DOI: https://doi.org/10.3897/arphapreprints.e111028

Valuation of Ecosystem Services, Karnataka State, India

T. V. Ramachandra, Vinay Shivamurthy, Bharath Settur, Bharath Aithal

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 15/08/2023. DOI: https://doi.org/10.3897/arphapreprints.e111028

Valuation of Ecosystem Services, Karnataka State, India

T V Ramachandra[‡,§], Vinay S[‡], bharath Settur[‡], Bharath H Aithal[|]

‡ Energy & Wetlands Research Group, Indian Institute of Science, Bangalore 560012, India
§ IISc_EIACP, Environmental Information System, Bangalore 560012, India
| Ranbir and Chitra Gupta School of Infrastructure Design and Management, Indian Institute of Technology, Kharagpur, Kharagpur, India

Corresponding author: T V Ramachandra (tvr@iisc.ac.in)

Abstract

Humans depend on the environment for their basic needs, such as food, fuel, minerals, water, air, etc. Burgeoning unplanned development activities to cater to the demands of the increasing population have put tremendous pressure on natural resources with the diversion of natural ecosystems to other uses. Over the years, the unsustainable practices involved in extracting and overexploiting natural resources have led to their degradation and depletion.

India has been trying to accelerate economic growth and relax environmental laws. Hence, there is a pressing need to undertake the natural capital accounting and valuation of the ecosystem services, especially intangible benefits, provided by ecosystems in India. The value of all ecosystem services, including the degradation costs, needs to be understood for developing appropriate policies toward the conservation and sustainable use and management of ecosystems. Ecosystem services were quantified following the ecosystem services valuation protocol of the System of Environmental Economic Accounting (SEEA). This communication focuses on ecosystem services in forest and agricultural ecosystems in Karnataka state, India, for 2005 and 2019. A comparison of values of services in 2019 with 2005 (values adjusted through consumer price index) highlights that there has been a considerable decline in ecosystem services in Karnataka– a 28.5% reduction in provisioning services (51.6% reduction in forest ecosystems), a 21% reduction in regulatory services (mainly in forest ecosystems - 27.1% reduction), and a 1.9% reduction in cultural services.

Ecosystem services were aggregated to compute the Total Ecosystem Supply Value (TESV). The TESV of forest and agricultural ecosystems in Karnataka was 3620 billion INR in 2005 (forest ecosystems: 2841 billion INR and agricultural ecosystems: 779 billion INR). However, overall, TESV declined in 2019 to 2912 billion rupees, with forest ecosystems driving this decline with a 35% decline in TESV. The TESV was also compared to the GDP of Karnataka, which is about 10128 billion rupees. The TESV of the forest ecosystem is equivalent to 18.1% of the GDP, and the TESV from agriculture ecosystems is equivalent to about 10.6% of the GDP in Karnataka. The decline in the TESV highlights the degradation of forest ecosystem assets from 2005 to 2019 due to the reduction in ecosystem extent and ecosystem condition. The decrease in value is also demonstrated by a fall in the net present value (NPV) of expected future returns of the ecosystem services supplied by forest ecosystem assets. The NPV of the assessed ecosystems based on 2005 ecosystem flows is about 93130 billion INR (forest ecosystem: 73099 billion INR, agriculture ecosystem: 20031 billion INR). However, the NPV of ecosystems in Karnataka, based on 2019 flows, indicates 74938 billion INR (forest ecosystem: 47214 billion INR, agriculture ecosystem: 27724 billion INR). The analysis highlights that there has been a decline of 35.4% in asset value of forest ecosystems with an increase in NPV of agriculture ecosystems by 38% due to transitions of forest ecosystems to croplands or horticulture (agriculture ecosystems).

Ecosystem accounts make the value of ecosystem services visible, allowing them to be internalized into decision-making, enabling 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 is tremendous pressure to relax forest laws and divert forests to non-forest uses without proper consideration of the sustainability of such actions.

Keywords

Ecosystem, Biodiversity, Natural Capital Accounting, Net Present Value (NPV), Total Ecosystem Supply Value (TESV)

Introduction

Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activities. 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 categorised as (i) provisioning 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 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 contributes to a range of cultural benefits (SEEA EA 2021).

The ecosystem service approach systematically capturing the full range of environmental impacts offers a way to understand and deal with the feedback created when ecosystems are used to meet anthropogenic needs (Rodríguez et al. 2006). Burgeoning unplanned development activities to cater to the demands of the increasing population have put tremendous pressure on natural resources (Kulkarni and Ramachandra 2009). An increased surge in developmental and technological activities over the last two decades, with no regard to their ecological implications, has led to indiscriminate disposal of wastes (liquid and solid), contributing to the degradation of the natural ecosystems, which has resulted in a substantial and largely irreversible loss in the diversity of life on Earth (MEA 2005, Foley et al. 2005).

GDP (Gross Domestic Product), a measure of the current economic well-being of a population, based on the market exchange of material well-being, will not represent the decline in these assets (wealth) at all. Thus, the existing GDP growth percentages used as yardsticks to measure the development and well-being of citizens in decision-making processes are substantially misleading, yet they are being used (Gundimeda et al. 2007, De Groot et al. 2020). The monetary valuation of ecosystem services can help to build a better understanding of their influence on well-being and can further facilitate information-driven decisions and policy reforms that align with the Sustainable Development Goals (SDGs).

Ecosystem services encompass all interactions between ecosystems and people, including in situ and remote interactions. 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. There has been a growing interest in ecosystem services (ESs), and ES conservation management strategies (Costanza et al. 1997, De Groot et al. 2020, MEA 2005, TEEB 2010).

Forests worldwide are critically essential habitats of biological diversity and ecological functions. The contributions range from the provision of clean water to the sequestration and storage of carbon to opportunities for recreation and relaxation. Forest ecosystems support numerous ecosystem goods and services, and cater to the economy directly or indirectly, evident from the earlier estimate of US$ 18 trillion/year (Costanza et al. 1997). Thus, forests are natural capital/ principal assets aiding human development while supporting numerous functions (MEA 2005).

Globally, forest ecosystems are under severe threat due to anthropogenic pressures. The loss of forests has been a causal factor for enchaining the disasters such as increased frequency of floods and droughts, global warming, extreme climatic conditions such as large-scale variations in rainfall characteristics, increasing temperatures (Ramachandra and Bharath 2020), etc. The appraisal of forest ecosystem services can help clarify trade-offs among conflicting environmental, social, and economic goals in the development and implementation of policies and to improve management. Policymakers need such information to support conservation funding, engage local communities, and develop market-based instruments for conservation (Ramachandra and Bharath 2020). Valuation studies have uncovered the significance of forest resources and provided a deeper understanding of many ways in which forest resources benefit humankind (De Groot et al. 2020, Ramachandra and Bharath 2020, Ramachandra et al. 2020).

Objectives, concept and approach

The ecosystem accounts have been developed as per the protocol of the System of Environmental-Economic Accounting –Experimental Ecosystem Accounts (SEEA EA 2021). In the current analysis, the accounts were developed using spatially explicit estimates of the supply of ecosystem services in physical terms and their benefits in monetary terms (Wang et al. 2021, Hein et al. 2020, La Notte and Rhodes 2020, Bagstad et al. 2020). The objectives of the current study are to (i) to assess the ecosystem services values for the forest, agriculture (croplands and horticulture) ecosystems, district-wise for Karnataka State, India for 2005 and 2019 (ii) the computation of the total ecosystem supply value (TESV), and (iii) the computation of Net present value (NPV) of ecosystem assets.

Methodology

Materials and Method

Study Area: Karnataka is one of the four southern states of Peninsular India with a spatial extent of 1,91,846 sq. km, which accounts for 5.8% of India’s geographical area (Fig. 1) and extends 760 km N-S (11˚34’ N and 18˚27’ N) and 420 km E-W (74˚3’ E and 78˚ 34’ E). The State is divided into seven agro-ecological zones based on physiography, soil, and bio-climate. Karnataka State has 3.83 million ha of recorded forest cover, and harbours the Western Ghats region with a significant variety of flora and fauna endemic and threatened species, one of the 36 global priority hotspots for conservation. The forest ecosystem of Karnataka is unique and includes tropical evergreen, semi-evergreen, moist deciduous, dry deciduous, thorny scrubs, sholas, and coastal mangroves account for about 22.61% of the State's geographical area is under forest cover (KSRSAC 2019, NRSC 2020). Karnataka has a repository of rich biodiversity with more than 1,20,000 known species, including 4,500 flowering plants, 800 fishes, 600 birds, 160 reptiles, 120 mammals, and 1,493 medicinal plants. The State has five national parks, 30 wildlife sanctuaries, 15 conservation reserves, and one community reserve, accounting to 23.59% of the total forest area.

Ecosystem extent account: Temporal remote sensing data is used for assessing the spatial extent of ecosystems in Karnataka.

Valuation of forest ecosystem services: The data for provisioning services (physical as well as monetary) of forest ecosystems for five years intervals (2001-2005 and 2014-2019) were collected from the field and the Karnataka Forest Department (KFD 2020, KSRSAC 2019). Ecosystem services are accounted for through the (i) residual value method, (ii) benefit transfer method, and (iii) biophysical models- InVEST, depending on the availability of data. The residual value method takes the gross value of the final marketed good (to which the ecosystem service provides input) and deducts the cost of all non-ecosystem inputs, including labour, produced assets, and intermediate inputs (as per SEEA Central Framework) has been used to estimate ecosystem services.

Fig. 2 and Table 1 summarises the method adopted for the computation of services from forest ecosystems. The supplementary section (Table S1, Suppl. material 1) provides details of the service-wise data source and method adopted for quantification.

Total Ecosystem Supply Value [TESV] and Net Present Value (NPV)

Monetary values of ecosystem services (provisioning, regulating, cultural services, and TESV) of 2005 and 2019 are compared to understand ES variations due to changes in the spatial extent and condition of the ecosystem. The monetary values of 2005 were adjusted to 2019 values by considering the GDP deflator (MOSPI 2020) of an inflation rate of 2.92 times (Inflation Calculator Indian Rupee 2019).

The net present value (NPV) of an asset (forests, agriculture) in Karnataka is computed using TESV -the total value of ecosystem flow based on a social discount rate of 3% and a period of 50 years (prices to remain the same with no inflations for 50 years).

Results

Assessment of ecosystem extent over time: Land use analysis was carried out using remote sensing data from 1985 to 2019 through a supervised classifier based on the Gaussian maximum likelihood algorithm (Ramachandra and Bharath 2020) to assess the extent of ecosystems. Temporal land use analyses reveal the decline of forest cover in Karnataka from 1985 to 2019 (Fig. 3). Currently, 15% of the State's geographical area is forested, compared to 21% in 1985 (Table 2). Natural forests show a decline in evergreen forests from 7.5% (1985) to 5.7% (by 2019), moist deciduous forests from 5.7% (1985) to 4.1% (by 2019), and dry deciduous forests from 4.0% (1985) to 2.2 % (2019), which have resulted in a disruption in the provision of ecosystem services, affecting the hydrologic regime and natural resources availability. The built-up area has increased from 0.5% (1985) to 3% (by 2019), and the horticulture area has increased from 8.8% (1985) to 11.1% (2019), and category-wise land-use transitions is presented in Supplementary Table (Table S2, Suppl. material 2).

Valuation of the ecosystem services

Ecosystem services and the natural capital stocks in Karnataka State make significant direct and indirect contributions to the district and state economies and human welfare. The evaluation of ecosystem services is done as per SEEA EA protocol (SEEA EA 2021), which will aid in formulating policy and legislation that can provide protection and sustainable management of ecosystems to sustain vital services.

The forest provisioning services (physical values), area of extraction for two five-year periods (2001-2005 and 2015-2019), and seigniorage (residual) value of goods were compiled from the Karnataka Forest Department. Averages of five years of goods were used to quantify goods in physical terms for 2005 and 2019. Ecosystem services were computed based on the ecosystem flows in 2005 and 2019. Ecosystem services values of 2005 were adjusted through the consumer price index or GDP deflator; these values reflect the real measures of ecosystem services, which could be compared with ecosystem services of 2019.

A comparison of values of ecosystem services in 2019 with 2005 highlights there has been a considerable decline in the services evident from 28.4% reduction in provisioning services (51.6% reduction in forest ecosystem), 14 % reduction in regulatory services (mainly in forest ecosystem - 27.1% reduction), and 0.2% reduction in cultural services. Supplementary tables (tables S3, Suppl. material 3 and Table S4, Suppl. material 4 list services by ecosystem type (forest, agriculture, and horticulture) for 2005 (at 2019) and 2019, respectively.

The provisional services of forest ecosystems in Karnataka amount to 517 (2005), declined to 531 (2019) billion rupees per year due to the degradation of forests (extent and condition). The total regulating services amount to 1270 (2005) and 926 (2019), and cultural services amount to 303 (2005) and 295 (2019) billion rupees per year. Forests in the Western Ghats showed higher values in terms of cultural services, primarily spiritual, recreation, and artistic services, emphasizing the intrinsic relation of forests with the culture of the society.

The total ecosystem supply value (TESV) amounts to 2,894 billion INR/year (2005) and 1,835 billion rupees/year (2019). Provisioning services constitute 44%, regulating services 45%, and cultural services 11% of TESV for 2005 (Fig. 4i. Similarly, provisioning services constitute 34%, regulating services 51%, and cultural services 16% of total TESV for 2019 (Fig. 4).

Table 3 lists TESV or GEP for Karnataka, considering forest and agriculture (croplands and horticulture) ecosystems. The TESV of these ecosystems was 3620 billion rupees in 2005 (forest ecosystem: 2,841 billion rupees and agriculture (croplands and horticulture) ecosystem: 779 billion rupees). Similarly, TESV computed for 2019 indicates 2,912 billion rupees (forest ecosystem: 1,835 billion rupees and agriculture 1,077: billion rupees). The analyses reveal of 35.4% reduction in TESV of forest ecosystems from 2005 to 2019, mainly due to the decline in ecosystem extent and condition.

The ***net present value (NPV)*** of ecosystem assets is presented in Table 4 for 2005-2019, which is about 93,130 billion INR (forest ecosystem: 73,099 billion INR; agriculture: 20,031 billion INR) in 2005 and declined by 19.5% to 74,938 billion INR (forest: 47,214 billion INR; agriculture: 27,724 billion INR) based on 2019 flows. A decline of 35.4% in NPV of forest ecosystems is due to the transition of forest ecosystems to either croplands or horticulture (agriculture ecosystems), which correlates to an increase in NPV of agriculture ecosystems by 23%. The analyses reinforce the critical role of a forest ecosystem with native species of vegetation in providing critical ecosystem services.

Discussion

Erosion in natural capital and consequent decline in the flow of ecosystem services during the post-industrialisation era necessitates developing appropriate metrics of ecological performance integrated into societal decision-making. This also entails developing integrated ecological and economic models to understand variations in the ecosystem services due to changes in ecosystem extent and conditions with anthropogenic activities. Comprehensible summary statistics of ecological performance would help in the prudent management of ecosystems. Integrating the economic accounting system with the environmental and ecological accounts would aid as a viable tool for impact assessments, as it provides insights into the consequences of policy implementation on well-being. Ecosystem accounting has been standardised by the United Nations (UN) in the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA-EA) by formalising the concepts of natural capital, which makes nature's contributions to society more visible and enables the impact of human activity to be reflected in changes to ecosystem condition and extent (SEEA EA 2021).

Ecosystem accounting entails quantifying the supply of ecosystem services at a landscape scale for a series of accounting periods (SEEA EA 2021), which requires ecosystem services data at a broad spatial scale for multiple periods, and the non-availability of data frequently constrains the accounting exercise in many regions. Long-term monitoring is essential to address the complexity and uncertainty inherent in ecological systems.

Environmental-Economic Accounting is explicitly designed to integrate natural capital through consistent accounting rules and structure to environmental information by quantifying stocks of environmental assets, environmental flows into and out of the economy, and economic activity related to the environment (SEEA EA 2021). But, ecosystems are not monitored in all regions, and data is rarely collected for the specific purpose of building ecosystem accounts, which poses serious challenges as (i) ecosystem data do not exist or are inadequate for accounting purposes, (ii) aggregation to a particular administrative unit is difficult based on the accounts developed for spatial subunits such as ecosystem types, (iii) requirement of higher spatial resolution of remote sensing data to maintain accuracy.

Natural capital accounting (NCA) is essentially a data-integration exercise, aiming to draw new insights by realigning environmental and economic data into a consistent framework (Bagstad et al. 2021) with key challenges of improving data quality. Developing ecosystem accounts require skills in spatial data analyses and environmental modeling, which is possible now with the availability of multi-resolution spatial data acquired through space-borne sensors at regular intervals and advancements in geoinformatics through machine learning algorithms. Challenges in implementing SEEA framework are the availability of reliable data with intra and inter-temporal methodological consistency. Natural capital analyzed at disaggregated levels would aid in accounting for local management practices, societal demands, and future scenarios. Modeled results can be aggregated at various scales, and limitations that exist when disaggregating statistical data reported by administrative divisions (Bagstad et al. 2020).

The ecosystem services embedded in forest products consumed in the accounting period are measured and valued in accordance with their resource rents. The average residual value is computed considering values for a 5-year period to minimise variations in input cost values. The economic value of ecosystem services and environmental income for each activity in the forest, provide relevant information for all agents interested in the interaction between ecosystem assets and services and the regional economy. However, a major shortcoming is the non-inclusion of environmental income (for example income by the tourism sector in natural areas does not include an increase in the marketed services of local services –lodging and boarding facilities, etc.) embedded in industries and household consumptions in the forest income (Lai et al. 2018). Other challenges are the availability of primary statistical data on ecosystem services and assets. However, spatially explicit income for forest ecosystems beyond strict market transactions at regional levels can be generated with the availability of adequate resources considering an accounting framework that effectively reflects stock variation, ecosystem services, and natural resource use in economic activities.

Natural capital accounting would enhance transparency and accountability of ecosystem use through the depiction of resource rents in a spatially explicit manner, providing an objective basis for their accounting in the regional accounts for taxation (Hein et al. 2020) and monitoring of resource use, including UN Sustainable Development Goals. Institutional challenges encountered while integrating data include compatibility of data formats maintained by various institutions/ organisations and reluctance of bureaucracy to share data. Other challenges are (i) non-capture of all interactions between humans and nature, (ii) non-inclusion of thresholds and feedbacks of ecosystems.

Spatially explicit integrated ecological–economic modelling to predict the flow of ecosystem services and economic valuation methods have been applied to estimate the value of ecosystem services (Ouyang et al. 2020, La Notte and Rhodes 2020, Hein et al. 2020, Bagstad et al. 2020, Wang et al. 2021). Total ecosystem supply value (TESV) or gross ecosystem product (GEP) would aid in decision-making with clear evidence of the monetary value of ecosystem services with insights into the values of nature and their contributions to human well-being. The current path of economic growth through GDP gives prominence to economic performance and excludes vital ecosystem services and the conservation of ecosystem assets. The ecosystem contributions are computed by subtracting the costs of other inputs (labor cost, machinery, purchased inputs, etc.) from the accounting value. Nonetheless, the major challenge is to separate nature's contribution from the contribution of anthropogenic assets and human labor for all ecosystem services. Hence the emphasis during the early stages of biophysical monitoring of an ecosystem is to compile the data pertaining to the quantity (physical), price, and costs of anthropogenic inputs. Though there are significant improvements with the availability of multi-resolution remote sensing data to assess the ecosystem extent and conditions, there are still challenges/gaps, especially for accounting ecosystem services, which require primary data collection with field measurements.

The assessment of ecosystem extent, service, and asset accounts using the SEEA EA has enabled a thorough analysis of the changes in the provision of ecosystem services in Karnataka between 2005 and 2019. The comparison of the values of goods of 2019 with 2005 highlights there has been a considerable reduction in ecosystem services – 51.6% reduction in forest ecosystem, a 27.1% reduction in regulatory services, and a 2.7% reduction in cultural services. In terms of the reductions in provisioning services, these included a 93% decline in bamboo, a decline in NTFP (honey reduced by 97%, tamarind reduced by 75%), a 42% decline in fodder and a 35% decline in medicine. The large decreases in provisioning and regulatory services can be attributed to the degradation of forests (extent and conditions) in Karnataka from 2005 to 2019.

The decline (35%) of TESV highlights the degradation of forest ecosystem assets from 2005 to 2019 due to the reduction of ecosystem extent and condition. The decrease in value is also demonstrated by a fall in the net present value of expected future returns of the ecosystem services supplied by forest ecosystem assets, as shown through the ecosystem monetary asset account.

The ecosystem services computed for Karnataka State support the viability of markets for particular services. Developing such markets requires additional institutional reforms, such as property rights changes and land and labor market reforms. Hence, ecosystem services need to be internalized in decision-making, strengthening the economic case for conserving forests in all states in India and developing countries, as there is tremendous pressure to relax forest laws and divert forests to non-forest uses with the illusion of boosting long-term economic growth. The main policy challenge is to promote conservation and develop such markets so that those bearing the cost of protection are adequately compensated. The valuation of ecosystem services done in Karnataka State and replicating this exercise in other states will undoubtedly play a vital role in conservation planning with ecosystem-based management in India. This requires:

i) Strengthening biophysical research on ecosystem services, with a focus on those that would seem to have the highest economic value potential (e.g., changes in the climatic, hydrologic regime, etc.);

ii) Inventorying, mapping, and monitoring ecosystems' spatial extent and conditions through the use of advanced spatial technologies with temporal remote sensing data;

iii) Promoting valuation studies reveals current incentives, i.e., the existing distribution of net ecosystem benefits/opportunity costs across stakeholders, which will aid in internalizing the regional policies; and

iv) Developing land-use policies that consider ecosystem types and respective ecosystem services.

Conclusions

Ecosystem services were quantified based on the ecosystem flows in 2005 and 2019. Values of 2005 were adjusted through the consumer price index or GDP deflector, and these values reflect the real measures of ecosystem services, which could be compared with ecosystem services of 2019. The comparison of the values of goods in 2019 with 2005 highlights there has been a reduction of 28.5% in provisioning services (51.6% reduction in forest ecosystem), 21 % in regulatory services (mainly in forest ecosystem 27.1% reduction), and 1.9% in cultural services.

TESV or gross ecosystem product (GEP) equals ***the sum of all final ecosystem services (i.e., used by economic units) from ecosystem assets.*** The TESV of ecosystems was 3620 billion INR in 2005 (forest ecosystem: 2,841 billion INR and agriculture ecosystem: 779 billion INR). TESV computed for 2019 indicates a 35.4% decline with 2,793 billion INR (forest ecosystem: 1,835 billion INR and agriculture 958 billion INR).

The GDP of Karnataka is about 10,128 billion rupees. The TESV of the forest ecosystem is about 18.1%, and agriculture is about 10.6% of the GDP in Karnataka. The presence of rich forests in the Western Ghats districts contributes to higher TESV, highlighting that TESV is correlated with the extent and conditions of forest ecosystems.

The NPV of forest and agriculture ecosystems based on 2005 ecosystem flows is about 93,130 billion INR (forest: 73,099 billion INR; agriculture: 20,031 billion INR). Similarly, the NPV of ecosystems in Karnataka based on 2019 flows indicates 74,938 billion INR (forest: 47,214 billion INR, agriculture: 27,724 billion INR). A decline of 35.4% in NPV of forest ecosystems, mainly due to the transition of forest ecosystems to either croplands or horticulture (agriculture ecosystems). These ecosystem conversions have increased the NPV of agriculture ecosystems by 23% between 2005 and 2019.

The drivers behind the land-use change and the decline of forest resources in Karnataka are mainly the expansion of agricultural activities coupled with industrialization and rapid urbanization. However, the increase in the values of agricultural TESV and NPV at the expense of a decrease in the TESV of forest ecosystems and NPV points to the need for an adequate assessment of trade-offs in land use policy. Hence, the current study emphasizes the need for the valuation of services of all ecosystems, capitalizing on the advances in geoinformatics, availability of spatial data at regular intervals to estimate the economic value of ecosystems forests, and reflect the value of forests in policy decisions.

Finally, it should be noted that the ecosystem accounts compiled for Karnataka have a large potential to be used for payment for ecosystem services schemes. The Supreme Court of India (2006) directed the national government to set up compensatory payments for the conversion of different types of forested land to non-forest uses and use these payments to improve forest cover in India. These accounts can provide important information on the values of ecosystems and their services which can help in creating transparent criteria with which to reward states. Afforestation in the degraded landscape would aid in mitigating changes in the climate due to global warming while sustaining the livelihood of people through (i) provision of ecosystem services, (ii) improvements in the crop yield, ii) sustenance of water in the landscape, etc.

Acknowledgements

The research is part of the international EU-funded Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project. We thank William Speller (UNEP) and Bram Edens (UNSD) for reviewing and valuable suggestions.

Grant title

Natural Capital accounting and Valuation of Ecosystem Service

Hosting institution

Indian Institute of Science, Bangalore, India

Ethics and security

1. **COMPETING INTERESTS:** We have no competing interests either financial or non-financial
2. RESEARCH ETHICS: The publication is based on the original research and has not been submitted elsewhere for publication or web hosting.
3. **ANIMAL ETHICS**: The research does not involve either humans, animals or tissues

Author contributions

All authors have contributed equally - conceptualisation, data analyses, field data collection, writing, editing and revie

Conflicts of interest

The authors have declared that no competing interests exist.

References

- Bagstad K, Ingram JC, Shapiro C, La Notte A, Maes J, Vallecillo S, Casey CF, Glynn P, Heris M, Johnson J, Lauer C, Matuszak J, Oleson KL, Posner S, Rhodes C, Voigt B (2021) Lessons learned from development of natural capital accounts in the United

States and European Union. Ecosystem Services 52 https://doi.org/10.1016/j.ecoser.2021.101359

- Bagstad KJ, Ingram JC, Lange G-, Masozera M, Ancona ZH, Bana M, Kagabo D, Musana B, Nabahungu NL, Rukundo E, Rutebuka E, Polasky S, Rugege D, Uwera C, Buckley Y (2020) Towards ecosystem accounts for Rwanda: tracking 25 years of change in flows and potential supply of ecosystem services. People Nature 2 (1): 163-188. https://doi.org/10.1002/pan3.10062
- Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387 (6630): 253-260. https://doi.org/10.1038/387253a0
- De Groot R, Luke B, Solomonides S (2020) Ecosystem Services Valuation Database (ESVD). Version June2020 URL: https://www.esvd.net/
- Foley J, DeFries R, Asner G, Barford C, Bonan G, Carpenter S, Chapin FS, Coe M, Daily G, Gibbs H, Helkowski J, Holloway T, Howard E, Kucharik C, Monfreda C, Patz J, Prentice IC, Ramankutty N, Snyder P (2005) Global consequences of land use. Science 309 (5734): 570-574. https://doi.org/10.1126/science.1111772
- Gundimeda H, Sukhdev P, Sinha R, Sanyal S (2007) Natural resource accounting for Indian states — Illustrating the case of forest resources. Ecological Economics 61 (4): 635-649. https://doi.org/10.1016/j.ecolecon.2006.07.035
- Hein L, Bagstad K, Obst C, Edens B, Schenau S, Castillo G, Soulard F, Brown C, Driver A, Bordt M, Steurer A, Harris R, Caparrós A (2020) Progress in natural capital accounting for ecosystems. Science 367 (6477): 514-515. https://doi.org/10.1126/science.aaz8901
- Inflation Calculator Indian Rupee (2019) Inflation Calculator Indian Rupee. https://www.inflationtool.com/indian-rupee
- KFD (2020) Karnataka Forest Department. https://aranya.gov.in/aranyacms/ English/Home.aspx. Accessed on: 2019-5-12.
- KSRSAC (2019) Karnataka Geographical Information System, Government of Karnataka. https://kgis.ksrsac.in/kgis/portal.aspx. Accessed on: 2019-5-12.
- Kulkarni V, Ramachandra TV (2009) Environmental Management. TERI Press, New Delhi, 450 pp.
- Lai T, Salminen J, Jäppinen J, Koljonen S, Mononen L, Nieminen E, Vihervaara P, Oinonen S (2018) Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland. Ecological Modelling 377: 51-65. https://doi.org/10.1016/j.ecolmodel.2018.03.006
- La Notte A, Rhodes C (2020) The theoretical frameworks behind integrated environmental, ecosystem, and economic accounting systems and their classifications. Environmental Impact Assessment Review 80 https://doi.org/10.1016/j.eiar.2019.106317
- MEA (2005) Millinium Ecosystem assessment. Island Press, Washington DC, 221 pp. URL: http://pdf.wri.org/ecosystems_human_wellbeing.pdf
- MOSPI (2020) The Ministry of Statistics and Programme Implementation, GoI. https://mospi.gov.in/documents/213904//649960//1614147361232_b3_ES2_2020.pdf. Accessed on: 2019-5-12.
- NRSC (2020) National Remote Sensing Centre-IRS data products. https://nrsc.gov.in. Accessed on: 2019-5-12.

- Ouyang Z, Song C, Zheng H, Polasky S, Xiao Y, Bateman I, Liu J, Ruckelshaus M, Shi F, Xiao Y, Xu W, Zou Z, Daily G (2020) Using gross ecosystem product (GEP) to value nature in decision making. Proceedings of the National Academy of Sciences 117 (25): 14593-14601. https://doi.org/10.1073/pnas.1911439117
- Ramachandra TV, Bharath S (2020) Carbon footprint of Karnataka: Accounting of sources and sinks. Environmental Footprints and Eco-design of Products and Processes53-92. https://doi.org/10.1007/978-981-15-9577-6_3
- Ramachandra TV, Vinay S, Bharath S, Subash Chandran MD, Aithal B (2020) Insights into riverscape dynamics with the hydrological, ecological and social dimensions for water sustenance. Current Science 118 (9). https://doi.org/10.18520/cs/v118/i9/1379-1393
- Rodríguez JP, Beard J,TD, Bennett E, Cumming G, Cork S, Agard J, Dobson A, Peterson G (2006) Trade-offs across space, time, and ecosystem services. Ecology and Society 11 (1). https://doi.org/10.5751/es-01667-110128
- SEEA EA (2021) System of environmental-economic accounting—ecosystem accounting, final draft, version 5,. Department of Economic and Social Affairs, Statistics Division, United Nations. UNSD. URL: https://seea.un.org/
- TEEB (2010) The economics of ecosystems and biodiversity, ecological and economic foundations. Earthscan, London and Washington. http://teebweb.org/. Accessed on: 2019-5-25.
- Wang L, Chen C, Xie F, Hu Z, Zhang Z, Chen H, He X, Chu Y (2021) Estimation of the value of regional ecosystem services of an archipelago using satellite remote sensing technology: A case study of Zhoushan Archipelago, China. International Journal of Applied Earth Observation and Geoinformation 105 https://doi.org/10.1016/j.jag.2021.102616

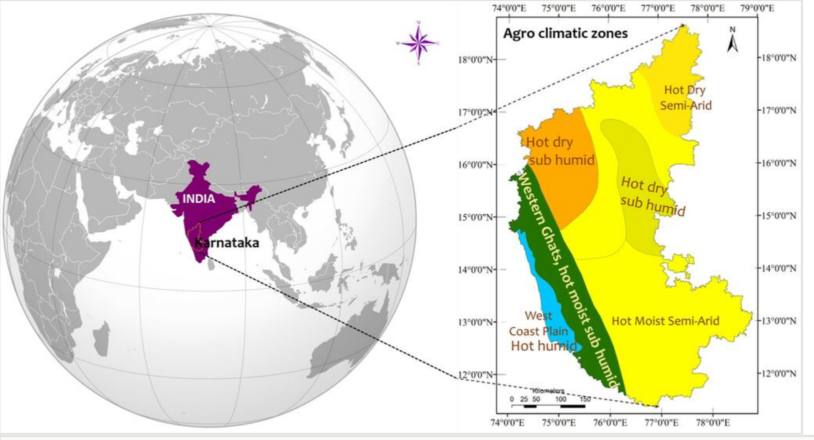

Figure 1.

Study Area -Karnataka State, India, with the agro-climatic zones.

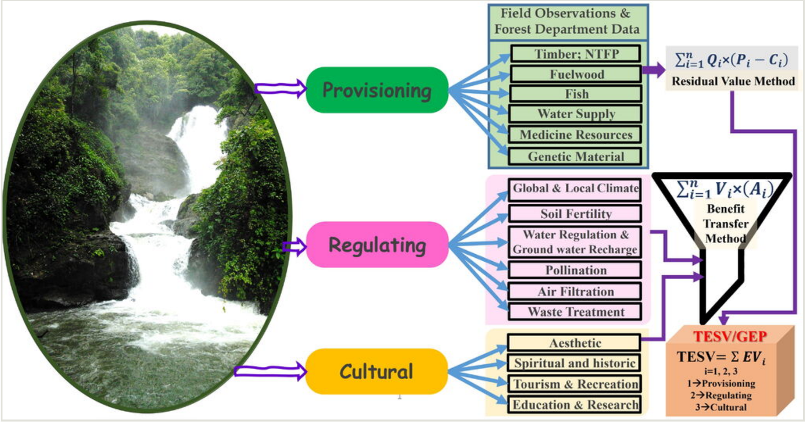

Figure 2.

Method illustrating the choice of method for the valuation of ecosystem services.

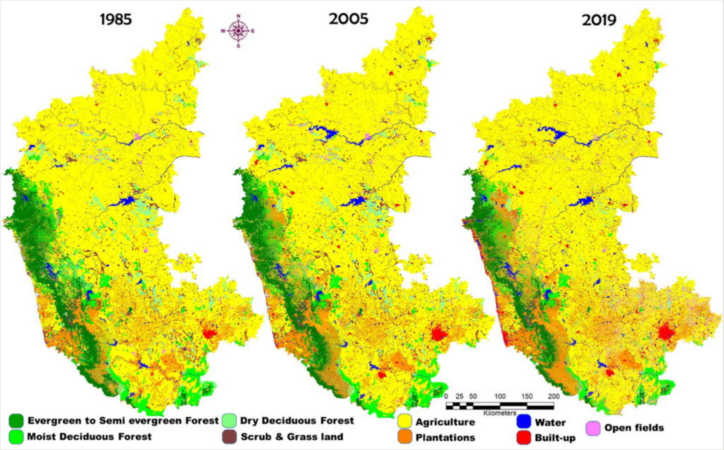

Figure 3.

Land uses from 1985 to 2019 in Karnataka.

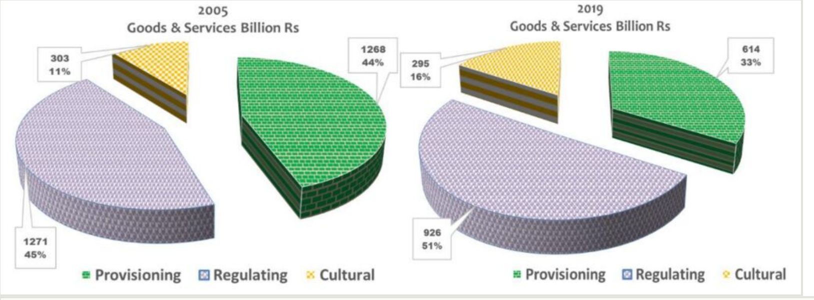

Figure 4.

Share of individual services in TESV.

Author-formatted, not peer-reviewed document posted on 15/08/2023. DOI: https://doi.org/10.3897/arphapreprints.e111028

Table 1.

Method for accounting goods and services from forest ecosystems

Note: Supplementary Table S1 (Suppl. material 1) provides the service-wise method details

Services	Variables	Approach
Provisioning services	Timber, Bamboo, Non-Timber Forest Produce (spices, etc.), Fuelwood Fish and other aquatic products Fodder, Water, Medicine, Genetic material	**Residual Method**; × Where Qi represents quantity, Pi is the price, Ci is the cost involved in the harvest
Regulating Services	Global climate regulation - carbon sequestration	Quantity of carbon sequestered annually through InVEST carbon model, based on land use data, above-ground biomass (quantified from field)
	Soil conservation & soil fertility	RUSLE, InVEST – quantified soil (sediment) using land use data and meteorological data (rainfall, temperature, evapotranspiration).and valuation based on Benefit transfer method based on case studies from India
	Water regulation and groundwater recharge	InVEST provides the quantum of water recharge within the natural forested areas.
	Pollination service	Benefit transfer method based on case studies from India × Where Vi represents the monetary values per hectare and Ai represents the area
	Water purification	
	Waste treatment	
	Air filtration services	
	Local (micro and meso) climate regulation services	
Cultural services	Aesthetic	
	Spiritual and historic	Residual method, travel cost method and supplemented with case-studies from India – benefit transfer method
	Tourism and recreational	Travel cost method Benefit transfer method
	Education, scientific and research	Based on funding – field research component
Total ecosystem supply value (TESV)	i = 1,2,3 1: Provisioning, 2: Regulating and 3 Cultural	

ARPHA Preprints *Author-formatted, not peer-reviewed document posted on 15/08/2023*. DOI: https://doi.org/10.3897/arphapreprints.e111028

Table 2.

Ecosystem extent account for land use - land cover (LULC) in – Karnataka.

Ecosystem type	**Disaggregated ecosystem type**	**Karnataka**				
		Opening stock 1985	Additions to stock	Reduction in stock	Closing stock 2019	Net change (in%) during 1985 to 2019
	Built-up	904	4866	45	5725	533.1
	Urban					
Built-up land	Rural					
	Mining					
	Sub-Total 1	**904**	**4866**	**45**	**5725**	**533.1**
	Horticulture	16790	9711	5129	21371	27.3
Agricultural land	Cropland	128468	13760	14317	127910	-0.4
	Fallow Land	1678	6284	968	6994	316.7
	Sub-Total 2	**146936**	**29754**	**20414**	**156275**	**6.4**
	Evergreen/Semi-Evergreen	14293	921	5196	10018	-29.9
	Moist Deciduous	10960	2333	5379	7914	-27.8
	Dry Deciduous	7622	981	5316	3288	-56.9
Forests	Scrub Forest	6733	922	4946	2710	-59.8
	Forest Plantation					
	Swamp/Mangroves					
	Sub-Total 4	**39607**	**5158**	**20836**	**23929**	**-39.6**
Grass / Grazing	Grass / Grazing					
	Sub-Total 5					
Snow and glacier	Snow and Glacier					
	Sub-Total 6					
	Inland Wetland					
Wetlands / water bodies	Coastal Wetland					
	River/stream/canals					
	Waterbodies	4344	2541	1023	5862	35.0
	Sub-Total 7	4344	2541	1023	5862	35.0
Grand total		191791	42319	42319	191791	

Table 3.

Comparison of provisioning, regulating, and cultural services and TESV during 2005 (in 2019 rupees) and 2019.

Ecosystems	Year	Units	Provisioning	Regulating	Cultural	TESV
Forests	2005	Million ₹	12,67,528	12,70,583	3,03,034	28,41,145
		%	44.6	44.7	10.7	100
Agriculture (Croplands and horticulture)		Million ₹	4,11,834	3,44,933	21,819	778,586
		%	52.9	44.3	2.8	100
Total		Million ₹	16,79,361	16,15,516	3,24,854	**36,19,731**
		%	46.4	44.6	9.0	100
Forests	2019	Million ₹	6,13,883	9,26,346	2,94,955	18,35,184
		%	33.5	50.5	16.1	100
Agriculture		Million ₹	5,89,283	4,59,037	29,305	10,77,625
		%	61.2	36.3	2.5	100
Total		Million ₹	12,03,166	13,85,383	3,24,260	**29,12,809**
		%	41.3	47.6	11.1	100

Table 4.

Monetary asset account (2005-2019).

	Units	Forest ecosystem	Agriculture ecosystem	Total NPV
Opening stock – 2005 (at 2019 values)	Billion ₹	**73,099**	**20,031**	**93,130**
Changes (absolute)	Billion ₹	-25,885	7,693	-18,192
Closing stock - 2019	Billion ₹	**47,214**	**27,724**	**74,938**

Supplementary materials

Suppl. material 1: Table S1. Method for computing goods and services from forest ecosystems

Authors: T V Ramachandra, Vinay S, Bharath Setturu, Bharath H Aithal
Data type: Text
Brief description: method adopted for data compilation for computing forest goods and services
Download file (1.94 MB)

Suppl. material 2: Table S2: Transitions across LU categories during 1985 to 2019 – Karnataka State (Extent in hectares and percentage)

Authors: T V Ramachandra, Vinay S, Bharath settur, Bharath H Aithal
Data type: Numerical
Brief description: Land use transitions from 1985 to 2019 nbased on temporal remote sensing data anlyses with training data from field (supervised classification) and validation through accuracy assessment
Download file (12.16 kb)

Suppl. material 3: Table S3 Ecosystem wise – Provisioning, regulatory and cultural services – 2005 (Million ₹)

Authors: T V Ramachandra, Vinay S, Bharath Settur, Bharath H Aithal
Data type: Numerical
Brief description: Ecosystem wise computation of provisioning, regulatinga nd cultural services for 2005
Download file (14.39 kb)

Suppl. material 4: Table S4. Ecosystem wise – Provisioning, regulatory and cultural services (Million ₹) – 2019

Authors: T V Ramachandra, Vinay S, Bharath Settur, Bharath H aithal
Data type: Numerical
Brief description: Ecosystem wise computation of provisioning, regulating and cultural services for 2019
Download file (14.39 kb)