), Springer, Singapore, pp. 461-489, 2021b.https://doi.org/10.1007/978-981-33-4203-3_13.

17. Jhariya, M.K., Vegetation ecology and carbon sequestration potential of shrubs in tropics of Chhattisgarh, India. *Environmental Monitoring and Assessment,* 189(10), 518, 2017. https://doi.org/10.1007/s10661-017-6246-2.
18. Jhariya, M. K. & Singh, L., Herbaceous diversity and biomass under different fire regimes in a seasonally dry forest ecosystem. *Environ. Dev. Sustain*., 23(5), 6800-6818, 2021b. https://doi.org/10.1007/s10668-020-00892-x.
19. Jhariya, M. K. & Singh, L., Effect of fire severity on soil properties in a seasonally dry forest ecosystem of Central India. *Int. J. Environ. Sci. Technol.,* 18, 3967-3978, 2021c. https://doi.org/10.1007/s13762-020-03062-8.
20. Khan, N., Jhariya, M. K., Yadav, D.K. & Banerjee, A., Herbaceous dynamics and CO_2 mitigation in an urban setup - A case study from Chhattisgarh, India. *Environ. Sci. Poll. Res*., 27(3), 2881-2897, 2020a. https://doi.org/10.1007/s11356-019-07182-8.
21. Khan, N., Jhariya, M. K., Yadav, D. K. & Banerjee, A., Structure, diversity and ecological function of shrub species in an urban setup of Sarguja, Chhattisgarh, India. *Environ. Sci. Poll. Res*., 27(5), 5418-5432, 2020b. https://doi.org/10.1007/s11356-019-07172-w.
22. Tuffery, L., Davi, H., López-García, N., Rigolot, E., Jean, F., Stenger, A. & Lefevre, F., Adaptive measures for mountain Mediterranean forest ecosystem services under climate and land cover change in the Mont-Ventoux regional nature park, France. *Reg Environ Change*, 21, 12, 2021.
23. Jhariya, M. K., Meena, R. S. & Banerjee, A., *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore, pp. 655, 2021a. Doi: 10.1007/978-981-33-4203-3.
24. Jhariya, M. K., Banerjee, A., Meena, R. S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management*. Springer Nature Singapore, pp. 870, 2021b Doi: 10.1007/978-981-16-3207-5.
25. MoEF, Sustainable development—learnings and perspectives from India. Ministry of Environment and Forest (MoEF), Government of India, 2002. https://moef.gov.in/wp-content/uploads/wssd/doc4/consul_book_final.pdf
26. IFAD, Smallholders, food security, and the environment. International Fund for Agricultural Development, Rome, 2013.
27. IFAD, Rural Development Report 2016: Fostering inclusive rural transformation. International Fund for Agricultural Development, Rome, 2016.
28. Chomitz, K., At Loggerheads? Agricultural Expansion, Poverty Reduction, and Environment in the Tropical Forests. World Bank Policy Research Report. Washington, DC: World Bank. 2007. https://openknowledge.worldbank.org/handle/10986/7190.
29. Gopalakrishnan, R., Jayaraman, M., Govindasamy, B. & Ravindranath, N.H., Climate change and Indian forests. *Curr Sci,* 101(3), 348-355, 2011.
30. Chaturvedi, R.K., Gopalakrishnan, R., Jayaraman, M., Bala, G., Joshi, N.V., Sukumar, R. & Ravindranath, N.H., Impact of climate change on Indian forests: a dynamic vegetation modeling approach. *Mitig Adapt Strat Glob Chang,* 16(2), 119-142, 2010.

31. Singh, C.P., Panigrahy, S., Thapliyal, A., Kimothi, M.M., Soni, P. & Parihar, J.S., Monitoring the alpine treeline shift in parts of the Indian Himalayas using remote sensing. *Curr Sci,*102(4), 559-562, 2012.
32. Ogawa-Onishi, Y. & Berry, P.M., Ecological impacts of climate change in Japan: the importance of integrating local and international publications. *Biol Conserv,* 157, 361-371, 2013.
33. Telwala, Y., Brook, B. W., Manish, K. & Pandit, M. K., Climate-induced elevational range shifts and increase in plant species richness in a Himalayan biodiversity epicentre. *PLoS One,* 8(2), e57103, 2013. Doi:10.1371/journal.pone.0057103.
34. IPCC, Climate Change 2014: Impacts, Adaptation and Vulnerability. Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 2014.
35. Blok, D., Sass-Klaassen, U., Schaepman-Strub, G., Heijmans, M.M.P.D., Sauren, P. & Berendse, F., What are the main climate drivers for shrub growth in Northeastern Siberian tundra? *Biogeosci,* 8(5), 1169-1179, 2011.
36. Rodríguez-Calcerrada, J., Sancho-Knapik, D., Martin-StPaul, N. K., Limousin, J. M., McDowell, N. G. & Gil-Pelegrín, E., Drought-Induced Oak Decline—Factors Involved, Physiological Dysfunctions, and Potential Attenuation by Forestry Practices. In: Gil-Pelegrín, E., Peguero-Pina, J., Sancho-Knapik, D. (eds), *Oaks Physiological Ecology. Exploring the Functional Diversity of Genus Quercus L.* Tree Physiology book series, (Tree Vol. 7), pp. 419-451, 2017.
37. Royo, A.A. & Knight, K.S., White ash (*Fraxinusamericana*) decline and mortality: The role of site nutrition and stress history. *For EcolManage,* 286, 8-15, 2012.
38. Camarero, J.J., Gazol, A., Sancho-Benages, S. & Sanguesa-Barreda, G., Know your limits? Climate extremes impact the range of Scots pine in unexpected places. *Ann Bot,* 116, 917-927, 2015.
39. Henneberry, T.J., Integrated Systems for Control of the Pink Bollworm *Pectinophoragossypiella* in Cotton. In: Vreysen, M.J.B., Robinson, A.S., Hendrichs, J. (Eds.), *Area-Wide Control of Insect Pests*. Springer, Dordrecht, 2007.
40. Thomson, L.J., Macfadyen, S. & Hoffmann, A.A., Predicting the effects of climate change on natural enemies of agricultural pests. *Biol Control,* 52(3), 296-306, 2010.
41. Anonymous, ENVIS Newsletter July–December 2008, Volume II, 2008. http://www.hpenvis.nic.in.
42. Gulati, V., From apple to kiwi, a journey of returns. 2009, http://www.commodityonline.com/news/From-apple-to-kiwi-%96-a-journey-of-returns-14070-3-1.html.

43. Deb, J. C., Phinn, S., Butt, N. & McAlpine, C. A., The impact of climate change on the distribution of two threatened Dipterocarp trees. *Ecol. Evol.*, 7, 2238-2248, 2017. https://doi.org/10.1002/ece3.2846.
44. Pramanika, M., Paudel, U., Mondal, B., Chakraborti, S. & Debd, P., Predicting climate change impacts on the distribution of the threatened Garcinia indica in the Western Ghats, India. *Climate Risk Management*, 19, 94-105, 2018.
45. Raj, A., Jhariya, M.K. & Harne, S.S., Threats to Biodiversity and Conservation Strategies, pp. 304-320. In: *Forests, Climate Change and Biodiversity*. KK Sood, V Mahajan (Eds.), Kalyani Publisher, India, pp. 381, 2018a.
46. Raj, A., Jhariya, M. K., Khan, N., Banerjee, A. & Meena, R. S., Ecological Intensification for Sustainable Development. In: M.K. Jhariya *et al*. (Eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore, pp. 137-170, 2021.https://doi.org/10.1007/978-981-33-4203-3_5.
47. Raj, A., Jhariya, M.K. & Bargali, S.S., Climate Smart Agriculture and Carbon Sequestration. In: *Climate Change and Agroforestry: Adaptation Mitigation and Livelihood Security*. C.B. Pandey, Mahesh Kumar Gaur and R.K. Goyal (Eds.). New India Publishing Agency (NIPA), New Delhi, India, pp. 1-19, 2018b.
48. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative Tool for Soil Sustainability. In: Meena RS, Das A, Yadav GS, Lal R (Eds.): *Legumes for Soil Health and Sustainable Managemen*t. Springer, pp. 315-345, 2018.https://doi.org/10.1007/978-981-13-0253-4_10.
49. *Prasad, R., Jhariya, M.K. & Banerjee, A., Advances in Sustainable Development and Management of Environmental and Natural Resources: Economic Outlook and Opinions* Volume I. CRC Press - a Taylor and Francis Group, Apple Academic Press, pp. 1-437, *2021a*.
50. *Prasad, R., Jhariya, M.K. & Banerjee, A., Advances in Sustainable Development and Management of Environmental and Natural Resources: Economic Outlook and Opinions* Volume II. CRC Press - a Taylor and Francis Group, Apple Academic Press, pp. 1-428, *2021b*.
51. Heal, G., *Nature and the Marketplace, Capturing the Value of Ecosystem Services* (2000). Washington DC: Island Press, pp. 1-2, 2000.
52. Jhariya, M. K., Banerjee, A., Meena, R. S. & Yadav, D. K., Agriculture, Forestry and Environmental Sustainability- A Way Forward. In: *Sustainable Agriculture, Forest and Environmental Management*. M.K. Jhariya, A. Banerjee, R.S. Meena and D.K. Yadav (Eds.). Springer Nature Singapore, pp. 1-29, 2019. Doi:10.1007/978-981-13-6830-1.
53. Raj, A., Jhariya, M.K., Yadav, D.K., Banerjee, A. & Meena, R. S., Soil for Sustainable Environment and Ecosystems Management. In: M. K. Jhariya *et al*. (Eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore, pp. 189-221, 2019.

54. FAO, Food and Agriculture Organization of the United Nations, The State of the World's Land and Water Resources for Food and Agriculture. Rome, 2010.
55. FAO, Global Forest Resources Assessment 2015: How are the world's forests changing? Second Edition. Rome, 2015.www.fao.org/3/a-i4793e.pdf.
56. FAO, Guidelines for National FIVIMIS: Background and Principles (No. 1). Rome, Italy, 2000.
57. Mofya-Mukuka, R. & Simoloka, A., Forest Resources for Rural Household Food and Nutrition Security: The Case of Eastern Province of Zambia. Working Paper 102; Indaba Agricultural Policy Research Institute (IAPRI) Lusaka, Zambia, pp. 36, 2015.
58. Raj, A. & Jhariya, M.K., Effect of environmental variables on *Acacia* gum production in the tropics of Chhattisgarh, India. *Environment, Development and Sustainability,* 24, 6435-6448, 2022. https://doi.org//10.1007/s10668-021-01709-1.
59. Arnold, M.J.E. & Perez, M.R., Can non timber forest products much tropical forest conservation and development objectives? *Ecological Economics,* 39, 437-447, 2001.
60. Banerjee, A., Jhariya, M.K., Khan, N., Raj, A.& Meena, R.S., Ecomodelling towards Natural Resource Management and Sustainability. In: M.K. Jhariya *et al*. (eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*, Springer Nature Singapore, pp. 491-519, 2021c.https://doi.org/10.1007/978-981-33-4203-3_14.
61. Kujur, E., Jhariya, M.K., Yadav, D.K. & Banerjee, A., Phytosociological attributes and regeneration potential of riparian vegetation in Northern Chhattisgarh, India. *Environment, Development and Sustainability,* 24, 2861-2886, 2022. https://doi.org/10.1007/s10668-021-01557-z.
62. Cerf, M., Guillot, M.N. & Olry, P., Acting as a change agent in supporting sustainable agriculture: how to cope with new professional situations? *J AgrEdu Ext,* 17, 7-19, 2011.
63. Roy, O., Meena, R.S., Kumar, S., Jhariya, M.K. & Pradhan, G., Assessment of land use systems for CO_2 sequestration, carbon credit potential and income security in Vindhyan region, India. *Land Degradation & Development*, 33(4), 670-682, 2022. https://doi.org/10.1002/ldr.4181.
64. Reed, M.S., Fraser, E.D.G. & Dougill, A.J., An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecol Econ,* 59, 406-418, 2006.
65. Meena, R.S., Yadav, A., Kumar, S., Jhariya, M.K. & Jatav, S.S., Agriculture ecosystem models for CO2 sequestration, improving soil physicochemical properties, and restoring degraded land. *Ecological Engineering,* 176, 106546, 2022.https://doi.org/10.1016/j.ecoleng.2022.106546.
66. Raj, A. & Jhariya, M.K., Forest for Sustainable Development: a Wakeup Call. *SF J Environ Earth Sci.,* 3(1), 1038, 2020.

67. Jhariya, M.K., Bargali, S.S. & Raj, A., Possibilities and Perspectives of Agroforestry in Chhattisgarh. In: *Precious Forests-Precious Earth*, Miodrag Zlatic (Ed.), InTech, Croatia, Europe, pp. 237-257, 2015. Doi:10.5772/60841.
68. Singh, N.R. & Jhariya, M.K., Agroforestry and Agrihorticulture for Higher Income and Resource Conservation. In: *Innovative Technology for Sustainable Agriculture Development*, Sarju Narain and Sudhir Kumar Rawat (Eds.), Biotech Books, New Delhi, India, pp. 125-145, 2016.
69. Meleshko, V.P. & Semenov, S.M., *Assessment Report on Climate Change and Its Consequences in the Russian Federation*: *General Summary*. Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet), RIHMI-WDC, Obninsk, Kaluga region, Russia, 24 pp, 2008.
70. Zhang, N., Yasunari, T. & Ohta, T., Dynamics of the larch taiga-permafrost coupled system in Siberia under climate change. *Env Res Lett,*6(2), 024003, 2011. Doi:10.1088/1748-9326/6/2/024003.

13

Unfolding Environmental Repercussions of Land Degradation in the Lone Municipal Council of Andaman, India, Using Geospatial Technologies: A Case Study

Venkatesan Shiva Shankar[1]*, Neelam Purti[2], Satyakeerthy T. R.[3] and Sunil Jacob[4]

[1]*Faculty of Environmental Science, ANCOL, Chakargaon, Port Blair, Andaman and Nicobar Islands, India*
[2]*Department of Environment and Forest, Manglutan Range, South Andaman Forest Division, Andaman and Nicobar Islands, Port Blair, India*
[3]*IGNOU Regional Centre, Trivandrum, Kerala, India*
[4]*Department of Chemistry, Catholicate College, Mahatma Gandhi University, Pathanamthitta, India*

Abstract
The Port Blair Municipal Council (PBMC) is a township in Andaman and Nicobar Islands (ANIs), of Indian sovereignty situated in the Bay of Bengal (BoB). In fact, it is a colonial township with an illustrious and gruesome history of alien regimes like the British and the Japanese. The PBMC presently has a geographical extent of 41.44 Km^2; it is the capital and the center of all ANIs activities. Land degradation is an difficult problem that triggers a chain of environmental challenges like increased soil erosion, increased runoff, poor groundwater recharge, shallow landslides, carbon sequestration, and land surface temperature (LST). Thus, land degradation and its aforementioned related environmental challenges were gauged by the changes in land-use and land cover (LULC). The LULC changes were quantified using multi-temporal Landsat time series (2000 and 2020) satellite data products. Various modules were deployed for assessing the environmental challenges on the geospatial platform. The modules include the climatic water balance (CWB) model, revised universal soil loss equation (RUSLE) model, InVEST,

**Corresponding author*: shivashankarvj@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (313–338) © 2023 Scrivener Publishing LLC

and LST. The results articulate that in two decades surface runoff, soil erosion, shallow landslides, and LST have increased significantly.

***Keywords*:** Carbon storage, carbon sequestration, LST, LULC, PBMC, shallow landslides, soil erosion

13.1 Introduction

Globally, degradation of land is one among the most obligatory grave problems with irreversible environmental implications [1, 2]. About 25% of the land area is believed to be ruthlessly damaged, while 36% is moderately degraded globally [3]. Anthropogenic influences like population explosion, deforestation, urbanization, etc., are considered as the reasons for land degradation [4] of which alteration in LULC is the major reason [5, 6]. Because of indiscriminate practices of LULC, 10%, 20%, and 30% of the world's grasslands, croplands, and woodlands respectively are lost annually [7]. Also, it adversely affects the nutrient value and water holding capacity of the soil [1, 8, 9]. Further, global changes in LULC especially through deforestation over the past century have rendered the planet Earth unable to maintain healthy, sustainable ecosystems, and this has huge economic and irreparable environmental repercussions [10].

Alteration in LULC triggers subsequent environmental implications like increased surface runoff [2, 6, 11, 12], enhanced soil erosion [1, 2, 6, 7, 11, 12–14], increased flooding [7], high susceptibility of landslides [15, 16], reduced carbon store and enhanced carbon emission [17–19], and increased land surface temperature (LST) [20, 21]. Importantly, land degradation contributes to climate change and vice versa [23, 24]. Land degradation and its aforementioned implications can be accurately quantified with the aid of geospatial technologies [1, 2, 5–12, 14–16, 18–26].

13.2 Study Area at a Glance

The study area, Port Blair Municipal Council (PBMC) is the only municipal council with an illustrious colonial history and is located in the picturesque Andaman Nicobar Islands (ANIs) in the Bay of Bengal (BoB). Also, it is the capital and center for all the ANIs activities with 24 wards. It was promulgated on 15th August 1957 [27] with ten revenue villages as wards viz., 1) Aberdeen village including Aberdeen Bazaar and Ross Island, 2) Phoenix Bay, 3) Delaneypur, 4) Bunyadabad, 5) Haddo, 6) Chattam, 7) Junglighat,

8) Shadipur, 9) South Point, and 10) Lillypur. Later during the three subsequent delimitation periods, 30th April 1985 [28], 6th May 1995 [29], and 23rd April 2015 [30] one, seven, and six revenue villages respectively were annexed to the first formulated ten wards. Thus, as on date, the PBMC encompasses 24 wards.

The current extent of the PBMC is 41.44 Km^2, circumscribed by the geographical coordinates 11°35'30" and 11°41'30" N and 92°41'30" and 92° 45'30" E, with a perimeter of 55.31 Km (Figure 13.1). According to the 2011 Census of India [31] more than half (1,44,418) of the island's population is residing within the PBMC limits. Owing to the huge population in a very small area, land degradation is pertinent with grave environmental repercussions. Hence, an investigation was undertaken to quantify the spatio-temporal degradation of land and its environmental implications using GIS and remote sensing technologies.

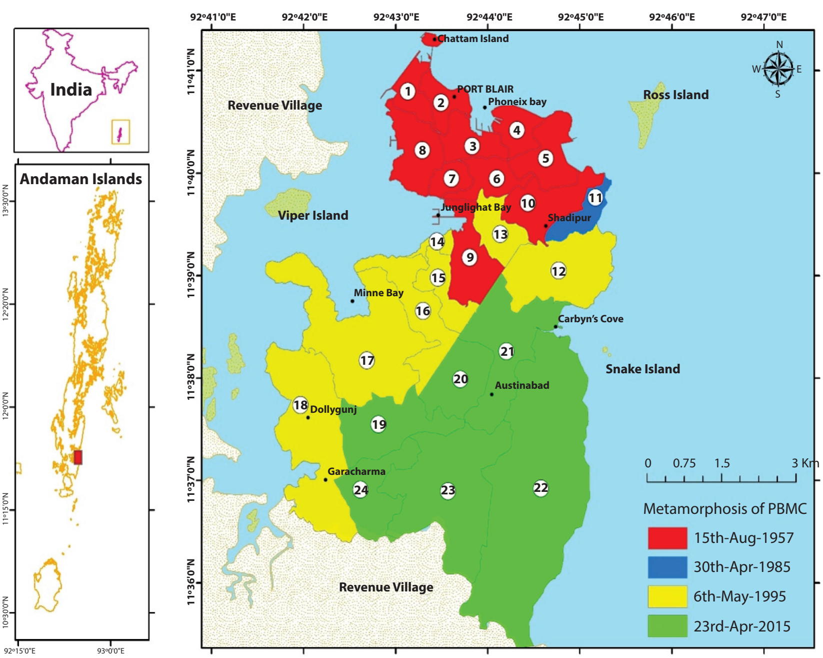

Figure 13.1 Study area map.

13.2.1 Meteorology

The annual average precipitation of the area under investigation is 3180 mm in 150 rain days. The annual relative humidity is around 81%, with temperatures ranges from 23.90°C to 30.20°C [32]. During the southwest monsoon (from May to September), the study area receives significant rainfall of 76.35%. During the northeast monsoon (October to December) 22% of precipitation was recorded and in the course of pre-monsoon (January to April), 1.64% of rainfall was received. Furthermore, tropical cyclones formed in the BoB frequently strike the area of research [33].

13.2.2 Physiography

The focus area is comprised of young folded mountains and is a furtherance of the Arakanyoma ranges [34]. All hill ranges in the focus region are dome-shaped, forested, and run parallel to one other trending north-south. The elevation range from 0m to 161m above the MSL. Generally, the landscape of the research area is rugged and rolling. The study area is categorized by four types of geomorphic features: 1) low to moderately steep hills, 2) narrow intermontane valley, 3) gradually sloping pediments on the coastal tracts, and 4) coastal plains.

13.2.3 Geology

The research region contains two major rock types: 1) sedimentary rocks, which consist mostly of an alternating array of greywacke, siltstone, shale, and conglomerate (Andaman flysch group) from the Oligocene epoch. Mithakhari group, another group of sedimentary rock, comprises conglomerate, girt, sandstone, shale, and limestone lenses produced from the Paleocene to the Eocene periods. 2) Volcanic rock (Andaman ophiolite suite) composed of pillow lava with pyroclastics, pelagic sediments with acid to intermediate intrusives, gabbro, and ultramafic containing dunite, harzburgite, and anorthosite, produced between the Jurassic and Cretaceous periods [34, 35].

13.2.4 Soil

The soils of the research area are either in situ on the hill ranges or emplaced in the valleys and alongside the coast. The soil around the coast is sandy and composed of old corals, shingles, etc., that are extremely porous.

On the hills, it is stiff clay and dark red loam but in contrast, clayey loam is encountered on the valley floor and on the downslope of hills [35].

13.3 Materials and Methodology

13.3.1 Materials

Two satellite data, viz., Landsat-7 ETM+ (2000) and Landsat-8 (2020) with path 134 and row 052 encompassing the study area were retrieved from www.earthexplorer.usgs.gov. Similarly, elevation data (ASTER-GDEM) was downloaded from www.asterweb.jpl.nasa.gov/gdem.asp. Port Blair municipal administrative boundary in *.shp format was obtained from the Town and Country Planning Section, Andaman Public Works Department. The soil and geology were inferred from the soil resource atlas of Andaman and Nicobar Island [36] and the Geological Survey of India map, respectively. Further, meteorological data (2000-2020) was procured from the Directorate of Economics and Statistics, Andaman and Nicobar Administration. All the data were curated in ArcGIS 10.5 software to get results of multi-temporal LULC, land surface temperature, soil erosion, and landslide, while the results of surface runoff and carbon storage and sequestration were derived using the climate water balance model [37] and InVEST 3.10.2 software, respectively.

13.3.2 Methodology

The methodology adhered to unfold the environmental implications of land degradation is synoptically presented as a flow chart (Figure 13.2). The secondary data like the soil map and geology map was geo-rectified with the aid of the PBMC administrative boundary map. Also, the aforementioned maps and the multi-temporal satellite data products (2000 and 2020) were clipped to the PBMC boundary, projected to UTM Zone 46N and WGS84 datum. Thematic features within the PBMC administrative boundary were digitized from respective sources in the ArcGIS 10.5 platform. Several researchers, for example [1–7, 11–19], opined that alteration in the LULC patterns has manifold environmental repercussions. Henceforth, quantification of LULC forms the strong foundation of the present study; also its derivatives in various dimensions were used to gauge the implications of land degradation.

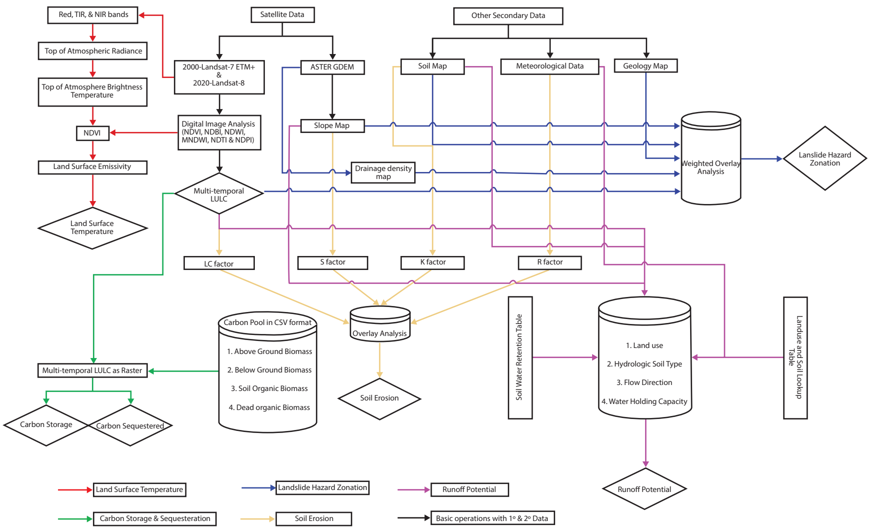

Figure 13.2 Methodology for quantifying the implications of land degradation.

13.3.2.1 LULC

The changes in LULC were delineated using six satellite image interpretation indices techniques. Those techniques are NDWI-Normalized Difference Water Index [38], NDBI-Normalized Difference Building Index [39], MNDWI-Modified Normalized Difference Water Index [40], NDVI-Normalized Difference Vegetation Index [41], NDTI-Normalized Difference Turbidity Index, and NDPI-Normalized Difference Pond Index [42]. The False Colour Composite (FCC) of NDVI, NDBI, and MNDWI; displayed on red, green, and blue panels respectively allowed the deciphering of LULC features like vegetation, built-up area, high tide line, and water body. Further, the FCC of NDTI, NDPI, and NDWI revealed on red, green, and blue panels respectively permitted the identification of mangrove forest, forest, plantation, etc. The values of all the indices ranged from -1 to +1.

13.3.2.2 Surface Runoff

A climatic water balance (Eq 13.1) is a budgeting exercise that determines the amount of precipitation that becomes runoff, evapotranspiration, and groundwater recharge [43–45]. Runoff is calculated separately for each rectangular grid cell of computational elements of the model developed by [37]. This model requires 1) monthly rainfall and temperature as tabular data (Andaman administration website: http://andssw1.and.nic.in/ecostat/index.php), 2) land-use classification records, 3) hydrologic soil group data, 4) flow direction map, and 5) soil-water holding capacity map. The workflow of this model is depicted in Figure 13.2.

$$P = ET + RO + \Delta SW \quad \text{(Eq. 13.1)}$$

Where, P, ET, RO, and ΔSW, are precipitation, evapotranspiration, runoff, and small change in soil moisture respectively.

The flow direction map was developed from the ASTER-GDEM using the hydrology toolset in ArcGIS. The available soil-water holding capacity (AWC) and its corresponding infiltration rate of four classes of soil texture of the study area by [46] were considered in this model (Table 13.1). Surface runoff from each rectangular grid cell was computed using the Natural Resources Conservation Service (NRCS) curve number rainfall-runoff relationship from the United States Department of Agriculture [47]. This rainfall-runoff relationship is determined by four basin characteristics: antecedent runoff condition, LULC soil type, and land surface condition. A drainage basin's curve number (CN) is calculated using a combination of land use, soil, and antecedent soil moisture condition (AMC). This classification is based on the least permeable infiltration rate of the soil stratum, as defined by the United States Department of Agriculture [48], as described above. Each soil and land-use groups combination was assigned an NRCS curve number.

13.3.2.3 Soil Erosion

The Revised Universal Soil Loss Equation (RUSLE) developed by [49, 50] was used to compute the amount of soil erosion and is given by the equation (Eq. 13.2).

$$REP = (S)^{1.5} * LC_{RER} * R * K/1000 \quad \text{(Eq. 13.2)}$$

Where, REP, S, LC_{RER}, R, and K are Relative Erosion Potential (ton/ha/ Year), Slope (Percentage rise), land cover associated with relative erosion rate (as per the standards of the International Geosphere-Biosphere Programme - IGGBP it is unitless), average rainfall (mm) and soil erodability factor (ton/ha/year) respectively.

The slope percentage is a topographic factor derived from the ASTER-GDEM using the surface toolset in ArcGIS. The LC_{RER} factor is assigned to various land-use classes of the study area based on IGGBP guidelines.

Table 13.1 Inputs for calculating surface runoff, soil erosion, landslides.

Surface Runoff					
AWC and infiltration rate for different soil textural classes [47]					
USDA Soil Class	**Textural class**	**Infiltration rate (cm/h)**		**AWC (mm/m)**	
Soil A	Sandy	>12.5		40 to 90	
Soil B	Loamy Sand	10.0 to 12.5		60 to 120	
Soil C	Sandy Clay Loam	1.0 to 3.5		110 to 150	
Soil D	Clay Loam	0.5 to 1.0		140 to 210	
NRCS Curve Number for different soil groups and LULC [48]					
	Curve Number				
LULC Code	**Land Use**	**Soil A**	**Soil B**	**Soil C**	**Soil D**
11	Settlement	59.0	74.0	82.0	86.0
22	Plantation	32.0	58.0	72.0	79.0
41	Forest	30.0	55.0	70.0	77.0
51	Water body	100.0	100.0	100.0	100.0

(*Continued*)

Table 13.1 Inputs for calculating surface runoff, soil erosion, landslides. (*Continued*)

Soil Erosion			
Relative erosion rate for land use based on IGGBP [49, 50]		**USDA soil erodobility factor for different soil texture class [49, 50]**	
Landuse	***LCRER***	**Soil Class**	**K (Erodability factor)**
Water body	0.5	Sandy	0.05
Evergreen forest	1.0	Loamy Sand	0.12
Plantation	12.0	Sandy Clay Loam	0.27
Urban and built up (Human settlement)	21.0	Clay Loam	0.28
Ranking for landslide hazard zonation			
Feature Class	**Ranking**	**Feature Class**	**Ranking**
Soil texture		**LULC**	
Sandy	3	Water body	0
Loamy Sand	3	Forest	1
Sandy Clay Loam	2	Plantation	2
Clay Loam	1	Human settlement	3
Geology		*Slope in degree*	

(*Continued*)

Table 13.1 Inputs for calculating surface runoff, soil erosion, landslides. (*Continued*)

Andaman flysch	2	Gentle (0 to 5) to Moderate (5 to 15)	1	
Oophilite suite	1	Moderate to steep (15 to 35)	2	
		Steep (>35)	3	
Drainage Density (Km^2)				
High (>2.5)	1	Low (0 to 1.5)	3	
Moderate (1.5 to 2.5)	2			
Carbon pool LULC lookup table of quantum of carbon stored in (in Mg/ ha) [53]				
LULC	**C-AGB**	**C-BGB**	**C-soil**	**C-dead**
Settlement	15	10	60	1
Water body	0	0	0	0
Plantation	125	5	115	1
Forest	350	129	129	58
wetland	10	5	20	0

C-AGB: quantum of carbon in above-ground biomass, C-BGB: quantum of carbon in below-ground biomass, C-soil: quantum of carbon stored in soil, and C-dead: quantum of carbon stored in dead organic matter

The susceptibility of particles to be affected by rainfall is known as rainfall erosivity. The soil erodibility factor was prepared based on the USDA guidelines (Table 13.1). The vector maps prepared based on the aforementioned parameters were converted into a raster of similar dimensions. Using the raster calculator toolset of ArcGIS the soil erosion is quantified.

13.3.2.4 Landslide Hazard Zonation

There are multi-parameters for demarcating landslide hazard zonation [15, 16, 51]. However, LULC, slope, soil, drainage density, and geology are the fundamental geo-environmental parameters through which landslide hazard zones can be efficiently and accurately demarcated. Drainage was automatically generated using the hydrology tool; thereafter density of drainage was estimated with the aid of line density algorithm in ArcGIS software. Similarly, the slope angle is derived from the ASTER-GDEM using the surface toolset. Individual ranking weightage was assigned to all the feature classes of the aforementioned geo-environmental thematic maps (Table 13.1) based on their vulnerability to landslides. The ranked vectors were converted into a raster of a similar dimension. Unlike the quantification of soil erosion, landslide hazard zonation was also demarcated using the raster calculator toolset of ArcGIS.

13.3.2.5 Carbon Storage and Sequestration

The Natural Capital Project at Stanford created InVEST 3.10.2 (Integrated Valuation of Environmental Services and Tradeoffs), a set of models to aid in environmental decision-making [52]. This model can calculate the net quantity of carbon stored in various land parcels throughout a timeline. The model necessitates an estimation of carbon quantity in at least one of the four basic carbon pools, that were first specified by [53] for each LULC type, and later, in 2006, it was standardized by [54]. The four carbon pools are 1) above-ground biomass, 2) below-ground carbon biomass, 3) soil organic carbon biomass, and 4) dead organic carbon. The classified LULC in raster format is linked with the carbon pool LULC lookup table. The carbon pool LULC lookup table of the study area was inferred from [54] and is presented in Table 13.1.

13.3.2.6 LST

Thermal bands of Landsat-7 ETM+ and Landsat-8 OLI are extensively deployed to quantify the land surface emissivity (LSE) and are a vital parameter to calculate LST [20, 55, 56]. The NDVI rationing method was used to calculate the emissivity per pixel of satellite images for the corresponding LSE [57]. LST of multi-temporal satellite data (2000 and 2020) was quantified based on the methodology adopted by [20].

13.4 Results and Discussion

13.4.1 LULC

A delimitation of the PBMC on 6th May 1995 resulted in the annexation of seven adjacent revenue villages. Similar delimitation on 23rd April 2015 led to the annexation of six more adjacent revenue villages (Figure 13.1). These delimitations led to massive deforestation in order to facilitate human occupancy and related infrastructural development activities (Figure 13.3 and Table 13.2). The forest cover in the year 2000 was 1156.73 ha that had considerably reduced to 478.18 ha in 2020. In contrast, the human settlement had increased from 2660.62 ha to3451.15 ha in 2000 and 2020 respectively. Similarly, the areal extent of coconut and arecanut plantations was also reduced during the aforementioned periods. A massive loss of

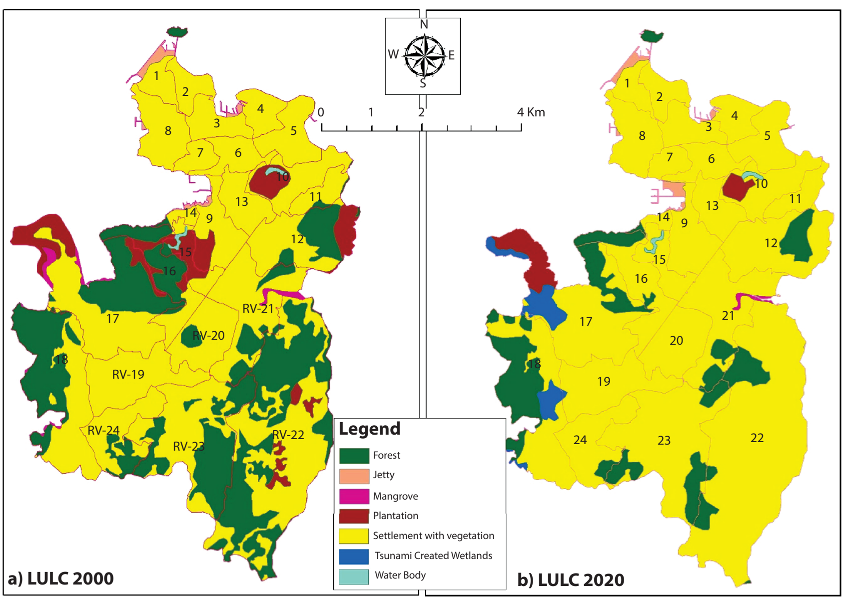

Figure 13.3 Pre- and post-tsunami LULC in PBMC.

Table 13.2 Detailed breakup of pre- and post-tsunami changes in LULC.

LULC class 2000	Area (ha)	2000 C Storage MKg/ha	LULC class 2020	Area (ha)	2020 C Storage MKg/ha	C sequestred in 2 decades MKg/ha
Forest	1156.73	770.38	Forest	478.18	318.47	451.91
Settlement with Vegetation	2660.62	228.81	Settlement with Vegetation	3451.15	296.80	-67.99
Jetty	27.53	2.367	Jetty	31.00	2.67	-0.30
Plantation	267.11	65.71	Plantation	88.14	21.68	44.03
Water Body	8.02	0.00	Water Body	8.03	0.00	0.00
Mangrove	25.81	0.90	Mangrove	7.24	0.25	0.65
			Tsunami- Created Wetlands	82.09	2.87	-2.87
Total	4145.82	1068.17	Total	4145.82	642.74	425.43

mangroves was observed due to the 2004 tsunami. Also, the down wrapping of landmass (82.09 ha), followed by permanent water-logging resulting in the formation of tsunami-created wetlands [35, 58, 59].

A sizeable amount of forest patch was present in ward no: 12, 16, 18 and revenue village (RV): 20, 21,22, 23, and 24 even after five years of the 6th May 1995 delimitation and the 2004 tsunami. Massive infrastructural growth was observed in PBMC coupled with 23rd April 2015 delimitation. The areal extent of the forest cover had shrunk considerably. It is imperative that the delimitation of the PBMC boundary resulted in the degradation of the land. The implications of land degradation are discussed below.

13.4.2 Quantification of Surface Runoff

The implementation of the climatic water balance model by [37] in the research area articulates that more than 60% (Table 13.3) of precipitation enters the sea as runoff [59]. The increased runoff is influenced by factors such as undulating topography, high-intensity tropical rains, low infiltration rate, climate change, and land degradation in the study area. In fact, alteration in the LULC, especially human settlement and related infrastructural development, is a key factor in the compaction of the sub-surface resulting in increased surface runoff, decreased infiltration, and accelerated soil erosion [6, 60]. Also, high-intensity tropical rains have inadequate capacity to infiltrate into the sub-surface regime [61]. It is imperative that the delimitation of the PBMC boundary resulted in decreased forest cover and accelerated runoff (Figure 13.4).

13.4.3 Quantification of Soil Erosion

During the pre-tsunami period majority of the PBMC encountered low soil erosion ranging from zero to 32 tonnes$ha^{-1}yr^{-1}$. However, after the 2004 tsunami and subsequent delimitation on 23rd April 2015 resulted in infrastructural developments on the steep slopes resulting in increased soil erosion [6, 60], especially in the recently annexed revenue villages (RV19 to RV24). Moderate (32 to 101 tonnes ha^{-1} yr^{-1}) to high (>101 tonnes ha^{-1} yr^{-1}) soil erosion was encountered in revenue villages annexed to PBMC wards (ward no: 19 to 24). Also, denudation of forest cover increased the risk of accelerated soil erosion [6]. The eroded materials were escorted to the adjacent sea through the streams rendering poor coastal water quality, eutrophication, drop in dissolved oxygen, etc. [1, 2, 6, 7]. Increased activity

Table 13.3 Year-wise breakup of hydro-meteorological water balance.

Year	Rainfall	PET (%)	Soil moisture (%)	Runoff (%)
	all values in mm & in brackets percentage			
2000	3756.60	1103.98 (29.39)	137.17 (12.42)	2515.45 (66.96)
2001	3776.30	1048.48 (27.76)	116.17 (11.08)	2611.65 (69.16)
2002	3783.70	1065.40 (28.16)	87.40 (8.2)	2630.90 (69.53)
2003	3783.70	1090.91 (28.83)	58.04 (5.32)	2634.74 (69.63)
2004	3816.70	1132.26 (29.67)	48.92 (4.32)	2635.51 (69.05)
2005	3321.30	1057.17 (31.83)	-67.79 (-6.41)	2331.92 (70.21)
2006	3305.90	1101.09 (33.31)	0.00 (0.00)	2204.81 (66.69)
2007	3029.80	1070.97 (35.35)	0.00 (0.00)	1958.83 (64.65)
2008	3109.60	1136.45 (36.55)	0.00 (0.00)	1973.15 (63.45)
2009	3273.40	1165.95 (35.62)	0.00 (0.00)	2107.45 (64.38)
2010	3437.40	1171.57 (34.08)	0.00 (0.00)	2265.83 (65.92)
2011	3647.00	1179.95 (32.35)	4.17 (0.35)	2462.87 (67.53)
2012	3204.00	1051.10 (32.81)	0.00 (0.00)	2152.91 (67.19)
2013	3190.70	1109.64 (34.78)	-9.84 (-0.89)	2090.90 (65.53)
2014	3183.40	1115.35 (35.04)	-10.46 (-0.94)	2078.50 (65.29)
2015	3183.40	1113.93 (34.99)	-6.55 (-0.59)	2076.02 (65.21)
2016	3203.60	1127.27 (35.19)	0.80 (0.07)	2075.53 (64.79)
2017	3169.90	1127.17 (35.56)	-32.71(-2.9)	2075.43 (65.47)
2018	3037.60	1094.11 (36.02)	0.00 (0.00)	1943.49 (63.98)
2019	3223.90	1160.15 (35.99)	0.00 (0.00)	2063.75 (64.01)
2020	2948.50	1081.26 (36.67)	0.00 (0.00)	1867.24 (63.33)

of soil erosion was observed during the southwest monsoon followed by the northeast monsoon because of high-intensity tropical precipitation. Further, deforestation on the slopes resulted in shallow landslides during tropical hydro-meteorological events [15, 51]. The pre and post tsunami soil erosion is been depicted in Figure 13.5.

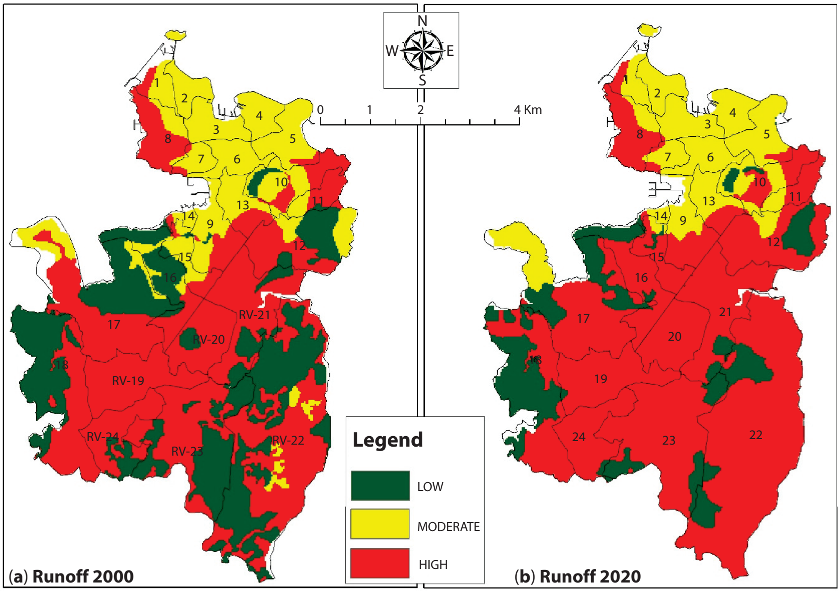

Figure 13.4 Pre- and post-tsunami surface runoff in PBMC.

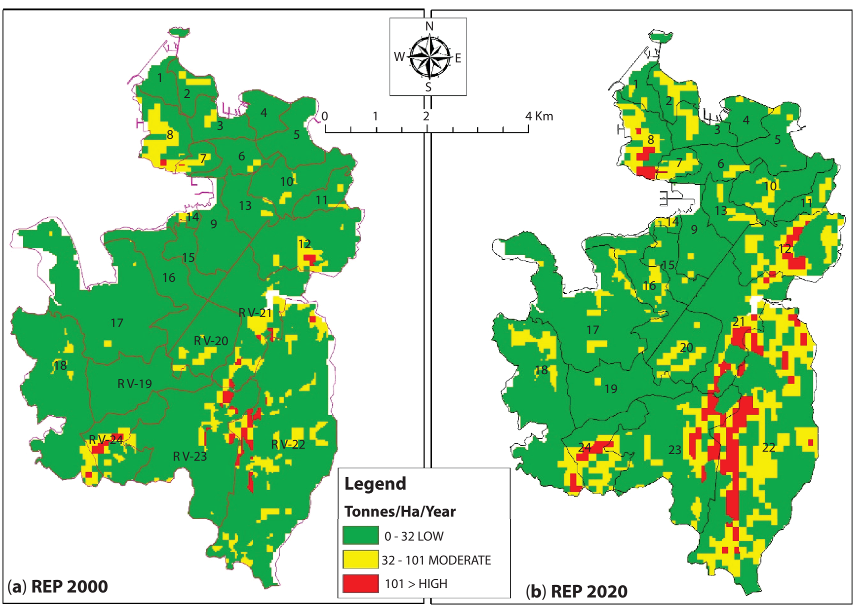

Figure 13.5 Pre- and post-tsunami soil erosion potential in PBMC.

13.4.4 Demarcation of Shallow Landslide Hazard Zonation

Landslides are caused by intricate interactions between a huge number of partially linked objects. These traits are divided into two groups: (1) quasi-static (preparatory) variables comprising the slope, soil characteristics, altitude, aspect, LULC, lithology, drainage density, etc., and (2) activating parameters like sesmic activity and intense rainfall [16, 51]. The distribution of the overall threat rating was used to create a landslide hazard zone. The threat rating ranged from 5 to 14. Thus, the threat rating was classified as low, moderate and high ranged as 5-8, 9-11, and 12-14 respecively. The results suggest that around 71% of the PBMC is not susceptible to landslides, while 19% and 10% of the study area are susceptible to moderate and high risk of landslides. Also, on-the-ground verification suggests that the bulk of the human populace lives in moderate to high-risk zones. Furthermore, historic landslides were documented in the high-risk zones (Figure 13.6) either during the southwest monsoon or the northeast

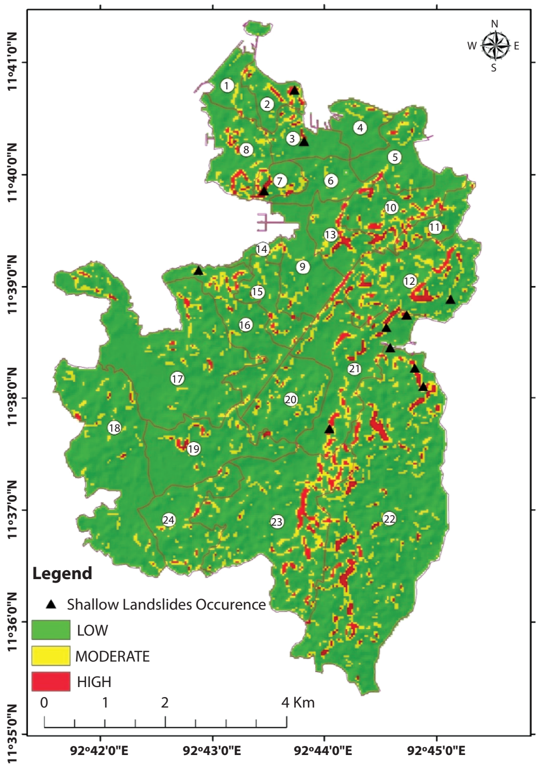

Figure 13.6 Shallow landslides vulnerable zones of PBMC.

monsoon, indicating that the triggering agent of shallow landslides in the probe area is due to intense tropical hydro-meteorological events [15, 16, 51].

13.4.5 Quantification of Carbon Sequestration

Carbon store is a widely used ecosystem health indicator in response to climate change [62, 63], and it was quantified using the most trustworthy InVEST model [64, 65]. Through this model, the total carbon stored in various land-use classes was estimated to be 1068.17 MKg/ha and 642.74 MKg/ha for the years 2000 and 2020 respectively. The amount of carbon sequestered in two decades accounts to be 425.43 MKg/ha. This quantum of carbon sequestration can be attributed to land degradation (Table 13.2).

13.4.6 Quantification of Land Surface Temperature

Urbanization is required for the world's fast-rising population to achieve a higher level of living standards. The primary effect of urbanization is a change in LULC, alteration in topography (landfilling or land cutting), and deforestation that encourages an increase in land surface temperature [20, 21, 66–70]. A comparison of pre- and post-tsunami LULC (Table 13.2 and Figure 13.3) articulates that human settlement has increased at the cost of degradation of forests and plantations in the study area. That is, 1156.73 ha of forest during pre-tsunami (2000) has reduced to 478.18 ha (post-tsunami, 2020). Similarly, the areal extent of plantation is reduced to 88.14 ha (2020) from 267.11 ha (2000). In contrast, human settlement has increased from 2660.62 ha (2000) to 3451.15 ha (2020). It is imperative that human settlement imparted huge pressure on the green zones like forests and plantations, resulting in an increase in LST [66]. Urbanization occurs at every nook and corner of PBMC as a result of human settlements, commercial establishments, job oppurtinities, thorough connectivity, all forms of services, mainly higher educational facilities, etc. [20, 21]. The quantified LST from 2000 and 2020 Landsat satellite data indicated that the temperature was 29.8°C and 30.6°C respectively. The satellite image quantified LST is at par with surface temperature data of PBMC for 2000 (29.93°C) and 2020 (30.77°C) which are taken from the Directorate of Economics and Statistics (http://andssw1.and.nic.in/ecostat/index.php). Thus, in a span of two decades, the LST has increased by 0.8°C.

13.5 Conclusion

The aim of the current investigation was well realized through the application of different models on geospatial platform. It was understood from the study that land degradation (alteration in the LULC) is the key factor having diverse implications for the past twenty years. This involves increased surface runoff, soil erosion, shallow landslides, and LST considerably in the past twenty years. In contrast, a decrease in the carbon store and increase in the carbon sequestration has not only increased the LST but also can have serious implications over the regional and global climate regime. The geospatial technologies not only aid in assessing the land degradation but also its implications effectively as well. Furthermore, the geospatial technologies are a candid tool for monitoring and predicting land degradation and its impacts commendably as well. PBMC is experiencing vertical expansion because of the paucity of land surfaces for horizontal expansion.

References

1. Jiang, C., Zhang, H., Zhao, L., Yang, Z., Wang, X., Yang, L., Wen, M., Geng, S., Zeng, Q., & Wang, J., Unfolding the effectiveness of ecological restoration programs in combating land degradation: Achievements, causes, and implications. *Science of the Total Environment*, 748, 141552, 2020. https://doi.org/10.1016/j.scitotenv.2020.141552
2. Nzuza, P., Ramoelo, A., Odindi, J., Kahinda, M., & Madonsela, S., Predicting land degradation using Sentinel-2 and environmental variables in the Lepellane catchment of the Greater Sekhukhune District, South Africa. *Physics and Chemistry of the Earth*, 2020https://doi.org/10.1016/j.pce.2020.102931
3. United Nations Convention to Combat Desertification (UNCCD). A Stronger UNCCD for a Land-Degradation Neutral World. Issue Brief, Bonn, Germany, 2013.
4. Kaushal, S., Gold, A., & Mayer, P., Land use, climate, and water resources-global stages of interaction. *Water*, 9, 815–825, 2017. https://doi.org/10.3390/w9100815
5. Kindu, M., Schneider, T., Döllerer, M., Teketay, D., & Knoke, T., Scenario modelling of land use/land cover changes in Munessa-Shashemene landscape of the Ethiopian highlands. *Science of the Total Environment*, 622, 534–546, 2018. https://doi.org/10.1016/j.scitotenv.2017.11.338
6. Degife, A., Worku, H., Gizaw, S., & Legesse, A., Land use land cover dynamics, its drivers and environmental implications in Lake Hawassa Watershed

of Ethiopia. *Remote Sensing Applications: Society and Environment*, 14, 178–190, 2019. https://doi.org/10.1016/j.rsase.2019.03.005

7. Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schuett, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L., & Panagos, P., An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8, 1–13, 2013.https://doi.org/10.1038/s41467-017-02142-7
8. Celentano, D., Rousseau, G.X., Engel, V.L., Zelarayan, M., Oliveira, E.C., Araujo, A.C.M., & de Moura, E.G., Degradation of riparian forest affects soil properties and ecosystem services provision in eastern Amazon of Brazil. *Land Degradation and Development*, 28, 482–493, 2017. https://doi.org/10.1002/ldr.2547
9. Duan, X., Bai, Z., Li, R., Li, Y., Ding, J., Tao, Y., Li, J., Li, J., & Wang, W., Investigation method for regional soil erosion based on the Chinese Soil Loss Equation and high resolution spatial data: case study on the mountainous Yunnan Province, China. *Catena*, 184, 104237, 2020.https://doi.org/10.1016/j.catena.2019.104237
10. Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M., Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem Services*, 28, 1–16, 2017. https://doi.org/10.1016/j.ecoser.2017.09.008
11. Yalew, S.G., Mul, M.L., van Griensven, A., Teferi, E., Priess, J., Schweitzer, C., & Zaag, V.D.P., Land-use change modelling in the upper Blue Nile basin. *Environments*, 3 (3), 21, 2016. https://doi.org/10.3390/environments3030021
12. Muyibul, Z., Xia, J., Muhtar, P., Shi, Q., & Zhang, R., Spatiotemporal changes of land use/cover from 1995 to 2015 in an oasis in the middle reaches of the Keriya River, southern Tarim Basin, Northwest China. *Catena*, 171, 416–425, 2018. https://doi.org/10.1016/j.catena.2018.07.038
13. Zhang, H., Fan, J., Cao, W., Warwick, H., Li, Y., Chi, W., & Wang, S., Response of wind erosion dynamics to climate change and human activity in Inner Mongolia, China during 1990 to 2015. *Science of the Total Environment*, 639, 1038–1050, 2018. https://doi.org/10.1016/j.scitotenv.2018.05.082
14. Toure, A.A., Tidjani, A.D., Rajot, J.L., Marticorena, B., Bergametti, G., Bouet, C., Ambouta, K.J.M., & Garba, Z., Dynamics of wind erosion and impact of vegetation cover and land use in the Sahel: a case study on sandy dunes in southeastern Niger. *Catena*, 177, 272–285, 2019. https://doi.org/10.1016/j.catena.2019.02.011
15. Shu, H., Hürlimann, M., Roberto, M-H., González, M., Pinyol, J., Abancó, C., & Ma, J., Relation between land cover and landslide susceptibility in Vald'Aran, Pyrenees (Spain): Historical aspects, present situation and forward prediction. *Science of the Total Environment*, 693, 133557, 2019. https://doi.org/10.1016/j.scitotenv.2019.07.363
16. Alsabhan, H.A., Singh, K., Sharma, A., Alam, S., Pandey, D.D., Rahman, S.A.S., Khursheed, A., & Munshi, M.F., Landslide susceptibility assessment

in the Himalayan range based along Kasauli – Parwanoo road corridor using weight of evidence, information value, and frequency ratio. *Journal of King Saud University – Science*, 34, 101759, 2022. https://doi.org/10.1016/j.jksus.2021.101759

17. Mizuta, K., Grunwald, S., Phillips, A.M., Moss, B.C., Bacon, R.A., & Cropper, Jr. P.W., Sensitivity assessment of metafrontier data envelopment analysis for soil carbon sequestration efficiency. *Ecological Indicators*, 125, 107602, 2021. https://doi.org/10.1016/j.ecolind.2021.107602
18. Bordoloi, R., Das, B., Tripathi, O.P., Sahoo, U.K., Nath, A.J., Deb, S., Das, D.J., Gupta, A., Devi, N.B., Charturvedi, S.S., Tiwari, B.K., Paul, A., & Tajo, L., Satellite based integrated approaches to modelling spatial carbon stock and carbon sequestration potential of different land uses of Northeast India. *Environmental and Sustainability Indicators*, 13, 100166, 2022. https://doi.org/10.1016/j.indic.2021.100166
19. Ghosh, S., Dinda, S., Chatterjee, D.N., Dutta, S., & Bera, D., Spatial-explicit carbon emission-sequestration balance estimation and evaluation of emission susceptible zones in an Easter Himalayan city using Pressure-Sensitivity-Resilience framework: An approach towards achieving low carbon cities. *Journal of Cleaner Production*, 336, 130417, 2022. https://doi.org/10.1016/j.jclepro.2022.130417
20. Das, S., & Angadi, P.D., Land use-land cover (LULC) transformation and its relation with land surface temperature changes: A case study of Barrackpore Subdivision, West Bengal, India. *Remote Sensing Applications: Society and Environment*, 19, 100322, 2022.https://doi.org/10.1016/j.rsase.2020.100322
21. Saha, S., Saha, A., Das, M., Saha, A., Sarkar, R., & Das, A., Analyzing spatial relationship between land use/land cover (LULC) and land surface temperature (LST) of three urban agglomerations (UAs) of Eastern India. *Remote Sensing Applications: Society and Environment*, 22, 100507, 2021.https://doi.org/10.1016/j.rsase.2021.100507
23. Chaplot, V., Evidences of plants' impact on land degradation and climate change: An urgent call for new multidisciplinary research. *Geoderma*, 392, 114984, 2021. https://doi.org/10.1016/j.geoderma.2021.114984
24. Hermans, K., & McLeman, R., Climate change, drought, land degradation and migration: exploring the linkages. *Current Opinion in Environmental Sustainability*, 2021. https://doi.org/10.1016/j.cosust.2021.04.013
25. Baroudy, E.A.A., Monitoring land degradation using remote sensing and GIS techniques in an area of the middle Nile Delta, Egypt. *Catena*, 87, 201–208, 2011. https://doi.org/10.1016/j.catena.2011.05.023.
26. Abdel Rahaman, E.A.M., Natarajan, A., Hegde, R., & Prakash, S.S., Assessment of land degradation using comprehensive geostatistical approach and remote sensing data in GIS-model builder. *Egyptian Journal of Remote Sensing and Space Sciences*, 2018. https://doi.org/10.1016/j.ejrs.2018.03.002
27. GPPB-179(a) C.C., Port Blair-22-8-1957, 1957.
28. MGPPB-18 Gztt/85-200., 30-4-1985, 1985.

29. Andaman and Nicobar Gazette, Extraordinary-92, 6-5-1995, 1995.
30. Andaman and Nicobar Gazette, Extraordinary-5-29/EC/A & N/2015, 23-4-2015, 2015.
31. Census of India, District census handbook Andaman & Nicobar Islands. Series 36, Part XII-A. 47pp. 2011.
32. Metrological Statistics, Directorate of economics and statistics. Andaman and Nicobar Administration Port Blair, 2021.
33. Goswami, P., Vinithkumar, N.V., & Dharani, G., First evidence of microplastics bioaccumulation by marine organisms in the Port Blair Bay, Andaman Islands. *Marine Pollution Bulletin*, 155, 2020.https://doi.org/10.1016/j.marpolbul.2020.111163
34. Ray, K.K., A review of the geology of Andaman and Nicobar Islands. *Geological Survey of India Miscellaneous Publications*, 41(2), 110–125. 1982.
35. Bandopadhyay, P.C., & Carter, A. (eds.), The Andaman–Nicobar Accretionary Ridge: Geology, Tectonics and Hazards. Geological Society, London, Memoirs, 47, 75–93, 2017.https://doi.org/10.1144/M47.6
35. Shankar, S.V., Purti, N., Singh, P.R., &Khudsar, A.F., Secondary Ecological Succession of Mangrove in the 2004 Tsunami Created Wetlands of South Andaman, India. In *Mangrove Ecosystem Restoration*, Sahadev Sharma (Eds.) Intecopen, 2020. http://dx.doi.org/10.5772/intechopen.94113
36. NBSS & LUP, Soil resource atlas Andaman Nicobar Islands. Directorate of Agriculture Andaman and Nicobar Administration, 1991.
37. Thorntwaite, C. W., & Mather, J. R., Instructions and tables for computing potential evapotranspiration and the water balance.*Publication in Climatology*, 10(3), 185–243, 1957.
38. McFeeters, S.K., The use of normalised difference water index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7), 1425–1432, 1996. https://doi.org/10.1080/01431169608948714
39. Zha, Y., Gao, J., & Ni, S., Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, 24(3), 583–594, 2003. https://doi.org/10.1080/01431160304987
40. Xu, H., Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27, 3025–3033, 2006. https://doi.org/10.1080/01431160600589179
41. Townshend, J.R., & Justice, C.O., Analysis of the dynamics of African vegetation using the normalized difference vegetation index. *International Journal of Remote Sensing*, 7(11), 1435–1445, 2007. https://doi.org/10.1080/01431168608948946
42. Lacaux, J.P., Tourre, Y.M., Vignolles, C., Ndione, J.A., &Lafaye, M., Classification of ponds from high-spatial resolution remote sensing: application to Rift Valley fever epidemics in Senegal. *Remote Sensing of Environment*, 106(1), 66–74, 2007. https://doi.org/10.1016/j.rse.2006.07.012
43. Mathobo, R., Marais, D., & Steyn, M.J., Calibration and validation of the SWB model for dry beans (*Phaseolus vulgaris* L.) at different drought stress

levels. *Agricultural Water Management*, 202, 113–121, 2018. https://doi.org/10.1016/j.agwat.2018.02.018

44. Msigwa, A., Komakech, C.H., Salvadore, E., Seyoum, S., Mul, L.M., & Griensven, V.A., Comparison of blue and green water fluxes for different land use classes in a semi-arid cultivated catchment using remote sensing. *Journal of Hydrology: Regional Studies*, 36, 100860, 2021. https://doi.org/10.1016/j.ejrh.2021.100860
45. Wang, Z., Wu,Y., Cao,Q., Shen,Y., & Zhang, B., Modeling the coupling processes of evapotranspiration and soil water balance in agroforestry systems. *Agricultural Water Management*, 250, 106839, 2021. https://doi.org/10.1016/j.agwat.2021.106839
46. Ganeshamurthy, A.N., Dinesh, R., Ravisankar, N., Nair, A.K., & Ahlawat, S.P.S., Land resources of Andaman and Nicobar islands. CARI publication, pp. 59, 2000.
47. Cronshey, R., McCuen, R., Miller, N., Rawls, W., Robbins, S., & Woodward, D., *Urban Hydrology for Small Watersheds*. TR-55 (2nd ed.): U.S. Dept. of Agriculture, Soil Conservation Service, Engineering Division, Technical Release 55 Washington, D.C., 64, 1986.
48. National Resources Conservation Service (NRCS), "Hydrologic soil groups", Chapter 7 in *National Engineering Handbook*, section 4, Hydrology: U.S. Department of Agriculture, Soil Conservation Service, 14 p., 2007.
49. Renard, K.G., Foster G.R., Weesies, G.A., & Porter, J.P., RUSLE: Revised universal soil loss equation. *Journal of Soil Water Conservation*, 46(1), 30–33, 1991.
50. Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C., Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation. U.S. Department of Agriculture, *Agriculture Handbook*. 703, 384, 1997.
51. Shankar, S., & Dharanirajan., Shallow landslides around Port Blair, Andaman, India using multi-variant geospatial analysis techniques. *Indian Journal of Geo-Marine Sciences*, 44(8), 1162-1170, 2015.
52. Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., Chaumont, N., Denu, D., Fisher, D., Glowinski, K., Griffin, R., Guannel, G., Guerry, A., Johnson, J., Hamel, P., Kennedy, C., Kim, C.K., Lacayo, M., Lonsdorf, E., Mandle, L., Rogers, L., Silver, J., Toft, J., Verutes, G., Vogl, A. L., Wood, S., & Wyatt, K., InVEST 3.10.2.post23+ug.g8cec8a3.d20220311 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund, 2020.
53. Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., & Wagner, F., Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme and Institute for Global Environmental Strategies, Kanagawa, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents, 2003.

54. Intergovernmental Panel on Climate Change (IPCC). "IPCC Guidelines for National Greenhouse Gas Inventories". Volume 4: Agriculture, Forestry and Other Land Use, 2006.
55. Dwivedi, A., & Khire, M., Application of Split-Window Algorithm to Study Urban Heat Island Effect in Mumbai through Land Surface Temperature Approach. *Sustainable Cities and Society*. 2018. https://doi.org/10.1016/j.scs.2018.02.030
56. Meng, X., Cheng, J., Zhao, S., Liu, S., & Yao, Y., Estimating land surface temperature from landsat-8 data using the NOAA JPSS enterprise algorithm. *Remote Sensing*, 11(155), 1–18, 2019. https://doi.org/10.3390/rs11020155
57. Wang, S., Ma, Q., Ding, H., & Liang, H., Detection of urban expansion and land surface temperature change using multi-temporal landsat images. *Resource Conservation and Recycling*, 1–9, 2016. https://doi.org/10.1016/j.resconrec.2016.05.011
58. Shankar, S. V., Narshimulu, G., Kaviarasan, T., Narayani, S., Dharanirajan, K., James, R.A., & Singh, R.P., 2004 Post Tsunami Resilience and Recolonization of Mangroves in South Andaman, India. Wetlands, 2019. https://doi.org/10.1007/s13157-019-01211-5
59. Shiva Shankar, V., Purti, N., Ganta, N., Mandal, K.K., Singh, R.P., Kaviarasan, T., Satyakeerthy, T.R., & Jacob, S., Assessment of the hydrological and erosive status of South Andaman's watersheds using drainage morphometric studies and climatic water balance model. *Geocarto International*, 2022.https://doi.org/10.1080/10106049.2022.2076927
60. Rahman, A.E.A.M., Natarajan, A., Srinivasamurthy, Hegde, R., Estimating soil fertility status in physically degraded land using GIS and remote sensing techniques in Chamarajanagar district, Karnataka, India. *Egyptian Journal of Remote Sensing and Space*, 2016. http://dx.doi.org/10.1016/j.ejrs.2015.12.002
61. Shiva Shankar, V., Dharanirajan, K., & Manoharan, K.,Quantification of Hydro-meteorological balance around Port Blair, South Andaman, India, using Soil Water Balance Model. *Indian Journal of Geo Marine Sciences*, 47(02), 456–463, 2018.
62. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, p. 112829, Elsevier, 2021. https://doi.org/10.1016/j.jenvman.2021.112829
63. Khan, N., Jhariya, M.K., Raj, A., Banerjee, A. & Meena, R.S., Soil Carbon Stock and Sequestration: Implications for Climate Change Adaptation and Mitigation. In: M.K. Jhariya et al. (eds.), *Ecological Intensification of Natural Resources for Sustainable Agriculture*, Springer, pp. 461–489, 2021 https://doi.org/10.1007/978-981-33-4203-3_13
64. Liang, Y., Hashimoto, S., & Liu, L., Integrated assessment of land-use/land-cover dynamics on carbon storage services in the Loess Plateau of China from 1995 to 2050. *Ecological Indicators*, 120, 106939, 2021. https://doi.org/10.1016/j.ecolind.2020.106939

65. Adelisardou, F., Zhao, W., Chow, R., Medlerly, P., Minkina, T., & Schou, J.S. "Spatiotemporal change detection of carbon storage and sequestration in an arid ecosystem by integrating Google Earth Engine and InVEST (the Jiroft plain, Iran)". *International Journal of Environmental Science and Technology*, 2021. https://doi.org/10.1007/s13762-021-03676-6
66. Chen, Y.C., Chiu, H.W., Su, Y.F., Wu, Y.C., & Cheng, K.S., Does urbanization increase diurnal land surface temperature variation? Evidence and implications. *Landscape and Urban Planning*, 157, 247–258, 2017.
67. Yang, J., Sun, J., Ge, Q., & Li, X., Assessing the impacts of urbanization-associated green space on urban land surface temperature: a case study of Dalian, China. *Urban Forestry & Urban Greening*, 22, 1–10, 2017.
68. Tayyebi, A., Shafizadeh-Moghadam, H., & Tayyebi, A.H., Analyzing long-term spatio-temporal patterns of land surface temperature in response to rapid urbanization in the mega-city of Tehran. *Land Use Policy*, 71, 459–469, 2018.
69. Fonseka, H.P.U., Zhang, H., Sun, Y., Su, H., Lin, H., & Lin, Y., Urbanization and its impacts on land surface temperature in Colombo metropolitan area, Sri Lanka, from 1988 to 2016. *Remote Sensing*, 11 (8), 957, 2019.
70. Guha, S., Govil, H., Gill, N., & Dey, A., A long-term seasonal analysis on the relationship between LST and NDBI using Landsat data. *Quaternary International*, 2020. https://doi.org/10.1016/j.quaint.2020.06.041

14

Acacia nilotica: A Promising Species for Soil Sustainability

Annpurna Devi[1], Manoj Kumar Jhariya[1*], Abhishek Raj[2], Arnab Banerjee[3], Krishan Pal Singh[4] and Beena Singh[5]

[1]Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[2]Pt. Deendayal Upadhyay College of Horticulture & Forestry, Dr. Rajendra Prasad Central Agriculture University, Pusa, Samastipur, Bihar, India
[3]Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur (C.G.), India
[4]College of Horticulture and Research Station, IGKV, Bastar, India
[5]S.G. College of Agriculture and Research Station, IGKV, Bastar, India

Abstract
Leguminous species is considered as one of the most important sources of biological nitrogen (N) fixation into the soil. This species has multifarious importance due to its diverse nature of utilization both in tangible and intangible forms. *Acacia nilotica* (L.) willd. Ex. Del (Babool) is an N-fixing multipurpose legume plant that is distributed in Asia, Africa, South America, Australia and Mexico. It is a complex species with nine varieties/subspecies, of which the majority (six) of species are native to tropics of African region and the remaining (three) species are native to India. *A. nilotica* is considered as an important economic species as it provides tannins, gums, fodder, wood and medicinal importance besides its biological N-fixing ability. Due to its hardy nature and wider adaptation range it can be utilized under agroforestry system towards the rehabilitation and restoration of drylands, wasteland and degraded lands along with the agricultural productivity.

***Keywords*:** Agroforestry, biological nitrogen fixation, restoration, soil health, sustainability

**Corresponding author*: manu9589@gmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (339–354) © 2023 Scrivener Publishing LLC

14.1 Introduction

Land degradation is a serious problem across the globe which affects agroecosystems, forest ecosystems and associated ecosystems to a greater extent. Land is degrading day by day due to faulty and unscientific farming practices, production technology and human interference which not only affect food security but also accelerate the various forms of footprints (land, water, carbon, etc.) in the ecosystem and environment. This changing scenario needs prior attention towards proper planning and management towards sustainability and sustainable development.

Under the scenario of land degradation, a scientific farming system that incorporates various stratified crops, vegetation and plant species can be a suitable option to fulfill the food requirement as well as sustainability. In this perspective, use of MPTs (multipurpose tree species) especially leguminous in nature can serve as a natural engineer of soil developments through biological nitrogen (N) fixation. Babool (*Acacia nilotica*) or Kikar or Indian gum Arabic tree is found throughout the African and South Asian regions and is commonly found in the dry parts of India, Iran, Pakistan, Iraq, etc. In Australia, South America and Mexico this species was introduced [1]. It grows naturally and also has been widely planted by farmers in Asian countries like Bangladesh, Pakistan and India and in semi-arid to arid zones globally. Babool has an important place in traditional agroforestry due to its multiple benefits and being hardy in nature as well as the fact that it can withstand waterlogging conditions in rice fields and provide fuel, fodder, timber, gums, etc. [2].

In an Indian context, nearly one-fifth of the total area is under wasteland. The increasing pressure on the natural forest stand has depleted the vegetal cover across the country to a significant level which leads to soil degradation and increases the land degradation scenario. In the Indian condition, soil is deficient in N reserve and other essential elements. Therefore, there is a need to explore the more potential and economic efficient practices and technology that can help towards stabilization, recovery and restoration of land degradation. In this perspective, *A. nilotica* seems to be promising and an important choice of species among the leguminous plants due to its fast-growing traits, adaptability, drought resistance capability, N fixing potential and multipurpose nature. This is a well-known species in the Indian condition and many authors have reported that it has good N fixation that enriches the soil N [3], thus it is mostly utilized in agroforestry, farm forestry and wasteland development programs. This chapter explores the *A. nilotica* role in land restoration, recovery, reclamation and management leading towards sustainable utilization of land resources.

14.2 Habitat, Distribution and Ecology

The species *A. nilotica* is distributed naturally and widely in drier belts of Africa, India, Burma, Egypt, Sri Lanka, Senegal, Arabia and Asian subcontinents. In India, the species is mostly distributed throughout the Sind tracts. Besides this, it appears in farmlands, agricultural lands, wastelands, roadsides and grazing lands, etc. *A. nilotica* seedlings, tree on field bunds and *Acacia* tree during flowering are depicted in Figure 14.1. Mostly Babool trees are found in isolated manner and rarely in contagious or clumped and a limited distribution in the forests. This is mostly planted in the farming lands in the plains of India.

The southern tropical thorn forest and southern tropical dry deciduous forest reflects its distribution in India [4]. It can resist severe temperature of >50°C and drought, and it grows in tropical to subtropical climatic conditions that receive rainfall from 250-1500 mm. The ecological implication of Babool is towards degraded land reclamation and it grows well in riverain alluvial, saline, alkaline, calcareous pans and black soils [5].

***Acacia* seedlings**

***Acacia* tree** ***Acacia* tree during flowering**

Figure 14.1 *Acacia nilotica* - seedlings, tree on field bunds and *Acacia* tree during flowering.

14.3 *Acacia nilotica*–Based Agroforestry

Agroforestry is the practice of integrating the crops with the forest tree species along with the domestic animal production in the same unit of the land. This promotes on-farm and off-farm tree production that leads to efficient natural resources utilization, management and sustainable production system with an eco-friendly approach [6–8]. *A. nilotica* is a component of the traditional agroforestry system in India and is prevalent in the central part of India. It boosts agricultural productivity and soil sustainability due to its leguminous nature and adds the N into the soil system through biological N-fixation process. *A. nilotica* seems to be the most potential species under traditional agroforestry in Chhattisgarh, due to its hardy nature and higher acclimatization potential under diverse environmental conditions providing various diversified agri-based products [9].

The productivity of the soil is the major concern of modern times due to the process of land degradation, deterioration of soil health and quality through biotic interferences. This leads to a focus on the judicious approach to the farming system that can accelerate productivity as well as the recovery of soil health and quality. In this perspective, the incorporation of leguminous trees in agroforestry systems seems to be promising and soil N can be managed efficiently through the biological N-fixation process. *A. nilotica* can play an important role due to rapid growth traits, resistance to drought, and multipurpose N-fixing. Due to these characteristics babool can be efficiently utilized as a component of agroforestry as well as utilizing the wastelands through diversified process and production potential which can fulfill the current needs and future demands of fuel, fodder, fibre, timber and other non-timber produces and soil health through biological N-fixation. *A. nilotica* has positive impact over paddy cultivation in terms of nitrogen-fixing ability and enhancement in organic matter which makes it one of the most preferred species in rice bunds.

14.4 *Acacia nilotica* and Soil Sustainability

Various research reports reflect the positive influence of *A. nilotica* on the improvement of the quality of the soil as well lowering the erosion of top soil by precipitation which protects the enhancement of sand particle and improves the clay contents. The rhizosphere of babool tree is widely colonized by the *Rhizobium* which directly signifies the nodule formation that determines and helps towards N-fixation in the soil. Moreover, the

N-fixing bacteria also help stabilization of nutrients with the assemblage of mycorrhiza [10]. This leads to an improvement in the root potential to explore high soil volume and thus accelerates the utilization of available nutrients as well as unavailable form to available forms. *A. nilotica* contributes towards restoration and sustainable development of saline soils due to its tolerant potential (moderate level, ECe 15-25 dS/m) [11]. Generally, the plant species was selected for land reclamation, short rotation forestry, as bio-drainage because the annual water use by *A. nilotica* was 1248 mm on a severely saline site and 2225 mm on a moderately saline site [12]. It is reported that babool tree improves the soil characteristics as well as fertility through N-fixation, nutrient loading, rhizosphere biology, litterfall, improvement in soil biota which lead to enhance the nutrient cycling that protect the soil from degradation [13].

Acacia species also have positive effects on soil conductivity and promote root growth for succeeding plants in any degraded land areas [14]. This species also enhances nutrient pools in the soils under any dry or saline conditions [15]. It also helps in the restoration of wastelands where the erosion through water is more and it helps in the stabilization of ravines as well as protecting and checking the development of the gullies which degrade the lands. The Multiple benefits of *Acacia nilotica* towards soil and environmental sustainability is depicted in Figure 14.2 [16].

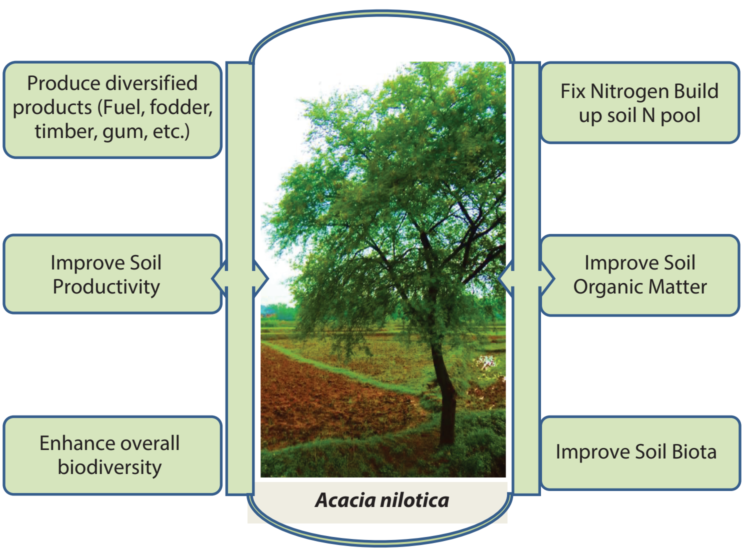

Figure 14.2 Multiple benefits of *Acacia nilotica* towards soil and environmental sustainability [16].

14.5 *Acacia* and its Role in Soil Carbon Sequestration

C storage and sequestration is a very important process for ensuring a climate resilient ecosystem [17, 18]. Many tree species in forest or any farming system have capacity to sequester atmospheric carbon and store it in the form of biomass and maintain carbon storage and flux for a long time in the ecosystem [19, 20]. Leguminous trees have great potential to store carbon in plant parts and soils as SOC pools. This species enriches soil quality by enhancing nutrient status and carbon pool into the terrestrial soil ecosystem. *Acacia nilotica* not only maintains nitrogen status but also improves soil carbon pools through greater potential of carbon sequestration process. This process helps in biomass production (fuelwood, timber and NTFPs) and mitigating C footprints and climate change. *Acacia nilotica* is a leguminous tree and integral component of many farming systems. This tree shed foliage on floor which decomposed and mixed with soil to maintain soil carbon status. As per Jhariya *et al.* [21] *Acacia nilotica* tree has potential to fix 228.4 kg/tree biomass carbon that further mixed with soil and enhanced SOC pool for better soil fertility. Similarly, legume trees have higher potential of carbon sequestration as compared to non-leguminous plants [22, 23]. *Acacia nilotica, Cassia siamia* and *Dalbergia sissoo* have greater potential to C sequestration as compared to *Tectona grandis* which is a non-leguminous tree species in the red laterite soil of Chhattisgarh, India [24].

Several authors have studied the integration of *Acacia* tree with other plants and their impacts on soil health and carbon pools. These integrated systems are greatly helpful in eco-restoration of degraded land through better soil carbon pools and related services. The integration of *Acacia nilotica* with other tree species (*Leucaena leucocephala, Ficus infecroria* and *Morus alba*) and grasses (*Panicum maximum*, *Cenchrus ciliaris* and *Chrysopogon sp.)* was helpful in eco-restoration of degraded land through better SOC pool by carbon sequestration process in the Bundelkhand region of India. These processes not only help in land and soil restoration but also check C footprint and climate change mitigation for sustainable environment. SOC pools were reported higher under an Acacia-based integrated system which becomes an effective tool for degraded land restoration in the tropical regions [25]. Similarly, integrating *Acacia nilotica* with Shisham (*Dalbergia sissoo)* tree is viable for land restoration program under social forestry scheme of the Haryana region, India. Approx. 32.8 and 8.5 Mg/ha of carbon pool have been reported in above and below ground in this region. A total 111.7 Mg/ha of carbon was reported in the depth of one meter of soil which comprises 95.9 and 15.7 Mg/ha of organic and inorganic carbon pool, respectively. Thus, not only a single *Acacia* tree but their integration with other plants is also helpful in maintaining SOC pools (through C sequestration) which ensure eco-restoration of land and mitigate climate change problems [26].

14.6 *Acacia nilotica*: A Promising N_2 Fixing Tree

Acacia nilotica is a promising nitrogen-fixing tree which integrates in any agroecosystem and restores degraded land. This has a fast-growing nature and great potential to fix atmospheric nitrogen into the soil. This species withstands drought condition and provides timber, fuelwood and NTFPs including gum which is highly valuable in the market [16, 27]. *Acacia nilotica*–based agroforestry system is recommended in wasteland for restoring land quality and soil fertility due to its N_2 fixing in nature. It enhances organic carbon and nitrogen status into the soil in the paddy cultivation [9]. This species has strong preference over biological nitrogen fixation. A symbiotic relationship exists between *Rhizobium* species and the root system of the babul. *Rhizobium* bacteria species initiates the formation of the root nodule in the babul tree which promotes BNF mechanism under nutrient (nitrogen) deficient areas. However, *Rhizobium* species execute a key role in greater ecological function by root nodules formation which enhances nutrient absorption rate, especially phosphorus under stress condition. However, fewer studies are available on *Acacia nilotica* and its significant effects on variation of the soil structure and quality. This legume species has greater significant effect on nitrate mobilization which is highly reported in this babul-soil based ecosystem [28, 29]. Moreover, combination of *Acacia nilotica* (babul) and *Prosopis julifiora* has significant effects on soil by increasing nitrogen status under Indian perspective [30]. Similarly, *Acacia* species promotes eco-restoration of the degraded land by enhancing nitrogen content in the surrounding vegetation, which helps in increasing horizontal structure of vegetation and its shading [31, 32].

14.7 *Acacia*: A Promising Tool for Land Restoration

The genus *Acacia* has many different species which are distributed in a wide range of S.E. Asia, Australia and other island regions [33]. Moreover, many species of *Acacia* are considered as highly invasive in the world [34]. *Acacia* species is a fast-growing, multipurpose and nitrogen-fixing tree species which reverts degraded land into a sustainable land use system.

This species enriches soil quality and enhances SOC pool and nitrogen status that ensure ecosystem restoration of the degraded land and wasteland. However, this species is reported as highly invasive in another eco-region where it has been introduced other than the native region. This species has greatest potential to restore nutrient status and perform significant nutrient cycling in wasteland and highly degraded areas. *Acacia* species enrich nitrogen status and soil carbon accretion in unfertile or unproductive land [34]. This species has potential to change the ecosystem by greater role of nitrogen fixation and organic carbon accumulation into the soil that ensure land health and quality [35, 36]. Other than babul, several other species of Australian *Acacia* have potential for biodiversity restoration and its conservation in degraded land. Also, it has potential to enhance nutrient cycling and nutrient restoration in degraded and wasteland [37]. Similarly, *Acacia mangium* has great potential to degraded land rehabilitation, soil fertility enhancement and ecosystem restoration [38]. This species provides approximately 190 kg of nitrogen per hectare annually along with 12 tons of dry litters, which is quietly helpful in restoration of degraded land in the region of Brazil [39]. Similarly, growth parameter of *Acacia nilotica* and some other leguminous trees are changed on the degraded land. Growth attributes of some leguminous tree species in alkaline soil environment in India is depicted in Table 14.1 [40, 41].

Table 14.1 Growth attributes of some leguminous tree species in alkaline soil environment in India [40, 41].

Species	**Survival (%)**	**Height (m)**	**Diameter (cm)**	**Dry biomass (t ha^{-1})**	**Plantation age**
Acacia nilotica	76.7-81.7	2.31-3.66	6.4-8.6	39.09-69.78	7
Acacia leucophloea	45.3-59.3	1.77-2.24	4.7-4.8	-	
Dalbergia sissoo	83.5-86.3	1.87-1.99	5.3-6.1	1.18-1.75	
Pithecellobium dulce	69.7-86.7	1.62-1.70	4.2-5.4	2.14-3.96	
Prosopis juliflora	86.0-97.4	2.59-3.98	5.3-8.3	22.06-51.27	
Parkinsonia aculeata	76.7-80.3	1.89-2.36	3.3-4.1	0.90-1.15	
Tamarindus indica	15.3-26.5	1.29-1.30	3.6-4.1	-	

14.8 *Acacia* and Its Other Sustainability Roles

Legumes play the greatest role in soil and environment health through restoration of degraded land. A legume towards soil quality, health and sustainability is depicted in Figure 14.3 [21, 42, 43].

Moreover, legume play an important role in maintaining carbon and nitrogen budgeting for ensuring ecosystem health and environmental sustainability [44]. The babul tree is also known for providing various services in a sustainable manner to resource-poor farming community through supply of various non-timber forest products besides the agricultural crops and timber. These facilitate livelihood opportunity through gum production which has diverse use in various industries such as paper, pharmaceutical, tannins, printing, clothe and textile, etc., and provides a good source of fuelwood production in the tropics. Its flowers attract the honeybee and can make a good base for beekeeping. The fruits (pods) are edible, nutritious and make good-quality fodder for domestic animals especially in lean periods when green fodder becomes limited or unavailable. Plants are also known to have medicinal value and are utilized for various purposes [1].

Besides N-fixing ability and potential, the species is also reported for the higher C sequestration potential among various legumes and nonlegume

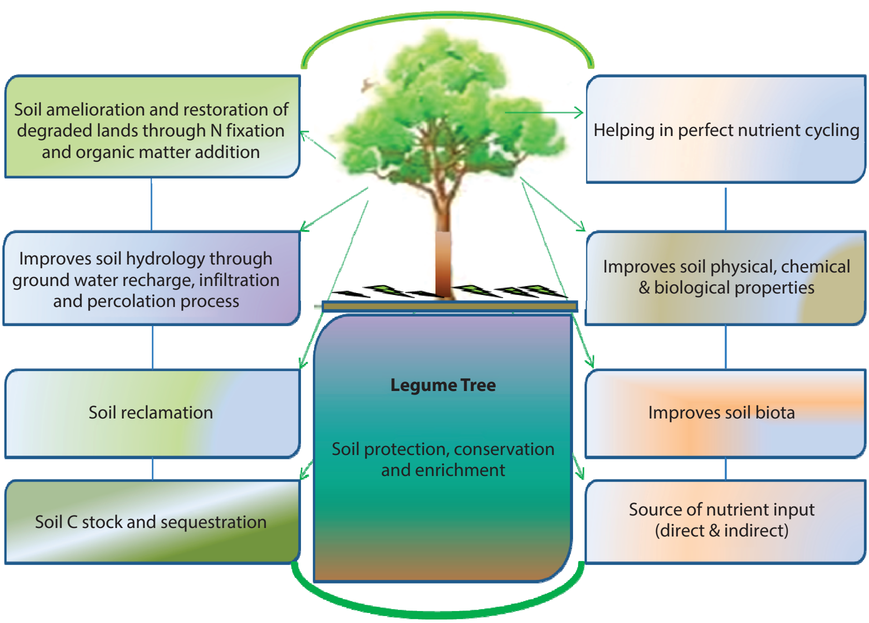

Figure 14.3 Legumes towards soil quality, health and sustainability [21, 42, 43].

species. It can add significant biomass C in the plant-soil systems. Besides, it has some allelopathic ability which performs as natural herbicide and is used as biological weed control [45]. The babool tree can produce 167 ton/hectare of wood at rotation period that have about 45 m^3 marketable wood [46]. Moreover, a single 15-year-old tree has a market value of Rs. 1,000 or 30,000-90,000 per hectare [46]. In India, babul is used for the rehabilitation of the Chambal ravines (over 50,000) for restoring soil health and inhibiting further land degradation [47].

14.9 Policy and Future Roadmap

Acacia nilotica is a leguminous and multipurpose tree species which is an integral component of forest plantation, agroforestry and any other sustainable land use system. This species provides several tangible (fuel wood & NTFPs) and intangible services and maintains fertility through land restoration program. However, this species becomes invasive to most regions of the world and also affects land quality and fertility. Integration of leguminous tree species in forestry and agriculture practices ensures ecosystem health and environmental sustainability [48]. This species also checks climate change by capturing atmospheric carbon through C sequestration process. Thus, *Acacia* and other leguminous MPTs-based plantation in any land use system (forestry and agroforestry) is involved in resource conservation, climate change mitigation, agro-ecosystem management and environmental services [49–51]. A policy must be framed for promotion of *Acacia* plantation for utilizing multifarious benefits including ecological stability. *Acacia* tree involved in C storage, biomass production, soil fertility enhancement, soil enrichment, maintenance of soil nitrogen and carbon pools which is amongst its great environmental services. A future roadmap design for promotion of *Acacia* plantations in any degraded and poor land areas also helps in restoring ecosystem and delivering several environmental services in sustainable ways. Scientific research and sound technology are needed for *Acacia* plantation to ensure soil and climate security.

14.10 Conclusions

Acacia nilotica (babul) is a multipurpose legume and drought tolerant characteristic having the inherent potential for rehabilitation and restoration of degraded soils. It helps to build up soil N and organic carbon that ameliorate the soil quality and health. It is a widely used species in the traditional agroforestry system in the central part of India. This species sequesters atmospheric carbon and stores into the tree parts and soil as SOC pool that helps in mitigating C footprint and climate change issues. Moreover, enhancing SOC status and nitrogen content improve soil health and quality. *Acacia* species rehabilitate degraded land by ecosystem restoration through greater C sequestration capacity. Thus, an effective policy and technological intervention are needed for promotion of *Acacia* plantation in degraded land that would enhance biodiversity and promise soil and climate security in sustainable ways.

References

1. Schmidt, L.H. & Mbora, A., *Acacia nilotica* (L.) Del. *Seed Leaflet*, 137, 1-2, 2008.
2. Pandey, C.B., *Acacia nilotica* based traditional Agroforestry system in central India. In: C.B. Pandey and Chaturvedi, O.P. (Eds.), *Agroforestry Systems and Prospects* (pp. 93-114), New India Publishing Agency, New Delhi, India, 2014.
3. Toky, O.P., Beniwal, R.S. & Sharma, P.K., Interaction between Rhizobium inoculation and nitrogen fertilizer application on growth and nodulation of *Acacia nilotica* subsp. *indica. J. Arid Environ.* 27, 49-54, 1994.
4. Champion, H.G. & Seth, S.K., *A revised survey of the forest types of India*. The manager Govt of India press Nasik, 1968.
5. Shetty, K.A.B., Social forestry in Tamil Nadu. *Indian Farming,* 26, 82, 1977.
6. Raj, A., Jhariya, M. K., Yadav, D. K., Banerjee, A. & Meena, R. S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (Eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore Pte Ltd. 2019. ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4
7. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
8. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., Sustainable Intensification for Agroecosystem Services and Management. Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
9. Jhariya, M.K., Bargali, S.S. & Raj, A., *Possibilities and Perspectives of Agroforestry in Chhattisgarh*, pp. 237-257. In: *Precious Forests-Precious Earth*, edited by Miodrag Zlatic (Ed.). ISBN: 978-953-51-2175-6, 286 p., 2015. InTech, Croatia, Europe, DOI: 10.5772/60841.

10. Kaushik, J.C. & Mandal, B.S., The role of mycorrhiza in stress management for seedling growth of *Dalbergia sissoo* and *Acacia nilotica*. *Bull NIE*, 15, 133-137, 2005.
11. Das, C.J., Sarangi, A., Singh, A.K., Dahiya, S., Bio-drainage: an alternate drainage technique to control waterlogging and salinity. *Journal of Soil and Water Conservation*,. 4(3&4), 149-155, 2005.
12. Patra, S.K. & Banik, M., Bioremediation of waterlogging and soil salinity for sustainability of agriculture: Problems and prospects. *International Journal of Multidisciplinary Research and Development*, 5(1), 144-152, 2018.
13. Pandey, C.B., Singh, A.K. & Sharma, D.K., Soil properties under *Acacia nilotica* trees in a traditional agroforestry system in Central India. *Agroforestry Systems*, 49, 53-61, 2000.
14. Yunusa, I.A.M., Mele, P.M., Rab, M.A., Schefe, C.R. & Beverly, C.R., Priming of soil structural and hydrological properties by native woody species, annual crops, and a permanent pasture. *Austral J Soil Res*, 40, 207-219, 2002.
15. Zuzana, M. & Ward, D., *Acacia* trees as keystone species in Negev desert ecosystems. *J Veget Sci*, 13, 227-236, 2002.
16. Raj, A. & Jhariya, M.K., Effect of environmental variables on *Acacia* gum production in the tropics of Chhattisgarh, India. *Environment, Development & Sustainability*, 24(5), 6435-6448, 2021a. https://doi.org/10.1007/s10668-021-01709-1
17. Raj, A. & Jhariya, M.K., Sustainable agriculture with agroforestry: adoption to climate change. In: P. Suresh Kumar, Manish Kanwat, P.D. Meena, Vinod Kumar and Rajesh A. Alone, editors. *Climate Change and Sustainable Agrculture*. New India Publishing Agency (NIPA), New Delhi, 2017. ISBN No. 9789-3855-1672-6, pp. 287-294.
18. Raj, A., Jhariya, M.K. & Bargali, S.S., Climate Smart Agriculture and Carbon Sequestration. In: C.B. Pandey, Mahesh Kumar Gaur and R.K. Goyal, editors. *Climate Change and Agroforestry*. New India Publishing Agency, New Delhi, India. pp. 1-19, 2017.
19. Raj, A. & Jhariya, M.K., Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. *Journal of Environmental Management*, 293, 112829, 2021b. Elsevier. https://doi.org/10.1016/j.jenvman.2021.112829
20. Raj, A. & Jhariya, M.K., Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. *Landscape and Ecological Engineering*, 17(1): 1-13, 2021c. https://doi.org/10.1007/s11355-021-00450-1
21. Jhariya, M.K., Banerjee, A., Yadav, D.K. & Raj, A., Leguminous Trees an Innovative tool for soil sustainability. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), *Legumes for soil sustainable management,* Springer Nature Singapore Pte Ltd. 2018. ISBN 978-981-13-0253-4; pp. 315-345. https://link.springer.com/chapter/10.1007/978-981-13-0253-4_10

22. Bilyaminu, H. & Wani, A.M., Carbon sequestration potential of different tree species in Allahabad, Uttar Pradesh. *International Journal of Farm Sciences*, 6(2),153-158, 2016.
23. Deka, M., Wani, A.M. & Hussain, M., Assessment of carbon sequestration of different trees species grown under agroforestry system. *Journal of Advances in Environmental Sciences* 1(4), 149-153, 2016.
24. Dhruw, S.K., Singh, L. & Singh, A.K., Storage and Sequestration of Carbon by Leguminous and Non-leguminous Trees on Red Lateritic Soil of Chhattisgarh. *Indian Forester*, 135(4), 531-538, 2009.
25. Ghosh, A., Kumar, R.V., Manna, M.C., Singh, A.K., Parihar, C.M., Kumar, S., Roy, A.K. and Koli, P., 2021. Eco-restoration of degraded lands through trees and grasses improves soil carbon sequestration and biological activity in tropical climates. *Ecological Engineering*, *162*, p.106176.
26. Arora, P. & Chaudhry, S., Vegetation and soil carbon pools of mixed plantation of *Acacia nilotica* and *Dalbergia sissoo* under social forestry scheme in Kurukshetra, India. *J. Mater. Environ. Sci*, *8*, 4565-4572, 2017.
27. Raj, A. & Singh, L., Effects of girth class, injury and seasons on Ethephon induced gum exudation in *Acacia nilotica* in Chhattisgarh. *Indian Journal of Agroforestry*, 19(1), 36-41, 2017.
28. Drury, C.F., Stone, J.A. & Findlay, W.I., Microbial biomass and soil structure associated with corn, grasses and legumes. *Soil Sci Soc Am J*, 55, 805-811, 1991.
29. Holtham, D.A.L., Matthews, G.P. & Scholefield D., Measurement and simulation of void structure and hydraulic changes caused by root-induced soil structuring under white clover compared to ryegrass. *Geoderma,* 142, 142-151, 2007.
30. Garg, V.K. & Jam, R.K., Influence of fuelwood trees on sodic soils. *Canadian Journal of Forest Research*, 22, 729-735, 1992.
31. Lehmann, J.R., Prinz, T., Ziller, S.R., Thiele, J., Heringer, G. & Meira-Neto, J.A., Open-Source processing and analysis of aerial imagery acquired with a low-cost Unmanned Aerial System to support invasive plant management. *Frontiers of Environmental Science*, 5, 2017. https://doi.org/10.3389/fenvs.2017.00044
32. Heringer, G., Thiele, J., Meira-Neto, J.A.A. & Neri, A.V., Biological invasion threatens the sandy-savanna mussununga ecosystem in the Brazilian Atlantic Forest. *Biological Invasions*, 21(6), 2045-2057, 2019. https://doi.org/10.1007/s10530-019-01955-5
33. Murphy, D.J., A review of the classification of the Acacia (Leguminosae, Mimosoideae). *Muelleria*, 26, 10-26, 2008.
34. Koutika, L.-S. & Richardson, D. M., *Acacia mangium* Willd: benefits and threats associated with its increasing use around the world. *Forest Ecosystems*, 6(2), 1–13, 2019. https://doi.org/10.1186/s4066 3-019-0159-1

35. Le Maitre, D.C., Gaertner, M., Marchante, E., Ens, E.J., Holmes, P.M. & Pauchard, A., Impacts of invasive Australian acacias: implications for management and restoration. Diversity and Distributions, 17(5), 1015-1029, 2011. https://doi. org/10.1111/j.1472-4642.2011.00816.x
36. Hellmann, C., Große-Stoltenberg, A., Thiele, J., Oldeland, J. & Werner, C., Heterogeneous environments shape invader impacts: Integrating environmental, structural and functional effects by isoscapes and remote sensing. *Scientific Reports*, 7, 4118, 2017. https://doi. org/10.1038/s41598-017-04480-4
37. Machado, M.R., Camara, R., Sampaio, P.T.B., Pereira, M.G. & Silva Ferraz, J.B., Land cover changes affect soil chemical attributes in the Brazilian Amazon. *Acta Sci-Agron,* 39(3), 385–391, 2017. https://doi.org/10.4025/actasciagron.v39i3.32689
38. Permadi, D.B., Burtona, M., Pandita, R., Walker, I. & Race, D., Which smallholders are willing to adopt *Acacia mangium* under long-term contracts? Evidence from a choice experiment study in Indonesia. *Land Use Policy,* 65, 211-223, 2017.
39. Franco, A.A. & de Faria, S.M., The contribution of N2-fixing tree legumes to land reclamation and sustainability in the tropics. *Soil Biol Biochem*, 29, 897-903, 1997.
40. Dagar, J.C. & Tomar, O.S., Utilization of salt affected soils and poor quality waters for sustainable biosaline agriculture in arid and semiarid regions of India. In: 12th ISCO conference, 8 pp., 2002.
41. Dagar, J.C., Sharma, H.B. & Shukla, Y.K., Raised and sunken bed technique for agroforestry on alkali soils of northwest India. *Land Degradation & Development*, 12(2), 107-118, 2001.
42. Meena, R.S., Das, A., Yadav, G.S. & Lal, R. eds., *Legumes for soil health and sustainable management*, p. 541, 2018. Singapore: Springer.
43. Kumawat, A., Bamboriya, S.D., Meena, R.S., Yadav, D., Kumar, A., Kumar, S., Raj, A. & Pradhan, G., Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 307-328, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00005-7
44. Meena, R.S., Kumawat, A., Kumar, S., Prasad, S.K., Pradhan, G., Jhariya, M.K., Banerjee, A. & Raj, A., Effect of legumes on nitrogen economy and budgeting in South Asia. In: R.S. Meena and Sandeep Kumar (Eds.). *Advances in Legumes for Sustainable Intensification,* 1st Edition, Elsevier Inc., pp. 619-638, 2022. eBook ISBN: 9780323886000. https://doi.org/10.1016/B978-0-323-85797-0.00001-X
45. Li., S.Y. & Wang, Y.F., Allelopathic potential of *Acacia confuse* and related species in Taiwan. *J. Chem. Ecol*, 24, 2131-2150, 1998.
46. Pandey C.B. & Sharma, D.K., Ecology of *Acacia nilotica* based traditional agroforestry system in Central India. *Bull. NIE,* 15, 109-116, 2005.

47. Bargali, K. & Bargali, S.S., *Acacia nilotica*: a multipurpose leguminous plant. *Nat Sci*, 7(4), 11-19, 2009.
48. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., Sustainable Agriculture, Forest and Environmental Management. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019a. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
49. Jhariya, M.K., Yadav, D.K. & Banerjee, A., Agroforestry and Climate Change: Issues and Challenges. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group. ISBN: 978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book), pp. 335, 2019b. https://doi.org/10.1201/9780429057274
50. Jhariya, M.K., Meena, R.S. & Banerjee, A., *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore. eISBN: 978-981-334-203-3, Hardcover ISBN: 978-981-334-206-6, pp. 655, 2021. Doi: 10.1007/978-981-33-4203-3.
51. Jhariya, M.K., Meena, R.S., Banerjee, A. & Meena, S.N., *Natural Resources Conservation and Advances for Sustainability*. Elsevier, Academic Press. ISBN: 9780128229767, pp. 650, 2022. https://doi.org/10.1016/C2019-0-03763-6

15

Farmland Evaluation to Stimulate the Rational Land Use and Soil Quality Enhancement: The Ukrainian Case

Inna Koblianska* and Olha Kovalova

Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine

Abstract

Preservation of soil fertility is an urgent current global problem and will continue to be so in the future. This is a crucial factor influencing the ability to achieve food security goals, overcome hunger, and achieve sustainability targets. Various mechanisms are suggested to be developed and implemented to stimulate sound land use practices, and economic ones are judged the most desirable. Developed market relations and fair farmland pricing are among the leading economic tools in this context. With 32.8 million ha of arable agricultural land, Ukraine, transforming the farmland relation system towards market mode, represents an excellent case to explore the elaboration of a fair, environmentally friendly approach for farmland pricing regulations. This chapter explains the overall conditions (starting points) for the development of the land market in Ukraine development with an emphasis on the environmental consequences of the Moratorium on farmland sales and the current state of agriculture development. This paper proposes the farmland value assessment approach by analysing the evolution of farmland valuation regulatory requirements in Ukraine and their compliance with current economic conditions and soil protection objectives. The suggested method is based on rental income calculations, assessment of the standard land use income gained due to compliance with crop rotation requirements, revision of capitalisation rate, and consideration of land plot distance to socioeconomic infrastructure. The obtained results complement the existing proposals for land valuation, stimulating the sound land use practices. They can also serve as a guide for regions experiencing the transformation of the farmland ownership system.

**Corresponding author*: koblianska@protonmail.com

Abhishek Raj, Manoj Kumar Jhariya, Arnab Banerjee, Sharad Nema, and Kiran Bargali (eds.)
Land and Environmental Management through Forestry, (355–370) © 2023 Scrivener Publishing LLC

Keywords**:** Farmland valuation, rental income, farmland price, soil fertility, crop rotation

15.1 Introduction

Land and its fertility are the main resources and assets in agriculture. This implies the need to value land like any other asset and moreover, the assetization of land is a way toward rural poverty alleviation [1]. Given that agricultural land totals 41.3 million hectares (68.4% of Ukraine's territory, as of January 1, 2020) of which 32.8 hectares are arable lands [2], the fair land valuation becomes a crucial issue under the launch of land reform, i.e., the transition from the moratorium on selling agricultural lands to the land market. It is worth saying that land value becomes a critical point in deciding about land sales or leases for 6.9 million landowners (16% of the country's population as of mid-2017) being hostage to the moratorium [3]. That is why the land value and conditions of its sale are such important social issues also. Moreover, the use of appropriate and fair land valuation methods is of paramount importance amidst the reform of power decentralisation launching in Ukraine. Agricultural land value affects the local budgets' inflows (this is the main income source for rural communities' budgets) and so, the development capacities of local communities and, consequently, the reform success. Transformation of land relations towards market mode opens new opportunities for rural revitalization and the realisation of the success story depends on the state's role in this process, regulations development, fairness and relevance of farmland value estimates [4]. The modern agricultural land's economic valuation method needs to be more reliable, and scientifically sound, simultaneously ensuring efficient ownership. The latter involves not only the achievement of short-term profits but rather guaranteeing land rational use and soil fertility increase in the long run [5]. Nowadays, soil restoration is one of the most important tasks of humanity, and the success of this task resolution determines the success in achieving the goals of sustainable development [6–9]. The land market is one of the tools to stimulate sustainable agriculture practices, primarily through land pricing [10, 11]. This chapter explores the specifics of Ukrainian agriculture's past and current development trends influencing the land value and outlines the conceptual and methodological provisions for the procedure of normative monetary valuation of agricultural land to comply with land market transformation challenges and the need to increase soil fertility.

15.2 Moratorium on the Sale of Agricultural Land and Its Social, Ecological, and Economic Consequences in Ukraine

The transitional provisions of the Land Code of Ukraine adopted in 2001 [12] establish the Moratorium on the sale of agricultural land in Ukraine – the temporary solution to ensure proper protection of newly formed landowners during the formation of the institutional, legal, organisational, and economic environment necessary for the full realisation of acquired rights in a market economy. Consequently, this temporary moratorium lasted for 20 years until the Law "On Amendments to Certain Legislative Acts of Ukraine on the Conditions of Agricultural Land Market" [13] introduced the land market launching on July 1, 2021. In view of the Moratorium duration and land question's social significance, this was a historic moment. Overall, the moratorium resulted in the establishment of a rental land use system distinctive as follows [14, 15]:

- An alternativeless model of land management for the landowner;
- landowner's full dependence on tenant and failure to exercise the property rights in full;
- land user's dictation concerning the lease terms;
- low efficiency of agricultural commodity production and low investment attractiveness, resulting in a lack of financial resources for production development, technical re-equipment, and renewal; for measures aimed at rationalising the land use;
- low rent;
- the spread of shadow land sales schemes;
- decrease of land value from the owner's viewpoint.

The system of rental land relations—formed following the moratorium—had catastrophic consequences for land use and soil health in Ukraine. The reduction of agricultural land area amounted to 326.3 thousand ha, a third of which was transformed into a building land; there was a reduction in the area of fallows, pastures and perennial crops, i.e., lands contributing to the soil's fertility and being of ecological importance. All that took place during the moratorium, meaning that the latter led to the formation of a land use system contradicting the principles of rational land use, preservation of natural resources and public and private property. As a result, the problem of agricultural land's deterioration has significantly deepened: soils have lost much of their humus, and the world's most fertile chernozems have become medium-fertile soils continuing to deteriorate. The main problems of soil health have only been exacerbated: dehumidification, erosion spread, nutrients and microelements shortage, oxidation, and alkalinisation [15, 16]. In the circumstances, land market development requires elaboration of a fair and relevant land valuation approach allowing the consideration of existing soils' quality and stimulating measures for its enhancement. As the land value directly depends on the agriculture state and specifics, the next paragraph analyses the latest trends in Ukrainian agriculture development.

15.3 An Overview of Agriculture in Ukraine

According to information of the State Statistics Service of Ukraine [2, 17], in recent years there has been a marked tendency of technical crops' sown area to increase annually (Table 15.1) at the expense of areas under cereals and legumes, potatoes, vegetables and melons.

As can be observed, the share of sunflower—the most harmful crop for soil fertility—has increased by 2.2 percentage points over five years. Most notably, sunflower's share in the total sown area exceeds 20% each year, being inconsistent with the requirements of agronomic science concerning crop rotation.

Harmful to the soil quality, a reduction of fodder crops' share is also noticeable during the period analysed. The declining number of farm animals (of all species except for poultry) is the main reason for this (Table 15.2). The livestock decrease ranges from 9.1% (sheep and goats) to 19.1% (pigs) and results from high input costs (primarily for feed) and low prices for outputs.

The decrease in livestock and a related significant drop in the livestock industry affect the agriculture output structure in Ukraine (Figure 15.1). The share of livestock production continued to decline all years in a row to only 20.9% in 2019, which is 3.2 points lower than in 2015. The optimal structure of agricultural output, as it is known, presupposes equal shares of crop and livestock production. Thus, the existing pattern negatively affects soil fertility: firstly, the insufficient livestock development makes the application of enough organic fertilisers into soils impossible; secondly, the livestock decline causes forage crops' reduction, leading to optimal crop rotation's failure.

Disparities in the structure of agricultural output affect the value of land as the primary resource. Investigating the land value change in the organic agriculture transition context, Meng *et al.* [18] point out the need

Table 15.1 Sown area under agricultural crops in Ukraine (authors' compilation on [2, 17]).

Indicator	2015	2016	2017	2018	2019	Change from 2015 to 2019
Agricultural crops, total, thsd. ha	26902	27026	27585	27699	28001	1099.0
Share in total sown area, %:						
Grain and leguminous crops	54.8	53.3	53.0	53.6	54.7	-0.1
including maize for grain	15.3	15.9	16.4	16.5	17.9	2.6
Industrial crops	31.0	32.8	33.6	33.5	32.6	1.6
incl. sunflower	19.0	22.5	21.9	22.1	21.2	2.2
Potatoes, vegetables, and cucurbits crops	6.8	6.8	6.7	6.6	6.5	-0.3
Fodder crops	7.4	7.1	6.7	6.4	6.2	-1.3

Table 15.2 Number of agricultural animals, thousands heads (authors' compilation on [2, 17]).

Indicator	2015	2016	2017	2018	2019	2015 to 2019, %
Cattle	3750	3682	3531	3333	3092	82.5
incl. cows	2167	2109	2018	1919	1789	82.6
Pigs	7079	6669	6110	6025	5727	80.9
Sheep and goats	1325	1315	1309	1269	1205	90.9
Poultry, million heads	204,0	201,7	204,8	211,7	220,5	108.1

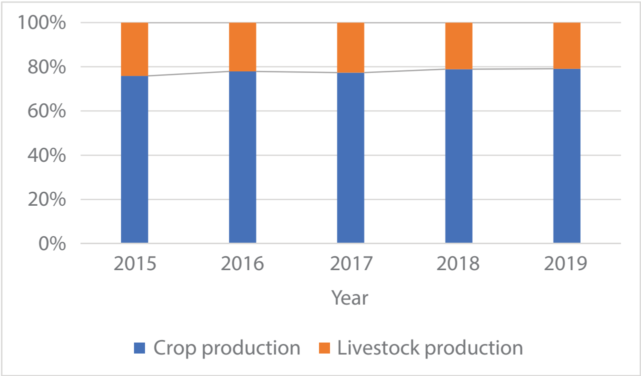

Figure 15.1 Agricultural output in Ukraine, % (authors' compilation on [2, 17]).

to consider the livestock industry's impact when assessing soil fertility. Scholars believe land will provide less income when used in organic farming than in the case of intensive agriculture. Hence, the former is accompanied by a land value decline.

15.4 Evolution of Monetary Valuation of Agricultural Land in Ukraine and Modern Challenges

The "Methodology of monetary evaluation of agricultural lands and lands in settlements" [19] first introduced the approach for agricultural land normative monetary valuation in 1995. Current regulation—approved by the Cabinet of Ministers of Ukraine in 2016 [20]—evidences a certain evolution of this approach. Both documents prescribe the use of a rent approach for land economic valuation in Ukraine. Although the last regulation (2016) is more consistent with the land relations market transformations, both documents have discussion issues. The first regulation fails to comply with the current socioeconomic conditions of the industry's development because of the use of outdated prices and capitalisation ratios. The regulation issued in 2016 ignores the land plot's location. Both methods fail to pay adequate attention to the promotion of rational land use and soil health preservation. The regulation of 1995 does not consider soil conditions in the land assessment procedure, while the last—the regulation of 2016—fails in stimulating rational land use.

Modern agriculture in Ukraine is mainly of intensive character involving monoculture production technologies accompanied by applying mineral fertilisers and chemical plant protection products. This affects soil quality and causes its changes. Intensive use of chemical fertilizers not only affects soil quality but also induces climate change and global environmental health [21–23]. Therefore, intensive agriculture and agricultural expansion destroy soil health and enhance land, energy and climate footprints [24, 25]. Given this, the regulation of 1995, applying the soil quality rating of 1993 as a basis for the normative land valuation, is outdated and does not correspond with the modern vision of soils' composition and fertility factors. In particular, Maurya *et al.* [26] suggest creating a minimum data set covering physical, chemical and biological parameters to assess soil quality being constantly affected by natural and anthropogenic factors.

Modern normative monetary land valuation approach should ensure the establishment of a fair price for land, allowing access to land resources to all agricultural producers (this is a universal problem relevant also to the United States [11, 27], for example). This fair price must reflect all qualitative land characteristics, including soil fertility, location, distance to large cities—centres of sales, and opportunity to use the land for different purposes. Sanz *et al.* [28] and Yagi H. and Garrod G. [29] mention the need to preserve agricultural lands located around cities, which is possible also with the land pricing mechanism. Establishing a fair price and its control is essential given that lower quality land can be sold at higher prices to be used for other purposes, i.e., decommissioning. Such an experience occurred in Slovakia [30].

Apart from land market establishment and development, preservation of soils from degradation and their restoration to expand the provision of ecosystem services are one of the main problems of land use globally. Applying sustainable intensification in farming system enhances soil fertility and restores land quality which ensures greater ecosystem services [31].

When applying principles of rational land use, soil fertility can increase, which can be judged as an ecosystem service delivered from land users to society. As for any services, the provision of ecosystem services must be paid for, for instance, through compensatory payments. These payments are an essential part of comprehensive soil management regulation and practice [32, 33]. They must go in line with land valuation, and increased soil fertility needs to be remunerated at higher rates [34]. Schild *et al.* [35] demonstrate that agricultural lands, providing additional ecosystem services measured via the variety of food produced, usually have a higher value. Due to this, scholars emphasise the need to consider ecosystem services while valuating the agricultural lands [35, 36]. At the same time, the existing methodological provisions for land valuation in Ukraine disregard the ecosystem services of agricultural land use and thus provide no incentive for soil and biodiversity protection and conservation.

15.5 Conceptual Provisions for the Assessment of Land Resources from the Standpoint of their Multifaceted Nature

Many factors affect the market price of agricultural land: soil physical characteristics, climate, land productivity, infrastructure availability, regional development scenarios, and investment [37]. Agricultural land could serve as a production resource (tool), an object of production, and a spatial basis for production development. When evaluating agricultural land, all characteristics contributing to such a multifaceted land nature need to be involved and assessed: soil's natural quality; features affecting the ease of cultivation; investment efficiency; location of the land plot (Figure 15.2).

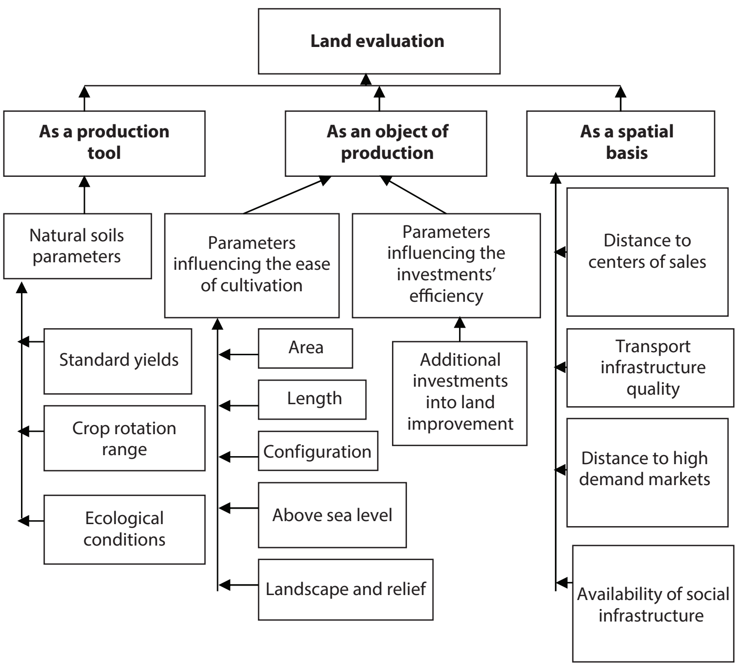

Figure 15.2 Three-dimensional views on the land: parameters to be accounted for when evaluating the land (Olha Kovalova's development).

The proposed concept models agricultural land as a multifaceted (three-dimensional) production factor. As a production tool, the land is affected by the natural qualities of the soil, determining a certain level of standard (biological) yield. Soil's natural qualities and the standard yield are, in turn, influenced by a crop rotation range to be followed in intensive agriculture mode. Therefore, we suggest considering the yield of a crop rotation range when evaluating the agricultural land. This will allow more accurate determination of the income gained from the land in the standard conditions, i.e., at the level of fertility caused by introducing the standard crop rotation range. Using a standard crop rotation set in the land evaluation will also help comply with the recommended crop range, ensuring the soil's quality preservation.

When assessing the land as an object of production, one should consider its properties affecting the ease of cultivation (area, configuration, landscape, etc.) and additional investment for soil fertility improvement. This will allow determining the income gained from the land more accurately.

The assessment of the land as a spatial basis for agriculture should consider the availability of infrastructure and logistics factors, such as the distance to the centres of sale and the quality of transport infrastructure affecting costs and, consequently, income. The distance to the high-demand markets affects the potential sales, influencing the land's income. The social infrastructure development provides for the availability of young, qualified personnel, controlling agricultural outputs and income. Thus, considering the above land characteristics offers a more objective valuation.

15.6 Development of a Methodology for the Normative Monetary Land Valuation to Stimulate Rational Land Use

Agriculture state and development directly affect the land value. Current trends in Ukrainian agriculture indicate the feasibility of using a crop rotation range, allowing the consideration of ecosystem services of agricultural land use instead of one group of crops (cereals, according to the regulations of 1995, 2016) when assessing agricultural land. This provides for the more accurate calculation of income gained from the land use and the preservation of soil fertility (when adopting the regulations on mandatory compliance with the recommended crop rotation set for land users). Madalla and Majule [38] note that cultivating profitable crops such as sunflower, corn, and sorghum significantly reduces soil fertility and, consequently, the land value. Other research [10] shows that in the intensive agriculture system, the primary value determinant is yield; however, accompanied by high greenhouse gas emissions. Given this, scholars try to find the right approach to involve environmental impact factors in decision-making [10]. In this context, using crop rotation range for land valuation allows finding the trade-offs between profitable crop production and soil fertility protection.

Using a standard crop rotation set for the normative monetary land valuation (with a constant review at the end of crop rotation duration) provides a more accurate land value calculation, including generated ecosystem services. Normative monetary value, calculated in this way, can be used to establish the scheme for paying fines for reducing fertility and compensation payments for increasing fertility. This goes in line with the Law of Ukraine "On Land Valuation," stating that the normative monetary land value is used "… for the development of indicators and mechanisms for economic incentives for rational use and land protection" [39].

We suggest the following steps for the development of a land evaluation methodological approach that would meet the conditions of the land market, agricultural production, and rational land use: 1) setting a basis for normative monetary land valuation, which should be a rental income; 2) calculation of a differential rental income in kind following the formula below. Like the idea of Sardaro *et al.* [10] to use implicit marginal prices to assess the environmental impact of land use, the difference between the income generated by soils of the best and worst quality is the main idea underlining the proposed approach (f.1.1).

$$R_d = \frac{\sum_{i=1}^{i=n} (SR_b - SR_w) P_{SR_i} P_{C_i}}{N} \qquad (15.1)$$

where R_d – differential rental income gained from one ha of arable land, uah/ha;

SR_b – soil quality rate for soils of the best quality, points;
SR_w – soil quality rate for soils of the worst quality, points;
P_{SRi} – price for one point of soil quality for the *i*-type crop;
P_{Ci} – sale price for the *i*-type crop from crop rotation range, uah/centner;
N – number of crops in the crop rotation.

The differential rental income is then used to determine the normative monetary land valueas follows (f. 1.2):

$$NLV = (R_d + R_a)\ T_c\ k_1\ k_2 * \ldots * k_n, \tag{15.2}$$

Where *NLV*– normative agricultural land value (for arable land), uah/ha;

R_a – absolute rental income gained from one ha of arable land, uah/ha;

T_c – capitalization period, years;

$k_1 \cdot k_2 \cdot \ldots \cdot k_n$– adjustment coefficients reflecting characteristics of the land as a spatial basis for agricultural production, according to Figure 15.1.

When calculating an absolute rental income, it is necessary to consider the data on state support of agriculture, including support for the livestock industry, and funds allocated to finance land protection measures. The total (absolute) rental income could be calculated based on the total estimates of the following costs: the lease payments, the amount of state-funded investments in agriculture; costs for the land management and land protection measures. The use of standard (biological) yield—which each type of soil provides due to fertility, rather than technology—underlies the calculation of revenue gained from the agricultural land.

To modernise the land evaluation approach, a review of the capitalization period is also needed. We suggest using a crop rotation duration of ten years as a capitalisation term. A new survey of soil quality and re-evaluation of land need to be conducted after this basic period. This period allows for timely review of land value estimates and to introduce a mechanism for land protection stimulation. This term corresponds to the Law of Ukraine "On Land Valuation" [39], according to which revaluation of land should be conducted every five or seven years. This approach will ensure that, first, the data of the normative monetary valuation of land will be constantly updated and correspond to modern realities; secondly, permanent soil monitoring made for land value reassessment at the end of crop rotation will stimulate the rational use and soil preservation practices implementation. The following mechanisms could be developed based on the proposed approach for land evaluation to enable rational land use: 1) control over crop rotation due to the frequency of evaluation; 2) fines (compensations) for changes in fertility.

To consider the availability of infrastructure and logistics factors when evaluating the land, we propose to add coefficients reflecting the characteristics of the land as a spatial basis for agricultural production: 1) distance to the centres of sale; 2) quality of transport infrastructure; 3) distance to the high-demand market; 4) social infrastructure development. Use of these coefficients will make it possible to adjust the normative monetary value according to the location conditions.

Further improvement (adjustment) of normative monetary valuation of agricultural land requires conducting modern soil quality grading based on an agrochemical survey of soils to determine the content of nutrients, trace elements, and pollutants. The development of mechanisms to stimulate rational land use and soil protection based on normative monetary valuation of agricultural land is another urgent issue.

15.7 Conclusion

A brief overview of the socio-ecological and economic consequences of the moratorium on the sale of agricultural land, designed to protect the interests of landowners in Ukraine, showed significant deterioration in soil quality, and exacerbation of problems in the field of agricultural land use. Against the background of the dominance of intensive agricultural production and the growing focus of producers to produce profitable crops, reducing livestock (and, accordingly, the quantity of organic fertilizers), a further deterioration of soil quality is observed. In these conditions, when transitioning to the land market, it is important to provide such regulatory tools that would stimulate rational land use, protection, and preservation of soils. Economic incentives, through the farmland pricing mechanism, are expected to be the most efficient.

Existing regulations of determining the normative monetary value of farmland in Ukraine are not perfect both in terms of matching the modern economic conditions and from the standpoint of incorporating the full range of functions performed by land resources in agriculture.

We propose an approach to the normative monetary valuation of farmland based on the consideration of the multifunctionality of land resources and the assessment of results that can be achieved following the recommended crop rotation set. The proposed method is built on the assessment of differential and absolute rental income gained due to compliance with the recommended crop rotation range, addressing of farmland's spatial parameters, and revision of the capitalization rate, which will allow periodic and timely monitoring of land use and revaluation of assets. In addition, when calculating income, it is also proposed to account for the land resources improvement costs, which will further encourage land users to make such investments.

This study reveals the problematic aspect of introducing market relations in the field of farmland use and deepens the existing approaches in farmland valuation to incentivise the best practices of land management. Those issues are relevant in a global context due to the need to protect biodiversity and soils, ensure food security, and achieve sustainable development targets. Farmland value determines the affordability of food in the long run and constitutes a sustainability concern: on the one hand, lower farmland price means lower food prices, and on the other hand, it means farmers' income decline and higher risks of losing soil fertility. A fair, scientifically sound, and environmentally friendly farmland pricing mechanism could allow finding the trade-offs. This chapter is an attempt to propose such an approach for arable land. The following research issues could constitute future studies in this field: valuation of other types of agricultural lands and lands in settlements; assessment of ecosystem services in agriculture and rural tourism; rethinking of taxation schemes to stimulate environmental-friendly land use practices.

References

1. Guo, Yu., & Liu, Ya., Poverty alleviation through land assetization and its implications for rural revitalization in China, *Land Use Policy*, 105, 105418, 2021. https://doi.org/10.1016/j.landusepol.2021.105418
2. SSSU, Ukraine in figures 2020. Statistical yearbook. State Statistics Service of Ukraine, Kyiv, Ukraine, 2021. http://www.ukrstat.gov.ua
3. StateGeoCadastre, The review of land relations in Ukraine. (2017). Vol. February 27. State Service of Ukraine for Geodesy, Cartography and Cadastre. 2017. https://land.gov.ua/wp-content/uploads/2017/03/Land-Review-Monthly_3_final-1.pdf
4. Kan, K., Creating land markets for rural revitalization: Land transfer, property rights and gentrification in China, *Journal of Rural Studies*, 81, 68-77, 2021. https://doi.org/10.1016/j.jrurstud.2020.08.006
5. Kobe, I.H., Olamide, O.E., Bamidele, F.S., Benedict, A.T., Yemisi, B.K. & Kamal, D.A., Economic Assessment of Agricultural Land Market in Rural Nigeria: Pattern and Drivers, *Journal of Land and Rural Studies*, *6*(1), 1-17, 2018. https// doi.org/10.1177/2321024917732889
6. Abhilash, P.C., Restoring the Unrestored: Strategies for Restoring Global Land during the UN Decade on Ecosystem Restoration (UN-DER), *Land*, 10, 201, 2021. https://doi.org/10.3390/land10020201

7. Koblianska, I., Pasko, O., Hordiyenko, M. & Yarova, I., Are peasant households policy wise feasible? The debate on the future of semi-subsistence households in Ukraine, *Eastern European Countryside*, 26(1), 127-179, 2020. DOI: https://doi.org/10.12775/eec.2020.006
8. Koblianska, I., Kalachevska, L. & Grenz, J., Biodiversity Mainstreaming Call or Fall? Evidence of Strategic and Agriculture-Specific Policy in Ukraine, *Ecology, environment and conservation,* 27(4), 1581-1594, 2021. http://www.envirobiotechjournals.com/article_abstract.php?aid=12042&iid=342&jid=3
9. Wentland, S.A., Ancona, Z.H, Bagstad, K.J., Boyd, J., Hass, J.L., Gindelsky, M. & Moulton, J.G., Accounting for land in the United States: Integrating physical land cover, land use, and monetary valuation, *Ecosystem Services,* 46, 101178, 2020. https://doi.org/10.1016/j.ecoser.2020.101178
10. Sardaro, R., De Pascale, G., Ingrao, C. & Faccilongo, N., Latent relationships between environmental impacts of cultivation practices and land market: Evidences from a spatial quantile regression analysis in Italy, *Journal of Cleaner Production*, 279, 2021. https://doi.org/10.1016/j.jclepro.2020.123648
11. Edwards, W., Evaluating a Land Purchase Decision: Economic Analysis. 2015. Available at: https://www.extension.iastate.edu/agdm/wholefarm/html/c2-76.html
12. Land Code of Ukraine: the Law of Ukraine of 25.10.2001 № 2768-III. The Verkhovna Rada of Ukraine. https://zakon.rada.gov.ua/laws/show/2768-14#Text
13. On Amendments to Certain Legislative Acts of Ukraine on the Conditions of Agricultural Land Market: the Law of Ukraine. (2020). The Verkhovna Rada of Ukraine. Available at: https://ips.ligazakon.net/document/view/T200552?an=71
14. Mishenin, Ye., Yarova, I. & Koblianska, I., Ecologically Harmonized Agricultural Management for Global Food Security. In Jhariya, M. K., Meena, R. S., Banerjee, A. (Eds.) 2021. *Ecological Intensification of Natural Resources for Sustainable Agriculture*. Springer Nature Singapore Pte Ltd, pp. 29-77. https://doi.org/10.1007/978-981-33-4203-3
15. Mishenin, Ye.V. & Koblianska, I.I., Social and economic aspects of Socioeconomic aspects of limiting the exercise of ownership of agricultural land in Ukraine, *Balanced Nature Use*, 1, 112–120, 2016.
16. Mishenin, Ye., Valentinov, V., Maslak, O. & Koblianska, I., Modern transformations in small-scale agricultural commodity production in Ukraine. *Marketing and management of innovations*, 4, 358-366, 2017. http://doi.org/10.21272/mmi.2017.4-32
17. SSSU, Ukraine in figures 2019. Statistical yearbook. State Statistics Service of Ukraine, Kyiv, Ukraine. 2020. http://www.ukrstat.gov.ua
18. Meng, F., Qiao, Y., Wu, W., Smith, P. & Scott, S., Environmental impacts and production performances of organic agriculture in China: A monetary valuation, *Journal of Environmental Management,* 188, 49-57, 2017. https://doi.org/10.1016/j.jenvman.2016.11.080
19. On the methodology of monetary evaluation of agricultural lands and lands in settlements. (1995). Resolution of the Cabinet of Ministers of Ukraine.

Cabinet of Ministers of Ukraine. Available at: http://zakon2.rada.gov.ua/laws/show/213-95-%D0%BF/ed20111031
20. On approval of the Methodology of normative monetary evaluation of agricultural lands. (2016). Cabinet of Ministers of Ukraine. Available at: http://zakon2.rada.gov.ua/laws/show/831-2016-%D0%BF/paran11#n11
21. Jhariya, M.K., Banerjee, A., Meena, R.S. & Yadav, D.K., *Sustainable Agriculture, Forest and Environmental Management*. Springer Nature Singapore Pte Ltd., 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore, pp. 606, 2019. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5. Doi: 10.1007/978-981-13-6830-1
22. Raj, A., Jhariya, M.K., Yadav, D.K., Banerjee, A. & Meena, R.S., Agroforestry: A Holistic Approach for Agricultural Sustainability. In: M. K. Jhariya *et al.* (eds.), *Sustainable Agriculture, Forest and Environmental Management*, Springer Nature Singapore Pte Ltd. 2019. ISBN ISBN 978-981-13-6829-5; pp. 101-131, 2019. https://doi.org/10.1007/978-981-13-6830-1_4
23. Raj, A., Jhariya, M.K., Yadav, D.K. & Banerjee, A., *Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies*. Apple Academic Press Inc., CRC Press - a Taylor and Francis Group, US & Canada. ISBN: 9781771888226, pp. 383, 2020. https://doi.org/10.1201/9780429286759
24. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Land Footprint Management and Policies. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021, ISBN 978-981-15-9495-3, pp. 221-246, 2021a. https://doi.org/10.1007/978-981-15-9496-0_7
25. Banerjee, A., Jhariya, M.K., Raj, A., Yadav, D.K., Khan, N. & Meena, R.S., Energy and Climate Footprint towards the Environmental Sustainability. In: A. Banerjee *et al.* (eds.), *Agroecological Footprints Management for Sustainable Food System*, Springer Nature Singapore Pte Ltd. 2021b, ISBN 978-981-15-9495-3, pp. 415-443, 2021b. https://doi.org/10.1007/978-981-15-9496-0_14
26. Maurya, S., Abraham, J.S., Somasundaram, S., Toteja, R., Gupta, R. & Makhija, S., Indicators for assessment of soil quality: a mini-review, *Environmental Monitoring and Assessment,* 192, 604, 2020. DOI: https://doi.org/10.1007/s10661-020-08556-z
27. Horst, M. & Gwin, L., Land access for direct market food farmers in Oregon, USA, *Land Use Policy*, 75, 594-611, 2018. DOI: https://doi.org/10.1016/j.landusepol.2018.01.018
28. Sanz Sanz, E., Martinetti, D. & Napoléone, C., Operational Modelling of Peri-Urban Farmland for Public Action in Mediterranean Context, *Land Use Policy*, 75, 757–771, 2018. DOI: https://doi.org/10.1016/j.landusepol.2018.04.003
29. Yagi, H. & Garrod, G., The future of agriculture in the shrinking suburbs: The impact of real estate income and housing costs, *Land Use Policy*, 76, 812-822, 2018. DOI: https://doi.org/10.1016/j.landusepol.2018.03.013
30. Lazíková, J., Rumanovská, Ľ., Takáč, I., Prus, P. & Fehér, A., Regional Differences of Agricultural Land Market in Slovakia: A Challenge for

Sustainable Agriculture, *Agriculture*, 11, 353, 2021. https://doi.org/10.3390/agriculture11040353

31. Jhariya, M.K., Banerjee, A., Meena, R.S., Kumar, S. & Raj, A., *Sustainable Intensification for Agroecosystem Services and Management*. Springer Singapore, pp. 748, 2021. eBook ISBN: 978-981-16-3207-5. DOI: 10.1007/978-981-16-3207-5. https://www.springer.com/gp/book/9789811632068
32. Bartkowski, B., Bartke, S., Helming, K., Paul, C., Techen, A. K. & Hansjürgens, B., Potential of the economic valuation of soil-based ecosystem services to inform sustainable soil management and policy, *PeerJ.* 8, e8749, 2020. https://doi.org/10.7717/peerj.8749
33. Holms, J., Arhipova, I., Tulbure, I. & Vitols, G., Ecosystem Provisioning Services Automated Valuation Process Model for Sustainable Land Management, *Procedia Computer Science*, 104, 65-72, 2017. https://doi.org/10.1016/j.procs.2017.01.063
34. Förster, J., Schmidt, S., Bartkowski, B., Lienhoop, N., Albert, C. & Wittmer, H., Incorporating environmental costs of ecosystem service loss in political decision making: A synthesis of monetary values for Germany, *PLoS ONE*, 14(2), e0211419, 2019. https://doi.org/10.1371/journal.pone.0211419
35. Schild, J.E.M., Vermaat, J.E., & van Bodegom, P.M., Differential effects of valuation method and ecosystem type on the monetary valuation of dryland ecosystem services: A quantitative analysis. *Journal of Arid Environments,* 159, 11-21, 2018. https://doi.org/10.1016/j.jaridenv.2017.09.001
36. Albert, C., Schröter-Schlaack, C., Hansjürgens, B., Dehnhardt, A., Döring, R., Job, H., Köppel, J., Krätzig, S., Matzdorf, B., Reutter, M., Schaltegger, S., Scholz, M., Siegmund-Schultze, M., Wiggering, H., Woltering, M. & von Haaren, C., An economic perspective on land use decisions in agricultural landscapes: Insights from the TEEB Germany Study, *Ecosystem Services*, 25, 69-78, 2017. https://doi.org/10.1016/j.ecoser.2017.03.020
37. Reydon, B.P., Plata, L.E.A., Sparovek, G., Goldszmidt, R.G.B. & Telles, T.S., Determination and forecast of agricultural land prices, *Nova Economia Belo Horizonte*, 24(2), 389-408, 2014. DOI: http://dx.doi.org/10.1590/0103-6351/1304
38. Madalla, N. & Majule, A., Economic Value of Agricultural Land for Community Livelihoods within the Context of REDD, *Journal of Agriculture and Ecology Research International,* 2(3), 180-195, 2016. DOI: 10.9734/JAERI/2015/14132
39. On Land Valuation: the Law of Ukraine. (2003). The Verkhovna Rada of Ukraine. Available at: http://zakon2.rada.gov.ua/laws/show/1378-15

About the Editors

Abhishek Raj, PhD, is an assistant professor in the Department of Forest Product and Utilization, Deen Dayal Upadhyay College, India. He has published over 20 papers in scientific journals, 50 book chapters, and three books.

Manoj Kumar Jhariya, PhD, is an assistant professor in the Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya University, India. He has published 86 scientific papers, 14 books, 75 book chapters, and several extension articles. He is an editorial board member for several journals and a life member of numerous societies.

Arnab Banerjee, PhD, is an assistant professor in the Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya University, India. He has published 80 research papers in reputed national and international journals, 15 books, and 50 book chapters. He is life member of the Academy of Environmental Biology.

Sharad Nema, PhD, is a professor and department head in the Department of Forestry and Wildlife in Saheed Mahendra Karma Vishwavidyalaya University, India. He has published various research papers, book chapters, books, reports and holds various prestigious and responsible administrative responsibilities at the university.

Kiran Bargali, PhD, is an associate professor in the Department of Botany, DSB Campus, Kumaun University, India. She has published more than 100 research papers and 2 books with various reputed national and international publishers.

Index

Also of Interest

Check out these related titles from Scrivener Publishing

GREEN CHEMISTRY FOR ENVIRONMENTAL REMEDIATION, Edited by Rashmi Sanghi and Vandana Singh, ISBN: 9780470943083. Presents high quality research papers as well as in depth review articles on the new emerging green face of multidimensional environmental chemistry.

BIOREMEDIATION AND SUSTAINABILITY: Research and Applications, Edited by Romeela Mohee and Ackmez Mudhoo, ISBN: 9781118062845. Bioremediation and Sustainability is an up-to-date and comprehensive treatment of research and applications for some of the most important low-cost, "green," emerging technologies in chemical and environmental engineering.

EMERGENCY RESPONSE MANAGEMENT OF OFFSHORE OIL SPILLS: Guidelines for Emergency Responders, By Nicholas P. Cheremisinoff, PhD, and Anton Davletshin, ISBN: 9780470927120. The first book to examine the Deepwater Horizon disaster and offer processes for safety and environmental protection.

COMPLEX BIOLOGICAL SYSTEMS: Adaptation and Tolerance to Extreme Environments, By Irina R. Fomina, Karl Y. Biel, and Vladislav G. Soukhovolsky, ISBN: 9781119510406. Written and edited by some of the most well-respected authors in the area of the adaptation of plants and animals to climate change, this groundbreaking new work is an extremely important scientific contribution to the study of global warming.

GLOBAL CLIMATE CHANGE DEMYSTIFIED, By James G. Speight, ISBN: 9781119653851. Tackling one of the most controversial subjects of our time, one of the world's foremost environmental and petroleum engineers explores the potential causes and ramifications of global climate change.