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Appraisal of Forest Ecosystems Goods and Services: Challenges and Opportunities for Conservation

T. V.Ramachandra[1,2,3], Divya Soman, Ashwath D. Naik[1] and M. D. Subash Chandran[1]

[1]Energy & Wetlands Research Group, Centre for Ecological Sciences (CES)
[2]Centre for Sustainable Technologies (ASTRA)
[3]Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP)
Indian Institute of Science, Bangalore 560 012, Karnataka, India
Telephone: 91-80-23600985, 22932506, 22933099, Fax: 91-80-23601428, 23600085, 23600683[CES-TVR], E-mail: <cestvr@ces.iisc.ernet.in>,<energy@ces.iisc.ernet.in>

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ABSTRACT Valuation of ecosystem goods and services is essential to formulate sustainable development policies oriented towards the protection or restoration of ecosystems. The present study estimates the value of forest ecosystem of Uttara Kannada district by market price method. The total value of provisioning goods and services from the forests of Uttara Kannada district was estimated at Rs. 15,171 crores per year, which amounts to about Rs. 2 lakh per hectare per year. The study highlights the undervaluation of forest goods and services that is evident when the estimated total economic value of forest and the value of forest resources calculated in national income accounting framework are compared. The quantification of all benefits associated with the forest ecosystem goods and services would help in arriving at an appropriate policy and managerial decisions to ensure conservation while opting sustainable development path.

INTRODUCTION

An ecosystem is a complex of interconnected living organisms inhabiting a particular area or unit space, together with their environment and all their interrelationships and relationships with the environment having well-maintained ecological processes and interactions (Ramachandra et al. 2007, 2015). Ecosystem functions include the exchange of energy between the plants and animals that are needed for the sustenance of life. These functions include nutrient cycling, oxygen regulation, water supply etc. The flow of goods or services which occur naturally by ecological interactions between biotic and abiotic components in an ecosystem is often referred as ecosystem goods and services. These goods and services not only provide tangible and intangible benefits to human community, but also are critical to the functioning of ecosystem. Thus, ecosystem goods and services are the process through which natural ecosystems and the species that make up sustain and fulfill the human needs (Newcome et al. 2005). Ecosystems are thus natural capital assets supporting and supplying services highly valuable to human livelihoods and providing various goods and services (MEA 2003; Daily and Matson 2008; Gunderson et al. 2016). The tropical forests are the rich source of biodiversity and are probably thought of containing more than half of world's biodiversity. Biodiversity is important to human kind in fulfilling its needs by way of providing food (80,000 species), medicine (20,000 species), drug formulations (8,000 species) and raw materials (90% from forests) for industries (Ramachandra et al. 2016a, b; Ramachandra and Nagarathna 2001: Ramachandra and Ganapathy 2007). Among the terrestrial biomes, forests occupy about 31 percent (4,033 million hectare) of the world's total land area and of which 93 percent of the world's forest cover is natural forest and 7 percent is planted (FAO 2010; TEEB 2010; Villegas-Palacio et al. 2016). Forest ecosystems account for over two-thirds of net primary production on land – the conversion of solar energy into biomass through photosynthesis, making them a key component of the global carbon cycle and climate (MEA 2003). The forests of the world harbor very large and complex biological species diversity, which is an indicator for biological diversity and the species richness increases as we move from the poles to the equatorial region. Forest ecosystem services can provide both direct and indirect economic benefits. India's forest has been classified into four major groups, namely, tropical, sub-tropical, temperate, and alpine (Champion and Seth 1968). Tropical forest in particular contributes more than the other terrestrial biomes to climate relevant cycles and biodiversity related processes. These forests constitute the earth's major genetic reservoir and global water cycles (Anderson and Bojo 1992; Gunderson et al. 2016).

The ecosystem provides various fundamental benefits for our survival such as food; soil production, erosion and control; climate regulation; water purification; bioenergy, etc. These benefits and services are very crucial for the survival of humans and other organisms on the earth (MEA 2003; de Groot et al. 2002; Villegas-Palacio et al. 2016). It includes provisioning services such as food and water, regulating services such as flood and disease control, cultural services such as spiritual, recreational and cultural benefits, and supporting services such as nutrient cycling that maintains the conditions for life on earth. Sustainable ecosystem service delivery depends on the health, integrity and resilience of the ecosystem. Policy-makers, interest groups and the public require reliable information on the environmental, social and economic value of regulating services to make informed decisions on optimum use and on the conservation of ecosystems (Kumar et al. 2010). The prime reason for ecosystem mismanagement is the failure to realise the value of ecosystem. Valuation of ecosystem is essential to respite human activities apart from accounting their services in the regional planning (Ramachandra et al. 2011). The range of benefits derived from ecosystem can be direct or indirect, tangible or intangible, can be provided locally or at global scale – all of which makes measurement particularly hard (TEEB 2010). Economic valuation of natural resources aids the social planners to design and better manage the ecosystems and related human wellbeing. Figure 1 shows the interrelationship of ecosystem, ecosystem functions, economic values and its impact on ecosystem through incentive/disincentive.

Valuation of ecosystems enhances the ability of decision-makers to evaluate trade-offs between alternative ecosystem management regimes and courses of social action that alter the use of ecosystems and the multiple services they provide (MEA 2003; Villegas-Palacio et al. 2016). Valuation reveal the relative importance of different ecosystem services, especially those not traded in conventional markets (TEEB 2010).The ecosystem goods and services are grouped into four categories as provisioning, regulating, supporting and information services (MEA 2003; de Groot et al. 2002), based on the Total Economic Value (TEV) framework with significant emphasis on intrinsic aspects of ecosystem value, particularly in relation to socio-cultural values (MEA 2003). TEEB (2010) excludes the supporting services (such as nutrient cycling and food-chain dynamic) and incorporates habitat service as a separate category.

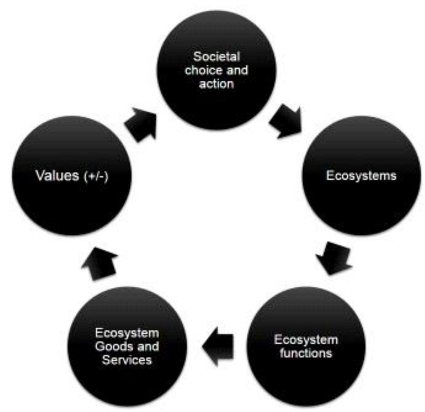

Fig. 1. Ecosystems health and economic values
Source: Author

Integrated framework for assessing the ecosystem goods and services (TEEB 2010; de Groot et al. 2002; Villegas-Palacio et al. 2016) involves the translation of complex structures and processes into a limited number of ecosystem functions namely production, regulation, habitat and information. These goods and services are valued by humans and grouped as ecological, socio-cultural and economic values. All values are estimated using the common metric, which helps in aggregating values of different goods and services (DEFRA 2007). When the market does not capture the value of environmental goods or services, techniques associated with 'shadow pricing' or 'proxy price' are used to indirectly estimate its value. Estimation of the economic values for 17 different ecosystem services (Costanza et al.1997; Villegas-Palacio et al. 2016) highlight that the annual value of the ecosystem services of the terrestrial and aquatic biomes of the world to be 1.8 times higher than the global gross national product (GNP). About 63 percent of the estimated values of ecosystem services were found to be contributed by the marine ecosystems while, about 38 percent of the estimated values were found to be contributed by the terrestrial ecosystems, mainly from the forests and wetlands.

Forests, particularly tropical forests, contribute more than other terrestrial biomes to climate relevant cycles and processes and also to biodiversity related processes (Nasi et al. 2002). Forest ecosystem services with great economic value (Ramachandra et al. 2011, 2016b; Costanza et al. 1997; Pearce et al. 2002), are known to be critically important habitats in terms of the biological diversity and ecological functions. These ecosystems serve as a central component of Earth's biogeochemical systems and are a source of ecosystem services essential for human well-being (Gonzalez et al. 2005; Villegas-Palacio et al. 2016). These ecosystem provides a large number of valuable products such as timber, firewood, non-timber forest product, biodiversity, genetic resources, medicinal plants, etc. The forest trees are felled on a large scale for using their wood as timber and firewood. According to FAO (2010) wood removals valued just over US$100 billion annually in the period 2003–2007, mainly accounted by industrial round wood. Further, 11 percent of world energy consumption comes from biomass, mainly fuel wood (CBD 2001). 19 percent of China's primary energy consumption comes from biomass and 42 percent in India. Non-commercial sources of energy (such as fire wood, agricultural and horticultural residues, and animal residues) contribute about 54 percent of the total energy in Karnataka (Ramachandra et al. 2000).

Timber and carbon wealth assessment in the forests of India (Atkinson and Gundimeda 2006) show the opening stock of forest resources as 4,740,858,000 cubic meters and about 639,600 sq. km of forest area. Biomass density/ha in Indian forests is about 92 t/ha and carbon values of Indian forests is 2933.8 million tones assessed considering a carbon content of 0.5 Mg C per Mg oven dry biomass (Haripriya 2002). The closing stock of the timber is 4704 million cum and the estimate of value is Rs. 9454 billion, the stock of the carbon is 2872 million tons with a value estimate of Rs.1811 billion. Apart from serving as a storehouse of wood which is used for various purposes, there are also equally important non-wood products that are obtained from the forests. The botanical and other natural products, other than timber extracted from the forest system are referred to as non-timber forest products (NTFPs). These resources/products have been extracted from the forest ecosystems and are being utilized within the household or marketed or have social, cultural or religious significance (Falconer and Koppell 1990; Schaafsma et al. 2014; Pittini 2011). NTFP is a significant component due to its important bearing on rural livelihoods and subsistence. NTFPs are also referred 'minor forest produce' as most of NTFP are consumed by local populations, and are not marketed (Arnold and Pérez 2001). These include plants and plant materials used for food, fuel and fodder, medicine, cottage and wrapping materials, biochemical, animals, birds, reptiles and fishes, for food and feather. Unlike timber-based products, these products come from variety of sources like: fruits and vegetables to eat, leaves and twigs for decoration, flowers for various purposes, herbal medicines from different plant parts, wood carvings and decorations, etc. The values of NTFPs are of critical importance as a source of income and employment for rural people living around the forest regions, especially during lean seasons of agricultural crops. NTFPs provide 40-63 percent of the total annual income of the people residing in rural areas of Madhya Pradesh (Tewari and Campbell 1996) and accounted 20-35 percent of the household incomes in West Bengal. The net present value (NPV) of the forest for sustainable fruit and latex production is estimated at US$6,330/ha considering the net revenue from a single year's harvest of fruit and latex production as US$422/ha in Mishana, Rio Nanay, Peru (Peters et al. 1989) on the assumption of availability in perpetuity, constant real prices and a discount rate of 5 percent.

Evaluation of the direct use benefits to rural communities' from harvesting NTFPs and using forest areas for agriculture and residential space, near the Mantadia National Park, in Madagascar (Kramer et al. 1995) through contingency valuation (CV) show an aggregate net present value for the affected population (about 3,400 people) of US$673,000 with an annual mean value per household of USD 108.

Estimation of the quantity of the NTFPs collected by the locals and forest department based on a questionnaire based survey in 21 villages of four different forest zones in Uttara Kannada district (Murthy et al. 2005), indicate the collection of 59 different plant species in the evergreen forests, 40 different plant species in the semi-evergreen forests, 12 different plant species in moist deciduous and 15 different plant species in dry deciduous forests and about 42–80 NTFP species of medicinal importance are marketed in herbal shops. Valuation reveal an annual income per household depending on the goods availability ranges from Rs. 3,445 (evergreen forests), 3,080 (moist deciduous), 1,438 (semi-evergreen) to Rs. 1,233 (dry deciduous).

Assessment of the marketing potential of different value added products from *Artocarpus* sp. in Uttara Kannada district based on field surveys and the discussions with the local people and industries (Ramana and Patil 2008), revealed that *Artocarpus integrifolia* collected from nearby forest area and home gardens is most extensively used for preparing items like chips, *papad*, sweets, etc. *Chips* and *papads* are commercially produced and sold in the markets, and primary collectors get 25 percent and the processing industry get 50 percent of the total amount paid by the consumers.

Forest ecosystems also provide other indirect benefits like ground water recharge, soil retention, gas regulation, waste treatment, pollination, refugium function, nursery function etc. in addition to the direct benefits (de Groot et al. 2002). Forest vegetation aids in the percolation and recharging of groundwater sources while allowing moderate run off. Gas regulation functions include general maintenance of habits through the maintenance of clean air, prevention of diseases (for example, skin cancer), etc.

Forests act as carbon sinks by taking carbon during photosynthesis and synthesis of organic compounds, which aids in maintaining CO_2/O_2 balance, ozone layer and also sulphur dioxide balance. Carbon sequestration potential of 131t of carbon per hectare with the above ground biomass of 349 ton/ha has been estimated in the relic forest of Uttara Kannada (Chandran et al. 2010) and 11.8 metric ton (1995) in forests in India (Lal and Singh 2000) with the carbon uptake potential of 55.48 Mt (2020) and 73.48 Mt (2045) respectively (projected the total carbon uptake for the year 2020 and 2045). The carbon sequestration potential was found to be 4.1 and 9.8 Gt by 2020 and 2045 respectively.

Vegetative structure of forests through its storage capacity and surface resistance plays a vital role in the disturbance regulation by altering potentially catastrophic effects of storms, floods and droughts. Soil retention occurs by the presence of the vegetation cover which holds the soil and prevents the loss of top soil. Pollination is an important ecological service provided by the forest ecosystem and the studies have revealed that forest dwelling pollinators (such as bees) make significant contribution to the agricultural production of a broad range of crops, in particular fruits, vegetables, fiber crops and nuts (Costanza et al. 1997).

Forest also helps in aesthetic benefit, recreational benefit, science and education, spiritual benefits, etc. The scenic beauty of forests provides aesthetic and recreational benefits through psychological relief to the visitors. An investigation of cultural services of the forest of Uttaranchal (Djafar 2006) considering six services namely aesthetic, recreational, cultural heritage and identity, inspirational, spiritual and religious and educational function, highlight the recreational value of forests US$ 0.82/ha/yr for villager's per visit. Aesthetic value derived by the preference of the villagers was estimated as US$ 7-1760 /ha/yr, derived by the preference of the villagers to live in the sites where there is good scenery. Cultural heritage and identity value was estimated as USD 1-25/ha/yr based on 24 places, 43 plant species and 16 animal species. Spiritual and religious areas was about USD 1-25/ha/yr. Educational value was obtained from the research activity and value was similar to spiritual and religious values.

Ecotourism benefit of the domestic visitor using the travel cost method in the Periyar tiger reserve in Kerala is Rs. 161.3 per visitor (Manoharan 1996), with average consumer surplus at Rs. 9.89 per domestic visitor and Rs. 140 for foreign tourists. The value of eco-tourism (as per 2005) is extrapolated as Rs. 84.5 million. The recreational value assessment of Vazhachal and Athirappily of Kerala (Anitha and Muraleedharan 2006) reveal that visitor flow on an average is 2.3 lakh (at Vazhachal) and 5.3 lakh (Athirappily) visitors/year and the average fee collection ranges from Rs. 10 (Vazhachal) to Rs.23.5 (Athirappily) lakh / year. Parking fee for vehicles itself is about Rs. 1.39 (Vazhachal) lakh /year and Rs. 2.7 (Athirappily) lakh/ year. About Rs. 5.6 lakh is earned from visitors entrance fee and parking charges. The estimated aggregate recreation surplus of the sample is equal to Rs 20, 69,214 with an average recreation surplus per visitor of Rs. 2,593.

Recreational value in the protected site of Western Ghats (Mohandas and Rema Devi 2011) based on the relationship between travel cost and visitation rate and the willingness to pay is Rs. 26.7 per visitor and the average consumer surplus per visit is Rs. 290. A similar study carried out in the valley of a national park show the net recreational benefit as Rs. 5,88,332 and the average consumer surplus as Rs. 194.68 (Gera et al. 2008). The total recreation value of Dandeli wildlife sanctuary using travel cost method during 2004-05 shows the total recreation value of Rs. 37,142.86 per Sq. km with the total value of Rs. 1,76,43,600 (Panchamukhi et al. 2008). Similarly, based on the willingness to pay for the preservation of watershed in Karnataka indicate a value of Rs.125.45 per hectare and the total value of Rs. 480 million (for 2004-05).

Valuation of forest in Uttarakhand, Himalayas using the benefit transfer method (Verma et al. 2007) shows a total economic value of Uttrakhand forests as Rs. 16,192 billion, accounting Rs. 19,035 million from the direct benefits (including tourism) and Rs. 173,120 million from the indirect benefits and silt control service is accounted as Rs. 2062.2 million. Carbon sequestration is accounted as Rs.2974 million at US $ 10 per t of C considering the net accumulation of 6.6 Mt C per year in biomass. Aesthetic beauty of the landscape is estimated as 10,665.3 million and pollination service value is accounted to be Rs. 25,610 million/yr. Natural ecosystems also provide unlimited opportunities for environmental education and function as field laboratories for scientific research (de Groot et al. 2002).

Sacred groves present in varied ecosystems viz., evergreen and deciduous forests, hill tops, valleys, mangroves, swamps and even in agricultural fields in Uttara Kannada district represent varied vegetation and animal profiles (Ray et al. 2011, 2015). The protection of patches of forest as sacred groves and of several tree species as sacred trees leads to the spiritual function provided by the forest (Chandran 1993). Sacred groves also play an important role in the cultural service provided by the forest. The groves do not fetch any produce which can be used for direct consumptive or commercial purpose. Creation of hypothetical market fetches price worth Rs. 600/quintal for a woody species and Rs. 40/quintal for non-wood product. The value of sacred grove assessed through willingness to pay to preserve the sacred grove in Siddapur taluk of Uttara Kannada district (Panchamukhi et al. 2008), show the value of Rs. 7280/ per hectare.

The major threat to the forests today is deforestation caused by several reasons such as rise in the population, exploitation activities which include expansion of agriculture land, ranching, wood extraction, development of infrastructure. Shifting cultivation is considered to be one of the most important causes of deforestation (Myers 1984). The loss of biodiversity is the second most important problem in nearly every terrestrial ecosystem on Earth. This loss is accelerating driven by the over-exploitation of natural resources, habitat destruction, fragmentation and climate change (MEA 2003). Even though the Convention on Biological Diversity (CBD) has adopted a target of reducing the rate of biodiversity loss at global, regional and national levels by 2010 (Mace 2005), still the loss of biodiversity is at a high pace. Nearly, 75 percent of the genetic diversity of domesticated crop plants has been lost in the past century. About 24 percent of mammals and 12 percent of bird species are currently considered to be globally threatened. Despite the essential functions of ecosystems and the consequences of their degradation, ecosystem services are undervalued by society, because of the lack of awareness of the link between natural ecosystems and the functioning of human support systems.

Objectives

Forest ecosystems are critical habitats for diverse biological diversity and perform array of ecological services that provide food, water, shelter, aesthetic beauty, etc. Valuation of the services and goods provided by the forest ecosystem would aid in the micro level policy design for the conservation and sustainable management of ecosystems. Main objective of the study is to value the forest ecosystems in Uttara Kannada forest. This involved computation of total economic value (TEV) of forest ecosystem considering provisioning, regulating, supporting and information services provided by the ecosystem.

MATERIAL AND METHODS

Study Area

The Uttara Kannada district with a spatial extent of 10,291sq.km is situated at $74^0$9' to 75^0 10' E and $13^0$55' to $15^0$31' N in the north-western part of Karnataka state (Fig. 2). It extends from north to south to a maximum of 180 km, and from west to east a maximum width of 110 km. Uttara Kannada is bounded by Belgaum district and Goa state in the north, Dharwad and Haveri districts in the east, Shimoga and Udupi districts in the south and the Arabian Sea to the west.

The district has the coastline of 120 km. in the western part. The coast stretches in a long nearly straight line to the south except the shallow Karwar and Belekeri bays (Kamath 1985). The topography of the region can be divided into three distinct zones. The coastal zone, comprising of a narrow strip of the coastline is relatively flat and starts sloping gently upwards towards the east. The ridge zone abruptly rises from the coastal strip, is much more rugged and is a part of the main range of the Western Ghats. Compared to other parts of the Western Ghats, the altitude of the ridge is much lesser and rises to about 600msl. The third zone is the flatter, geographically more homogenous zone that joins the Deccan plateau.

The four major rivers of the district are Kalinadi, Gangavali, Aghanashini and Sharavathi. Varada, Venkatapura, Belekeri, Badagani are some of the minor river and streams in the district. Apart from these river system, large number of other wetlands such as lakes, reservoirs, ponds, puddles, lateritic bogs, wet grasslands, marshes, swamps are present in the district (Ramachandra and Ganapathy 2007; Rao et al. 2008). The district comprises of 11 *Taluks* namely, Supa, Haliyal, Mundgod, Yellapur, Karwar, Ankola, Sirsi, Siddapur, Honnavar, Kumta and Bhatkal. Supa is the largest taluk in Uttara Kannada in terms of area. The district has 11 *taluks* (an administrative sub-division for dissemination of the government programmes) spread over the

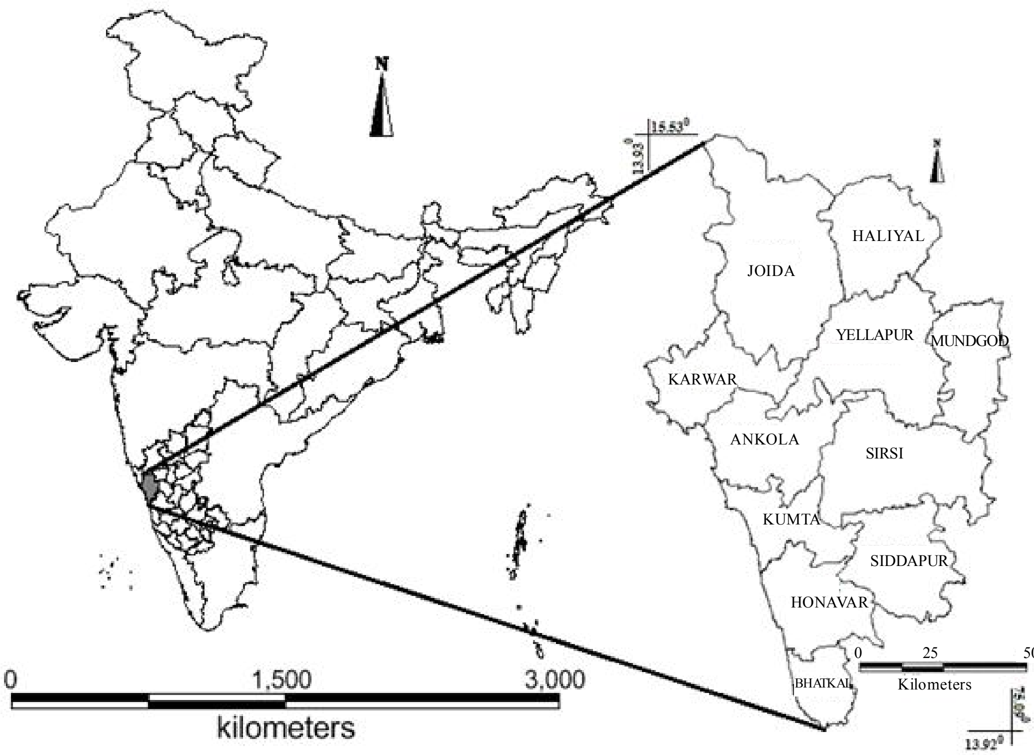

Fig. 2. Uttara Kannada district, Karnataka state

three regions described above. The coast lands comprise of Karwar, Ankola, Kumta, Honnavar and Bhatkal taluks, the forested interior areas which are part of the Western Ghats range comprises of Supa, Sirsi, Siddapur, major parts of Yellapur taluk and the eastern areas which are plateau regions comprises of Haliyal, Mundgod and parts of Yellapur taluks. The climate of the region is tropical monsoon. Generally, the weather is hot and humid in the coastal areas throughout the year. The district experiences south-west monsoon and the rainfall are received mostly between June and September. Average annual rainfall in the district is about 2887 mm which ranges from 4172 mm in Bhatkal *taluk* to 1345 mm in Haliyal taluk. Population density ranges from 0.26 (Supa) to 4.28 (Bhatkal) persons/hectare with an average of 1.69 ±1.09. Spatial extent of forest ranges from 48.14 (Mundogod) to 86.5 (Supa) percent of the respective *taluk.*

Vegetation of Uttara Kannada District

There are mainly five different types of forest in the district – Evergreen, Semi-evergreen, Moist deciduous, Dry deciduous and Scrub land. The district's high rainfall supports lush green forests, which cover approximately 70 percent of the district. Uttara Kannada vegetation is divided into 5 broad zones by Daniels (1989) namely, Coastal zone, Northern evergreen zone, Southern evergreen zone, moist deciduous zone and dry deciduous zone. Uttara Kannada has 21 habitat types according to Daniels (1989), based on a study in 181, 5x5 km grids. They are, Evergreen forests (65 percent), Rocky cliffs (14%), Degraded evergreen thickets (17%), Moist grasslands (9%), Moist/dry teak (29%), Humid *betelnut* (50%), Freshwater marshes (25%), Exotic tree plantations (25%), Rivers (10%), Hill streams (55%), Coastline (9%), Beaches (6%), Coastal coconut (9%), Estuaries (5%), Scrub (2%), Dry deciduous forest (5%), Moist/Dry Bamboo forests (6%), Moist/Dry cultivation (31%), Moist/ Dry Eucalyptus (10%), Moist Deciduous forests (18%), Urban population > 1000 (22%). However, in the last few years the evergreen forests of the district have undergone tremendous changes. Most of the evergreen forested area has been transformed into semi-evergreen forests, and some have been converted into plantations such as, Teak, Arecanut, Acacia spp., etc. (Ramachandra and Ganapathy 2007). It is found that evergreen and semi-evergreen to moist deciduous forest types predominate the forested area of Uttara Kannada (Fig. 2). The complete stretch of the central ridge zone (Ghats section), which was once dominated by the evergreen forests, is now dominated by the semi-evergreen forest. Evergreen is seen in patches mainly towards the south-west and in the Ghats section. Moist deciduous is seen in almost all places distributed throughout the district. It is more common in the eastern Sirsi, south of Yellapur, eastern Siddapur and western region of the coastal taluks. Dry deciduous forests are spotted in the taluks of Mundgod, Haliyal, western Sirsi and north-eastern part of Yellapur.

Figure 3 depicts the land use in the district based on the analysis of IRS P6 (Indian remote sensing) multi spectral data of spatial resolution 5.8 m. Area under forest covers 72 percent of the total geographic area of the district (Fig. 4). The forest cover ranges from 50 percent in Mundgod *taluk* to 88 percent in Supa and Yellapur

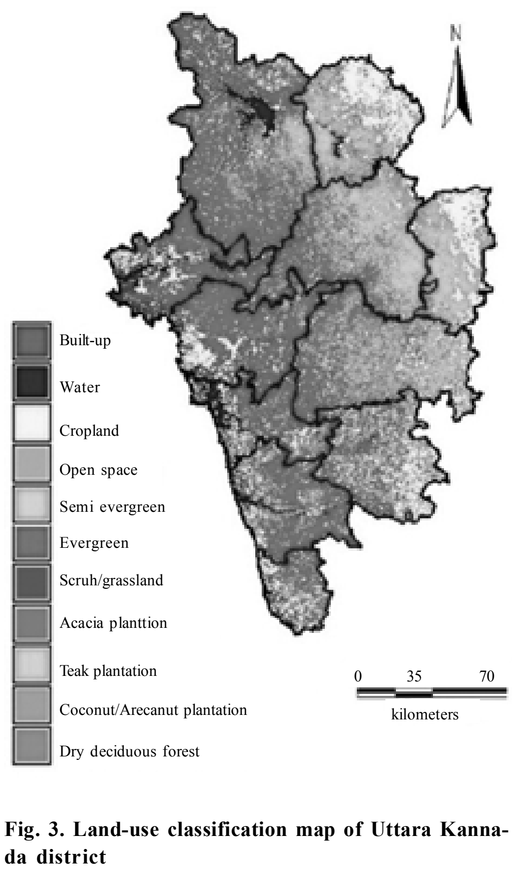

Fig. 3. Land-use classification map of Uttara Kannada district

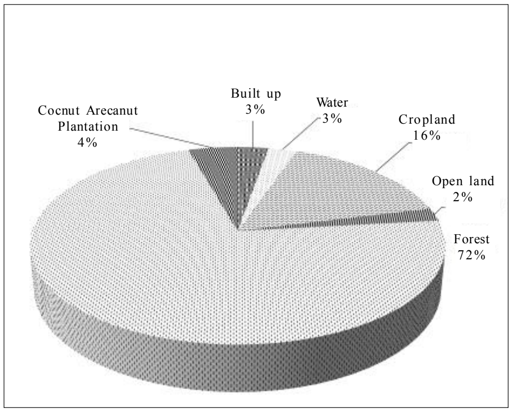

Fig. 4. Share of different land use in Uttara Kannada district
Source: Author

taluks. The forest was categorized as evergreen, semi evergreen to moist deciduous, dry deciduous, teak and bamboo plantations, scrub forest and grasslands and acacia plantations. Table 1 illustrates that about 53 percent of the total forest land in the district is of evergreen type followed by 21 percent of semi-evergreen to moist deciduous forests. Dry deciduous forests are very less and are found in the eastern part of Haliyal and Mundgod taluk. There has been a significant amount of forest loss owing to various developmental activities across district and conversion of natural forests into plantations. Taluks such as Ankola, Bhatkal, Honnavar, Karwar, Siddapur and Supa has rich presence of evergreen forest out of the total forest area, whereas the least share of evergreen forest is found in Mundgod and Haliyal *taluks.* The share of semi evergreen to moist deciduous forest out of total forest area is found to be highest in Sirsi taluk. A considerable share of forest area in Haliyal and Mundgod *taluks* is comprised of plantations of teak, acacia and bamboo.

Method

The framework for incorporating the true value of forest requires thorough valuation of the benefits derived from forest ecosystems. *Taluk* wise forest valuation has been done through the quantification of goods, estimation of values based on the market price, and compilation of values of ecosystem services from literatures. Total economic value of the forest ecosystems in Uttara Kannada has been done considering i) provisioning services, ii) regulating services, iii) supporting services and iv) information services (MEA 2003). Various components of provisioning, regulating, cultural and supporting services are listed in Figure 5. The research includes compilation of data from primary (field investigations) and secondary sources (government agencies, published scientific literatures in peer reviewed journals). Data on quantity of timber and non – timber forest products harvested were collected from Divisional Office (Sirsi) of Karnataka Forest Department, Government of Karnataka. Data on the prices of various marketed forest products were collected through market survey. Data on various other provisioning goods and services were compiled from literature pertaining to ecological and socio-economic studies in the district and also through interview with the subject experts.

Framework of Valuation

Figure 6 outlines the method adopted for valuing forest ecosystems (taluk wise) in Uttara Kannada district. The work entails:

i. Assessment of Different Land Uses in the District: This was done considering remote sensing data of space borne sensors (IRS P6) with spatial resolution of 5.8m. The remote sensing data were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India (1:50000, 1:250000).

Table 1: Vegetation Distribution in Uttara Kannada

Evergreen forest	*Semi evergreen to moist deciduous forest*	*Dry deciduous forest*	*Teak / Bamboo plantations*	*Scrub forest/ Grass lands*	*Acacia/ Eucalyptus plantations*	*Total*
53.02	20.60	0.19	4.75	4.19	17.24	100.00

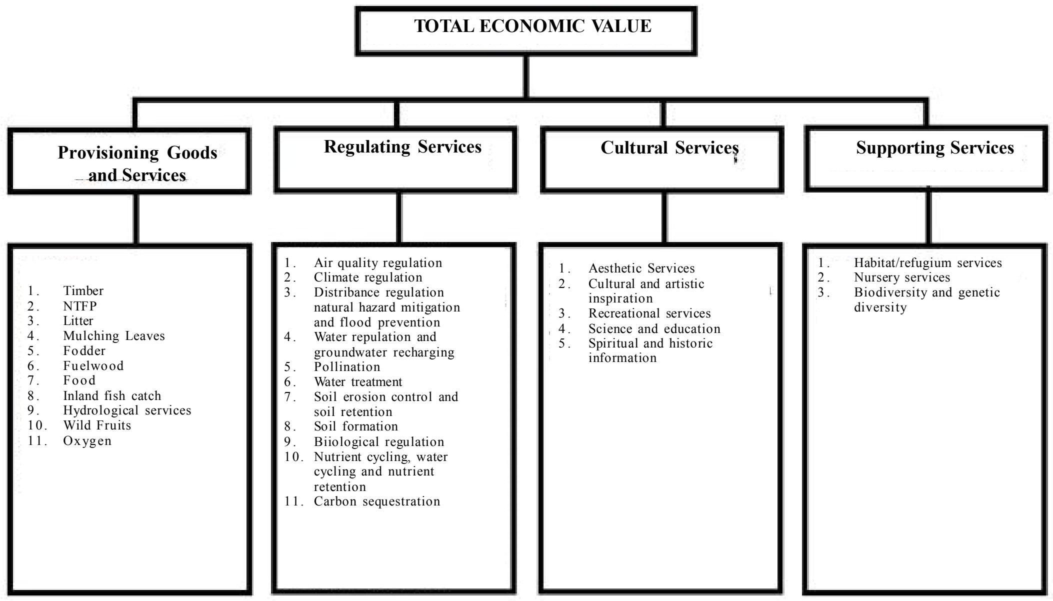

Fig. 5. Classification of forest ecosystem goods and services
Source: Author

Remote sensing data analysis involved i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape; ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15 percent of the study area and uniformly distributed over the entire study area; iii) loading these training polygons co-ordinates into pre-calibrated GPS; vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field; iv) supplementing this information with Google Earth (http://earth.google.com); and v) 60 percent of the training data has been used for classification, while the balance is used for validation or accuracy assessment. Land use analysis was carried out using supervised pattern classifier - Gaussian maximum likelihood algorithm based on probability and cost functions (Ramachandra et al. 2012, 2016a). Accuracy assessment to evaluate the performance of classifiers was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients and proportion of correctly allocated cases. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include

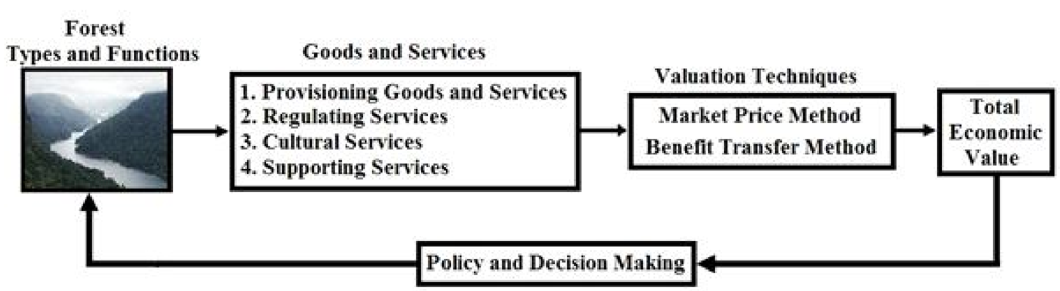

Fig. 6. Framework for valuation of goods and services from forest ecosystem
Source: Author

computation of kappa (κ) statistics and overall (producer's and user's) accuracies.

The forest was classified as evergreen, semi evergreen to moist deciduous, dry deciduous, teak and bamboo plantations, scrub forest and grasslands and acacia plantations. The extent of forest fragmentation was assessed for estimating the carbon sequestration potential of forests through the quantification of the extent of interior and fragmented forests at *taluk* level.

ii. Quantification of Goods and Services: compilation of data from primary (field investigations) and secondary sources (government agencies, published scientific literatures in peer reviewed journals). Data on quantity of timber and non – timber forest products harvested were collected from Divisional Office (Sirsi) of Karnataka Forest Department, Government of Karnataka.

iii. Valuation of Goods and Services: Various functions of forests are the results of interaction between structure and processes, which may be physical (for example, infiltration of water, sediment movement), chemical (for example, reduction, oxidation) or biological (for example, photosynthesis and de-nitrification). Further, various goods and services obtained from the functioning of forest ecosystem were classified as provisioning goods and services, regulating services, cultural services and supporting services. The study uses two approaches of valuation for the computation of TEV of forest ecosystem, namely: 'market price' method and 'benefit transfer' method of valuation.

a. *Market Price:* This technique estimates the economic values of those goods and services that are bought and sold in established markets. Valuation of provisioning goods and services has been done through 'market price' valuation. For those goods and services which do not pass through market transaction process (viz. water utilization for irrigation and power generation, ecological water, wild fruits) well adopted technique of proxy/ shadow prices have been used.
b. *Benefit Transfer:* This technique involves the application of value estimates, functions, data and/or models developed in one context to address a similar resource valuation question in an alternative context. The cost of surveys in terms of time and money could be avoided by this approach. Benefit transfer method of valuation is used to compute the value of regulating, cultural and supporting services. Some of the components of these services were computed based on unit values of those services for different types of forest based on the discussion and interview with subject experts.

***iv. Quantification of Goods and Services*:** The detailed procedure of valuation of different components of ecosystem services is discussed below:

a. *Provisioning Services from Forest Ecosystem:* Goods derived from the forests are quantified as follows:

- *Timber:* Timber is an important component of value on forestland properties. In many cases, the value of the timber can be several times the value of the land. Timber includes rose wood, teak wood, jungle wood, etc. Timber is mainly prominent in deciduous forest while it is found in less amount in Evergreen forest patches. Plantation forest is mainly abundant in timber producing trees like Acacia, Teak etc. Industrial produce is also present from the forest which includes round wood, soft wood, match wood etc. The data regarding the quantity of timber harvested and sold was obtained from the Karnataka Forest department (KFD 2015) and the valuation is based on the current market price.
- *Non Timber Forest Product:* The data on the harvesting of non-timber forest product was obtained from the Forest department. The total value of NTFP includes the value of a) NTFPs extracted by Forest Department, b) NTFPs collected by households (Murthy et al. 2005), c) bamboo extracted by the Karnataka Forest department, d) annual bamboo productivity in the forest (NABARD 2015; WCPM 2016), e) cane extracted by Forest department and f) annual cane productivity in the forest .
- *Litter:* Litter is used as manure in horticulture and agriculture fields. Quantity of litter productivity per year for different taluks was based on the earlier work (Ramachandra et al. 2000).
- *Mulching Leaves:* Mulching leaves is used as manure in arecanut gardens. Per year requirement of mulching leaves from forest were quantified by the area of areca-

nut gardens in each taluka multiplied by the minimum quantity of mulching leaves per hectare of arecanut garden.

- *Fodder:* Total value of fodder supplied from forest were quantified by using the data from literature (Prasad et al. 1987a,b) on herb layer productivity in different types of forests, extent of different types of forest and unit market price of the fodder in the district.
- *Medicinal Plants:* Various medicinal plants used by the local people were identified (Harsha et al. 2005; Hegde et al. 2007) and the value of medicinal plants per unit area of forest area (Simpson et al. 1996; Database of Medicinal Plants 2015; SCIL 2015) was extrapolated to different types of forest in the district.
- *Fuel Wood:* The total value of fuel wood includes the value of fuel wood used for domestic purpose, that is, for cooking and water heating and also the value of fuel wood used for various industrial and commercial purposes like jaggery making, areca processing, cashew processing, restaurants and bakery, parboiling, cremation, etc. The quantity of fuel wood for domestic usage in different locations of the district was obtained from Ramachandra et al. (2000) and the quantity of fuel wood required for various other purpose were based on field experiments (Ramachandra et al. 2000; Ramachandra 1998).
- *Food:* 22 varieties of food products derived from forest were identified and the value of food extracted per unit area of forest obtained from literature (Hebbar et al. 2010; PSP 2016; SCIL 2015) was extrapolated to the total forest area in the taluk. Also, the household honey collection which is an important provisioning service from forest was quantified (Ramachandra et al. 2012) for all *talukas* and valued.
- *Inland Fish Catch:* Inland fishing is an important economic activity and a determinant of nutritional requirement of large number of people. Inland fishing happens in rivers, rivulets, streams, reservoirs, lakes, etc. which are inseparable part of the forest area in the district. The quantities of inland fish catch in different taluks were obtained from Fisheries Department, The Government of Karnataka and the economic value of it was determined.
- *Hydrological Services:* Most of the water resources come from the forested catchments. Hydrological services is quantified by the quantity of domestic water utilization, water for irrigation purpose (Ramachandra et al. 1999, 2012, 2016a), water for industrial use and water used for power generation (5 hydro power stations and 1 nuclear power station). The quantity of water required for sustenance of forest ecosystem that is, ecological water available for different types of forest was quantified as per the following equation (Ramachandra et al. 1999; 2016a; 2016b; Raghunath 2006; KPCL 2016; NPCIL 2016; Ray et al. 2015).
- Quantity of Ecological Water = Run off Coefficient x Annual Precipitation x Forest Area

The value of 'runoff coefficient' for different types of forest varied from 0.1 to 0.4.

- *Wild Fruits*: Information on various wild fruits were obtained from literature (Hebbar et al. 2010; Bhat et al. 2003). The productivity of wild fruits was estimated based on Bhat et al. (2003), transect survey data in different types of forest and information from local people. For economic valuation of wild fruits proxy price (in comparison with the price of fruits collected as NTFP) was used.
- *Oxygen Provision*: Value of oxygen provision from forests was quantified based on the values of oxygen production per hectare of subtropical forest (Maudgal and Kakkar 1992).

These provisioning services were valued as per the equations in Table 2 based on market price method.

b. *Regulating Services from Forest Ecosystem:* Regulating services provide many direct and indirect benefits to humans. The maintenance of the Earth's biosphere in a hostile cosmic environment depends on a delicate balance between these regulating services (de Groot et al. 2002). However, regulating services unlike provisioning services poses much greater challenges in valuation. Though regulating services are seldom marketed, the economy heavily depends upon the utility of these services. In the present study,

Table 2: Valuation method for comonents of provisioning services of forest

Provisioning services	*Equation*	*Details*
Timber	$V_{Timber} = \sum_{i=1}^{11}\sum_{j=1}^{6} Q_{i,j} \times P_{i,j}$	Q=Quantity of timber; P = Price of timber; i = no. of taluks; j = variety of timber
NTFP	$V_{NTFP} = \sum_{i=1}^{11}\sum_{j=1}^{30} Q_{i,j} \times P_{i,j}$	Q=Quantity of NTFP; P = Price of NTFP; i = no. of taluks; j = variety of NTFP
Litter	$V_{Litter} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of litter; P = Price of litter; i = no. of taluks
Mulching Leaves	$V_{Mulch} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of mulching leaves; P = Price of mulching leaves; i = no. of taluks
Fodder	$V_{Fodder} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of fodder; P = Price of fodder; i = no. of taluks
Fuelwood	$V_{Fuelwood} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of fuelwood; P = Price of fuelwood; i = no. of taluks
Food	$V_{food} = \sum_{i=1}^{11}\sum_{j=1}^{22} Q_{i,j} \times P_{i,j}$	Q=Quantity of food; P = Price of food; i = no. of taluks; j = variety of food product
Inland Fish Catch	$V_{Fish} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of fish catch; P = Price of fish; i = no. of taluks
Hydrological Services	$V_{water} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of water utilization for different purpose; P = Price of water used for different purpose; i = no. of taluks
Wild Fruits	$V_{wild\ fruits} = \sum_{i=1}^{11} Q_i \times P_i$	Q=Quantity of wild fruits; P = Price of wild fruits; i = no. of taluks
Oxygen	Value of oxygen provision from forests was quantified based on the values of oxygen production per hectare of subtropical forest (Maudgal and Kakkar 1992).	

ten variables of regulating services were quantified as per the published literatures (Costanza et al. 1997; Maudgal and Kakkar 1992; Seema and Ramachandra 2010), given in Table 3 and the value of carbon sequestration was estimated for each taluk based on the biomass stock and productivity (Ramachandra et al. 2000, 2004; Maudgal and Kakkar 1992; Seema and Ramachandra 2010).

Table 3: Unit values of regulating services from forests (Rs. per hectare)

Regulating services	*Unit value (Rs. per hectare)*
Air quality regulation	6384
Climate regulation	10704
Disturbance regulation, natural hazard mitigation and flood prevention	217872
Water regulation and groundwater recharging	261360
Pollination	1200
Waste treatment	4176
Soil erosion control and soil retention	11760
Soil formation	480
Biological regulation	1104
Nutrient cycling, water cycling and nutrient retention	44256

The value of carbon sequestration has both flow and stock value. The productivity of biomass per hectare per year and the volume of standing biomass for different types of forests of Uttara Kannada were obtained from literature (Ramachandra et al. 2000, 2004; Seema and Ramachandra 2010). The volume of carbon was computed with the assumption that 50 percent of the dry biomass contains carbon (Seema and Ramachandra 2010). The value of carbon sequestration was calculated by considering 10 Euros per tonne of CO_2 (EEC 2012). The total value of carbon sequestration per year for different taluks includes the value of per year increment in the carbon sequestration and per year value of interest (considering 5% interest rate) over the total stock/ volume of carbon in the forest till date.

c. Cultural Services from Forest Ecosystem: Forest has a high cultural value; the main reason can be attributed to the aesthetic

Table 4: Unit values of cultural services from forest

S. No.	*Cultural services*	*Value (in Rs./ hectare)*	*Source*
1.a	Recreational services (for interior evergreen forest)	2,88,000	de Groot et al. 2002
1.b	Recreational services (for other types of forest)	28,944	Costanza et al. 1997
2.a	Spiritual and historic information (for interior evergreen forest)	72,000	Discussion with subject experts
2.b	Spiritual and historic information (for interior evergreen forest)	1,200	de Groot et al. 2002
3	Aesthetic Services	1,500	Discussion with subject experts
4	Cultural and artistic inspiration	480	Discussion with subject experts
5	Science and education	48,000	Discussion with subject experts

beauty, recreational benefit and Kan forest which are the sacred groves present in the district. Sacred groves are communally-protected forest fragments with significant religious connotations (Ray and Ramachandra 2011; Ray et al. 2015). Further, recreational benefits provided by the forest include gaming, walking, hunting etc. Aesthetic beauty of the forest is valuable, the presence of waterfalls and caves adds to the aesthetic value in the district. Science and educational value provided by the forest are also indispensable. The unit value for the services, listed in Table 4 was derived from de Groot et al. (2002) and Costanza et al. (1997), and also the values were finalized in consultation with subject experts.

d. *Supporting Services From Forest Ecosystem:* The supporting service provided by the forest includes the habitat/refugium function, nursery function and biodiversity and genetic diversity function. The forest provides living space for a large number of plants and animals thus, playing an important role in the refugium function. It also acts as a nursery for immense plants and animals. The forest also serves as a store house of information. To maintain the viability of this genetic library, the maintenance of natural ecosystems as habitats for wild plants and animals is essential. The unit value of habitat/ refugium function and nursery function were derived from literature and the unit value of biodiversity and genetic diversity was estimated (Table 5) based on the flow value of selected provision services that represent the least value stock of biodiversity and genetic diversity.

Total Economic Value

The total economic value (TEV) of forest ecosystem is obtained by aggregating provision goods and services (provisioning, regulating, cultural and supporting services).The total economic value that has been calculated for one year is divided by the area of forest in each taluk to obtain the per hectare value of forest in respective *taluk.*

RESULTS AND DISCUSSION

Ecosystem services and the natural capital stocks of the Western Ghats forests make significant direct and indirect contributions to national economies and human welfare. Forests, both natural and planted, and including trees spread across the terrain, have a critical role in the ecology, aesthetics and recreational benefits. The goods and services derived from forest ecosystem are categorized as provisional goods and services, regulating services, cultural services and supporting services (MEA 2003). Land

Table 5: Unit value of supporting services from forest

S. No.	*Supporting services*	*Value (in Rs./ hectare)*	*Source*
1	Habitat/ refugium services	73104	de Groot et al. 2002
2	Nursery services	9360	de Groot et Al. 2002
3	Biodiversity and genetic diversity	40000	Calculated from the flow value selected provisioning services like NTFP, medicinal plants, etc.

Table 6: Talukwise area under different types of forest (in hectares)

S. No.	Taluk	Evergreen forest	Semi evergreen to Moist deciduous	Dry deciduous forest	Teak / Bamboo Plantations	Scrub forest/ Grass lands	Acacia/ Eucalyptu splantations	Total
1	Ankola	53943	8227	0	62	4598	6911	73741
2	Bhatkal	15189	5335	0	130	230	851	21734
3	Haliyal	9853	11609	1253	7720	2532	16062	49030
4	Honnavar	36782	6403	0	0	1508	4007	48700
5	Karwar	39176	9264	0	0	1878	4097	54414
6	Kumta	19873	10697	0	0	746	4615	35931
7	Mundgod	1161	3047	171	10080	1554	16144	32156
8	Siddapur	35882	10214	0	124	3479	9615	59315
9	Sirsi	24666	44070	0	1670	2620	20133	93159
10	Supa	124118	21923	0	492	6090	10882	163504
11	Yellapura	34003	22541	0	15108	5987	35017	112656
	District Total	394645	153330	1424	35385	31223	128334	744341
	%	53.02	20.60	0.19	4.75	4.19	17.24	100.00

use analysis (Table 6) show that Supa taluk has highest forest area (1635 sq.km) and Bhatkal has lowest spatial extent of forests (217 sq.km). Evergreen to semi evergreen type of vegetation cover is about 3946 sq.km (53 %), followed by moist deciduous type (1533 sq.km). Area under monoculture plantations is about 1283 sq.km (17.24%).

Provisioning Goods and Services

Based on the consideration and inclusion of various components in ecological perspectives, total value of provisioning goods and services are presented in scenarios as follows:

- *Scenario - I:* provisional services include timber, NTFP, litter and mulching leaves, fodder, medicinal plants, fuel wood, food, inland fishing and hydrological services;
- *Scenario - II:* components in Scenario-I and wild fruits;
- *Scenario - III:* components in Scenario-II and oxygen services;

Table 7: Provisioning goods and services (different scenarios) for Uttara Kannada

Scenario	Value of provisioning goods and services (in Rs. crores)	Values of provisioning goods and services (Billion Rs)
Scenario I	9707	97.07
Scenario II	11842	118.42
Scenario III	15171	151.71

The estimated total value of provisioning goods and services for Uttara Kannada district per year for three different scenarios are presented in Table 7, which reveals the value of goods and services from forests in Uttara Kannada district ranges from INR 97.07 billion per year (scenario 1) to 151.71 billion per year (scenario 3).

Goods derived from the forests were quantified as discussed earlier and details are:

i. *Timber:* Timber accounts to Rs. 1,457 crores per year with the share of 10 percent in scenario – III of the total value of provisioning goods and services obtained from the forest.

ii. *NTFP:* NTFP being the largest contributor among all the components of provisioning goods and services is estimated at Rs. 3,601 crores per year for the district.

iii. *Litter and Mulching Leaves:* Litter and mulching leaves which is a vital component of sustainable agricultural system of the district is valued at Rs. 689 crores per year.

iv. *Fodder:* The value of total fodder productivity in the forests of the district is valued at Rs. 205 crores per year.

v. *Medicinal Plants:* The value of medicinal plants that has been estimated from the benefit transfer method and extrapolated to the different types of forest is found to be worth of Rs. 25 crores per year.

vi. *Fuel Wood:* Forest, being the important source of energy for domestic and various commercial purposes in the district supplies fuel wood of Rs. 366 crores per year.

vii. *Food:* The value of various food products extracted from forest is of worth Rs. 59 per year. Further the inland fishing in the district is valued at Rs. 22 crores per year.

viii. *Hydrological Services:* The total value of water usage for domestic purpose, industrial purpose, agricultural, water requirement for livestock, power generation and ecological water was termed as hydrological services from the forests. It was found that the forests in the district provide hydrological services of worth Rs. 2,313 crores per year.

ix. *Wild Fruits:* Wild fruits being the important component in ecological sustenance of forest ecosystem are being valued at Rs. 1,922 crores per year that is obtained from the forests of entire district.

x. *Oxygen:* The value of oxygen which is computed by benefit transfer method. The result of the study shows that the total forests in the district supplies the oxygen to the atmosphere of worth Rs. 3,000 crores per year. Further, 10 percent of the total value of provisioning services supplied from forest being considered as miscellaneous benefits that are derived from forest ecosystem is of value Rs. 1517 crores per year (for scenario – III).

In all the three scenarios, NTFP is the major contributor to the total value. The share of the value of food, inland fishing, medicinal plants, fuel wood, fodder, litter and mulching leaves varies from 14 percent in Scenario - I to 8 percent in Scenario - III. These goods have an important bearing on the livelihood of people and especially the livelihood of local people. The value of wild fruits and oxygen provision comprises to about thirty five percent share in the total value in Scenario – III. These components are often neglected in valuation of forest and policy making but they play an important role in ecosystem sustenance, protection of biodiversity and thus, in human wellbeing in the long run. Table 8 presents the taluk-wise breakup in the total provisioning goods and services. This illustrates that Supa taluk contributes the high-

Table 8: Value of various provisioning goods and services across taluks (in Rs. crores)

S. No.	*Provisioning goods and services*	*Ankola*	*Bhatkal*	*Haliyal*	*Honnavar*	*Karwar*	*Kumta*	*Mundgod*	*Siddapur*	*Sirsi*	*Supa*	*Yellapur*	*Total*
1	Timber	10.18	2.64	267.47	104.34	77.23	174.38	271.00	62.52	311.31	95.28	80.45	1456.80
2	NTFP	473.83	135.84	98.93	324.02	345.36	180.37	17.43	333.55	278.31	1095.93	317.04	3600.61
3	Litter and Mulching leaves	48.92	13.29	57.13	41.19	33.80	27.85	52.39	62.41	102.35	139.88	110.25	689.44
4	Fodder	24.18	6.70	9.92	15.11	17.14	10.38	2.96	18.00	24.27	52.09	23.80	204.55
5	Medicinal plants	2.88	0.92	1.04	1.96	2.20	1.38	0.23	2.13	3.12	6.65	2.66	25.17
6	Fuelwood	24.99	34.17	45.05	38.59	32.35	35.57	25.81	34.17	55.45	15.51	24.60	366.26
7	Food	5.65	1.91	3.98	4.81	4.42	3.12	2.57	4.81	7.26	12.08	8.43	59.04
8	Inland fishing	0.77	0.35	2.06	4.02	1.54	1.62	0.73	2.35	1.83	4.34	2.13	21.74
9	Hydrological services	172.74	140.66	341.64	279.89	118.27	185.32	127.89	218.26	319.62	223.46	184.85	2312.58
10	Wild fruits	228.20	71.96	71.62	157.08	174.01	104.36	13.51	164.75	213.22	531.33	191.87	1921.91
11	Oxygen	303.97	94.24	178.13	207.19	230.47	150.88	106.14	240.13	372.87	693.21	418.56	2995.81
12	Others	144.03	55.85	119.65	130.91	115.20	97.25	68.96	127.01	187.74	318.86	151.63	1517.09
	Total	1440.35	558.51	1196.54	1309.11	1152.00	972.47	689.60	1270.08	1877.36	3188.63	1516.25	15170.90

Table 9: Value of various regulating services across taluks (in Rs. crores)

S. No.	Taluk	Ankola	Bhatkal	Haliyal	Honnavar	Karwar	Kumta	Mundgod	Siddapur	Sirsi	Supa	Yellapur	Total
1	Air quality regulation	47	14	31	31	35	23	21	38	59	104	72	475
2	Climate regulation	79	23	52	52	58	38	34	63	100	175	121	797
3	Disturbance regulation, natural hazard mitigation and flood prevention	1607	474	1068	1061	1186	783	701	1292	2030	3562	2454	16217
4	Water regulation and groundwater recharging	1927	568	1281	1273	1422	939	840	1550	2435	4273	2944	19454
5	Pollination	9	3	6	6	7	4	4	7	11	20	14	89
6	Waste treatment	31	9	20	20	23	15	13	25	39	68	47	311
7	Soil erosion control and soil retention	87	26	58	57	64	42	38	70	110	192	132	875
8	Soil formation	4	1	2	2	3	2	2	3	4	8	5	36
9	Biological regulation	8	2	5	5	6	4	4	7	10	18	12	82
10	Nutrient cycling, water cycling and nutrient retention	326	96	217	216	241	159	142	263	412	724	499	3294
11	Carbon sequestration	494	153	143	301	375	209	54	307	391	1171	417	4016
	Total value of regulating services	4619	1368	2885	3025	3419	2219	1853	3625	5602	10316	6718	45647

Table 10: Talukwise value of cultural services (in Rs. crores)

S. No.	*Taluk*	*Aesthetic services*	*Cultural andartistic inspiration*	*Recreational services*	*Science and education*	*Spiritual andhistoric information*	*Total*
1	Ankola	11	4	1196	354	277	1841
2	Bhatkal	3	1	349	104	81	539
3	Haliyal	7	2	243	235	34	522
4	Honnavar	7	2	599	234	131	973
5	Karwar	8	3	893	261	208	1373
6	Kumta	5	2	437	172	95	713
7	Mundgod	5	2	103	154	7	271
8	Siddapura	9	3	584	285	120	1000
9	Sirsi	14	4	656	447	117	1239
10	Supa	25	8	2885	785	679	4381
11	Yellapura	17	5	824	541	150	1536
	District Total	112	36	8770	3573	1897	14388

Table 11: Talukwise value of supporting services (Rs. in crores)

S. No.	*Taluk*	*Habitat/ refugium Services*	*Nursery services*	*Biodiversity and genetic diversity*	*Total*
1	Ankola	539	69	295	903
2	Bhatkal	159	20	87	266
3	Haliyal	358	46	196	600
4	Honnavar	356	46	195	596
5	Karwar	398	51	218	666
6	Kumta	263	34	144	440
7	Mundgod	235	30	129	394
8	Siddapura	434	56	237	726
9	Sirsi	681	87	373	1141
10	Supa	1195	153	654	2002
11	Yellapura	824	105	451	1380
	District Total	5441	697	2977	9115

est amount of provisioning goods and services with Rs. 3,188 crores per year (21% of the district), while Bhatkal taluk contributes the least with the provisional services of Rs. 558 crores per year (4 % of the district).

Regulating Services

Regulation service quantification includes the estimated value of carbon sequestration in each taluk and other regulation services (Table 3 in methods section) multiplied by the forest area. The total value of regulating services in the district from forest ecosystems estimated at Rs. 45,657 crores per year. Table 9 shows the share of each taluks in the district's regulating services. Regulating services such as disturbance regulation, natural hazard mitigation and flood prevention, water regulation and groundwater recharging, and carbon sequestration has the major share in the regulating services provided by the forest ecosystem.

Cultural Services

The cultural services from forest can be aesthetic, recreational, spiritual, science and education. The district of Uttara Kannada is rich in places of recreational interest. There are immense number of waterfalls like Jog falls, Lalguli falls, Magod falls, Sathodi falls and Unchalli falls which adds to recreational and aesthetic values. The recreational sites also include the Anashi-Dandeli Tiger Reserve, Attiveri bird sanctuary and caves in Yana, Kavala, Uluvi, Sintheri, etc. The spiritual value of the Uttara Kannada district is also high due to the presence of many temples and pilgrimage centres like Gokarna, Murdeshwar, and Dhareshwar, Idagunji, Banavasi, etc. The cultural and heritage function is another important cultural service provided by forest. The presence of sacred groves is important for the cultural services as there are many cultural beliefs associated with the sacred groves in India. Some groves have valuable timber in

Table 12: Total economic value goods and services from forest ecosystem in Uttara Kannada district (in Rs. crores)

Scenario	*Provisioning services*	*Regulating services*	*Cultural services*	*Supporting services*	*Total economic value*
Scenario - I	9,707	45,647	14,388	9,115	78,857
Scenario - II	11,842				80,993
Scenario - III	15,171				84,321

them but are not harvested for timber due to sacred beliefs. The taluks of Siddapur and Sirsi in Uttara Kannada district have higher cultural values as the region is rich in sacred grooves. The presence of wild life sanctuaries and grooves in turn increases the educational value of the forest ecosystem. The unit value of different components of cultural services was as per Table 4, considering the conditions and type of forests in Uttara Kannada. The total cultural value of the district was estimated at Rs. 14,388 crores. Talukwise value of each component of cultural services and total value of cultural services is presented in Table 10.

Supporting Services

Table 11 lists taluk wise values of supporting services. The components of supporting services as per Table 5 were considered with the types and spatial extent of forest. The total value of supporting services obtained from forest ecosystem is estimated at Rs. 9,115 crores per year.

Total Economic Value of Forest Ecosystem in Uttara Kannada District

Total economic value (TEV) is calculated by aggregating provisioning services, regulating services, cultural services and supporting services. Total economic value (TEV) for all three scenarios and are presented in Table 12. The TEV of forest ecosystem in Uttara Kannada district is Rs. 78,857 crores, Rs. 80,993 crores and Rs. 84,321 crores for Scenario -I, II and III respectively.

Table 13 presents the share of different categories of services from forest ecosystem for scenario – III. Regulating services underpin the delivery of other service categories (Kumar et al. 2010), contributes to half of the share (54%) of the total economic value of forest ecosystem in the district. Provisioning services (18 %), cultural services (17 %) and supporting service (11 %) contributes to the other half of total economic value. Table 13 also shows that the total value of services per hectare of forest per year in the district. Value of provisioning services provided by the forest ecosystem is about Rs. 2,03,818 per hectare per year and the total value is about Rs. 11,32,832 per hectare per year which is implicit in the subsistence, income and local employment.

Supa taluks with Rs. 19,887 crores per year is the largest contributor (with 24 percent share) to the TEV of forest ecosystem in the district (Table 14) and Bhatkal taluk with the contribution of Rs. 2,732 crores per year is the least contributor (with 3% share) to the TEV of forest ecosystem of the district.

Total Economic Value of Forest Ecosystem and GDDP

Sector-wise district's Gross District Domestic Product (GDDP) is given in Table 15. GDDP of Uttara Kannada is about Rs. 5,978 crores and the contribution of forests' goods is about Rs.

Table 13: Total value of goods and services from forest ecosystem in Uttara Kannada

Services from forest ecosystem	*District value per year (in Rs. crores)*	*Value of services per hectare per year (in Rs.)*	*Percent share*
Provisioning services	15,171	2,03,818	18
Regulating services	45,647	6,13,254	54
Cultural services	14,388	1,93,296	17
Supporting services	9,115	1,22,464	11
Total Value	84,321	11,32,832	100

Table 14: Taluk wise total economic value goods and services from forest ecosystem

S. No.	*Taluk*	*TEV of forest ecosystem (in Rs. crores per year)*
1	Ankola	8803
2	Bhatkal	2732
3	Haliyal	5204
4	Honnavar	5904
5	Karwar	6610
6	Kumta	4344
7	Mundgod	3207
8	Siddapur	6622
9	Sirsi	9859
10	Supa	19887
11	Yellapur	11150
	District Total	84321

180 crores (3% of GDDP), in contrast to the estimated valuation of provisioning services (ranges from 9707 to 15171 crores per year). *This highlights the undervaluation of forest resources in the regional accounting system.* TEV of forest ecosystem of Uttara Kannada district is about Rs. 84,321 crores.

Table 15: GDDP of Uttara Kannada with sectors

Sector	*Sectoral contribution (in Rs. crores)*	*Sectoral share (in percent)*
Primary Sector (Agriculture, Forestry, Fishing, Mining)	1060	18
Forestry and Logging Sector	180	3
GDDP of Uttara Kannada	5978	100

Source: Directorate of Economics and Statistics, Government of Karnataka

The forest products included in the national income account framework includes: (a) Industrial wood (timber, match and pulpwood) and fuel wood and (b) minor forest products (Haripriya 2001). It includes only the recorded values by forest department and thus, all other benefits from forests are unaccounted in the national income. This necessitates relook at the current approach of computations of Gross Domestic District Product (GDDP), State Domestic Product (SDP) and Gross Domestic Product (GDP). Gross underestimation and non-accounting of natural resources and forest resources in particular is responsible for unsustainable utilization of natural resources. Under valuation of ecosystem goods and services is evident from GDDP of Rs. 5,978 crores in 2009-10 (at current prices), which accounts as the sectoral share of forests of Rs. 180 crores, contrary to the estimated valuation of provisioning services (ranges from 9707 to 15171 crores per year). TEV of forest ecosystem accounts to Rs. 84,321 crores per year.

CONCLUSION

Forest resources in the Uttara Kannada district has undergone tremendous change and degradation because the value of it is being poorly understood and not considered in the policy making process. However, valuation of regulating services, cultural services and supporting services are more difficult to estimate and thus pose serious challenges to planners and practitioners. As a consequence the values of these services are often overlooked. Hence, valuation of these services in income accounting of a region/nation is essential to make the plans and policies more sustainable.

Goods and services that forest ecosystems provide are grossly undervalued, evident from GDDP of Uttara Kannada, about Rs. 5,978 crores, which accounts goods of forests as Rs. 180 crores (3% of GDDP), in contrast to TEV of Rs. 84,321 crores from forest ecosystems of Uttara Kannada district. The comprehensive valuation has the potential to provide effective options for management of ecosystem. If the total economic value of forests ecosystem in particular and ecosystem in general are not considered in decision and policy making, the policies thus adopted would lead to detrimental effect on human and societal welfare in the long run. Policies therefore, have an important role in ensuring that benefits from forest ecosystem are accounted in decision making to avoid underestimation of the values of forest, value of conservation and sustainable use of forest resources. Incorporating the values of ecosystem services plays an important role in making the economy resource efficient

RECOMMENDATIONS

Forest resources in the Uttara Kannada district have undergone tremendous change and degradation because the value of it is being poorly understood and not considered in the policy making process. However, valuation of regulating services, cultural services and supporting services are more difficult to estimate and thus pose serious challenges to planners and practitioners. As a consequence the values of these services are often overlooked. Hence, valuation of these services in income accounting of a region/ nation is essential to make the plans and policies more sustainable.

Major threats are habitat fragmentation, negligence, conflict of interest and ineffective restoration/improvement strategies. Poor understanding of the complex ecological processes and proper estimation of the ecosystem benefits have often lead to the destruction of fragile ecosystems. To improve the scenario, thorough understandings of the complex ecosystem dynamics as well as its socio-religious association with community life both are important from conservation and management point of view.

Conservation activities are mostly implemented by Government agencies, NGOs and sometimes by communities. However community participation is often activated by extra mural support which has serious problem in long term sustainability due to financial limitation. The problem could be mitigated to some extent by awareness generation so to raise the interest among people to safeguard its future for their own benefit. The premium should be on conservation of the remaining fragile ecosystems, which are vital for the water security (perenniality of streams), food security (sustenance of biodiversity) and uplift the livelihoods of local population due to carbon credits.

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ORIGINAL ARTICLE

Salient Ecological Sensitive Regions of Central Western Ghats, India

T. V. Ramachandra[1,2,3] · Setturu Bharath[1] · M. D. Subash Chandran[1] · N. V. Joshi[1]

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Abstract

Ecologically sensitive regions (ESRs) are the 'ecological units' with the exceptional biotic and abiotic elements. Identification of ESRs considering spatially both ecological and social dimensions of environmental variables helps in ecological and conservation planning as per Biodiversity Act, 2002, Government of India. The current research attempts to integrate ecological and environmental considerations into administration, and prioritizes regions at Panchayat levels (local administrative unit) in Uttara Kannada district, Central Western Ghats, Karnataka state considering attributes (biological, Geo-climatic, Social, etc.) as ESR (1–4) through weightage score metrics. The region has the distinction of having highest forest area (80.48%) in Karnataka State, India and has been undergoing severe anthropogenic pressures impacting biogeochemistry, hydrology, food security, climate and socio-economic systems. Prioritisation of ESRs helps in the implementation of the sustainable developmental framework with the appropriate conservation strategies through the involvement of local stakeholders.

Keywords Ecologically sensitive region · Landscape dynamics · Biodiversity · Cluster-based economic development

1 Introduction

Ecosystems are the distinct biological entities that sustain the biosphere and are characterised by a range of functions: nutrient cycling, bio-geochemical cycle, hydrologic cycling, etc. The ecological sensitivity of ecosystems refers to their ability to cope with various kinds of environmental disturbances that have the potential of adversely changing the character of the natural landscapes. The conservation and sustainable management of ecosystems are the vital components in the pursuit of ecologically sound, economically viable and socially acceptable development goals (Kibert et al. 2011). 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 (Ramachandra et al. 2007). This requires an understanding of the complex functioning of ecosystems, diversity of resources, values, ecological services and their significant ability in influencing climate at local as well as global scale. In this regard, an integrated holistic approach considering all components and functions of the ecosystems is quintessential for the developmental planning. Ecosystem conservation has become a challenging task in the face of increasing human pressures due to unplanned activities. The intensity of anthropogenic disturbances is higher compared to the natural disturbance (such as wind and fire), which alter abiotic and biotic environments across wide areas (Kivinen and Kumpula 2013). Unsustainable use of land resources for different purposes, such as tourism, mining, monoculture plantations has severe impacts on land cover leading to the scarcity of natural resources. Large scale land cover transformations have resulted in the enhanced instances of human–animal conflicts, conversion of perennial streams to seasonal streams and affected the livelihood of dependent population with the impaired biological and economic productivities (Berkres and Davidson-Hunt 2006; Moen and Keskitalo 2010).

Decision making based on the biophysical, economic and socio-cultural information provides an opportunity

✉ T. V. Ramachandra
cestvr@ces.iisc.ernet.in; energy@ces.iisc.ernet.in
http://ces.iisc.ernet.in/energy

1 Energy Wetland Research Group, CES TE 15, Centre for Ecological Sciences, Indian Institute of Science, New Bioscience Building, Third Floor, E-Wing, [Near D-Gate], Bangalore 560012, India

2 Centre for Sustainable Technologies (astra), Indian Institute of Science, Bangalore 560012, India

3 Centre for Infrastructure, Sustainable Transportation and Urban Planning [CiSTUP], Indian Institute of Science, Bangalore, Karnataka 560 012, India

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to overcome these constraints while ensuring sustainability of natural resources (Opdam et al. 2006; Watson et al. 2011a). Sustainable landscape planning aims for stability in ecological, physical and social systems (cultural, economic functions) by maintaining the sustainability of natural resources with intergeneration equity (Opdam et al. 2006). Prioritisation of sensitive regions for conservation (Myers et al. 2000) through a multidisciplinary approach is widely accepted norm to identify hotspots of biodiversity. Ecologically sensitive region (ESR) is a bio-climatic unit (as demarcated by entire landscape) wherein human impacts may cause irreversible changes in the structure of biological communities (as evident in number/composition of species and their relative abundances) and their natural habitats. A range of conservation actions being practiced, includes protecting altitudinal gradients (Watson et al. 2011b), protecting contiguous forests with native vegetation, habitat of endemic flora and fauna, sacred patches of forests/kans/groves and creating large-scale corridors that allow shifts in species ranges due to environmental changes (Boyd et al. 2008; Toth et al. 2011). Spatial components such as riverine corridors, upland-lowland gradients and macroclimatic gradients have been identified as proxies of key ecological processes at regional scales and participatory or incentive-based instruments at the local scale (Rouget et al. 2006; Levin et al. 2013). In addition, knowledge of landscape dynamics due to the natural and anthropogenic activities is required for evolving apt conservation measures (Pressey et al. 2007; Vigl et al. 2016). The local conservation endeavors involving effective strategic landscape planning processes also help in mitigating the impacts of climate changes (Blicharska et al. 2016; Conradin and Hammer 2016).

The spatial conservation planning considers ESR based on both ecological and cultural dimensions. Ecological dimension refers to the natural environment such as ecosystems and ecological processes, while cultural dimension refers to the political, social, technological and economic aspects. Section 5(1) of Environment Protection Act 1986 (EPA), the Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India stipulate the location of industries or implementation of developmental projects based on the ecological sensitivity or fragility of a region considering permanent and irreparable loss of extant life forms; or significant damage to the natural processes of evolution and speciation (Sen 2000). Gadgil et al. 2011 prepared an outline for determining eco-sensitive regions based on biological, economic, socio-cultural values depending upon the context and the area or location for conservation. ESRs are the 'unique' areas of ecological and economic importance, vulnerable to even mild disturbances, irreplaceable if destroyed and hence demand conservation. Various empirical and statistical approaches based on regression or probability analysis have been applied widely to assess regional conservation priorities. However, these approaches lack spatial visualisation, which are essential for effective planning and understanding the implications of decisions (Margules and Pressey 2000; Li et al. 2006). Geo-informatics fortified with free and open source softwares have gained significance in recent times due to the contribution to spatial conservation planning of a region by providing a consistent spatial analytical visualisation and modelling abilities for an understanding of ecological systems (Wang et al. 2010; Bourne et al. 2016). Spatial decision support tools are playing an important role in increasing accountability and transparency of the planning process and leading to more economically efficient conservation actions (Knight et al. 2006; Marignani and Blasi 2012). The objective of the current endeavour is to identify and prioritise ecologically sensitive regions based on ecological, biological, social and geoclimatic attributes. This will involve (i) demarcating local hotspots of biodiversity for conservation based on biotic, abiotic and social criteria with an integrated biodiversity database and management prescriptions to beneficiaries at every level from the village communities to the Government; (ii) compiling primary data related to biodiversity, ecology, energy, hydrology and social aspects and (iii) developing of a comprehensive management framework with measures to mitigate forest loss and attain sustainable growth and support to preserve biodiversity.

2 Materials and Method

2.1 Study Area

The Western Ghats, a rare repository of endemic flora and fauna is one of the 35 hotspots of global biodiversity and a home to diverse social, religious, and linguistic group. The range of ancient hills that runs parallel to the west coast of India forms several ecological regions depending upon the altitude, latitude, rainfall, and soil characteristics. Uttara Kannada district located in the central Western Ghats (Fig. 1) lies between 13.769°–15.732° N and 74.124°–75.169° E covering approximately an area of 10, 291 km^2. The district extends N-S to a maximum of 180 km and W-E to a maximum width of 110 km. The Arabian sea border it on west creating a long continuous through narrow, coastline of 120 km. Goa, Belgaum, Dharwad form Northern-Eastern and Shimoga-Dakshina Kannada form Southern boundaries for the district, respectively. The district has varied geographical features with thick forest, perennial rivers and abundant flora, fauna. It has the unique distinction of having 3 agro-climatic zones and for the regional administrative purpose, 11 taluks (also known as tehsil or mandal is an agglomeration of villages) have been structured. The coastal region, which has hot humid climate and rainfall varies

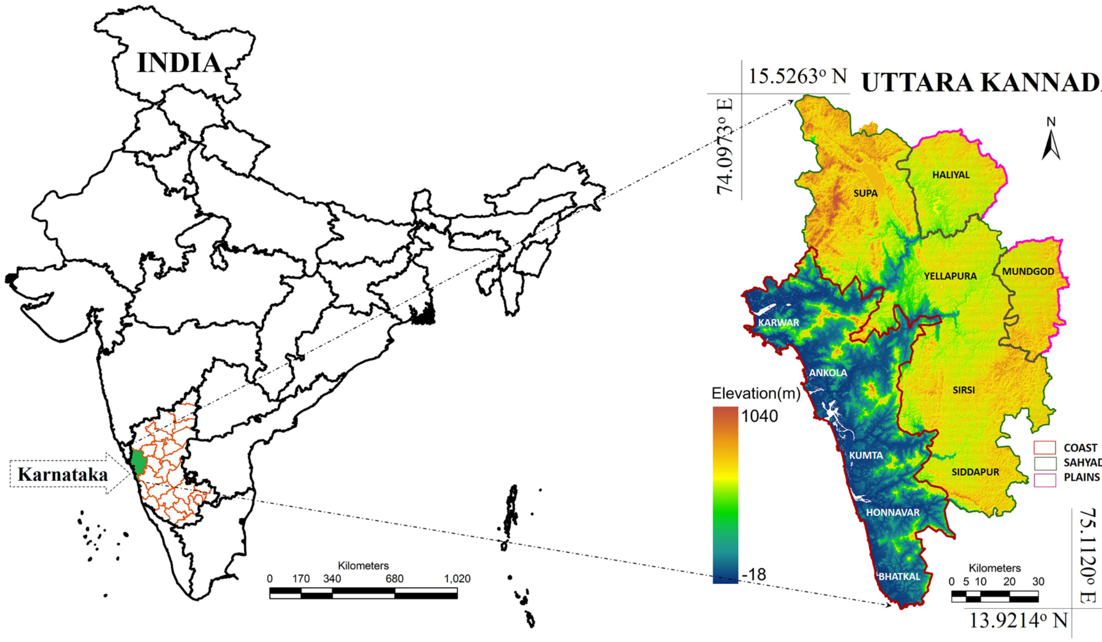

Fig. 1 Study area and its agro-climatic zones

between 3000 and 4500 mm. The Sahyadri interior region of the Western Ghats (500–1000 m elevation), which is very humid to the south (rainfall varies from 4000 to 5500 mm). The plains are regions of transition, which are drier (rainfall varies between 1500 and 2000 mm).

3 Method

ESRs in the district were prioritized considering biological (terrestrial and aquatic flora and fauna, estuarine biodiversity), ecological (diversity, endemism, conservation reserve), geo-climatic (altitude, slope, rainfall), renewable energy prospects (bio, solar, wind), and social (population, forest dwelling communities) variables as outlined in Fig. 2. The study area has been divided into $5' \times 5'$ equal area grids (168) covering approximately 9×9 km^2 (Fig. 3) for prioritizing ESR.

Table 1 lists the weightages assigned to each variable of various themes considering the minimal impact on the landscape and also to prioritise conservation regions for future planning. The weightages were assigned iteratively across the landscape with varied themes for a development solution and monitoring.

Developing a weightage metric score analysis requires knowledge of multi disciplines (Termorshuizen and Opdam 2009) and planning integrates the present and future needs in the landscape. Assigning weightages based on the relative significance of themes (Beinat 1997) provides a transparent mechanism for combining multiple data sets together to infer the significance. The weightage is given by,

$$\text{Weighatge} = \sum_{i=1}^{n} W_i V_i, \quad (1)$$

where n is the number of data sets (variables), V_i is the value associated with criterion i, and W_i is the weight associated with that criterion. Table 1 expresses the theme wise decision variable considered with their level of significance, ranked between 1 and 10. Value 10 corresponds to highest priority for conservation whereas 7, 5 and 3 correspond to high, moderate and low levels of prioritisation. Assigning weightages based on individual proxy based extensively on GIS techniques has proved to be the most effective for prioritizing ESR. Visualisation of levels of ESR help the decision makers in opting eco-friendly development measures. A detailed database has been created for various themes covering all aspects from land to estuarine ecosystem. The theme wise description is given below highlights the consideration of variables for study and their significance in conservation priority.

3.1 Land

Landscape dynamics is essential to investigate forest landscape pattern and process to understand how forest ecosystems change under anthropogenic disturbances. Land uses based on the analysis of remote sensing data were considered and grids were prioritised based on the proportion forest

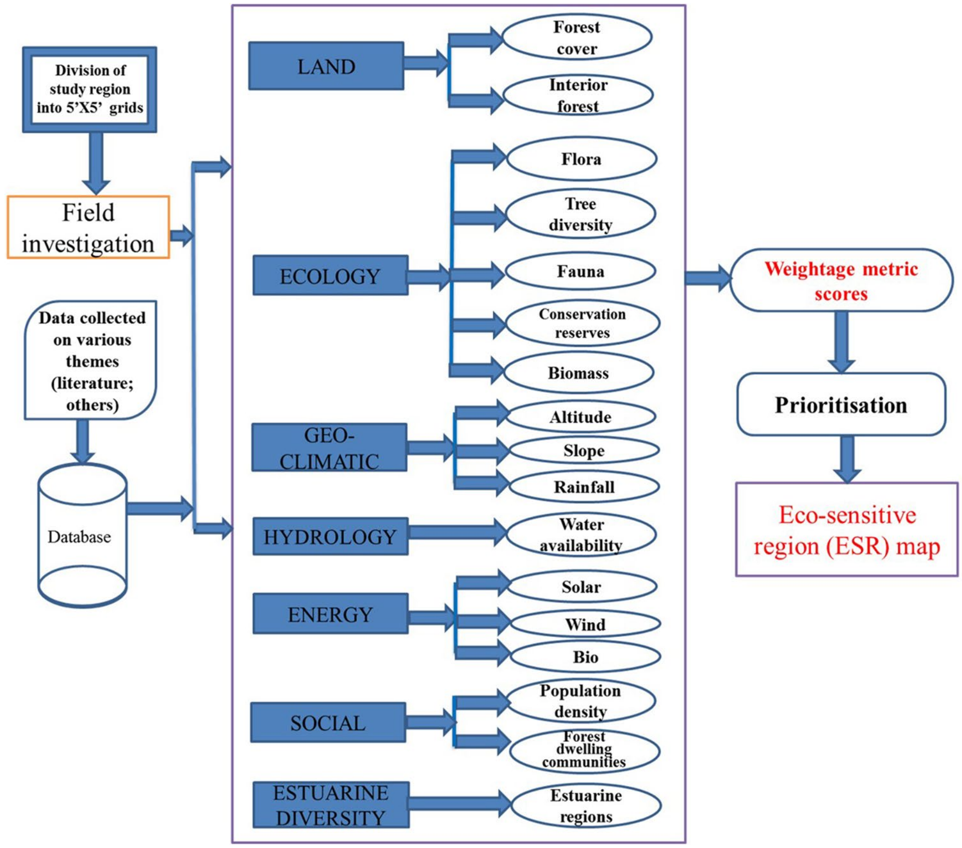

Fig. 2 Weightage metric criteria for prioritizing ESR

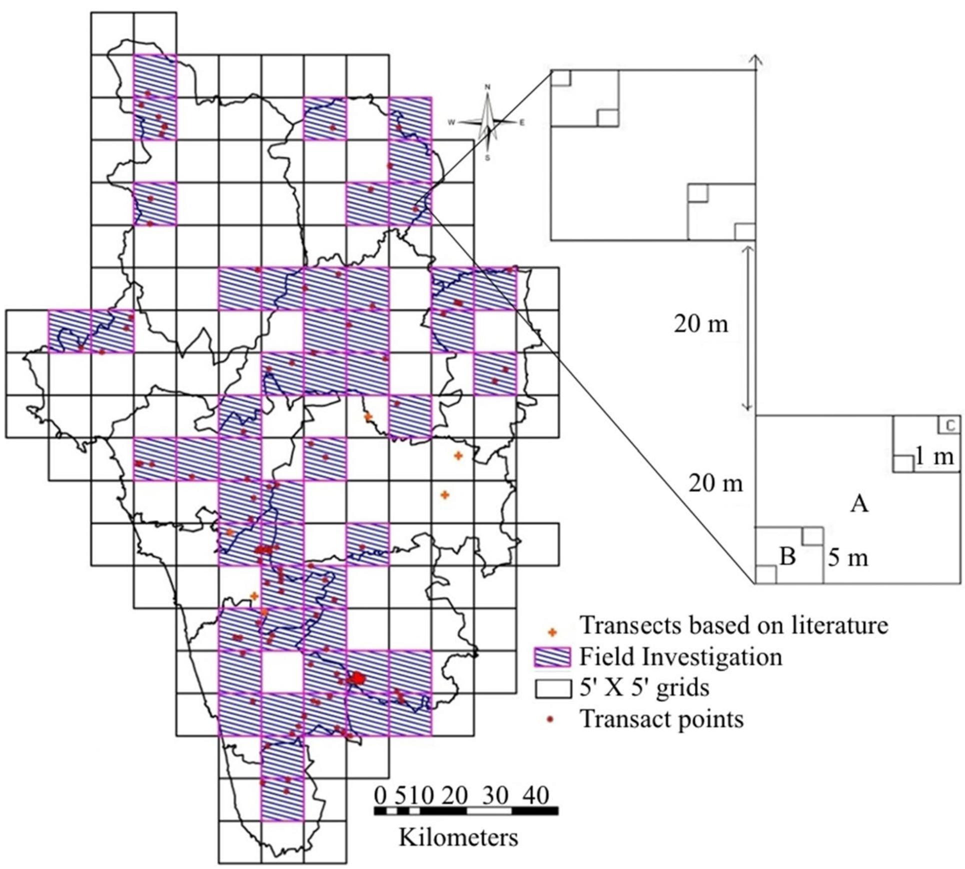

Fig. 3 Grids with the distribution of transects and transect cum quadrats (2 of 5 quadrats of 20 × 20 m only shown)

Table 1 The various themes considered and their weightages

S. No	Themes	Weightages/Ranking					Theme
		1	3	5	7	10	
1.	Land use	FC < 20%	20 < FC < 40%	40 < FC < 60%	60 < FC < 80%	FC > 80%	Land
	Interior forest	IF < 20%	20 < IF < 40%	40 < IF < 60%	60 < IF < 80%	IF > 80%	
	Flora	NEND	END < 30%	30 < END < 50%	50 < END < 70%	END > 70%	
	Tree diversity	SHD < 2	2 < SHD < 2.5	2.5 < SHD < 2.7	2.7 < SHD < 3	SHD > 3	
	Fauna	–	NEND	–	–	END	
2.	Conservation reserves (CR)	–	–	–	–	National parks, Wild life reserves, Myristica swamps, Sanctuaries	Ecology
	Biomass (Gg)	BM < 250	250 < BM < 500	500 < BM < 750	750 < BM < 1000	BM > 1000	
3	Altitude						Geo-climatic
	Slope	–	–	–	Slope > 20%	Slope > 30%	
	Precipitation	–	1000 > RF > 2000 mm	2000 > RF > 3000 mm	3000 > RF > 2000 mm	RF > 4000 mm	
4.	Stream flow	WA < 4	4 < WA < 6	6 < WA < 9	9 < WA < 12	WA = 12	Hydrology
5.	Solar	–	–	<5 kWh/m^2/day	5–6 kWh/m^2/day	6–6.5 kWh/m^2/day	Energy
	Wind	–	–	2.4–2.55 m/s	2.5–2.6 m/s	2.6–2.7 m/s	
	Bio	SD < 1	SD > 1	1 > SD < 2	2 < SD < 3	SD > 3	
	Population density (PD)	PD > 200	100 < PD < 200	100 < PD < 150	50 < PD < 100	PD < 50	
6.	Forest dwelling communities (Tribes)	–	Tribes are present then assigned 10; if no tribal population exists, then assigned as 0				Social
7	Estuarine regions	–	Low	Moderate	High	Very high	Estuarine diversity

FC forest cover, *IF* interior forest cover, *END* endemic, *NEND* non-endemic, *BM* biomass, *SD* supply to demand ratio, *WA* water availability

cover (Ramachandra et al. 2016). Forest fragmentation statistics computed as per the standard protocol (Riitters et al. 2004; Ramachandra et al. 2016). The interior forest cover refers to the undisturbed core forest patches that are devoid of any edge effects and other land use influences, which is considered as another proxy under land theme. The intact primeval forests (interior) would aid in preserving the structure of the ecosystem while enhancing functional aspects.

3.2 Ecology

Field investigations were carried out in 116 sample transects (Fig. 3) for data on the plant species diversity, basal area, biomass, estimates of carbon sequestration, percentage of evergreenness and Western Ghats endemism and about the distribution of threatened species, etc. Along a transect length ranging up to 180 m, quadrats each of 20 × 20 m were laid alternatively on the right and left, for tree study (minimum girth of 30 cm at GBH (Girth at breast height) or 130 cm height from the ground), keeping intervals of 20 m length between successive quadrats. A number of quadrats per transect depended on species-area curve and most transects had a maximum of 5 quadrats. Within each tree quadrat, at two diagonal corners, two sub-quadrats of 5 m × 5 m were laid for shrubs and tree saplings (< 30 cm girth). Within each of these 2 herb layer quadrats, 1 sq.m area each, were also laid down for herbs and tree seedlings. Supplementary data were compiled through the review of published literature, unpublished datasets and ground-based surveys other than transects. Approaches adopted in documenting flora and fauna are outlined by earlier studies (Ramachandra et al. 2015).

The health of ecosystem and its significance is derived based on the key variables—endemism, floral diversity, evergreeness, etc., for evolving the composite conservation index. Data compilation included combination of field and literature. Tree species diversity was another measure calculated using a Shannon's diversity index (H'). This method was selected as it provides an account for both abundance and evenness (Brose et al. 2003). It also does not disproportionately favour specific species over the others as it counts all species according to their frequencies (Lou 2006). Shannon's diversity index, (H′) is defined as,

$$(H)' = -\sum_{i=1}^{n} (p_i) \ln p_i, \quad (2)$$

where i is the proportion of the species relative to the total number of species (p_i) multiplied by the natural logarithm of this proportion ($\ln p_i$) and the final product multiplied by − 1. The Shannon's index ranges typically from 1.5 to 3.5 and rarely reaches 4.5. Higher diversity range was assigned higher weightage for conservation.

Faunal diversity is another surrogate variable used to assess the eco-sensitivity of a region. The region is storehouse of endemic fauna, in which occurrence of endemic species increase in the undulating terrains of upper Ghats. Species richness and endemism are two key attributes of biodiversity that reflect the complexity and uniqueness of natural ecosystems (de Lima et al. 2013). Myers et al. (2000) prioritises regions as 'biodiversity hotspots', based on the presence of exceptional concentrations of endemic species and experiencing exceptional loss of habitat. The setting of regional conservation priorities based on combinations of modelling individual endemic species' distributions, evaluating regional concentrations of species richness, and using complementarity of areas by maximizing inclusion of species in the overall system is most appropriate (Peterson et al. 2000). The current study investigates floristic diversity associated with different forests and computes basal area, biomass and carbon sequestration in forests. Apart from the inventorying, mapping of the endemic tree, documentation of faunal species has been done to find out areas of high endemism and congregations of threatened species. A set of criteria for prioritising the regions has been prepared based on field investigation, interaction with stakeholders (researchers working in this region, forest officials, local people, subject experts).

Mammals are well represented in this chain of mountains and many endemic birds are found in all other places of the district. The endemic and non-endemic status of all faunal diversity is categorised based on literature and also field sampling. Many hill birds are common to the Sahyadris (mountainous part of the district) and also move locally up and down the Ghats from the plains to the coastline forests seasonally. Disturbances in the migration movements, increasing forest fragmentation with the isolation of the forest patches could be responsible for major losses of avifauna in the near future. Conservation Reserves (CR) are being established under the framework of Protected Areas (PA) under the Wildlife (Protection) Amendment Act of 2002. CRs are typically buffer zones or connectors and migration corridors between National Parks, Wildlife Sanctuaries and reserved protected forests in the district (Table 2). These reserves protect habitats that are under private ownership also, through active stakeholder participation. The biological diversity in these zones like National parks, Sanctuaries, Botanical gardens, Zoological gardens hosts threatened (rare, vulnerable, endangered) flora/fauna. Higher weightage is assigned for CR's.

3.2.1 Biomass

Biomass is another important indicator of forest health and reveals its role in a global carbon sink. Trees play an important role as carbon sink, during the process of photosynthesis, the atmospheric CO_2 is utilized by the leaves for the manufacture of food in the form of glucose, later on, it gets converted to other forms of food materials, i.e., starch, lignin, hemicelluloses, amino acids, proteins, etc., and is diverted to other tree components for storage, which is referred as biomass, measured in Giga grams. Most of Uttara

Table 2 Details of conservation reserves in Uttara Kannada

Name	Area (sq.km)	Conservation priority species	Priority locations
Anshi Dandeli Tiger reserve (ADTR)	1365	Conservation Tigers and Hornbills	Joida, Haliyal and Karwar taluks
Aghanashini LTM Conservation Reserve	299.52	Lion tailed macaque (LTM), Myristica swamps	Unchalli Falls, Kathalekan, Muktihole
Bedthi Conservation Reserve	57.07	Hornbills and *Coscinium fenestratum* (medicinal plant)	Magod Falls, Jenukallu gudda, Bilihalla valley, Konkikote
Shalmala Riparian Eco-system Conservation Reserve	4.89	Diverse flora, fauna and as an important corridor in Western Ghats of Karnataka	Ramanguli
Hornbill Conservation Reserve	52.50	Hornbills	Kali river
Attiveri Bird Sanctuary	2.23	Endemic birds	Mundgod taluk

Kannada falling in the high rainfall zone, except Mundgod and eastern parts of Haliyal and Yellapura support trees with higher biomass. Undisturbed forests tend to have more biomass than disturbed and secondary forests or savannas. Details of biomass quantification, flora and fauna diversity are available in Ramachandra et al. 2015 and http://wgbis.ces.iisc.ernet.in/biodiversity/database_new/. The analysis has calculated total standing biomass of forest's vegetation (Brown 1997; Ramachandra et al. 2000) based on field data and remote sensing data. Transect wise basal area per hectare were estimated using allometric equations. The basal area is also computed using regression equations and compared with field transect wise estimations. This approach has revealed the strong relationship between predicted basal area and estimated values using regression.

3.3 Geo-Climatic Variables

Geo-climate plays a major role in determining the speed of recovery (lag-time) of a landscape (and the ecosystem that governs it) and the studies reveal that variables such as altitude (elevation, slope, rainfall), easterly aspect, steepness and longer dry seasons have significant role in local ecology (Daniels and Vencatesan 2008). The patterns of altitude, slope, and rainfall bring about the sensitivity, heterogeneity, complexity of climate, soil, vegetation, land use, land cover in connection with socio-economic interactions (Wondie et al. 2011, 2012, 2013). The elevation map is generated using Cartosat DEM of 1 arc second resolution. Areas with steep slopes and high altitudes are likely to be eroded more easily, and hence vulnerable to natural erosion or landslides, need to be considered as least resilient and hence environmentally sensitive zones areas. The analysis has considered that the slopes and altitudes can be normalized within each grid from 0 (least average slope or lowest average altitude) to 10 (high slope and high altitude) and assigned to the grids. The slope map is generated from DEM dataset using GRASS (Geographical Resources Analysis Support System- http://wgbis.ces.iisc.ernet.in/grass/index.html)—free and open source tool. The rate of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from the center cell determine the slope. Slope values are (measured in degrees) extracted using slope the algorithm (Burrough and McDonell 1998) as,

$$\text{Slope degrees} = \text{ATAN}\left(\left(\left[{}^{dz}/_{dx}\right]^2\right) + \left(\left[{}^{dz}/_{dy}\right]^2\right)\right) \times 57.296, \tag{3}$$

where dz/dx is the rate of change in the x-direction; dz/dy is the rate of change in the y-direction.

Hydrology provides a fundamental basis for understanding material flows, environmental quality and stream ecosystem in a basin (Nagasaka and Futoshi 1999). Conservation of high biodiversity forest landscapes is justified on the basis of hydrological benefits—in particular, reduction of flooding hazards for downstream floodplain populations (Calder 2012). Forest conservation leads to preservation of hydrological flows, mitigation of extreme hydrologic events, retention of soils and sediments, conservation of productivity and biodiversity, as well as maintenance and purification of water supply. Point based daily rainfall data from various rain gauge stations in and around the study area between 1901 and 2010 were considered for analysis of rainfall (Vinay et al. 2013; Ramachandra et al. 2015). The rainfall data used for the study were obtained from Department of Statistics, Government of Karnataka; Indian metrological data (IMD), Government of India. Rainfall trend analysis was done for selected rain gauge stations to assess the variability of rainfall at different locations in the study area. The average monthly and annual rainfall data were used to derive rainfall throughout the study area through the process of interpolation (isohyets). Monthly monitoring of hydrological parameters reveals that streams in the catchments with undisturbed primary forest (evergreen to semi-evergreen and moist deciduous forests with spatial extent > 60% in the respective catchment) cover have reduced runoff as compared to catchments with disturbed/altered forest covers. Runoff and thus erosion from monoculture plantation forests was higher from that of natural forests. Forested catchment has higher rates of infiltration as soil is more permeable due to enhanced microbial activities with higher amounts of organic matter in the forest floor. Hydrological investigations of 18 months covering all seasons in the representative streams (Ramachandra 2014), reveal that streams in the catchment with the undisturbed native forest cover (vegetation of native species) carry water all 12 months (perennial) compared to the ones dominated by monoculture plantations (6–8 months water flow) and degraded catchment (4 months, only during monsoon). Native forests in the catchment while allowing infiltration during monsoon aid as sponge and retains the water, which are steadily released during the lean seasons. This is evident, as streams with the catchment dominated by agricultural and monoculture plantations (of *Eucalyptus globulus*. and *Acacia auriculiformis*) are seasonal with water availability ranging between 4 and 6 months. The grids where water is available during all months in a year (perennial flow) are assigned higher values.

3.4 Energy

Dependence on the conventional energy resources for electricity generation is eroding the natural resources at faster rate by causing significant adverse effect on ecology by producing enormous quantities of by products including nuclear waste and carbon dioxide. Improving energy efficiency, switch over to renewable sources of energy and de-linking economic development from energy consumption (particularly of fossil fuels) is essential for sustainable development of a region. Potential of renewable energy sources are assessed (Solar, Wind, Bioenergy) month wise and captured the variations (Ramachandra et al. 2014a, b, c). The Solar energy datasets are derived based on NASA's Surface Meteorology and Solar Energy (SSE) methodology The solar energy is available greater than 10 months with higher potential. Availability of wind energy and its characteristics of Uttara Kannada District have been analysed based on primary data collected from India Meteorological Department (IMD) observatories. Wind energy conversion systems would be most effective during the period May to August. Energy Pattern Factor (EPF) and Power Densities are computed shows that the coastal taluks such as Karwar, Ankola and Kumta have good wind potential. The household survey carried out to understand the spatio-temporal patterns in the domestic fuelwood consumption, reveals that 82–90% of the households still depend on fuelwood and agro residues. Analyses of sector-wise contribution in the energy surplus zones shows that horticulture residues contribute in the central dry zone, southern transition zone and the coastal zone, while in the hilly zone, forests contribute more towards the available bioenergy. Adaptation of green technologies would aid in cutting down carbon footprint. Weightages are assigned based on the level and quantum of availability of energy from renewable resources.

3.5 Social Aspects

The Biological Diversity Act (BDA) of 2002 stipulates the conservation of biological diversity, sustainable use of its components with fair and equitable sharing of the benefits arising out of the use of biological resources, knowledge and for matters connected therewith or incidental threat. Forest Rights Act 2006, Government of India seeks to recognize and vest the forest rights and occupation in forest land in forest dwelling Scheduled Tribes and other traditional forest dwellers who have been residing in forests for generations but whose rights could not be recorded. A large chunk of the population is directly dependent on these resources even today; trading them in conservation will be the unfruitful approach. Forest dwelling communities (tribes) of the district is mapped at village level and the grids with tribal population are assigned higher weightage. In the regional planning, demographic aspect is essential to many applications across the science and policy domains including assessment of human vulnerability to environmental changes. Land degradation is due to population pressure which leads to intense land use conversions without proper management practices. Increase in population density will lead to the increasing exploitation of natural resources and the resulting loss of species and ecosystem richness, nature conservation (Paloniemi and Tikka 2008). Village-wise population density is computed considering 2011 population census data (http://censusindia.gov.in). Population density per sq. km is considered as one of the influencing social factors for prioritisation and the grids with lower population density are assigned higher weightage. The need for combining nature conservation with social aspect is to emphasise receiving a livelihood from natural resources and participation in enriching biodiversity.

3.6 Estuarine Diversity

Estuarine ecosystems are biologically productive, socio-economically vital and aesthetically attractive while providing food and shelter for many vital biotic species and some are commercially very important (Zhang and Shuzhen 2001). West coast estuaries of the district were assessed based on productivity, biodiversity and human pressure (Mesta et al. 2014). The analysis has identified the mangroves at species level using remote sensing data with field-based measurements. Estuarine productivity based on goods and services of the district (Boominathan et al. 2012) bring out the disparity in productivity and diversity between the neighbouring estuaries due to major human intervention in the form of construction of hydroelectric projects in upstream. Estuaries were given weightages based on the productivity and diversity.

4 Results and Discussion

ESRs in the district were prioritized considering biological, ecological, geo-climatic, renewable energy and social prospects. Weightages were assigned to the grids for prioritizing eco-sensitiveness based on the relative significance of themes based on the aggregate metric score as ESR 1 (Regions of highest sensitivity), ESR2 (Regions of higher sensitivity), ESR3 (Regions of high sensitivity) and ESR4 (Regions of moderate sensitivity), respectively. Land use of 2013 was assessed using remote sensing data of Landsat ETM + sensor 30 m resolution. Land use analysis revealed that the region has about 32.08% under evergreen-semi-evergreen forests (Fig. 4a; Table 3) and higher forest cover (> 80%) was confined to the grids in Sahyadri region (Supa, Yellapura, Ankola, Sirsi taluks). The coastal taluks were having forest cover in the range 60–80% towards eastern part whereas western side totally degraded due to higher pressure. The plains showed least cover (< 20%) reflecting higher degradation and the natural forest cover in the district is only 542,475 Ha. The land clearing and subsequent agricultural expansion, exotic plantations resulted in the degradation of large forest patches at temporal scale. Weightages

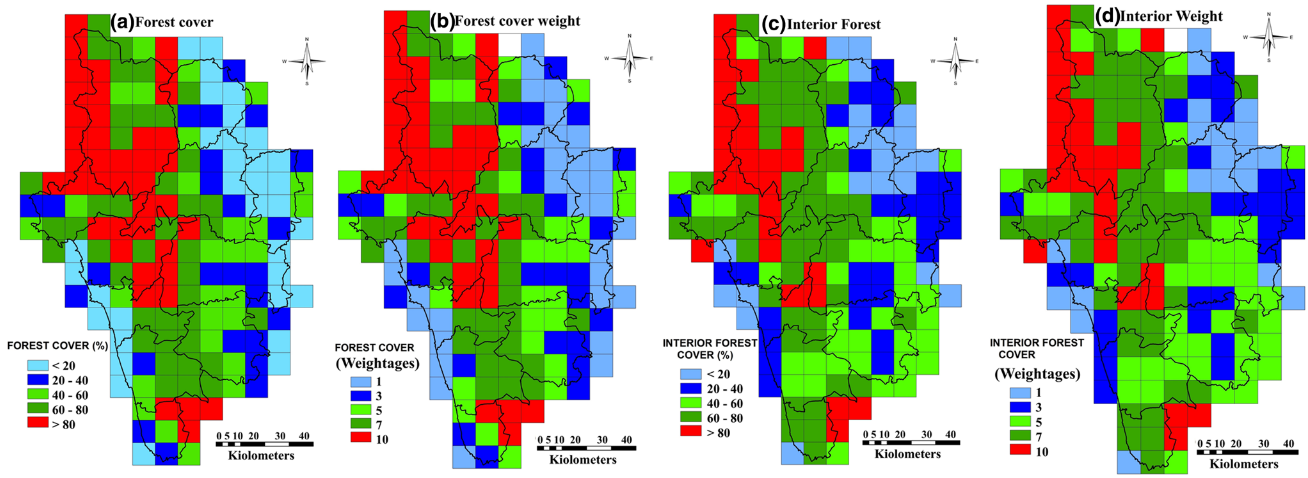

Fig. 4 Forest cover and interior forest cover status of Uttara Kannada district and their weights/rank

Table 3 Land use and fragmentation of forests in Uttara Kannada

Category	Land use analysis		Fragment type	Spatial extent	
	Ha	%		Ha	%
Built-up	31,589	**3.07**	Transitional	59,435	5.78
Water	28,113	2.73	Perforated	8909	0.87
Cropland	145,395	14.13			
Open fields	37,660	3.66	Patch	30,618	2.98
Moist deciduous forest	**161,996**	**15.74**			
Evergreen to semi-evergreen forest	**330,204**	**32.08**	Edge	179,870	17.48
Scrub/grass	40,402	3.93			
Acacia/Eucalyptus/hardwood plantations	122,927	**11.94**	Interior	**263,643**	**25.62**
Teak/Bamboo/softwood plantations	67,111	**6.52**			
Coconut/Arecanut/Cashew nut plantations	53,993	**5.25**	Non-forest area	**486,611**	**47.3**
Dry deciduous forest	9873	0.96			
Total area (Ha)	1,029,086				

Major changes in land uses are indicated in bold

were assigned to the grids based on the extent of forest cover (Fig. 4b), grids in Sahyadri region has highest ranking (10) compared to plains (1). Fragmentation analysis considering the spatial extent of forests, reveal that contiguous forests (interior forests) cover only 25.62%, land use under non-forest categories (cropland, plantations, built-up, etc.) covers 47.29% of the landscape (Fig. 4c) and Fig. 4d gives the relative wightages based on the extent of interior forests across grids in coast, Sahyadri and plains.

Flora and fauna of terrestrial and aquatic ecosystems have been studied through field investigations and compilation of information from published literature. These strategies helped in documenting 1068 species of flowering plants, representing 138 families. Among these 278 were trees species (from 59 families), 285 shrubs species (73 families) and 505 herb species (55 families). Moraceae, the family of figs (*Ficus* spp.), keystone resources for animals, had maximum tree sp (18), followed by Euphorbiaceae (16 sp.), Leguminosae (15 sp.), Lauraceae (14 sp.), Anacardiaceae (13 sp.) and Rubiaceae (13 sp.). Shrub species richness was pronounced in Leguminosae (32 sp.), Rubiaceae (24 sp.) and Euphorbiaceae (24 sp.) families. Among herbs, grasses (Poaceae) were most dominant (77 sp.); followed by sedges (Cyperaceae) with 67 sp. and Orchids (Orchidaceae). The high endemic species like *Gymnacranthera canarica, Myristica fatua, Mimusops elengi, Mesua ferrea, Mangifera indica, Mammea suriga, Aegle marmelos, Dipterocarpus indicus, Hopea Ponga, Vateria indica, Syzygium travancoricum, Semecarpus kathalekanensis*, etc., are well distributed in the district. Figure 5a depicts the distribution of flora and endemism and Fig. 5b depicts prioritized grids (weights based on the occurrence of endemic flora species), illustrating Honnavar, Kumta, Sirsi, Bhatkal, Siddapur are

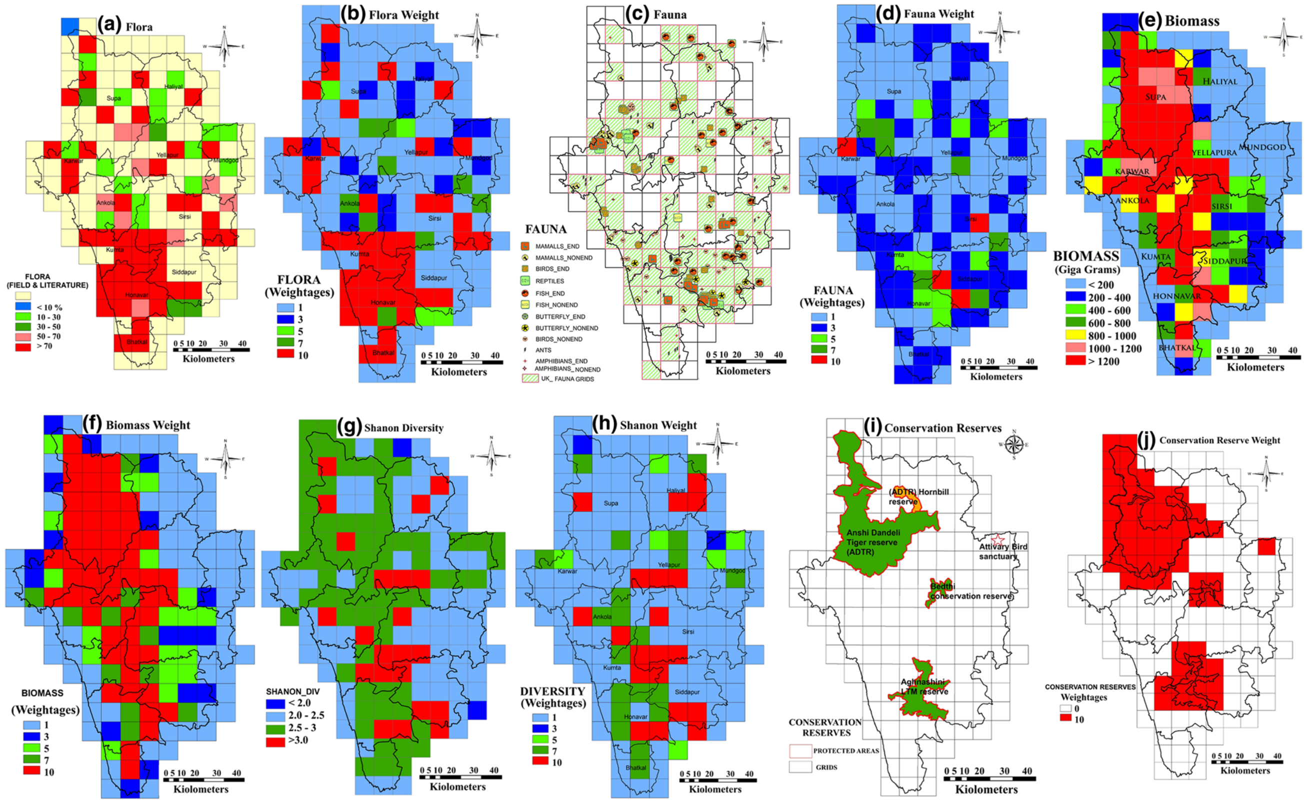

Fig. 5 Variables of ecology theme and their weights

representing greater weights and Mundgod and Haliyal shows lower endemism.

Figure 5c represents faunal distribution in Uttara Kannada district. The main predators are tiger (*Panthera tigris*), leopard, wild dog (dhole) and sloth bear. Leopards are wide spread in the forested regions and small numbers of wild dogs are usually sighted in Kulgi and Phansoli ranges of Dandeli. Sloth bears are frequently sighted in Ambikanagar, Virnoli, Bhagavati, Yellapura areas. Prey animals are barking deer, spotted deer (*Axis axis*), wild boar, sambar (*Cervus unicolor*), gaur (*Bos gaurus*). Kali River accommodates about 200 + marsh crocodiles. The district has an important elephant corridor between Karnataka and Maharashtra for about 60 elephants which are frequently sighted near Sambrani and Bommanahalli dam backwaters. The district is a paradise for birds, 272 birds are listed in the Dandeli, out of which 19 are considered to be endemic (Daniels and Vencatesan 2008). Attivery bird sanctuary at Mundgod is a home for endemic species as well as roosting place for migratory birds from other countries. Prominent birds of this region are Malabar Trogon, Malabar Pied Hornbill, Malabar Grey Hornbill, Indian Grey Hornbill, Great Indian Hornbill, Emerald Dove, Ceylon Frog mouth, Pompador Pigeon, etc. Wide variety of snakes are King Cobra, Cobra, Malabar Pit Viper, Hump nosed pit Viper, Bamboo Pit Viper, Kraft, Ornate flying snake, wolf snake etc. Butterflies include Crimson Rose, Common Rose, Leaf, Clipper, Tigers, Southern Bird wing, Cruiser, etc. The district has a rich endemic fish species such as *Batasio sharavatiensis, Ehirava fluviatilis, Gonoproktopterus kolus, Tetraodon travancoricus, Puntius sahyadriensis, Puntius filamentosus, Salmostoma novacula*, etc. The distribution of fresh water fishes is highly correlated to terrestrial landscape elements, of which quantity and quality of evergreen forests are more important. Higher weightages (10) were assigned (Fig. 5d) to the grids with endemic species and least (3) were assigned for grids with non-endemic fauna.

Biomass was estimated grid-wise and depicted in Fig. 5e, based on the spatial extent of forest and per hectare basal area. The total biomass of the district is **113823.58** Gg, with Sahyadri taluks such as Supa, Sirsi and Yellapura are having greater biomass (> 1200 Gg) followed by the costal taluks (Karwar, Ankola, Kumta, Honnavar). The plains and part of coastal regions have least biomass (< 200 Gg) in the district. The plains constitute mainly agriculture lands, built-up environments with sparse deciduous forest cover. Deciduous forests of Haliyal, Mundgod taluks in plains have relatively lower biomass. Hill slopes and sacred groves had higher basal area and biomass with diverse species. Net Carbon uptake by the forests of Uttara Kannada was estimated as half of the biomass. Grids with higher standing biomass regions were assigned higher weightages (Fig. 5f), as these regions help in maintaining global carbon through sequestration. Tree diversity was computed through Shannon diversity index (Fig. 5g, h) showed that most evergreen to semi-evergreen forests with diversity values ranging between 3 and 4. The evergreen tracts of Supa, Sirsi, Kumta and Siddapur are with diversity greater than 3. The moist deciduous forests in the rugged terrain of Ankola–Yellapur areas had relatively higher diversity, compared to such forests in plainer areas. Lower Shannon diversity was in dry deciduous and highly disturbed forests of Mundgod, Haliyal, Yellapura (eastern grids), which were disturbed extensively, and are with the monoculture plantations of teak. Uttara Kannada district has two important protected areas namely **Anshi National Park** and **Dandeli Wildlife Sanctuary** (Fig. 5i). Higher weightage is assigned to locations of these protected areas (Fig. 5j) as they are key eco-sensitive regions with diverse biodiversity.

Geo-climatic variables such as altitude, slope and rainfall were analysed to identify sensitive zones. Figure 6a depicts the altitude profile of the district; highest elevation is 758 m in Supa taluk. Grids were assigned weights (Fig. 6b) with regions > 600 m as higher priority for conservation and > 400 m is moderate and rest is of least concern. Figure 6c depicts the slope in the region while Fig. 6d depicts the grids with weights assigned based on the sensitiveness of the slope. Rainfall pattern (Fig. 6e) shows district falls in the high rainfall zone, except Mundgod and eastern parts of Haliyal, Yellapura. Grids are assigned weights based on the quantum and duration of rainfall (Fig. 6f). High rainfall areas have high biodiversity values and higher conservation values. High rainfall areas of Sahyadri and coastal taluks are major seats of endemic biodiversity of both plants and animals. The subbasin wise analyses were carried out to

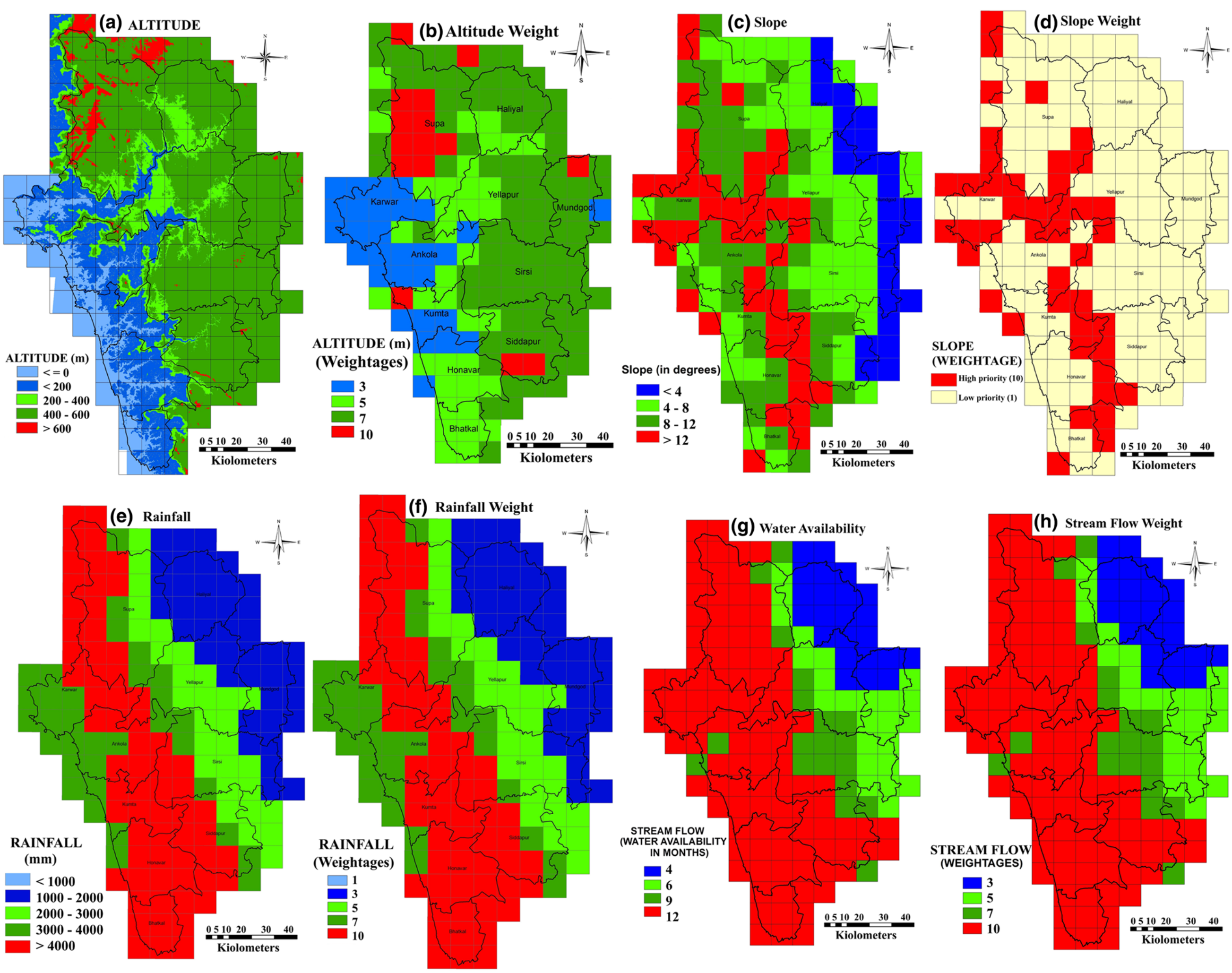

Fig. 6 Geo-climatic variables and weight

account perennial, seasonal flows of the region (Fig. 6g). Hydrological regime analysis reveals the existence of perennial streams in the catchment dominated by diverse forests with native vegetation (> 60% cover) compared to the streams in the catchments of either degraded forests or dominated by monoculture plantations. Higher water yield (> 5 times) is observed even during the non-monsoon season in the streams with catchment dominated by native forests. Grids in Sahyadri regions show 12 month's water availability in the streams and were assigned higher weightages (Fig. 6h). Haliyal, Mundgod, eastern part of Yellapura showing stream flow as only 4 months due to scarce rainfall and monoculture plantations.

Environmentally sound alternative sources of energy resources (Solar, Wind, Bio) potential were considered for prioritization (Fig. 7a, c, e). The region receives an average solar insolation of 5.42 kWh/m^2/day annually and has more than 300 clear sunny days. This solar potential can be utilized to meet the domestic and irrigation electricity demand. Wind resource assessment shows Wind speed varies from 1.9 m/s (6.84 km/h.) to 3.93 m/s (14.15 km/h.) throughout the year with a minimum in October and maximum in

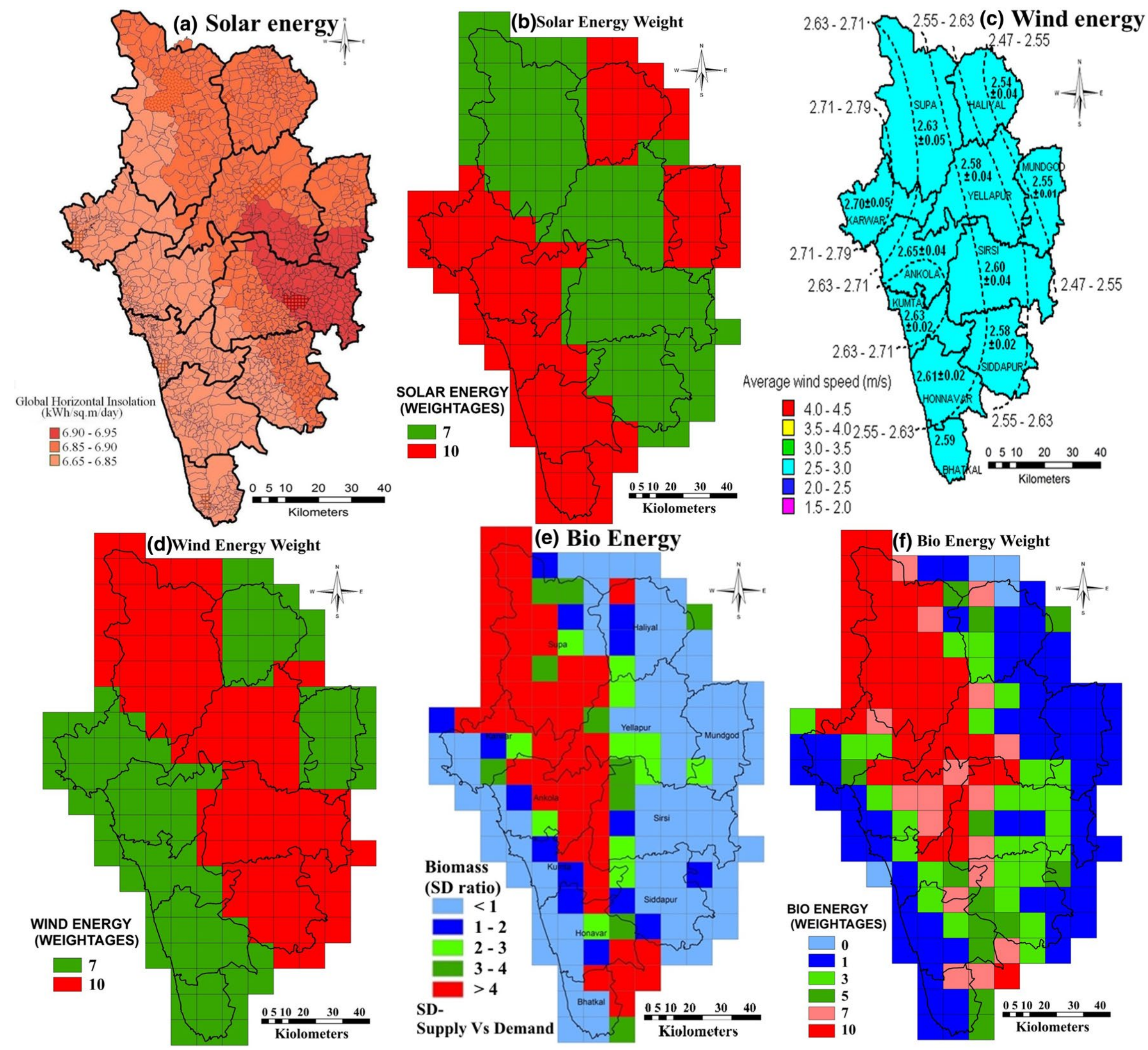

Fig. 7 Energy prospects and its weight

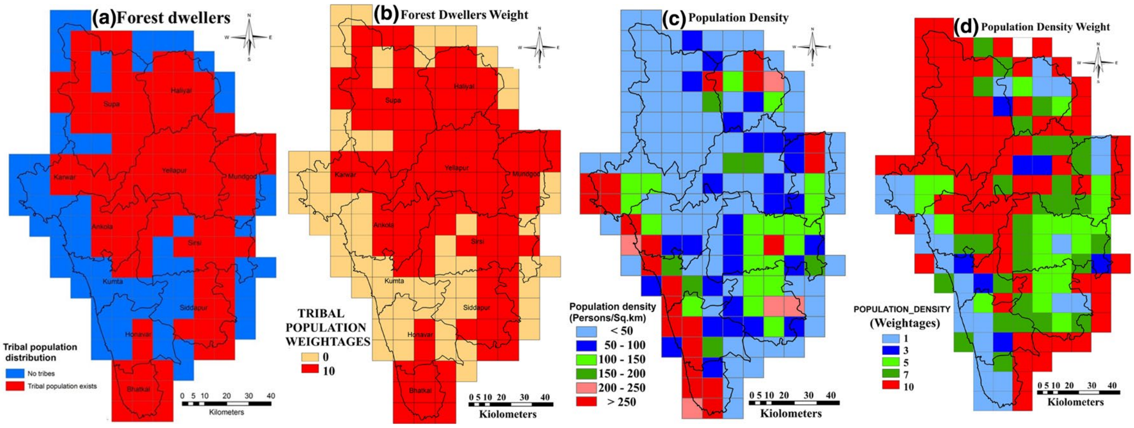

Fig. 8 Socio variables and weight

June and July. Bioresource availability was computed based on the compilation of data on the area and productivity of agriculture and horticulture crops, forests and plantations. Sector-wise energy demand was computed based on a primary household survey of 2500 households, the National Sample Survey Organisation (NSSO study) data and the information compiled from literature. The supply/demand ratio in the district ranges from less than 0.5 to greater than 2. Sirsi, Siddapur, Yellapur, Supa and eastern hilly areas of Kumta, Honnavar and Ankola are fuelwood surplus regions. Hybridizing wind energy systems with other locally available resources (solar, bioenergy) would assure the reliable energy supply to meet the energy demand at decentralized levels and weights were assigned based on the availability (Fig. 7b, d, f).

Forest dwelling communities such as Kunbis, Siddis, Goulis, Gondas were spatially mapped (Fig. 8a) and were assigned highest weights (Fig. 8b), because these people are directly and indirectly dependent on forest resources and protecting forests. Grid wise population was computed by aggregating villages in the respective grid for 2011. Population density was computed for each grid (Fig. 8c) weightages were assigned (Fig. 8d). Grids with the lowest population density (< 50 persons) were assigned higher weight

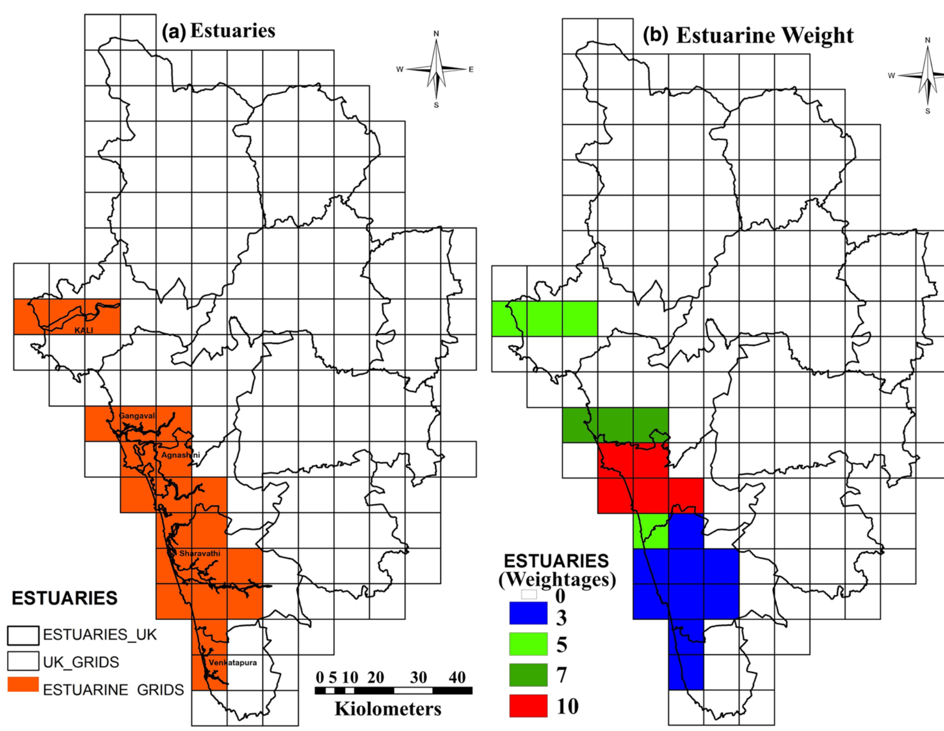

Fig. 9 Estuarine diversity and weight

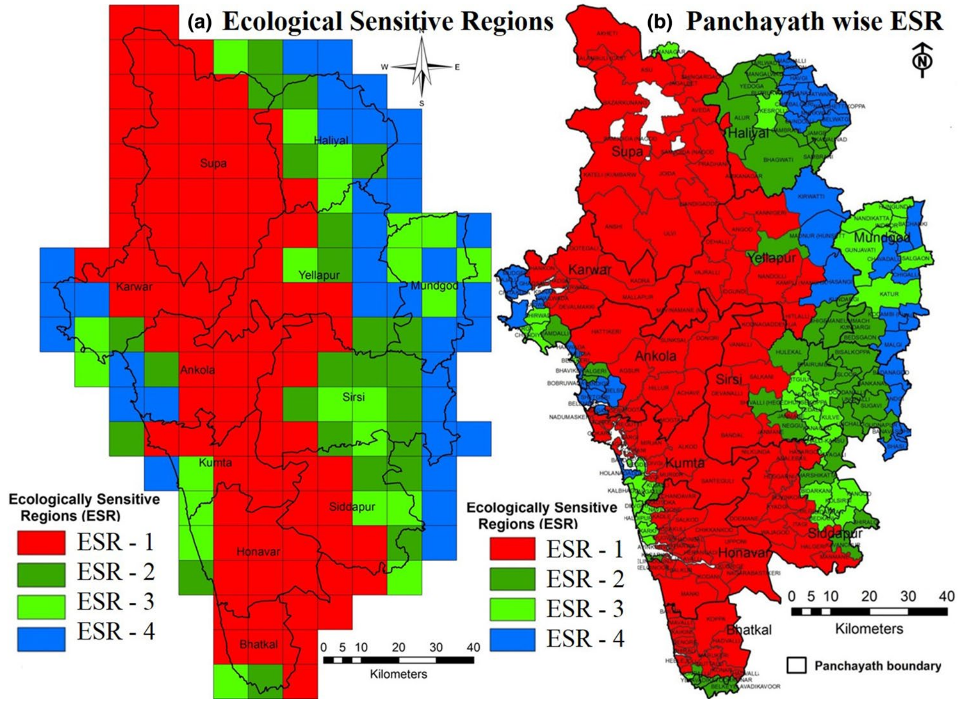

Fig. 10 Ecological sensitive regions of Uttara Kannada at panchayath level

(considering the likely lower anthropogenic stress) and vice versa. The four major estuaries viz. Kali, Gangavali, Aghanashini, and Sharavathi (Fig. 9a) are rich in mangrove species diversity and vital for fishery and cultivation of Kagga rice (salt tolerant) varieties. The biological diversity analysis shows Aghanashini and Ganagavali estuaries have higher fish diversity and mangrove species due to the absence of major anthropogenic activities (dam or hydro projects). Estuaries such as Sharavathi and Kali are severely disturbed with unplanned developmental activities, which have affected the productivity of livelihood resources (fish, bivalves, etc.). Coastal grids were assigned weightages (Fig. 9b), based on the biological diversity and productivity (considering provisional goods—fish, bivalves, sand and salt).

Figures 4a, 5, 6, 7, 8 and 9b give the relative weight of metric corresponding to biological, ecological, geo-climatic, renewable energy and social variables. Aggregation of these spatial layers, grids was graded as ESR 1, ESR 2, ESR 3 and ESR 4, respectively (Fig. 10a) based on the composite metric score. Spatially 52.38% of the district represents ESR 1, 14.29% of area represents ESR 2, 13.1% of area represents ESR 3 and about 20.23% of the district is in ESR 4. Figure 10b depicts ESR with taluk and gram panchayath (decentralized administrative units with a cluster of few villages) boundaries. Uttara Kannada district has 11 taluks and 209 panchayaths. ESR analyses reveals that ESR 1 consists mainly Supa, Yellapura, Ankola, Sirsi, Siddapur, Honnavar and Kumta taluks. Considering Panchayath level analyses, 102 panchayaths are in ESR 1, while 37 panchayaths in ESR 2, 33 panchayaths in ESR 3 and 37 panchayaths in ESR 4. Sahyadri and eastern part of coastal regions represents highest ecological sensitiveness. Annexure I lists permitted, regulated and prohibited activities across ESRs. ESR 1 represents ecologically highly sensitive requiring strict conservation measures with sustainable management involving VFCs (Village forest committees). ESR 2 is as good as ESR 1, except degradation of forest patches in some localities. ESR 3 represents moderate conservation region and only regulated development is allowed in these areas. ESR 4 represents less sensitiveness.

5 Conclusion

ESRs are the 'ecological units' that may be easily affected or harmed. The ESR prioritization (ESR 1–4) via varied themes (biological, Geo-climatic, Social, etc.) at panchayath level is a major step towards an ecological audit that eventually result in the conservation and sustainable use of biodiversity. Spatially 52.38% of the district represents ESR 1, while 14.29% of area represents ESR 2, 13.1% of area represents ESR 3 and about 20.23% of the district is in ESR 4. Regions under ESR 1 and 2 are "no go area" for any developmental activities involving large scale land cover changes. ESR 2 has eco-sensitiveness similar to ESR 1 and has the potential to become ESR 1 with the appropriate eco-restoration measures. Persistence of the endemic (rare, threatened, etc.) species in ESR 1 and 2 calls for serious attention from conservationists and decision makers to initiate programs immediately for conservation. Forests with innumerable streams (i.e., water course forests) in the Western Ghats, offer tremendous potential for carbon stocking per unit area while also bettering the hydrology of these mountains, which form the main watershed for the entire Indian peninsula. These water course forests are not only rich with biodiversity, but are also with high biomass, which highlights the greater carbon sequestration potential and their prime role towards mitigation of impacts of global warming. This emphasizes the need for the review of existing forest policies to ensure sustenance of ecological services through the sustainable forest management strategies. Millions of subsistence farmers and other forest dwellers of Western Ghats can not only be partners in micro-level planning for prudent water use, but also stand to gain in a big way from carbon credits for their new role as promoters and guardians of watershed vegetation. Rendering such service for mitigating global climatic change can also, same time, serve well the cause of eco-sensitive regions in an otherwise much impacted biodiversity hotspot. The premium should be on conservation of the remaining ecologically sensitive regions, which are vital for the water security (perenniality of streams), mitigation of global carbon and food security (sustenance of biodiversity). There still exists a chance to restore the lost natural evergreen to semi-evergreen forests in the Western Ghats region through appropriate conservation and management practices. The management of biodiversity hotspot regions should focus on the conservation as well as socio-economic developmental aspects.

These ESRs or eco-clusters approach aids in the conservation of ecology, biodiversity, water resources, culture and traditions while paving way for location specific economic development, primarily aimed at elevating levels of livelihood security. ESRs are seen in the context of sustainability and environmental friendly behavior as means for a socio-ecological transition in the long run. The eco-clusters at decentralized levels aid as driver for conservation of ecologically sensitive regions and implementation of an appropriate regional economic policy with the necessary incentive structures to foster eco-innovation as well as growth and employment at local levels (with the region specific industries such as agro processing, etc.). This envisage the foundation of an on-going process to integrate ecological and environmental considerations into administration in the ecologically fragile and biodiversity rich districts of Western Ghats. The integrated database on biodiversity and socio processes furnishes analyzed data, advice and management prescriptions to beneficiaries at every level from the village communities to the Government. It is shown that eco-clusters are crucial for a sustainable development and thus need political commitment and incentives for the development of eco-industry sector (based on the local renewable natural resources). Thus, ESRs will aid as catalysts in a well-ordered decision making process through stake holder's active participation with the priorities for sustainable livelihood.

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Annexure I: Activities that can be Allowed in ESR -1, 2 3 and 4

SNO	ACTIVITIES	ECOLOGICALLY SENSITIVE REGIONS			
		ESR-1	ESR-2	ESR-3	ESR-4
1	ENERGY a. Solar (Roof top)	✓	✓	✓	✓
	b. Wind power	×	×	✓	✓
	c. Bio energy	✓	✓	✓	✓
	d. Coal based (Thermal power)	×	×	×	×
	e. Gas or liquid fuel based	×	×	×	✓
	f. Hydro power (Major)	×	×	×	×
	g. Hydro power (Micro)	×	×	×	✓
	h. Nuclear power	×	×	×	×
2	FORESTS a. Land use change (Forest to non-forest usages)	×	×	×	×
	b. Monoculture plantations	×	×	×	×
	c. Extraction of medicinal plants (with strict regulations)	×	✓	✓	✓
	d. Forest improvement through VFCs	✓	✓	✓	✓
	a. NTFP collection	✓ (Strict regulation by department)	✓(Strict regulation by department)	✓(Strict regulation by department)	✓
	b. Encroachment of forests and Myristica swamps	×	×	×	×
3	AGRICULTURE a. Agroforestry	✓	✓	✓	✓
	b. Organic farming	✓	✓	✓	✓
	c. Land use change / Encroachments	×	×	×	×
	d. Genetically modified crops	×	×	×	×
	e. Animal Husbandry	✓	✓	✓	✓
4	HORTICULTURE a. Organic farming	✓	✓	✓	✓
	b. Nitrogen and Phosphorus (N&P) fertilizers	×	×	×	✓ Dosage as prescribed by Agriculture department
	c. Endosulfan	×	×	×	×
	d. Pesticide, weedicide	×	×	×	✓
	e. Watermelon & Muskmelon	✓	✓	✓	✓

	farming				
5	**INDUSTRIES (Larger scale)**				
	a. Agro-processing industries	✓	✓	✓	✓
	b. Information Technology industries (IT)	✗	✗	✓	✓
	c. Red category (Polluting) industries	✗	✗	✗	✗
	d. Garment industries	✗	✗	✓	✓
	e. New establishment of Industries	✗	✗	✗	✓ (Allowed only after critical review by local stake holders and experts)
	f. Nonpolluting (Green) Industries	✗	✗	✓	✓
6	**INDUSTRIES (Small scale)**				
	(A) Garment industries	✗	✗	✓	✓
	(B) Domestic (Home based) industries a. Papad	✓	✓	✓	✓
	b. Mango processing	✓	✓	✓	✓
	c. Areca nut processing & Coir industries	✗	✓	✓	✓
	d. Milk products and processing	✓	✓	✓	✓
	e. Dry fruits & Spices	✓	✓	✓	✓
	f. Fruit processing (Ex: Kokum Juice-*Garcinia indica*)	✓	✓	✓	✓
	g. Fish and sea products processing	✓	✓	✓	✓
	h. Bee keeping and bee nurseries	✓	✓	✓	✓
	i. Pongamia plantations for biofuel (in private lands)	✗	✗	✓	✓
	j. Bio pesticides manufacturing	✗	✗	✓	✓
	k. Poultry farms and powdered eggs	✗	✓	✓	✓
	l. Vegetable dyes; fruits and vegetables preservation	✓	✓	✓	✓
	m. Medicinal plants cultivation and processing	✓	✓	✓	✓
	n. Aromatic plants and essential oil distillation; orchids and cut flowers harvesting industries	✗	✓	✓	✓
7	**TOURISM**				
	a. Ecotourism	✓	✓	✓	✓
	b. Organic village and home stay	✓	✓	✓	✓
	c. VFC managed tourism	✓	✓	✓	✓
	d. VFC managed home stay tourism in higher forest cover regions and protected areas	✓	✓	✓	✓
	e. Arts and handicrafts museum and trade center	✓	✓	✓	✓

8	**MINING AND MINERAL EXTRACTION** a. Iron ore	×	×	×	×
	b. Manganese	×	×	×	×
	c. Bauxite	×	×	×	×
	d. Limestone	×	×	✓	✓
	e. Quartz	×	×	✓	✓
	f. Sand extraction (on sustainable basis by ban on exporting)	×	×	✓	✓
9	**WASTE DISPOSAL** a. Hazardous waste processing units	×	×	×	×
	b. Solid waste disposal	×	×	×	✓ (For composting and manure preparation)
	c. Liquid waste discharge	×	×	×	✓ (Treatment plants (STP) for processing)
	d. Recycling and waste processing units	×	×	×	✓ (compliant with PCB)
10	**TRANSPORTATION** a. Widening of highways b. Roads and express ways	×	×	×	✓ (Allowed only after strict EIA)
	c. Rail and freight corridors	**Hubli - Ankola rail connectivbity**: Implementation with EMP, mechanism (post project monitoring, strict regulation and social audit) **Talaguppa - Honnvar**: Passes through Lion-tailed macaque (LTM) habitat and ecologically sensitive – not to be permitted			
	d. Up gradation of existing infrastructure	×	×	✓(Subject to EIAs, strict regulation and social audit)	✓

Remarks

- ESR_1 represents a zone of highest ecological sensitiveness, no further degradation be allowed. ESR-2 has the potentiality to become ESR-1 provided strict implementation norms and regulations for improvement of degraded patches of forests. Further erosion of ESR-2 will have more adverse effects in ESR-1.
- Forest Rights Act to be implemented in its true spirit.
- Monoculture plantations are not allowed, existing exotics should be replaced by planting location specific native species.
- Promote the use of renewable energy sources such as (solar, wind power) through incentive-based decentralized electricity generation.
- Mining is to be banned in ESR 1, ESR 2 and ESR 3.
- No new licenses to be given for quarry and sand mining in ESR 1 and 2.@@
- Local agro-based industry to be promoted with strict regulations and social audit.
- Adapt development projects (discussed in the next section) which will have least environmental impact by involving local community members in decision making and environmental monitoring.
- No new major roads, widening of highways.
- Proposed Talaguppa—Honnavar rail link to be shelved (affects LTM habitat, and ESR1).
- Ecotourism (comparable to Goa and Kerala model and based on MoEF regulations) after taking into account social and environmental costs.

- The laterite formations are aesthetically pleasing, and particularly with the massive flowering of rainy season herbs. The terrain is ideal for tourism and scientific studies.

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Research Article Open Access

Geoinformatics based Valuation of Forest Landscape Dynamics in Central Western Ghats, India

Ramachandra TV[1*] **and Bharath S**[2]

[1]*Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India*

[2]*Energy and Wetlands Research Group, Center for Ecological Sciences [CES], d Lab of Spatial Informatics, IIIT-H, Hyderabad, India*

[*]**Corresponding author:** Ramachandra TV, Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India, Tel: +91-80-2293-3099; E-mail: tvr@iisc.ac.in

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Abstract

Landscape dynamics driven by land use land cover (LULC) changes due to anthropogenic activities altering the functional ability of an ecosystem has influenced the ecology, biodiversity, hydrology and people's sustainable livelihood. Forest landscape dynamics have been quantified using spatial data acquired through space borne sensors along with collateral data. Vegetation cover assessment of Central Western Ghats shows the decline of vegetation from 92.87% (1973) to 80.42% (2016). Land use analyses reveal the trend of deforestation, evident from the reduction of evergreen-semi evergreen forest cover from 67.73% (1973) to 29.5% (2016). The spatial patterns of diverse landscape have been assessed through spatial metrics and categorical principal component analysis, reveal a transition of intact forested landscape (1973) to fragmented landscape. The analysis has provided insights to formulate appropriate policies to mitigate forest changes in the region to safeguard water and food security apart from livelihood of the local people for sustainable development.

Keywords: Landscape dynamics; Forest fragmentation; Land use; Land cover changes; NDVI; CATPCA; Spatial metrics

Research Highlights

- The objective of the current study is to assess the spatial patterns of landscape changes in the forested district (Uttara Kannada district) of Central Western Ghats in Karnataka, India.
- Vegetation cover assessment shows the decline of vegetation from 92.87% (1973) to 80.42% (2016).
- Land use analyses reveal the trend of intensive deforestation, evident from the reduction of evergreen-semi evergreen forest cover from 67.73% (1973) to 29.5% (2016).
- The present communication is aimed to understand the role of landscape metrics to define relationship between land use and landscape structure.
- The spatial patterns of diverse landscape have been assessed through spatial metrics and categorical principal component analysis; reveal a transition of intact forested landscape (1973) to fragmented landscape with the increased patchiness (2016).
- This analysis provided insights to formulate appropriate policies to mitigate forest changes and devising appropriate effective management and decision making towards the sustainable development of the region.

Introduction

Landscape consists of heterogeneous biophysical elements with dynamic interactions [1] that ensures the sustainability of natural resources. The complex interactions among ecological, economic, social and cultural entities, which depend on the structure of the landscape play a decisive role in the respective ecosystem's functions (cycling of water and nutrients, bio-geo-chemical cycles, etc.). This necessitates understanding of landscape structure (size, shape, and configuration) and constituent's spatial patterns (linear, regular and aggregated) through land use land cover [LULC] analysis. 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 [2-4]. Land use [LU] provides human uses of the landscape, e.g., habitations, agricultural lands, etc. Accelerated LULC changes in the recent decades by the enhanced anthropogenic activities have been playing a major role in altering climate and biogeochemistry patterns at global as well as at regional scales [5,6]. Burgeoning population and increased consumption levels has led to the conversion of about 40 percent of Earth's surface to cropland, etc. at the expense of forests and natural grasslands [7]. Uncontrolled LULC changes affect health of ecosystem [8,9] and determine the vulnerability of humans, locations due to climatic, economic or socio-political perturbations [10-12]. Temporal LULC information is vital for elucidating landscape dynamics, essential for regional planning and sustainable management of natural resources [7,13].

LULC information has become prime prerequisites to overcome the problems of haphazard, uncontrolled development, quantifying deteriorating environmental quality through time. Monitoring and management of natural resources requires accurate, timely, synoptic and repetitive coverage over large area across various spatial scales. Remote sensing (RS) data along with Geographic Information System (GIS) and GPS (Global positioning system) help in inventorying, mapping and monitoring of earth resources for an effective and sustainable landscape management [3,14,15] with better spectral (Multi Spectral data, Hyper spectral data, etc.) and spatial resolution data (Low, Medium, High). Landscape metrics also known as spatial metrics or spatial pattern statistics are universally well acknowledged to perceive shape and pattern of landscape heterogeneity of different patches at local scale [16-21]. Cluster analysis helps in grouping the

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components to compute the universality, strength, and consistency of the landscape structure components [22,23]. Categorical Principal Component Analysis (CATPCA) is an effective method to reduce the number of dimensions in the data while retaining variability. Standard Principal Components Analysis (PCA) assumes linear relationships among variables but CATPCA optimally quantifies variables in the specified dimension helps in modeling nonlinear relationships among variables [24,25]. In CATPCA, model estimation and optimal quantification are alternated through use of an iterative algorithm that converges to a stationary point where the optimal quantifications of the categories do not change further.

Objectives

The objective of the current study is to assess the spatial patterns of landscape changes in the forested district (Uttara Kannada district) of Central Western Ghats in Karnataka. This involves,

- Temporal analysis of LULC changes considering RS data;
- Analyses of the spatial patterns of landscape changes through spatial metrics at temporal scale to define relationships between land use and landscape structure; and
- Prioritization of regions through visualization of spatial patterns of landscape dynamics.

Materials and Methods

Study area

Uttara Kannada district in Karnataka State, India (Figure 1) is blessed with highest forest cover (among all districts in India), perennial streams and productive estuaries. The district has a tropical climate with the mean annual rainfall of 4237 mm and elevation ranges from 0 to 1050 m (above Sea level). The district has 140 km coastal line and surrounded by Belgaum district, Goa state in North, Shimoga and Udupi districts in the South, Dharwad district in the East, Arabian Sea forms the West border. The west flowing rivers (Kali, Bedthi, Aganashini, Sharavathi, Venkatapur) break the shoreline of Uttara Kannada by deep and wide mouthed estuaries, larger creeks with ample biodiversity. The district forms three distinct agro climatic zones covering 11 taluks (local administrative division) due to its varied topography, i.e., coast, hilly or Sahyadri Interior and plains. The total population of the district is 1502454 (as per 2011 census) with 146 persons per sq.km density. The costal and plains are expressing higher population presence compared to the undulating hilly taluks. The forests are stimulated by heavy rainfall, start growing within a few kilometers from the coast with lofty, dense canopies of tree crowns and shrub growth. As one moves from coast to Ghats (Sahyadri Interior), the forests are semi-evergreen to evergreen with grassy banks. Forest ecosystems in Uttara Kannada district have witnessed major transformations during the past four decades. Implementation of developmental activities without taking into account the ecological significance and services provided by them in meeting the livelihood of local population has resulted in the degradation of forests through large scale land use changes.

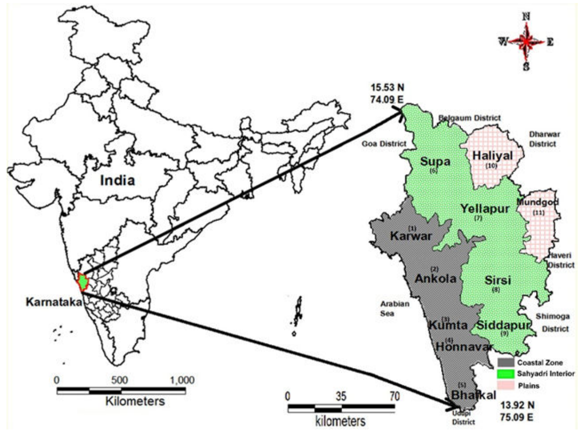

Figure 1: Study area-Uttara Kannada district, India.

Data

Land cover change elucidation relies on an accurate interpretation of baseline conditions and changes in the surface spectral properties over time. LULC dynamics of Uttara Kannada district have been analyzed using temporal Landsat series RS data (1973-2016) with ancillary data and field data as given in Figure 2. Ancillary data include cadastral revenue maps (1:6000), the Survey of India (SOI) topographic maps (1:50000 and 1:250000), vegetation map (1:250000) of South India developed by French Institute (1986). Digitized topographic maps helped in the extraction of ground control points (GCP's) to rectify RS data. Vegetation map of South India (1986) of scale 1:250000 [26] was useful in identifying various forest cover types during 1980's, required for classifying 1980's RS data. Other ancillary data includes land cover maps, administration boundary data, transportation data (road network), etc. Pre-calibrated GPS (Garmin GPS unit) were used for field data collection and used in geo-referencing, classifying RS data as well as validation. The Landsat data of 1973 with a spatial resolution of 57.5 m × 57.5 m (nominal resolution) were resampled to 30 m (nominal resolution) to maintain the uniform resolution across different time (1989-2016) data. Landsat ETM+ bands of 2013 were corrected for the SLC-off through image enhancement and restoration techniques, followed by nearest-neighbor interpolation.

Land cover analysis essentially involves delineating the region under vegetation and non-vegetation, which is done through the computation of vegetation indices NDVI (Normalized Difference Vegetation Index), given in equation 1. Among all techniques of land cover mapping through NDVI is most widely accepted and being applied [21,27], which ranges from +1 to -1. Very low values of NDVI (-0.1 and below) correspond to non-vegetation (soil, barren areas of rock, sand, built up, etc.) and NDVI of zero corresponds to water bodies. Moderate values represent low density vegetation (0.1 to 0.3), while high values indicate thick canopy vegetation (0.6 to 0.9). The outcome of NDVI (for the latest time period) was verified through field investigation.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

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Land use analyses involved (i) generation of False Color Composite (FCC) of RS data (bands–green, red and NIR). This composite image helps in locating heterogeneous patches in the landscape, (ii) selection of training polygons by covering 15% of the study area (polygons are uniformly distributed over the entire study area) (iii) loading these training polygons co-ordinates into pre-calibrated GPS, (vi) collection of the corresponding attribute data (land use types) for these polygons from the field, (iv) supplementing this information with Google Earth and (v) 60% of the training data has been used for classification based on Gaussian Maximum Likelihood algorithm, while the balance is used for validation or accuracy assessment (ACA). The land use analysis was done using supervised classification technique based on Gaussian maximum likelihood algorithm with training data. The land use is classified under 11 categories such as Built-up (B), Water (W), Crop land (C), Open fields (O), Moist deciduous forest (MD), Evergreen to semi evergreen forest (ES), Scrub/grass (SG), Acacia/Eucalyptus/Hardwood plantations (HP), Teak/Bamboo/Softwood plantations (SP), Coconut/Areca nut/Cashew nut plantations (CP), Dry deciduous forest (DD). GRASS GIS (Geographical Resources Analysis Support System, http://ces.iisc.ernet.in/grass)-free and open source software has been used for analyzing RS data by using available multi-temporal "ground truth" information. Earlier time data were classified using the training polygon along with attribute details compiled from the historical published topographic maps, vegetation maps, revenue maps, land records available from local administrative authorities.

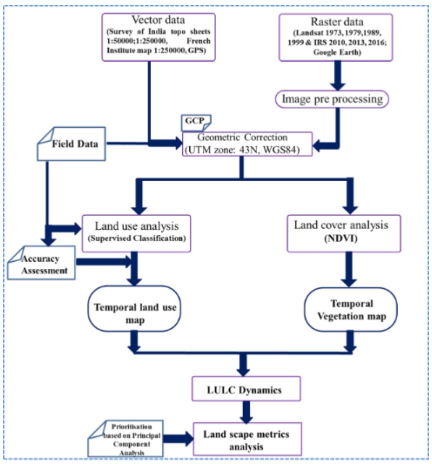

Figure 2: Method followed in the study.

ACA is done through error matrix (also referred as confusion matrix), and computation of kappa (κ) statistics, overall (producer's and user's) accuracies to evaluate the quality of the information derived from remotely sensed data considering training data. Kappa statistic compares two or more matrices and weighs cells in error matrix according to the magnitude of misclassification [28-30]. LU change rate for each category are computed by considering respective land use spatial extent in two time periods. The annual rate of change is computed using equation 2 to identify magnitude of changes in the respective land use category [31-33]. This approach helps to determine change rates from "known cover" as observed forest cover by providing areas that had changed to non-forest [34]. This computation is based on the area that was classified as forest in the first date and changed to non-forest in the second date.

$$Change\ rate = \left(\frac{\ln(A_{t1}) - \ln(A_{t0})}{(t_1 - t_0)}\right) \times 100 \quad (2)$$

Where A_{t1} is area of land use class in current year, A_{t0} is area of class in base year, t_1 is current year, t_0 is base year and Ln is natural logarithm. The equation will result % change of each land use class with negate and positive. The negative changes indicate to rate of loss; whereas positive change rate indicate gain in land use class.

Spatial patterns of landscape dynamics are assessed through prioritised [3,35-40] spatial metrics computed using Fragstats 3.3 [16]. Prioritised indices such as Class area (CA) has provided temporal change in forest area over non-forest cover in the landscape. Number of patches (NP) is a fragmentation based indices to account forest status, as less NP value represents intact forest and greater values results more fragmented patches. PAFRAC (Perimeter-Area Fractal Dimension) index indicates forest patch perimeter, stating either simple (homogeneous aggregation or intact forest present) or complex (the fragment that are being formed by intrusion). Patch indices (such as LPI- largest patch index) is computed to understand the process of deforestation as it provides larger patch in the landscape. Edge density (ED) analyses whether the region has simple edges or complex due to fragmentation. AREA_MN illustrates mean of forest area representing higher mean as more aggregation and vice versa. Shape metrics such as Landscape Shape Index (LSI), NLSI (Normalized Landscape Shape Index), Mean shape index (SHAPE_MN) and Mean patch fractal dimension (FRAC_MN) explain shape complexity and dynamic pattern of land use. Mean Euclidean nearest neighbour distance (ENN_MN) provides the information of disturbance regimes, as intermediate patches such as developments, clearing of forest patches lead to increase in nearest neighbour distance of forest patches. Clumpy Index shows clumped/aggregation of forest patches in the landscape, Aggregation index (AI) refer to specific forest class aggregation and is independent of landscape composition. Interspersion and Juxtaposition (IJI) is a measure of patch adjacency, values will decrease due to increase in the neighbouring forest patch distance in all the directions. CATPCA is the nonlinear PCA used to reduce the observed variables to a number of uncorrelated principal components by using student copy of IBM SPSS version 20.

Results and Discussion

Spatio temporal Landscape dynamics the spatial extent of temporal vegetation computed through NDVI reveals a decline of vegetation from 97.82% (1973) to 80.42% (2016). Areas under non-vegetation have increased (Figure 3) to 19.58% (2016) from 2.18% (1973), due to anthropogenic activities (Figure 4). Comparative assessment of land use categories reveals the decline of vegetation cover in the district (Table 1) during 1973 to 2016, Figure 5). The reduction of area under evergreen forests from 67.73% (1973) to 29.5% (2016) due to anthropogenic activities. Transition of evergreen-semi evergreen forests to moist deciduous forests, and some have been converted into plantations (such as *Acacia auriculiformis, Casuarina equisetifolia,* Eucalyptus spp., and *Tectona grandis* etc.) constitute 10.78% and 7.67% respectively. Enhanced agricultural activities is evident from the increase of agricultural land use from 7 (1973) to 14.3% (2016) and the area under human habitations have increased during the last four decades, evident from the increase of built-up area from 0.38% (1973) to 4.97% (2016). The dry deciduous forest cover is very less (1.27%) and is found mainly in the north eastern part of the district in Mundgod taluk and partly Haliyal taluk.

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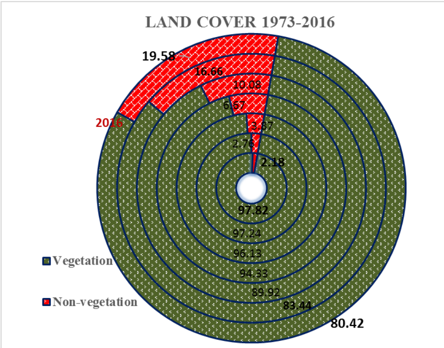

Figure 3: Temporal land cover analysis.

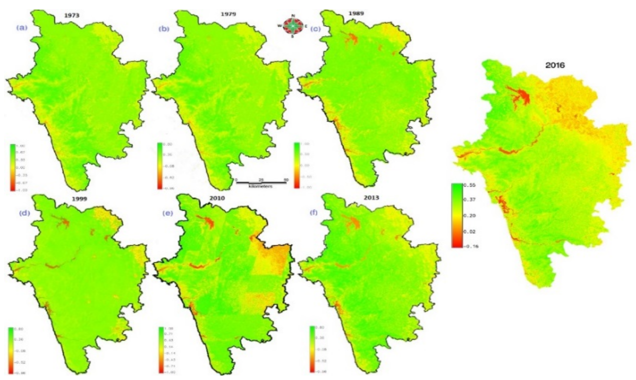

Figure 4: Land cover analysis from 1973 to 2016.

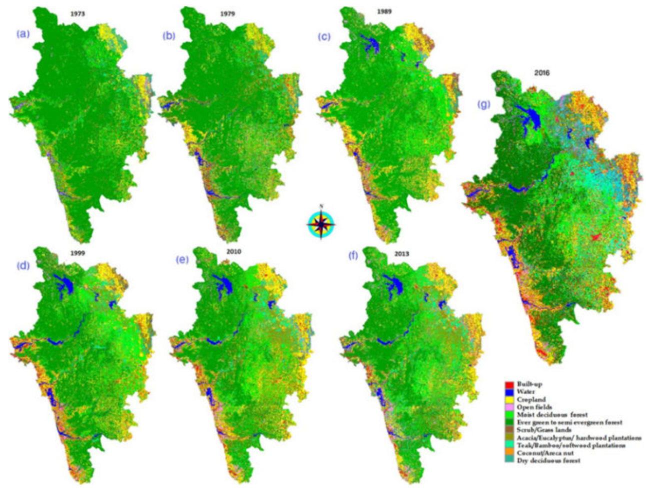

Figure 5: Uttara Kannada district land use change from 1973 to 2016.

Unplanned developmental activities coupled with the enhanced agriculture and horticultural activities have aided as prime drivers of deforestation, leading to the irreversible loss of forest cover with the reduction of ecosystem goods and services. The ACA (Table 2), verified using field data and Google earth data shows an accuracy of 82-92% with consistent results. Cautious steps were taken to make sure separate data sets used for training and validation to attain greater accuracy by consistent classification and confirmation. Category-wise land use change rates were computed; higher changes are noticed during 1973-79 followed by 2010 to 2016 (Figure 6).

Year ? Category (Ha)	1973	1979	1989	1999	2010	2013	2016	Loss/Gain (1973-2016)
B	3886	9738	12982	21635	28491	31589	51132	47246
W	7681	18527	16604	32983	26119	28113	28228	20547
C	71990	103163	121167	138458	148187	145395	147109	75119
O	14071	15988	34783	21945	30813	37660	42634	28563
MD	95357	102967	143849	179075	166266	161996	164239	68882
ES	696978	589762	531872	423062	367064	330204	303585	-393393
SG	38109	58936	44123	47366	35158	40402	42083	3974
HP	40905	50321	55694	73977	119717	122927	110950	70045
SP	13997	20896	21937	38588	44794	67111	78953	64956
CP	20702	29675	32227	43623	53646	53993	47135	26433
DD	25410	29113	13848	8374	9008	9873	13038	-12372
Total Area	1029086							

Table 1: Spatio temporal land use changes during 1973 to 2016.

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Non-forest regions such as agriculture, built environments show an increasing trend in each time period. The built-up area shows a positive increase of 15.31% y^{-1}(per year). The evergreen forest shows change of -2.78% y^{-1} (1973-1979) and -2.80% y^{-1} (2013-2016). The grater loss of evergreen forests can be seen as 3.53% y^{-1} (2010-2013) due to major motor ways expansion. Forest plantations and horticulture show an increase during 1973 to 2016, indicating market's role in land conversion. The abrupt land use changes are due to large-scale developmental activities, increased agriculture to meet the growing demand of population.

Year	Overall Accuracy	Kappa
1973	82.52	0.81
1979	84.29	0.81
1989	92.22	0.89
1999	90.71	0.87
2010	91.51	0.89
2013	91.98	0.90
2016	90.0	0.88

Table 2: ACA of the study. Here, PA Producer's Accuracy and UA User's Accuracy.

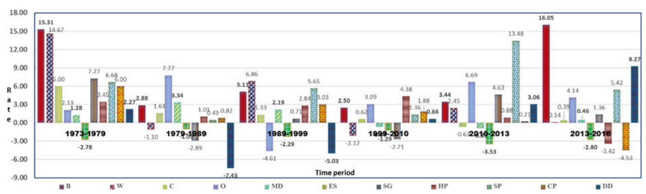

Figure 6: Temporal variation of land use change rate from 1973 to 2016.

Spatial metrics analysis and landscape prioritization

Spatial metrics were computed to quantify spatial patterns among three diverse landscapes at class level over time. The analysis of spatial metrics representing area, edge/border, compactness/dispersion, shape categories provided an overall summary of landscape composition and configuration over a period of four decades. CATPCA was carried out with relative weights of spatial metrics that provided vital insights to the spatial patterns of landscape. CATPCA considering 1973 and 2016 metrics data retained all components that were significant and the resulting components that are the major independent dimensions (Table 3) shows the combination of the categories. The two dimensions together explained 74.49% cumulative variance with eigenvalues of 7.98 (Dimension-1), 3.196 (Dimension-2) in 1973. The Dimension-1 has significantly positive correlation with SHAPE_MN, FRAC_MN, PAFRAC, NLSI, CA representing shape complexity property and negatively with CLUMPY, AI. The Dimension-2 represents NP, ED as positive and AREA_MN, LPI are showing negative correlation for the year 1973. Figure 7a shows taluks 1, 3, 4, 5, 9 and 10 representing forested regions (corresponding to major taluks of three agro-climatic regions) in 1973 form a single cluster with simple shapes and least number of patches. Taluks 7 and 2 form a cluster with higher influence of LPI and IJI indicating the presence of largest forest patches in these regions. Sirsi (8) taluk show higher fragmentation evident from NP, ED and large number of edges in the peripheral forested patches. CATPCA analysis for 2016 depicts cumulative variance of 69.14% under two dimensions with eigenvalues of 5.7 and 4.7 respectively. Figure 7b shows response variables exhibited a range of behaviours with respect to different levels of class proportion at temporal scale. In Dimension 1, NP, LPI, ED, LSI, SHAPE_MN are positively correlated and PARA_MN, CLUMPY, AI are negatively correlated. Dimension-2 represents CA, AREA_MN as positive and ENN_MN, NLSI represents negative correlation depicting the property of disaggregation of forest patches.

As class proportion of forest cover has decreased, there is a large increase in the standardized CLUMPY and aggregation indices, which lead to form a single cluster for all coastal taluks with similar spatial patterns of changes (coastal taluks 1, 2, 3, 4 and partly 5). The Sahyadri Interior region show intra spatial heterogeneity highlighted by CA, IJI. The high forested taluk Supa (6) has not expressing any influence of shape and patch metrics. Taluk 7 has major influence of SHAPE_MN, ED represents the irregular forest shape by alternation with the increase of non-forest activities. Taluks 8 had major influence of NP, LSI and PAFRAC depicting their shape irregularity followed by fragmentation. The development of new individual non-forest patches, as reflected by the slightly increases in NP and LSI resulted in more complicated patch shapes in the meantime, also produced many smaller and isolated fragmented patches at a temporal scale. Plains (taluks 10, 11) cluster shows influence of ENN_MN, NLSI as increase of nearest neighbour of forest patch with decrease of mean area cover indicating the region is losing its forest cover abruptly at temporal scale with increase in shape complexity. ED indicates that all taluks representing simple edges (almost square) in 1973 and transform to complex with convoluted edges in all directions in 2016 due to fragmentation with newly developing edges. The landscapes of three agro climatic zones differ in several ways, most clearly in their proportion of forest cover and spatial heterogeneity by 2016. Landscape metrics aided in quantifying the spatial patterns among three distinct and diverse landscapes. This approach has provided context for interpretable set of landscape patterns that objectively represent temporal land use changes in each forested taluk.

Component loadings (1973 and 2016)					
SNO	Spatial metrics	Dimension (1973)		Dimension (2016)	
		1	2	1	2
1	CA	0.649	-0.688	0.35	0.806
2	NP	0.370	0.743	0.786	-0.423

3	LPI	-0.228	-0.634	0.767	0.556
4	ED	0.633	0.676	0.801	0.072
5	LSI	0.991	-0.113	0.764	-0.348
6	AREA_MN	-0.044	-0.762	0.187	0.86
7	SHAPE_MN	0.986	-0.146	0.907	0.009
8	FRAC_MN	0.986	-0.146	0.618	-0.106
9	PARA_MN	-0.272	0.165	-0.783	-0.099
10	PAFRAC	0.986	-0.146	0.701	-0.201
11	ENN_MN	-0.352	0.306	-0.35	-0.806
12	CLUMPY	-0.986	0.146	-0.543	0.551
13	IJI	-0.349	-0.581	-0.013	0.942
14	AI	-0.896	-0.391	-0.558	0.633
15	NLSI	0.986	-0.146	-0.291	-0.598
Variance accounted for each time period					
Dimension		**1973**		**2016**	
		Total (Eigenvalue)	**% of Variance**	**Total (Eigenvalue)**	**% of Variance**
1		7.979	53.192	5.7	38.07
2		3.196	21.306	4.7	31.07
Total		11.175	74.498	10.4	69.14

Table 3: Component loadings of CATPCA among two dimensions and variance accounted.

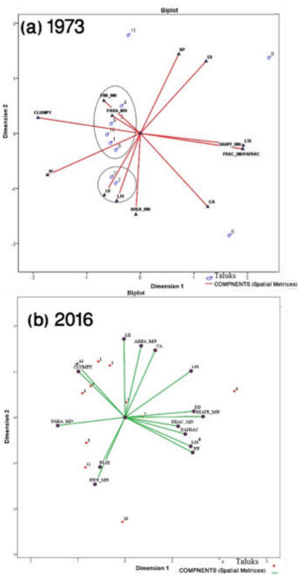

Figure 7: Spatial patterns of (a)1973 and (b) 2016.

Conclusion

Analysis of LULC dynamics using temporal RS data aided in understanding causes of changes, focussing on conservation and restoration of ecosystems. The LULC analyses of Uttara Kannada during 1973 to 2016 show significant variation during the last four decades as evergreen forests have declined from 67.73% (1973) to 29.5% (2016) and area under human habitations and paved surfaces have reached 4.97% (2016). Decline in forest cover in Costal taluks is due to housing, agriculture, transportation, etc. Sirsi, Siddapur, Haliyal, Yellapur and Mundgod regions have experienced changes in forest cover due to encroachments by disturbing local ecology. Market based economy has motivated Honnavara, Siddapur regions conversion of land for commercial crops. Landscape metrics helped in understanding spatial patterns of landscape, similar configurations and variation across the forested area of Uttara Kannada for devising appropriate effective management and decision making towards the sustainable development. Spatial metrics depicts the whole landscape in 1973 represents a simple spatial pattern except Mundgod and Sirsi. In 2016, due to continued changes in the structure by deforestation, the three agro climate regions are represented by dissimilar patterns. The costal taluks are more fragmented towards west (higher NP) and plain taluks expressing higher nearest neighbor distance (ENN_MN) of forest patches as shown by due to intermediate by exotic plantations. Edge effects have a rapidly increasing impact on Sahyadri Interior taluks forest dynamics in lower elevations and Sirsi taluk has higher

NP due to more intermediate patches of non-forest types. CATPCA along with spatial metric clustering information visually demonstrated the ability of these metrics to express the variation of patterns at the landscape scale. Variation in landscape spatial heterogeneity/similarity has provided regional level picture of the district, which can be used to frame conservation policies to protect social and ecological sustainability of ecosystems.

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