Environmental Science and Engineering

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Gouri Sankar Bhunia *Editors*

Spatial Modeling in Forest Resources Management

Rural Livelihood and Sustainable Development

Springer

Environmental Science and Engineering

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Spatial Modeling in Forest Resources Management

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ISSN 1863-5520 ISSN 1863-5539 (electronic)
Environmental Science and Engineering
ISBN 978-3-030-56541-1 ISBN 978-3-030-56542-8 (eBook)
https://doi.org/10.1007/978-3-030-56542-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Dedicated to beloved teachers and parents

Foreword

It is a great pleasure to pen the Foreword of the book *Spatial Modelling in Forest Management: Rural Livelihood and Sustainable Development* edited by Dr. Pravat Kumar Shit, Dr. Hamid Reza Pourghasemi, Dr. Pulakesh Das, Dr. Gouri Sankar Bhunia. This book is comprised of 28 empirical research articles contributed by dedicated researchers from various disciplines.

This book has been divided into three parts. The first part comprises nine articles related with forest resource measurements, monitoring systems and mapping techniques. Nine articles of the second part deal with modelling, risk assessment and vulnerability. The final part with ten articles throws light on rural livelihood and sustainable management.

These 28 research papers encompass in-depth scientific analysis of various socio-economic perspectives of forest resources. This publication volume critically analyses the recent trend of forest resource utilisation with particular reference to micro and macro-level issues. Moreover, this book gives emphasis to rural livelihood for the sustainable management of forest. Concisely, this book covers almost all the emerging forest-related issues of the present era.

This book would be a piece of extreme appreciation for researchers, conservationists and social workers. I wish all the very best for its wide circulation and admiration.

July 2020

Malay Mukhopadhyay
Professor and Former Head
Department of Geography
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Preface

Climate change is one of the leading ecological, economical and geopolitical issues of the twenty-first century. According to the United Nations Framework Convention on Climate Change (UNFCCC 1992 and IPCC 2007), natural climate variability along with the ever-increasing anthropogenic disturbances (via land-use change, deforestation, urban and cropland expansion, increase of artificial surface, use of fossil fuels, exercise of agro-chemicals, etc.) has led to increasing 'greenhouse gas' concentrations in the atmosphere and uprising the average global temperature. Forest ecosystem, as a source of huge carbon pool, plays key role in reducing the greenhouse gases and maintaining the water and energy fluxes and regulating the atmospheric processes. To mitigate greenhouse gas effects while maintain the forest ecosystem services, it is essential to provide managers and policymakers with accurate information on the current state, dynamics and spatial distribution of carbon sources and sinks point in forest area.

This book has considered 28 chapters associated to spatial modelling in forest resources issues, management and researches on forest health, forest biomass, carbon stocks and climate change studies, preferably. Currently, there are various challenges and uncertainties due of climate change and man-made interferences, which imposes great difficulties in adopting the appropriate decision. On the other hand, suitable management activities and policies for forest conservation have gained much attention globally. The latest advances in geo-spatial (remote sensing [RS] and GIS) technology, data processing platforms and modelling approaches have proven the potentially in developing sustainable and climate adaptive management plans. The integration of various geo-spatial and non-spatial data via advance data processing packages enables to generate reliable data for decision making. Various studies on forest health, forest conservation, carbon stock assessment, non-timber forest resources and climate change mitigation using the evident-based research and supplemented by the latest satellite data and data processing platforms will contribute to the development of appropriate policy and action plans for sustainable livelihoods.

We are very much thankful to all the authors who have meticulously completed their documents on a short announcement and paid in building this a very edifying and beneficial publication. We do believe that this will be a very convenient book for the geographers, ecologists, forest scientists and others working in the field of forest resources management including the research scholars, environmentalists and policymakers.

Midnapore, West Bengal, India

Pravat Kumar Shit
Hamid Reza Pourghasemi
Pulakesh Das
Gouri Sankar Bhunia

Acknowledgements

We are obliged to a chunk of experts for their kind support and valuable time to evaluate the chapters succumbed for insertion in this book. We are very much thankful to our respected teacher's Prof. Maloy Mukhopadhya, Prof. Sunando Bandyopadhyay, Prof. L. N. Satpati, Prof. Ashis Kumar Paul, Prof. Ramkrishna Maiti, Prof. Soumendu Chatterjee, Prof. Nilanjana Das Chatterjee, Prof. Dilip Kr. Pal, Prof. Sanat Kumar Guchait, Prof. N. C. Jana, Dr. Jatishankar Bandopadhay and Dr. Ratan Kumar Samanta for sharing their experiences, useful suggestions, continuous encouragement and immense support throughout the work.

We would like to thank the anonymous reviewers, acted as independent referees. Their input was consistently constructive and has substantially improved the quality of the final product.

We would also like to thank Ranita and Debjani, whose love, encouragement and support kept us motivated up to the final shape of the book. Finally, the book has been several years in the making and we therefore want to thank family and friends for their continuous support.

Dr. Pravat Kumar Shit would like to thank Dr. Jayasree Laha, Principal, Raja N. L Khan Women's College (Autonomous), Midnapore for her administrative support to carry on this project. We also acknowledge the Department of Geography, Raja N. L. Khan Women's College (Autonomous) for providing the logistic support and infrastructure facilities.

Dr. Hamid Reza Pourghasemi would like to thank the Shiraz University, College of Agriculture and Watershed Management Society of Iran for kind supports during preparation of this book.

This work would not have been possible without constant inspiration from my students, lessons from my teachers, enthusiasm from my colleagues and collaborators, and support from my family.

Midnapore, West Bengal, India

Pravat Kumar Shit
Hamid Reza Pourghasemi
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Pravat Kumar Shit Assistant Professor has been working in the Postgraduates Department of Geography, Raja N. L. Khan Women's College (Autonomous), Gope Palace, Midnapore, West Bengal, India. He received his Ph.D. in Geography from Vidyasagar University (India) in 2013, M.Sc. in Geography and Environment Management from Vidyasagar University in 2005 and PG Diploma in Remote Sensing & GIS from Sambalpur University in 2015. His main fields of research are soil erosion spatial modelling, non-timber forest and rural livelihood, forest biomass and carbon stocks, water resources and natural resources mapping and environmental modelling and published more than 50 international and national research articles in various renowned journals. His research work has been funded by the University Grants Commission (UGC), Government of India and Department of Science and Technology (DST), Government of West Bengal. He is an associate editor and on the editorial boards member of three international journal in geography, and earth environment science. He has served as a reviewer for many international journals. He published seven (07) books. Also, he published five books in Springer. He is currently the editor of the GIScience and Geo-environmental Modelling (GGM) Book Series, Springer-Nature.

Hamid Reza Pourghasemi is an Associate Professor of Watershed Management Engineering in the College of Agriculture, Shiraz University, Iran. He has a B.Sc. in Watershed Management Engineering from the University of Gorgan (2004), Iran; an M.Sc. in Watershed Management Engineering from Tarbiat Modares University (2008), Iran; and a Ph.D. in Watershed Management Engineering from the same University (February 2014). His main research interests are GIS-based spatial modelling using machine learning/data mining techniques in different fields such as landslide, flood, gully erosion, forest fire, land subsidence, species distribution modelling and groundwater/hydrology. Also, he works on multi-criteria decision-making methods in natural resources and environment. He has published more than 130 peer-reviewed papers in high-quality journals and three books in Springer and Elsevier as editor. Also, he is an active reviewer in more of 60 international journals.

Pulakesh Das is currently work in World Resources Institute India (WRII), New Delhi, India. Previously, he was teaching as an Assistant Professor in the Department of Remote Sensing & GIS, Vidyasagar University, Midnapore, West Bengal, India. He has received his Ph.D. degree from the Indian Institution of Technology (IIT) Kharagpur, India in July 2019. He completed his M.Sc. (2012) in Remote Sensing & GIS and B.Sc. (2010) in Physics from the Vidyasagar University, Midnapore, West Bengal, India. His primary research area includes land use forest cover (LUFC) modelling, hydrological modelling, forest cover dynamics and climate change, digital image processing, microwave remote sensing for soil moisture and forest biomass estimation, plant biophysical characterisation, etc. He has published more than 13 research articles in reputed peer-reviewed journals.

Gouri Sankar Bhunia received his Ph.D. from the University of Calcutta, India, in 2015. His Ph.D. dissertation work focused on disease transmission modelling using geospatial technology. His research interests include health geography, environmental modelling, risk assessment, data mining, urban planning and information retrieval using geospatial technology. He is an Associate Editor and on the editorial boards of three international journal in Health GIS and Geosciences. Currently, he is involved various smart city planning programme in India. He is also working as a visiting faculty in a private university of West Bengal. He has worked as a 'Resource Scientist' in Bihar Remote Sensing Application Centre, Patna (Bihar, India). He is the recipient of the Senior Research Fellow (SRF) from Rajendra Memorial Research Institute of Medical Sciences (ICMR, India) and has contributed to multiple research programs kala-azar disease transmission modelling, development of customised GIS software for kala-azar 'risk' and 'non-risk' area, and entomological study. He has published more than 60 paper in in reputed peer-reviewed national and international journal and three books in Springer. He is currently the editor of the GIScience and Geo-environmental Modelling (GGM) Book Series, Springer-Nature.

Part I
Forest Resources Measurement, Monitoring and Mapping

Chapter 1
Forest Management with Advance Geoscience: Future Prospects

Gouri Sankar Bhunia and Pravat Kumar Shit

Abstract The creation and implementation, involving key stakeholders, of context-specific forest management practices plays a significant role in the achievements of sustainable forest management. A number of site-growth modelling studies have been funded in recent years with the goal of developing quantitative relations between the site Index and specific biophysical indicators. With considerable time period, the role of forests in meeting the requirements for minor resources and ecological services has been recognized beyond the mere supply of forest. Present chapter describes advance geoscience application in forest management and also suggesting present research work to be adopted in future forest management plan. Counter-measures and recommendations were suggested on different forest management aspects, including developing consolidated structured data sets, designing top-ranking model monitoring and analysis and creating a multi-scenario decision support network. Finally, we proposed the main field of research in forestry research by incorporating and developing the participatory method, crowd sourcing, crisis mapping models and simulation systems and by linking data integration framework of geospatial technology, evaluation system and decision support system, to enhance forestry management by systematically and efficiently.

Keywords Forestry · Geospatial science · Crowd sourcing · Crisis mapping · Participatory mapping · Sustainable management

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P. K. Shit et al. (eds.), *Spatial Modeling in Forest Resources Management*, Environmental Science and Engineering,
https://doi.org/10.1007/978-3-030-56542-8_1

1.1 Introduction

Forest resource modelling and its status are very important economically and ecologically. Scientific community and policy makers are becoming increasingly aware of the fact that sustainable forest management is affected by several factors linked to global change. Between 1999 and 2012, the rapid rise in population contributed to the increase of €1 trillion, leading to an over 7 trillion people worldwide that need to be maintained by Earth resources. Forests are important to humanity because they provide a broader range of critical ecosystem resources, but the increasing depletion of forest cover means that the need for an ever-shrinking resource must be met with increased demand (Brockerhoff et al. 2013). Today, forest cover is about 31 percent of the land area or 4 billion ha. About half of the Earth's largest forests have been destroyed from land development, with the remaining 16 million hectares losing annually. At the same time, forests became more and more popular as sources of water and food, drugs, wood goods, and other leisure, economic, artistic, and spiritual advantages. Forests have been adequately or abusively exploited, but more effort to make sustainable use of them has been made. Forests are assessed annually at the global and country levels in terms of their scale, quality, usage and importance. In fact, as trees greatly add to the Earth's carbon balance. International interest in the identification of biomass is closely related to the protection of trees, photosynthetic development, and other carbon cycle processes and climatic variation (Houghton et al. 2009). In fact, the inventory of forests gives information on forest activities, conservation of forests and associated decision-making. Forest canopy and booth information was retrieved mainly by remote sensing and space-borne technologies (Tomppo et al. 2008) for wide areas of the world. Other environmental changes caused by human beings, such as increase in low ozone levels, deposition of nitrogenic contaminants, introduction of exotic insect pests and pathagogens, the fragmentation of ecosystems, and increased destruction such as fire may worsen these consequences (Bernier and Schöne 2009). Forestry can also have other consequences of climate change.

Some forest surveillance currently relies on data on development, i.e. improvements to forest cover, and two methods are used (DeVries and Herold 2013). Most environmental regulations are currently focussed on details on environmental operations, i.e. changes in land cover, and two methods are applied: top-down and bottom-up. The top-down approach utilizes satellite systems, while the bottom-up approach employs ground observation by government agencies, community-based surveillance (CBM), participatory surveillance or voluntary data (Danielsen et al. 2009). Satellite data provide global coverage and improved acquisition speed at a low cost, necessary for near-real-time forest surveillance (NRT) (Lynch et al. 2013). The scientific community is now generally recognized as major factors to latest increases in greenhouse gasses in the atmosphere and changes in the global hydrological cycle deforestation and degradation of forests (Hansen et al. 2013). The sample plot data reference data is still obtained largely through manual measurements while significant work is underway for, for example, terrestrial laser scanning, mobile laser scanning (MLS). The characteristics calculated in the inventories of operating forests are primarily the number of trees, tree types and breast height diameters (BHDs). Satellite Observations (SOs)—including Earth Observation (EOs) surveillance of the Earth's home planet; International Space Station (ISS) calculation, experiment and photo surveys; observations of the space science (SS); and Global Satellite Navigation System (GNSS) observations—are the basis for research to better understand our atmosphere and our environment.

The globalization of global trading networks and an increase in the volume of traded goods have been a contributing factor to population growth (Hulme 2009). Climate change can exacerbate invasions and impacts of forest pests. Climate change may, for example, promote the spread of both native pests and exotic ones (insects and pathogens) or affect tree pest resistance (Jactel et al. 2012) and there is growing evidence of an increasingly widely used phenomenon (Anderegg et al. 2015). Trumbore et al. (2015) described invasive species and diseases, as well as climate change, and deforestation as the major stressors in today's world's forests. The ongoing escalation and mechanization of forest management, which has increased forest vulnerability to biological invasion, climate change and other stressors, is an additional contributory to the forest health issue (Seidl et al. 2011). There have been several shifts in the forests in recent global warming (Lucier et al. 2009). Climate change effects can be beneficial in certain areas for certain tree species. In some areas, the growth of trees is increasing in longer growing seasons, hotter temperatures and higher CO_2 rates. Many of the expected climate changes and their indirect impacts are likely to adversely impact forests. Observed changes in vegetation (Lenoir et al. 2010) or increased mortality from drought and heat in forests around the world (Allen et al. 2010) may not be caused by climate change triggered by human beings but may demonstrate the potential consequences of the rapid environment. However, the vulnerability of tropical humid forests has been discussed recently (Huntingford et al. 2013) and temperate forests may be at greater threat in areas subject to a more extreme climate (Choat et al. 2012). A variety of viewpoints are available to consider adjusting to these changing and unpredictable future circumstances (McEvoy et al. 2013). Forest management would have to prepare on a variety of spatial and time levels in order to resolve potential problems and implement more flexible and collaborative management strategies. The tacit belief that local climate conditions will continue to be constant is often the basis of local forest activities (Guariguata et al. 2008). Additional social and economic developments in forest management will also continue to push transition (Ince et al. 2011). A growing global population, rapid economic growth, and increased wealth, for example, are driving demand in multiple developing countries for food and fiber crops and forest conversions into agriculture (Gibbs et al. 2010). The goals of climate change mitigation are to raise demand for biomass-based bioenergy and biomass in construction and manufacturing systems. Increasing urbanization shifts the essence of social demands for forests, and a reduction in rural communities decreases the supply of labor and capacity for intensive initiatives on forest management.

Regional climate, biodiversity, domestic environmental protection, even global environmental changes are strongly affected by the change in forestry area. The further squandering of ecological building space and the greater demands for strict forest red line expansion and industrialisation. In current land use and ecological cultures, how forest resource management is optimized and improved by complex monitoring for change in forest areas has become an extremely significant and urgent mission. Dynamic surveillance needs database tools have been developed to direct forest area surveillance capacity building (Gillis et al. 2005). For dynamic monitoring, a georeferenced digital database is commonly used as a basis of capacity building monitoring work. As an indicator of changes to forest area (Illera et al. 1996), temporary evolution of vegetation indices may be possible. With the exponential growth of earth observation technology (EO) and the continuing launch of remote sensing satellites, the Earth observation data resolution is growing and the number and range of data are rising as well, indicating that EO data are increasingly entering the age of big data (Xia et al. 2018). The Earth Observation Satellites Committee's (CEOS) figures indicate that over the last half century in 500 EO satellites were deployed, and more than 150 satellites will be launched in the next 12 years (Guo 2017). The Big Earth Observation Data (BEOD) slowly supported the growth of the world industries, research institutions, and application sectors which had a profound effect upon the Earth system science, contributing to human activities, environmental monitoring, and climate change (Yao et al. 2020). Furthermore, Web-based Geographic Information Systems (WGIS) is accessible in order to allow access to digital maps and geographic models. The reports are available publicly. It is a significant step in democratizing exposure for various users to geographical information. There are no spatial analysis resources available in current WGIS programs for this area, which use specific data sources, and easy access to reports with maps, graphs, text and table data.

In particular for data collection, for the production of a technical model and for research platform construction there remain many defects and limitations in technology and capacity building. Failure to coordinate forest land knowledge resulted from a lack of inventory requirements (Managi et al. 2019). Forest region adjustments are difficult to incorporate details based on the different forest land inventory and land grading requirements. There are significant issues with the uniformity of reporting practices in the reporting implementation process. Further development is required in conjunction with an integrated research model and a dynamic monitoring of forestry change. Systematic analysis for forestry area changes includes comprehensive data bases and models, and a system development tool is also required to help the conversion process from data analysis to application decision-making study. Spatial data items for the Multi-Period and Multi-Scenario Forest Region must be routinely analyzed and planned. The current state and rising forest area patterns combine with environmental and socio-economic influences interacting with each other. By using methods of GIS and Space Economics, the findings of the analyzes can be better adapted to natural change and better decision-making data for the optimal management of forest lands and other land types, using methodological methodologies. The findings of such research are focused on the effects of the natural changes. In addition, it is necessary for forest change to be improved in prediction and dynamic analysis, for development paths to be framed and regional development objectives to be recognized. The basic project to improve the study of forest dynamic change is the perfecting of data integration—model study—policy modelling Integrated development and the realization of scenarios for forest land changes under various systems. Restrictive factors influencing the growth of forestry areas must be identified, forest growth adaptive management measures examined and transition and strategies for development based on different stages promoted. The essential pre-conditions under the current climate change, urbanization growth, industrial system transformation, environmental protection and so on are the identification of the major contradictions in the cycle of forest growth and the main factors restricting development and implementing adaptive management.

1.2 Geosciences to Improve Forest Assessment

Through technical and statistical advancement, the processing of forestry data and their analyzes have steadily progressed (Kleinn 2002). Of starters, field dimensions, such as diameter or height scales, usually measured using tape or wood compasses and relascopes are now being improved with the use of emerging technology, including laser scope discoverers. In addition, the technology of remote sensing has been used rapidly to enhance soil sampling (Maniatis and Mollicone 2010), to measure improvements in vegetation and areas and to monitor other value variables, including forest fires, rodents and trees outside forest (Barducci et al. 2002). The usage, along with ground-based observations, of remote sensed data has gained considerable interest in estimating greenhouse gas emissions and forest-related removals, especially in the context of REDD+ (GFOI 2014). Recently a free Landsat satellite sample has been used by Food and Agriculture Organization of the United Nations (UN-FAO) to record forest land and area changes figures for the period 1990–2005 (FAO and JRC 2012) for woodland, other forested land and other ecosystem services. Therefore, a specific challenge for enhancing forest cover projections, carbon reserves and complexities is to efficiently integrate numerous top-down and ground-up strategies, a suggestion issued by the United Nations Framework Convention on Climate Change in the sense of emission reduction from deforestation and forest loss (REDD+) (UNFCCC 2009).

In the last few years, major changes have been made in LiDAR's systems leading to a boost in LiDAR position precision and surface density. LiDAR technology applies to a vast range of laser measurement devices, three primary approaches to the sensing of forest structures being terrestrial, airborne and space-borne approaches (Yao et al. 2011). Terrestrial laser scanning (TLS) has the ability to estimate tree diameters, height of the tree, tree volume and thus biomass in a structured and automatic manner (Hosoi et al. 2013). There is still an overview of these massive, three-dimensional datasets, but many ongoing methodological advances will make this technology useful soon. A digital elevation model (DEM) can be created from the point-cloud data created with LiDAR from the points reaching the ground and a canopy height-model from those intercepted by the upper canopy can be made. LiDAR's precision, combined with high spatial and point density, makes airborne LiDAR systems an enticing data acquisition method for estimating a large array of tree and forest parameters (Laes et al. 2011) like tree height (Detto et al. 2013), tree biomass (Li et al. 2008), leaf area index (Morsdorf et al. 2006) or stem volume (Heurich and Thoma 2008). Spaceborne data like LiDAR enables forest structures to be mapped globally with a vertical structure (e.g. by the Geoscience Laser Altimeter System (GLAS)) (Simard et al. 2011). In 2018, a similar sensor, ICESat2, has a smaller footprint than the previous GLAS instrument. Finally, the Global Ecosystem Dynamics Investigation (GEDI) project aims to make a high-resolution observation of a forest vertical structure at the global level using a LiDAR-backed instrument embarked on the International Space Station (https://science.nasa.gov/missions/gedi/). Moreover, a system called Synthetic Aperture Radar (SAR) is used to improve resolution beyond physical antenna aperture limits in order to achieve a high radar spatial resolution. For example, since it has a wavelength (5–6 cm), a C-band SAR signal is known to quick saturate with forest biomass (Thurner et al. 2014). In April 2014, Sentinel-1A was successfully launched with C-Band Radar as part of the European Space Agency's Copernicus Mission (ESA). Nonetheless, a loss of sensitivity at values greater than 100–150 Mg ha^{-1}, sometimes interpreted as signal saturation, was also observed in several studies (Woodhouse et al. 2012). Mermoz et al. (2015) have shown recently that L-band scatters appear to attenuate, rather than saturate, over and above this biomass threshold which could result in new opportunities in the mapping of L-band SARs. Currently, the L-band ALOS PALSAR is the single, wavelength radar sensor for monitoring the structure of forests, and in 2014, its sequel—ALOS2—was launched. In the case of forest-carbon evaluation, LiDAR, radar, textural and stereo-photogrammetry analysis have made considerable progress and allow the measurement (LVG 2012), over a significant shorter duration than conventional field sampling campaigns, of several variables of interests—for example, the diameter of tree, the height of tree and crown size (Table 1.1).

However, it is currently little understood how precise additional forestry characteristics such as timber volume per hectare are modellable by high-resolution data (almost 1.0 m and < 5 m) and high-resolution satellite stereo data (<1.0 m). For forestry survey methods, such as the extraction of quantitative information on canopy structure and forest biomass estimates, also in a setting of high biomass (Bastin et al. 2014). Therefore, it was possible for researchers to study ecologic structures with far greater detail than those provided by the start of high-resolution satellite sensors such as CARTOSAT (Spatial Resolution: 2.5 m), IKONOS, (spatial resolution in MS: 4 m), Quickbird (spatial resolution in MS: 2.88 m), and OrbView-3, (spatial resolution in the MS: 4 m),GEOEYE (Straub et al. 2013; Goward et al. 2003; Gibbs et al. 2007). For the calculation of the heights of individual pine trees and lading stands at Appomattox-Buckingham State Forest in Virginia, USA Popescu and Wynne (2004) used LiDAR and ATlAS multi-spectral (visible, near-IR and mid-IR) optical data with spatial resolution of 4 m. Table 1.2 illustrated the high spatial resolution satellite data in forestry mapping and monitoring. They showed that combined multi-spectrum imaging and LiDAR data can reliably predict forest inventory and evaluation tree heights of value. Nagendra (2001) assessed 'remote sensing capacity for determining the diversity of the ecosystem.' He concluded that a decade ago it was

Table 1.1 Satellite data and methods for forestry resources mapping and monitoring

Satellite/sensor	Aims	Methods	Reference
Synthetic aperture radar (SAR) and/or LiDAR	To detect and map forest degradation; Estimates above ground biomass	Spectral fractions, unmixing or classification	Mitchell et al. (2017)
Airborne X-band SAR data	To enhance discriminability of the forest types and features	Leaf Area Index; Spatial textural analysis	Roy et al. (1994)
Japanese Earth Resource Satellite (JERS)-1 Synthetic Aperture Radar (SAR)	Assesses the feasibility of forest cover mapping and the delineation of deforestation	Multi-image segmentation, post-classification detection	Thiel et al. (2006)
JERS-1, ERS-1 SAR and RADARSAT	Objectives are biomass estimation, forest and land-cover-type recognition in boreal forests	Textural measures, multitemporal approach, mixed pixel approach	Kurvonen et al. (2002)
Passive Microwave Remote Sensing (C-band, L-band and X-bands)	To compute the emissivity e of forests	Radiative transfer theory, matrix doubling algorithm	Ferrazzoli and Guerriero (1996)
Synthetic aperture radar (SAR); airborne and terrestrial LiDAR	Degradation and forest change assessment	Random forest (RF), REDD+ mechanism	Calders et al. (2020)
Synthetic Aperture Radar (SAR)	Quantification of spatial and temporal changes in forest cover	Random Forests, Extremely Randomised Trees	Devaney et al. (2015)

not yet possible to delineate a large number of species with spectral data. However, a 2-m spatial resolution was launched in 2009 for WorldView-2 (WV2) (Coastal, Blue, Green, Red, Red-Edge, near infrared (NIR)—1 and NIR—2) with a high resolution of 0.5 m (Coastal, Blue, Green, Yellow and NIR). Several studies in recent years have used WV2 images for the study of tree habitats. The accuracy of mapping six species/groups of trees improved with WV2 imagery by 16–18% compared to IKONOS satellite images. The research, however, covered trees/groups with sparse vegetation and not in a forest, within a dense urban area. Carter's (2013) use of multitemporal data from June and September 2010 in a multi-temporal forest mix in Upstate New York from two WV2 images for classifying ash, maple, oak, beech, evergreen and 6 other tree classifications. This would also promote the grouping of tree species into mixed near-nature, natural, urban forests with a wide variety of tree species. Very high spectral resolution imaging often mounted on aerial systems offers important, unreviewed eye information on forest function with a greater number

Table 1.2 Use of high spatial resolution satellite data in forest mapping and monitoring

Satellite/sensor	Region of study	Aims	Methods	Outcome	Reference
IKONOS II	Italy	Forest Inventory and Mapping	Supervised classification, Object-based approach	Forest cover density and dominant tree species composition	Giannetti et al. (2003)
IKONOS; QuickBird	Costa Rica, Central America	To evaluate tree death rates	Calibration factor	Calculated a landscape-scale annual exponential death rate	Clark et al. (2004)
QuickBird	Tully, New York	Tree identification and tree crown delineation	Rule-based classification; segmentation algorithm	Classification trees were built and results were evaluated using a cross-validation approach; spectral metrics, texture, elevation features, and geometric features were calculated for each image object	Ke and Quackenbush (2007)
WorldView-2, LiDAR	Ljubljana	Tree species inventory	Object-based image analysis; Digital elevation model (DEM); Principal component analysis (PCA)	The accuracy of the proportions of individual tree species that form the forest stand canopy was lower than in some other studies. The distinction between deciduous and coniferous tree species was the most reliable	Verlič et al. (2014)
QuickBird, IKONOS	Nepal	Forest Condition Monitoring	Geographic object-based image analysis (GEOBIA)	Tree crown detection, delineation, and change assessment	Uddin et al. (2015)

(continued)

Table 1.2 (continued)

Satellite/sensor	Region of study	Aims	Methods	Outcome	Reference
LiDAR, WorldView-2	Victoria, Australia	Characterisation and classification of forest communities	k-means clustering algorithm; TreeVaW algorithm; support vector machines (SVMs) and decision trees	Identified individual trees, including locations and crown sizes identification of Myrtle Beech and adjacent tree species—notably at individual tree level	Zhang (2017)
WorldView-2	Long Island, New York (US)	Assessment of forest fire	Multiple Endmember Spectral Mixture Analysis (MESMA) fraction; spectral indices	Forest burn severity mapping from VHR data	Meng et al. (2017)
Unmanned aerial vehicles (UAVs), Pléiades	Czech Republic	Estimation of basic tree attributes, such as tree height, crown diameter, diameter at breast height (DBH), and stem volume	Structure from motion (SfM) algorithms; spectral Correlation	Predict tree characteristics with high accuracy (i.e., crown projection, stem volume, cross-sectional area (CSA), and height)	Abdollahnejad et al. (2018)
Airborne LiDAR	Peru	measure and monitor carbon stocks and emissions; measurements of top-of-canopy height	Random forest machine learning regression	Aboveground carbon stocks and emissions	Csillik et al. (2019)

of narrow spectral bands (up to 200 or more contiguous spectral bands). Imaging spectroscopy, for example, may relay valuable information on variability in canopy chemistry (Baccini and Asner 2013) and thus provide direct information on the functioning of the Ecosystem. The taxonomic and functional structure of canopy trees can also be described in a highly successful way.

For research and development, the bulk of the above technological methods are still considered. Technology development, modifying and implementing existing systems in accordance with country circumstances, has the possibility, as necessary, of improving field measurement alertness, reducing time and expense of field sampling campaigns and improving forest extrapolation estimates over broad spatial scales including remote or conflict areas. The implementation of transparent national forest surveillance systems can also be assisted by new technologies. However, national and subnational corporations, private businesses, research and academic institutions, NGOs and civil society face a great many constraints in implementing, adapting and activating these technologies. Of these, minimal technical skills are possibly the most critical when using these new technologies; thus, training and capacity building are necessary and must be expected.

1.3 Cloud Computing and Forest Management

The rapid advancement of cloud computing technology in recent years provides strong computing power, especially for the efficiency of big geospatial data management and processing, which makes it possible to perform complex simulations on a global scale. Cloud computing is used as a framework to allow users to access a common community of computational tools that is configurable and can easily be supplied and published with minimal management effort and/or interference between service providers (Li and Huang 2017). Cloud computing has transformed the conventional information technology model entirely by offering at least three types of services: infrastructure as a service (IaaS), platform as a service (PaaaS) and software as a service (SaaS). In order to address persistent spatial data model problems spatial cloud computing (SCC), a data layer as a service (DaaS) was proposed (Yang et al. 2011). The discrete global grid systems (DGGS) have had a fairly flawless theoretical statistical history and basic functions over the last two decades (Zhao et al. 2016). DGGS is known as an Earth reference system (ERS) which uses cells to divide and address the globe (Bauer-Marschallinger et al. 2014). The DGGS Standards Working Group was set up in 2014 and an international specification was adopted by the Open Geospatial Consortium.

Cloud technologies, and particularly in the field of data storage, have begun to infiltrate all facets of life. Cloud computing cannot make use of itself explicitly for the visualization and maintenance of forest resources, because it essentially lacks the functionality of the spatial data collection. This effort aims to address four strength