T. V. Ramachandra · Bharath Haridas Aithal · Bharath Setturu · S. Vinay · K. S. Asulabha · V. Sincy

Natural Capital Accounting and Valuation of Ecosystem Services, Karnataka State, India

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T. V. Ramachandra
Energy and Wetlands Research Group
Centre for Ecological Sciences
Indian Institute of Science
Bengaluru, Karnataka, India

Bharath Haridas Aithal
Ranbir and Chitra Gupta School
of Infrastructure Design and Management
Indian Institute of Technology Kharagpur
Kharagpur, West Bengal, India

Bharath Setturu
Energy and Wetlands Research Group
Centre for Ecological Sciences
Indian Institute of Science
Bengaluru, Karnataka, India

S. Vinay
Energy and Wetlands Research Group
Centre for Ecological Sciences
Indian Institute of Science
Bengaluru, Karnataka, India

K. S. Asulabha
Energy and Wetlands Research Group
Centre for Ecological Sciences
Indian Institute of Science
Bengaluru, Karnataka, India

V. Sincy
Energy and Wetlands Research Group
Centre for Ecological Sciences
Indian Institute of Science
Bengaluru, Karnataka, India

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Preface

Humans depend on ecosystems for their basic needs, such as food, fuel, minerals, water, and air. All forms of interaction between ecosystems and people, including in situ and remote interactions, are often referred to as ecosystem services. The supply of an ecosystem service is associated with an ecosystem structure or process or a combination of ecosystem structures and processes that reflect the biological, chemical, and physical interactions among ecosystem components. Ecosystem services are broadly categorized as (i) provisioning services, which are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems; (ii) regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological, and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society, (iii) cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits.

India is attempting to accelerate economic growth and relax environmental laws, and there is tremendous pressure to divert natural systems to other uses. Hence, there is a pressing need to undertake the natural capital accounting and valuation of the ecosystem services, especially intangible benefits, provided by ecosystems. The value of all ecosystem services, including the degradation costs, needs to be understood to develop appropriate policies for the conservation and sustainable management of ecosystems. Scientific efforts during the past decade have refined the understanding of ecosystem function and demonstrated the links between functions and the provision of ecosystem services. This knowledge needs to be communicated effectively to decision-makers and the public, which will lead to developing policies that adequately consider the trade-offs between the conservation of ecosystems and natural resources and economic growth.

There is an urgent policy need for more comprehensive assessments of the natural capital of ecosystems, which will aid in comparing these aggregate values with the opportunity cost of this land. Policymakers need such information to gain support for conservation funding, engage local communities, and develop market-based instruments for conservation, which necessitates accounting for the natural capital found in ecosystems and incorporating their economic worth into the measurement of the wealth of a region.

Ecosystem accounts make the value of ecosystem services visible, allowing them to be internalized into decision-making. Accounting of ecosystem services enables an assessment of trade-offs between economic development and environmental conservation and restoration, resulting in better-informed decisions. It also strengthens the economic case for conserving forests in states in India and developing countries where there can be tremendous pressure to relax forest laws and divert forests to non-forest uses without proper consideration of the sustainability of such actions.

United Nations (UNSD and UNEP) developed the System of Environmental-Economic Accounting (SEEA) framework for natural capital accounting and valuation of ecosystem services (NCAVES) by integrating economic and environmental data and providing a comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets, as they bring benefits to humanity. Karnataka state was chosen by UNSD (SSFA/2019/1502), to pilot the compilation of selected ecosystem accounts in physical and monetary terms based on policy priorities and to contribute to policy mainstreaming.

The research focussing on natural capital accounting and valuation of ecosystem services was carried out by the Energy and Wetlands Research Group at CES, Indian Institute of Science, in collaboration with the United Nations Environment Programme (UNEP), United Nations Statistics Division (UNSD), the Ministry of Statistics and Programme Implementation (MoSPI), Government of India and the ENVIS division, The Ministry of Environment Forests and Climate Change (MoEFCC), Government of India and Ranbir and Chitra Gupta School of Infrastructure Design and Management (RCG SIDM), and Indian Institute of Technology Kharagpur (IIT-KGP) as part of the international, EU-funded Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project.

The valuation of ecosystem services (forests, agriculture, and aquatic) is implemented district-wise for Karnataka State, India, as per the validated statistical framework for natural capital accounting—SEEA: System of Environmental-Economic Accounting (SEEA.un.org). According to SEEA protocol, ecosystem services are defined as the contributions of ecosystems to the benefits that are used in economic and other human activities. The valuation of ecosystem services (VES) provides an unbiased framework to value unaccounted ecosystem benefits and helps in developing meaningful policy interventions. The approach allows for adjusted regional or national accounts, which reflect the output of ecosystem services as well as the depletion of natural resources and the degradation costs (externalized costs of the loss of ecosystem services) of ecosystems in economic terms. In this perspective, the current publication, focusing on the natural capital accounting and valuation of ecosystem services in Karnataka, India, will help raise awareness and provide a quantitative tool to evaluate the sustainability of policies.

Bengaluru, India T. V. Ramachandra
Kharagpur, India Bharath Haridas Aithal
Bengaluru, India Bharath Setturu
Bengaluru, India S. Vinay
Bengaluru, India K. S. Asulabha
Bengaluru, India V. Sincy

Acknowledgments

The valuation of ecosystem services of terrestrial (forests and agriculture) and aquatic ecosystems is implemented district-wise for Karnataka State, India, as per the validated protocol—System of Environmental-Economic Accounting (SEEA EA; SEEA.un.org) protocol, which constitutes the statistical framework for natural capital accounting. According to this protocol, ecosystem services are defined as the contributions of ecosystems to the benefits that are used in economic and other human activities. The valuation of ecosystem services (VES) allows for adjusted national accounts that reflect the output of ecosystem services as well as the depletion of natural resources and the degradation costs (externalized costs of the loss of ecosystem services) of ecosystems in economic terms, which will help raise awareness and provide a quantitative tool to evaluate the sustainability of policies. It provides an unbiased and dependable national framework to value so far unaccounted ecosystem benefits and helps develop meaningful policy interventions.

The research focussing on natural capital accounting and valuation of ecosystem services in Karnataka State, India, was commissioned by the United Nations Environment Programme (UNEP) as part of the international, EU-funded Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project. The NCAVES project was carried out as a collaboration between UNEP, the United Nations Statistics Division (UNSD), the Ministry of Statistics and Programme Implementation (MoSPI), Government of India and ENVIS Division, The Ministry of Environment Forests and Climate Change (MoEF&CC), Government of India.

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The work was carried out using (i) field data; (ii) collateral data compiled KSRSAC, GoK; KSCST, GoK; Department of Agriculture, GoK, Karnataka Forest Department, GoK; (iii) spatial data (Landsat series available in the public domain); and (iv) spatial data (IRS LISS Data) procured from the National Remote Sensing Centre, GoI, Hyderabad.

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Introduction

Ecosystems (terrestrial and aquatic) are vital for the survival of humans on the earth. Ecosystems and the biological diversity within them provide a number of goods (food, fodder, etc.) and services (remediation, clean air, water, etc.) essential to sustain life with economic prosperity among other aspects of human welfare. The well-being of humans is entirely dependent on the health of the ecosystems. Humans, directly and indirectly, are dependent on the goods and services provided by the ecosystems in their surroundings to meet their everyday needs. These goods and services are generated as a consequence of the biotic and abiotic interactions that take place within the ecosystem. This implies that any change in the nature of their components would affect their capacity to generate the said goods and services. Ecosystem services can be understood as the benefits (often indirect) humans obtain from ecosystems. Forest ecosystems, in particular, owing to their abiotic and biotic diversity and abundance, foster goods and services that are of high economic importance. The direct benefits are mostly in the form of goods and include food, timber, fuelwood, etc., while the indirect benefits include air purification, flood mitigation, carbon sequestration, pollination, cultural amenities, etc. These goods and services are often not given any economic importance as most of them do not directly enter the market and, hence, do not possess a market value. This has led to the development of policies focussing on the economic benefits of any given activity without taking into consideration the environmental loading caused by the same. Taking into account the natural capital found in the form of forest ecosystems among others in such a way that their economic worth is being added to the measurement of the wealth of a nation is of importance. Valuation of ecosystem goods and services is a step taken towards the same with the agenda of assigning an economic value to the various goods and services provided by an ecosystem.

Human beings are dependent on diverse ecosystems to meet their basic needs, such as food, fuel, minerals, water, and air. In developing countries, on average, 40% of the Gross Domestic Product (GDP) is contributed by agriculture, with nearly 70–80% of the labour force engaged in agricultural or resource-based activities. This massive dependency on natural resources and overexploitation over the years have led to their degradation and depletion owing to the unsustainable practices involved in their extraction. Unplanned development activities coupled with the increasing population have put tremendous pressure on environmental resources and increased concerns over environmental degradation. An increased surge in the developmental and technological activities after the industrial revolution and opening up of markets over the last two decades have led to an increase in the quantities of chemicals contributing to damage caused in the natural ecosystems. Over the past 50 years, rapid environmental changes have resulted in a substantial and largely irreversible loss in the diversity of life on earth. Unsustainable utilisation of land and other natural resources persists, despite the increasing understanding of the impacts that human activities have on the environment. The linkage between the health of the environment and the sustenance of humankind makes it imperative to maintain a balance between the carrying capacity of the environment and the availability of natural resources by ensuring their prudent extraction. Conservation of natural ecosystems has long-term benefits for humans in utilitarian terms through their provision of food, timber, minerals, and a variety of valuable resources that have provided the backbone for economic development. Going beyond the utilitarian values, it has also been a source for the maintenance of gene pools, biodiversity, and other potentially useful factors that are of indirect use to humans. Hence, the ecosystems' intrinsic values and rights, regardless of human needs, therefore, should be taken into account apart from considering it a resource to be exploited for human settlement, food, and energy production. The dilemma associated with rapid land use change for accommodating the growing demand for the use of natural resources is that the more we change the land to meet our needs for food, water, fuel, shelter, etc., the more we impact and possibly degrade the ecosystems. Hence, it necessitates a structured economic development that optimises the economic and social benefits without jeopardising the likely potential for similar benefits in the future. Sustainable development of a region requires a synoptic ecosystem approach that relates to the dynamics of natural variability and the effects of human interventions on key indicators of biodiversity and productivity. The ecosystem service approach offers a way to understand and deal with the negative feedback loop that is ultimately created when ecosystems are used up to meet the needs of society. The ecosystem services framework allows the analyst to capture the full range of environmental impacts more systematically by linking the ecological effects to the changes in human welfare. The benefits from ecosystems include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; and cultural services such as recreational, spiritual, aesthetic, and science.

There is a pressing need to undertake the natural capital account and valuation of the ecosystem services, especially intangible benefits, provided by ecosystems. The value of all ecosystem services, including the externalized costs of their loss, needs to be understood for developing appropriate policies toward the conservation and sustainable management of ecosystems. Scientific efforts during the past decade have refined the understanding of ecosystem function and demonstrated the links between functions and the provision of ecosystem services, and this knowledge needs to be communicated effectively to decision-makers and the public, which will lead to the development of policies focussing on the economic benefits of any given activity with consideration of the environmental loading caused by the same.

There is an urgent policy need for more comprehensive assessments of the natural capital of ecosystems, which will aid in comparing these aggregate values with the opportunity cost of this land. Policymakers need such information to gain support for conservation funding but also to engage local communities and develop market-based instruments for conservation. This necessitates accounting for the natural capital found in the forest ecosystems (among others) and incorporation of their economic worth added to the measurement of the wealth of a region. Valuation of ecosystem goods and services is a step taken towards the same with the agenda of assigning an economic value to the various goods and services provided by an ecosystem.

The purpose of environmental-economic accounting has been the derivation of adjusted measures of value added and wealth that take into account the cost of using up environmental assets. This is considered in ecosystem accounting by measuring ecosystem degradation as reflecting the loss of future flows of ecosystem services.

The ecological interaction among biotic and abiotic factors results in the flow of goods and services essential for human survival and can be measured as tangible and intangible. The direct benefits are primarily in the form of goods such as food, timber, and fuelwood while the indirect services include air purification, flood mitigation, carbon sequestration, pollination, the prevention of soil erosion, pest control, regulating local and global climate, ameliorate weather events, regulate the hydrological cycle, climate change mitigation, control of disease vectors, and local ecosystem resilience and stability, cultural amenities, etc. and provide a vast store of genetic information much of which has yet to be uncovered. These goods and services, directly and indirectly, support livelihoods but are often not assigned any economic significance as most of them do not directly enter the market and, hence, do not possess a market value.

Ecosystems deliver goods and services to humankind and, therefore, have an economic value defined as their contribution to human welfare (financial, social, hydrological, environmental, and health). Ecosystem values are broadly classified into use values and non-use values, based on the benefits derived from the ecosystems to sustain the present and future generations. Use value refers to a value arising from an actual use made of a given resource, whereas the non-use value refers to one that is available independent of the ecosystem's interaction with humans. The use value is further classified into direct, non-direct, and option use values. Direct use value is derived from direct interactions with the ecosystem that may be consumptive or extractive by nature, like timber extraction, fruits, and fishing. Indirect use value is understood as the value derived from the functions served by the ecosystem. It does not have a direct market value but can be analysed using several techniques available that use proxy variables. It includes functions like nutrient removal, prevention of downstream flooding, and microclimate regulation. The option value refers to that value people put on a particular ecosystem owing to having the option of using the resources available in the future, etc.

The non-use value is classified into existence, bequest, altruistic, and option values. It deals with the value provided by an ecosystem without any interaction with humans and necessarily entails intangible benefits. Existence value is derived simply from the satisfaction of knowing that a particular ecosystem continues to exist irrespective of the benefits gained from it and is often also understood as the intrinsic value held by an ecosystem. The bequest value is associated with the knowledge that ecosystems and their services will be passed on to future generations so that they can enjoy them as well, which also happens to be the underlying theme of sustainable development. Altruistic value is the value derived from knowing that people can enjoy the goods and services provided by ecosystems. Finally, option value is also a part of the non-use value where the value is derived from the option of using a particular service/function in the future.

Most resource management decisions are influenced by ecosystem goods entering markets; as a result, the non-marketed benefits are often lost or degraded. Both renewable resources (water supply, air quality, etc.) and non-renewable resources (mineral deposits, some soil nutrients, fossil fuels, etc.) are capital assets and provide the backbone for numerous economic activities that account for the development of a region. Hitherto, traditional national accounts have not included resource depletion or degradation measures. The Gross Domestic Product (GDP), a measure of the current economic well-being of a region based on the market-exchange of material well-being, will therefore not be representative of the decline in these assets (wealth) in correspondence to the positive gain in the economy that is contributed through the process. Hence, GDP cannot be a true measure of the country's sustained economic wealth and cannot be a proxy for understanding its future economic well-being. Quantitative evidence on the economic value of such assets is thereby necessary for most of these services and goods provided by them are not traded in the markets and hence do not have a market value. The monetary valuation of the various services and goods provided by the ecosystems can help in building a better understanding of their influence on the economic well-being and can further facilitate information-driven decisions and policy reforms that align with the Sustainable Development Goals (SDGs), a successor to the Millennium Development Goals (MDGs) identified by the United Nations Development Programme (UNDP). Environmental accounting systems seek to set out a region's environmental, social, and economic assets and can be used to assess whether economic development is consistent with sustainable development or to help ensure optimal use of natural resources and environment. Recent efforts, especially the System of Environmental-Economic Accounting, Central Framework, and Experimental Ecosystem Accounting (SEEA CF and SEEA EEA), aim to extend and integrate the national accounts for environmental and ecosystem assets.

The stock of ecosystem resources (biotic and abiotic) that provide goods and services is referred to as natural capital. The services provided by these ecosystems support the economy and society. However, the contributions by the ecosystems or natural capital are often undervalued while making economic decisions. This necessitates accounting of natural resources to minimize overexploitation, mismanagement, etc. The process of accounting stocks and flows of goods and services (natural resources) in a given ecosystem of a region is often termed as natural capital accounting.

United Nations Statistical Division (UNSD) has proposed a System of Environmental-Economic Accounting—Experimental Ecosystem Accounting (SEEA—EEA) framework for ecosystem accounting. A key feature of ecosystem accounting, as per SEEA, is its capacity to integrate spatially referenced data about ecosystems, i.e. data about the location, size, and condition of ecosystems within a given area and how these are changing over time. The ecosystem accounting framework related to ecosystem services concerns (i) the supply of ecosystem services to users; and (ii) the contribution of ecosystem services to benefits (i.e., the goods and services ultimately used and enjoyed by people and society). Ecosystem services are structured into three broad categories:

- *Provisioning services* are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.
- *Regulating services* are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological, and biochemical cycles, and hereby maintain environmental conditions beneficial to individuals and society.
- *Cultural services* are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits.

Together, these ecosystem goods and services contribute to the Total Ecosystem Supply Value (TESV) of the natural resource. The key stages in the valuation of ecosystem services are: (i) natural capital accounting—establishing the environmental baseline through assessment of ecosystem extent and condition accounts, (ii) quantification of goods and services, (iii) valuation of ecosystem services, (iv) identify and provide qualitative assessment of the potential impacts of policy options on ecosystem services, (iv) quantify the impacts of policy options on specific ecosystem services and assess the effects on human welfare, and (v) value the changes in ecosystem services.

The ecosystem accounts have been developed as per the protocol of the System of Environmental-Economic Accounting—Experimental Ecosystem Accounts (SEEA—EEA) considering the following:

- **Ecosystem extent** accounts record the total area of each ecosystem, which is classified by type within an ecosystem accounting area and, over time, in a specified area (district, Karnataka State, India).
- **Ecosystem condition** accounts record the condition of ecosystem assets in terms of selected characteristics at specific points in time and, over time, record the changes to their condition. These changes are mainly due to human activities with economic interventions.
- **Ecosystem services** accounts record the supply of ecosystem services by ecosystem assets and the use of those services by economic units, including households. Ecosystem services accounts are presented both in physical and monetary units, using techniques for the valuation of ecosystem services.

- **Ecosystem monetary asset** accounts record information on stocks and changes in stocks (additions and reductions) of ecosystem assets. This includes accounting for ecosystem degradation and enhancement.

Ecosystem accounting entails the estimation of the extent of different ecosystem assets (EAs) in the study region (district and federal state) using remote sensing data (acquired through space-borne sensors at regular intervals and available since the 1970s). This spatial data helps in compiling ecosystems extent account and provides an underlying infrastructure for measuring ecosystem conditions and modeling ecosystem services. The analyses of temporal data helped in assessing the extent of changes in an ecosystem over time.

The outline of this book is as follows: Chap. 1 presents ecosystem extent, and Chap. 2 assesses the condition of terrestrial (forests and agriculture) ecosystems. Chapter 3 focuses on the valuation of terrestrial ecosystem services. Chapter 4 quantifies the impacts of policy options on specific ecosystem services and assesses the effects on human welfare. Chapter 5 presents the worth of aquatic (inland wetlands and estuaries) ecosystems.

Contents

About the Authors

Dr. T. V. Ramachandra FIE, FIEE (UK), FNIE obtained Ph.D. in Ecology and Energy from the Indian Institute of Science. At present, Coordinator of Energy and Wetlands Research Group (EWRG) and Convener of Environmental Information System (ENVIS) at Centre for Ecological Sciences (CES). During the past 25 years, he has established an active school of research in the area of energy and environment (http://wgbis.ces.iisc.ac.in/energy). He is a member of Karnataka State Wetland Authority (since 2018), Kerala Wetland Authority (since 2022), National Wetland Committee, GoI., and Karnataka State Audit Advisory Committee. He was a Member of the Karnataka State-level Environment Expert Appraisal Committee (2007–2010), appointed by the Ministry of Environment and Forests, Government of India, and a member of the Western Ghats task force appointed by the Government of Karnataka. Apart from this TVR is serving in many committees of NGT (National Green Tribunal) related to the wetlands of Bangalore.

TVR is a recipient of Johny Biosphere Award for Ecology and Environment (2004), Satish Dhawan Young Scientist Award, 2007 of the Karnataka State Government, ENVIS Award (Thrice: 2004, 2014 and 2015) of the Ministry of Environment, Forests, and Climate Change, GoI, Namma Bangalorean, 2016 award (Namma Bengaluru Foundation) and Rotary Exemplars 2017—Citizen Extraordinaire award (Rotary Club of Bangalore), **Karnataka State Parisara Award, 2017–2018** (Environment Award, Government of Karnataka), Khadri Achuathan Memorial Samvahana

Award (Environment) 2018, on World Communicators Day by PRCI, research advisor at the Nanyang Academy of Sciences, Singapore (2019), and Eminent Engineer, Institution of Engineers, Karnataka (2019).

TVR features in the recent global ranking of top 2% of scientists (developed by Stanford University) with ranking in Environment: 0.1887, Energy: 0.2138, Enabling and strategic technologies: 0.2642. He is a honorary fellow, Karnataka Science and Technology Academy (2022), *Elected Fellow* of National Institute of Ecology (2011), Indian Association of Hydrologists (India; 2006), Indian Social Science Academy (ISSA), Institution of Engineers (IE, India; 2003), the Institution of Electrical Engineers (IEE, UK; 2005), and a Senior Member, IEEE (USA; 2000) and Association of Energy Engineers (USA; 2000).

TVR's research interests are in the area of aquatic ecosystems, biodiversity, ecological modeling, Western Ghats ecology, energy systems, renewable energy, energy conservation, energy planning, geoinformatics, environmental engineering education research, and curriculum development at the tertiary level. He has published over 352 research papers in the reputed peer-reviewed international and national journals, 75 book chapters, 333 papers in the international and national symposiums as well as 19 books. In addition, he has delivered a number of plenary lectures at national and international conferences. Publication "Milking diatoms for energy" is seminal work in biofuel research evident from reports in Scientific American, BBC, national dailies, etc.

He has guided 178 students for Master's dissertation and nineteen students for Doctoral degrees. He teaches courses (i) environmental management and (ii) Principles and application of GIS and remote sensing for masters and doctoral students. TVR has travelled widely across the country for field research and also for delivering lectures (1500+) at Schools, Colleges, Research Institutes, etc. He has taken initiatives through biennial symposium (popular as Lake series, conducted 12 events since 1998), Environment management course for in-service working professionals (18 sessions) training programmes and workshops for capacity building at various levels. Publications are available at https://www.researchgate.net/profile/T_V_Ramachandra/publications, https://scholar.google.co.in/citations?user=Woh1fa8AAAAJ&hl=en

Co-ordinator, Energy and Wetlands Research Group, Centre for Ecological Sciences [CES]

Convenor, Environmental Information System [ENVIS], CES TE 15, Indian Institute of Science

Associate Faculty, Centre for Sustainable Technologies (astra)

Centre for infrastructure, Sustainable Transportation and Urban Planning [CiSTUP]

Indian Institute of Science, Bengaluru, Karnataka, India

Web URL: http://wgbis.ces.iisc.ernet.in/energy; http://wgbis.ces.iisc.ernet.in; http://wgbis.ces.iisc.ac.in/energy

E-mail: tvr@iisc.ac.in; energy.ces@iisc.ac.in

Dr. Bharath Haridas Aithal is currently an Associate Professor in Ranbir and Chitra Gupta School of Infrastructure Design and Management at the Indian Institute of Technology Kharagpur. He obtained his Ph.D. from Indian Institute of Science. His area of interest is spatial pattern analysis, Urban growth modelling, natural disasters, geoinformatics, landscape modelling, urban planning, open-source GIS, and digital image processing. He has published over 50 research papers in reputed peer-reviewed international and national journals, 100 papers in the international and national symposiums as well as three books and six book chapters to his credit. https://sites.google.com/view/bharathhaithal/home

Bharath Setturu is currently an assistant professor at Chankya University (School of Mathematics and Natural Sciences) and a post-doctoral fellow at Energy and Wetlands Research Group (EWRG), Centre for Ecological Sciences, Indian Institute of Science, Bengaluru. His research contributions are as follows: 40 research papers in peer-reviewed international journals, five book chapters, 55 papers in national and international conference proceedings, 50+ technical reports, and one book. His work has received a large appreciation across the globe. He is a recipient of "Sahyadri Ecologist (2016 and 2020)" award. He has received the best research paper awards during NSRS-2019 Conference at Bengaluru, CCIVA-2019 Conference at IIT-Kharaghpur, BDCC-2018 Conference at IIT-Kharaghpur, and WEIZ-2017 Conference at Kolkata by IIT-Kharaghpur. He has also received "Dr. Parameshwaran Research Grant" in the year 2016.

S. Vinay is an Associate Professor in the Department of Civil Engineering, Alva's Institute of Engineering and technology, Moodbidri, Karnataka, India. He has received his Bachelors in Civil Engineering from R. V. College of Engineering, Bengaluru, India; Masters in Geoinformatics from Karnataka State Remote Sensing Centre—VTU RRC, Bengaluru, India; and Ph.D. from Visvesvaraya Technological University, Belagavi, India. He was a post-doctoral fellow at RCGSIDM, IIT Kharagpur, India. Since 2013 he is associated as a researcher at EWRG, CES, IISc. His research interest areas are Environmental flows, Hydrology, applications of Remote Sensing and GIS in disaster risk assessment, visualisaiton of landscape, spatial modelling for forecasting, Climate, and Environment aspects. He has published over 100 articles as journals, conferences, book chapters, and conference proceedings. He has been a reviewer in national and international journals and conferences.

K. S. Asulabha is currently a research scholar in Ecoinformatics working in the Microalgae spatial decision support system at the Energy and Wetlands Research Group, CES TE15, Indian Institute of Science, Bengaluru. Her areas of interest are monitoring aquatic ecosystems, water quality assessment, wetland ecosystem evaluation, soil quality assessment, algal culturing, algae, fish, and zooplankton documentation, and open-source GIS. She has published over seven research papers in reputed peer-reviewed international and national journals, 19 papers in international and national symposiums, one strategy paper, 20 technical reports, and two book chapters.

V. Sincy is currently a Research Scholar in Ecoinformatics working in the Ichthyofauna spatial decision support system at the Energy and Wetlands Research Group, CES TE15, Indian Institute of Science, Bengaluru. Her areas of interest are wetland ecosystem evaluation, monitoring of aquatic ecosystems, water quality assessment, soil quality assessment, algal culturing in wastewater, fish, algae, and zooplankton, and open-source GIS. She has published over 6 research papers in reputed peer-reviewed international and national journals, 19 papers in international and national symposiums, one strategy paper, 21 technical reports, and two book chapters.

Ecosystem Extent Account for Karnataka State, India

Abstract Ecosystems (terrestrial and aquatic) are vital for the survival of humans on the Earth. Ecosystems provide an array of goods (food, fodder, etc.) and services (remediation, clean air, water, etc.) that humans depend upon to sustain their lives. The stock of ecosystem resources (biotic and abiotic) that provide goods and services is referred to as natural capital. The services provided by these ecosystems support the economy and society. However, the contributions by the ecosystems or natural capital are often undervalued while making economic decisions. This necessitates accounting of natural resources to minimize overexploitation, mismanagement, etc. The process of accounting stocks and flows of goods and services (natural resources) in a given ecosystem of a region is often termed natural capital accounting. In natural capital accounting, ecosystems are assets that provide ecosystem services to people.

A key feature of ecosystem accounting is its capacity to integrate spatially referenced data about ecosystems, which includes data about the location, size, and condition of ecosystems within a given area and how these are changing over time as per the official international framework for natural capital accounting (The System of Environmental-Economic Accounting, SEEA).

Ecosystem accounting entailed estimation of the extent of different ecosystem assets (EAs) in the study region (district and federal state) using temporal remote sensing data (acquired through space-borne sensors at regular intervals and available since 1970's. This spatial data helps in compiling ecosystem extent accounts and provides an underlying infrastructure for measuring ecosystem conditions and modeling ecosystem services. The analyses of temporal remote sensing data helped in assessing the extent of changes of an ecosystem over time. Ecosystem extent accounts record the total area of each ecosystem, which is classified by type within an ecosystem accounting area and, over time, in a specified area (Karnataka State, India).

The objective of this chapter is to assess the extent of ecosystems for select districts in Karnataka State through temporal remote sensing data with collateral data. This involves the assessment of land use dynamics using temporal remote sensing (RS) data. The latest RS data (2018/19) was analysed using supervised classification techniques, and compared with the land uses of the earlier years to understand the extent of ecosystems, extent of degradation, habitat loss, and deforestation rates.

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Ecosystem extent through land use analyses reveals that the agriculture ecosystem, with a spatial extent of 127,962 sq.km (66.72%) constitutes the major asset in Karnataka, India. This is followed by plantations (21,325 sq.km., 11.123%), evergreen forests (10,887 sq.km, 5.68%), moist deciduous forests (7892 sq.km, 4.12%), dry deciduous forests (4280 sq.km., 2.23%) and scrub grasslands (4906 sq.km, 2.56%). The State has 5.7% area under evergreen forest cover (2019) compared to 6.5% (2005) and 4% moist deciduous forests compared to 5.2%. The loss of evergreen and deciduous forest cover across the State articulates the anthropogenic pressure, which signifies an increase in monoculture and built-up areas. The State had 1.4% of the area under built-up (2005) compared to 3% in 2019.

District-wise analyses reveal that the evergreen forest cover has lost from 68 to 29% in Uttara Kannada district, and the area under human habitation has increased during the last four decades, evident from the increase of built-up area from 0.38 to 5.2% (1973–2018).

LU analyses of Shimoga highlight the loss of forest cover from 43.83% (1973) to 34% (2018) with the increase of built-up from 0.63% (1973) to 2.35% (2018), plantations (9–30%), industrial and cascaded developmental activities.

Temporal LU analyses highlight that the major portion of Mysore district is under agriculture (66.57% in 2019), and a loss of moist deciduous forest cover from 3.8 to 2.2% is noticed. The built-up cover has increased from 0.3 to 5% due to the growth in Mysore city and its sub-urbans.

The land use analysis of Belgaum district shows loss of evergreen forest cover from 7.75 to 5.64% from 1989 to 2019.

Land use analyses portray changes in deciduous forest cover and an increase in scrub forest cover over four decades in Chamarajanagar district. Recurring fires in the Bandipur region have transformed large tracts of forests from deciduous to scrub cover. The region has shown an increase in agriculture by 37–43%.

The spatio-temporal land use analysis of Kodagu district highlights the loss of evergreen cover and the increase in built-up and monoculture plantation areas. The region had an evergreen cover of 40.47–24.17% by 2019. The increase in resorts, buildings, and other infrastructure developments has resulted in an increase in built-up cover from 0.42 to 2.34%.

The Davangere district has undergone changes in land use in built-up cover from 0.47% to 3.15%, horticulture area from 0.89 to 2.5%, and agriculture area from 83 to 79% from 1989 to 2019. The non-forest cover has increased to 85.31%.

List of Abbreviatons

ADTR	Anshi-Dandeli Tiger Reserve
ESR	Ecologically Sensitive Regions
ETM+	Enhanced Thematic Mapper Plus
FCC	False Colour Composite
GHG	Green House Gas

GIS	Geographic Information System
GLP	Global Land Project
GPS	Global Positioning System
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing
LANDSAT	Land Remote-Sensing Satellite (System)
LISS 4 MX	Linear Imaging Self-Scanning Sensor 4 Multispectral
LULC	Land Use Land Cover
MoEFCC	Ministry of Environment and Forests and Climate Change
MSS	Multi-Spectral Scanner
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NRSC	National Remote Sensing Agency
QGIS	Quantum GIS
RS	Remote Sensing
SOI	Survey of India
TM	Thematic Mapper
USGS	United States Geological Survey

1 Introduction

Ecosystems (terrestrial and aquatic) are vital for the survival of humans on Earth. Ecosystems provide an array of goods (food, fodder, etc.) and services (remediation, clean air, water, etc.) that humans depend upon to sustain their lives. The stock of ecosystem resources (biotic and abiotic) that provide goods and services is referred to as natural capital. The services provided by these ecosystems support the economy and society. However, the contributions by the ecosystems or natural capital are often undervalued while making economic decisions. This necessitates the accounting of natural resources to minimize overexploitation, mismanagement, etc. The process of accounting stocks and flows of goods and services (natural resources) in a given ecosystem of a region is often termed natural capital accounting. In natural capital accounting, ecosystems are assets that provide ecosystem services to people.

Landscapes are composed of many dynamic components (landscape elements/ ecosystems) with their dynamics. A natural landscape has complex ecological, economic, and cultural qualities on which humans and other life forms depend directly. Landscape is the heterogeneous land area of interacting systems that forms an interconnected system called ecosystems (Forman and Gordron 1986). The functional aspects (interaction of spatial elements, cycling of water and nutrients, biogeo-chemical cycles) of an ecosystem depend on its structure (size, shape, and configuration) and constituent's spatial patterns (linear, regular, aggregated). The status of a particular landscape is derived from land use land cover [LULC] information. Temporal land use and land cover information of a region provides a base for accounting the natural resources availability and their utilization. The information pertaining to LULC provides a framework for decision-making towards sustainable natural resources management. The analysis of the LULC change addresses issues like climate change, deforestation, soil erosion by water and wind, salinization etc.

Land use, Land cover [LULC] dynamics: Land cover [LC] relates to the discernible Earth surface expressions, such as vegetation or non-vegetation (soil, water or anthropogenic features), indicating the extent of Earth's physical state in terms of the natural environment (Lambin et al. 2001; Ramachandra et al. 2012). Variations in topography, vegetation cover, and other physical characteristics of the land surface influence surface-atmosphere fluxes of sensible heat, latent heat, and momentum of heated air particulates caused by conduction, convection and radiation, influencing weather and climate. Land use [LU] expresses human uses of the landscape, e.g., for residential, commercial, or agricultural purposes. Land cover changes induced by human and natural processes play a significant role at global and regional scale patterns of the climate and biogeochemistry of the Earth system. Land use information is vital for regional planning and management activities and has been considered essential for modeling and understanding the Earth as a system (Ramachandra and Shruthi 2007).

Land use changes alter the homogeneous landscape into a heterogeneous mosaic of patches. The LULC changes are due to natural as well as human-induced alterations. These changes are highly dynamic and characterized by a heterogeneous landscape facilitating socioeconomic–environmental interactions. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics initiate changes in land cover. Globally, land cover is altered principally by direct anthropogenic use such as agriculture, livestock raising, forest harvesting & management, population change, urbanisation, and other developmental activities (Meyer 1995). Natural disturbances tend to alter forest landscape patterns differently from anthropogenic impacts (Mladenoff 1993), human-induced impacts are quantified as more deleterious effects between patches as compared with natural changes (Hudak et al. 2007). The undisturbed (or wilderness) areas represent only 46% of the Earth's land surface (Mittermeier et al. 2003). Forests covered about 50% of the Earth's land area 8000 years ago, as opposed to 30% today (Ball 2001).

Land use categories in a region depend on the agroecological aspects. Hence, in districts located in hot dry arid or hot dry semi-arid and arid, do not have all categories of land use (especially forest classes). Hence, land use/land cover categories were classified based on the agroecological and agro-climatic zones, using a supervised classification technique based on a Gaussian maximum likelihood algorithm with training data (collected from the field using GPS).

A key feature of ecosystem accounting as per the official international framework for natural capital accounting (The System of Environmental-Economic Accounting, SEEA) is its capacity to integrate spatially referenced data of ecosystems (i.e., data about the location, size, and condition of ecosystems) within a given area and account how these are changing.

Ecosystem accounting entails estimation of the extent of different ecosystem assets (EAs) in the study region (district and federal state) using remote sensing data (acquired through space-borne sensors at regular intervals and available since the 1970s. The spatial information helped to compile an ecosystem extent account and provided an underlying infrastructure for measuring ecosystem conditions and modeling ecosystem services. The temporal data analyses help assess the extent of changes in an ecosystem over time. Ecosystem extent accounts record the total area of each ecosystem, which is classified by type within an ecosystem accounting area and, over time, in a specified region (district, Karnataka State, India),

The objective of the current chapter is to compile ecosystem extent accounts of Karnataka State across districts using temporal remote sensing data, collateral data and field data (collected using pre-calibrated global positioning system from districts, chosen based on agro-climatic zones) in Karnataka State.

2 Study Region: KARNATAKA STATE, INDIA

Karnataka is one of the four southern states of Peninsular India and came into existence with the States Re-organisation Act (1956, Nov 1). Extending 760 km N–S (11˚34′ N and 18˚27′ N) and 420 km E–W (74˚3′ E and 78˚ 34′ E), Karnataka has a spatial extent of 1,91,846 sq.km, which accounts for 5.8% of India's geographical area (Fig. 1).

Karnataka is bounded by the Arabian Sea and the Laccadive Sea on the west, Goa on the north-west, Maharashtra on the north, Telangana on the north-east, Andhra

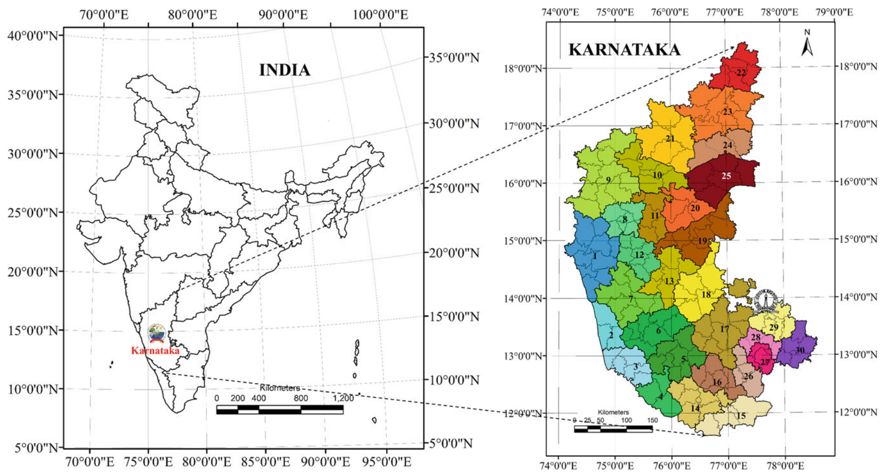

Fig. 1 Karnataka State, India with the administrative (district and taluk) boundaries

Pradesh on the east, Tamil Nadu on the south-east and Kerala on the south-west. It is situated on a tableland where the Western and Eastern Ghats' ranges converge into the Nilgiri hill complex.

Karnataka is divided into 30 Districts, which consist 178 Sub-districts (taluks), with 367 towns and 27,397 villages (Table 1 and Fig. 1) according to the Census of India.

Table 1 Karnataka administrative divisions (Census 2011)

Sl. no	District	Area km^2	Taluks	City/Town	Villages
1	Uttara Kannada	10,306	11	21	1243
2	Udupi	3573	3	21	233
3	Dakshina Kannada	4850	5	42	331
4	Kodagu	4105	3	5	291
5	Hassan	6821	8	14	2418
6	Chikkamagaluru	7214	7	9	1022
7	Shimoga	8479	7	9	1444
8	Dharwad	4258	6	6	361
9	Belagavi	13,392	10	34	1263
10	Bagalkot	6567	7	15	613
11	Gadag	4658	5	9	322
12	Haveri	4821	7	10	696
13	Davanagere	5919	6	6	800
14	Mysore	6321	7	20	1199
15	Chamarajanagar	5636	4	5	428
16	Mandya	4946	7	9	1368
17	Tumkur	10,600	10	12	2582
18	Chitradurga	8436	6	9	948
19	Bellary	8457	7	13	522
20	Koppal	5578	4	6	595
21	Vijayapura	10,965	5	6	679
22	Bidar	5446	5	8	595
23	Kalburgi	10,507	7	13	871
24	Yadgir	5282	3	7	487
25	Raichur	8468	5	9	815
26	Ramanagara	3524	4	6	820
27	Bengaluru (Urban)	2193	4	19	562
28	Bengaluru (Rural)	2298	4	8	957
29	Chikkaballapura	4245	6	8	1324
30	Kolar	3981	5	8	1608