Conservation and Sustainable Management of Local Hotspots of Biodiversity

T. V. Ramachandra, B. Setturu, S. Vinay, N. M. Tara, M. D. Subashchandran and N. V. Joshi

1 Introduction

Ecosystems are the distinct biological entities that sustain the biosphere and are characterized by a range of functions: nutrient cycling, bio-geochemical cycle, hydrologic cycling. The conservation and sustainable management of ecosystems are the vital components in the pursuit of ecologically sound, economically viable and socially acceptable development goals. 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 [1]. 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 [2]. Decision-making based on the biophysical, economic and socio-cultural information provides an opportunity to overcome these constraints while ensuring the sustainability of natural resources [3]. 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 [1]. Prioritization of sensitive regions for conservation [4] 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

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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, sacred patches of forests, riverine corridors [5, 6] and participatory or incentive-based instruments at the local scale [7, 8]. In addition, the local conservation endeavours involving effective strategic landscape planning processes help in mitigating the impacts of climate changes [9, 10].

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. In India, section 5(1) of Environment Protection Act 1986 (EPA), the Ministry of Environment, Forests and Climate Change (MoEFCC) stipulates 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 [11]. *E*co-sensitive regions have to be determined based on biological, economic, socio-cultural values depending upon the context and the area or location for conservation [12]. ESRs are the 'unique' areas of ecological and economic importance, vulnerable to even mild disturbances, irreplaceable if destroyed and hence demand conservation [13]. Geo-informatics fortified with free and open-source software (FOSS) has gained significance in recent times due to the contribution to spatial conservation planning of a region by providing a consistent spatial analytical visualization and modelling abilities for an understanding of ecological systems [14, http://wgbis.ces.iisc.ernet.in/grass/; http://wgbis.ces.iisc.ernet.in/foss/]. 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 [15]. The objective of the current endeavour is to develop spatial decision system to prioritize ecologically sensitive regions based on ecological, biological, social and geo-climatic attributes. This involved (i) demarcation of 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) compilation of primary data related to biodiversity, ecology, energy, hydrology and social aspects and (iii). Development 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. 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 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. 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, the district is further divided into 11 taluks (also known as tehsil or mandal is an agglomeration of villages). The coastal region, which has hot humid climate and rainfall, varies between 3000 and 4500 mm. The Sahyadri interior region of the Western Ghats (500–1000 m high)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).

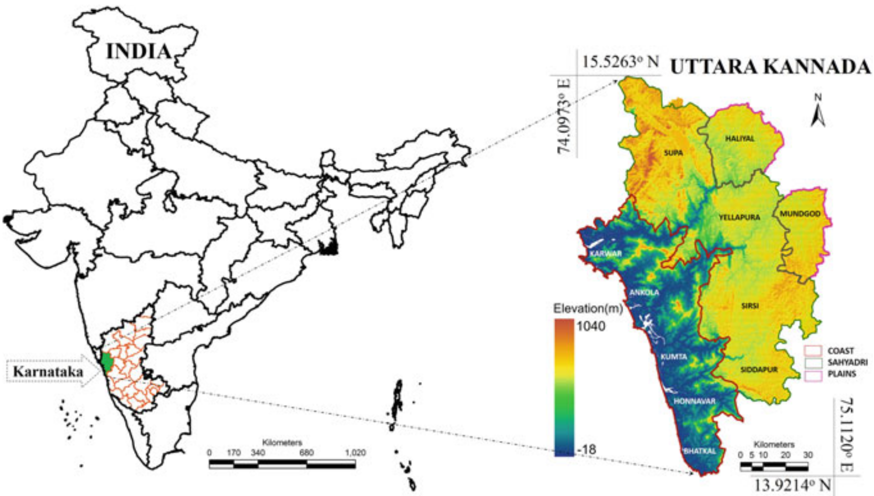


Fig. 1 Study area: Uttara Kannada district, Karnataka state, Central Western Ghats

2.2 Method

Local hotspots of biodiversity or ESRs in the district are 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), social (population, forest-dwelling communities) 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 prioritize 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 multidisciplines [16], and planning integrates the present and future needs in the landscape [17], and weightage is given by

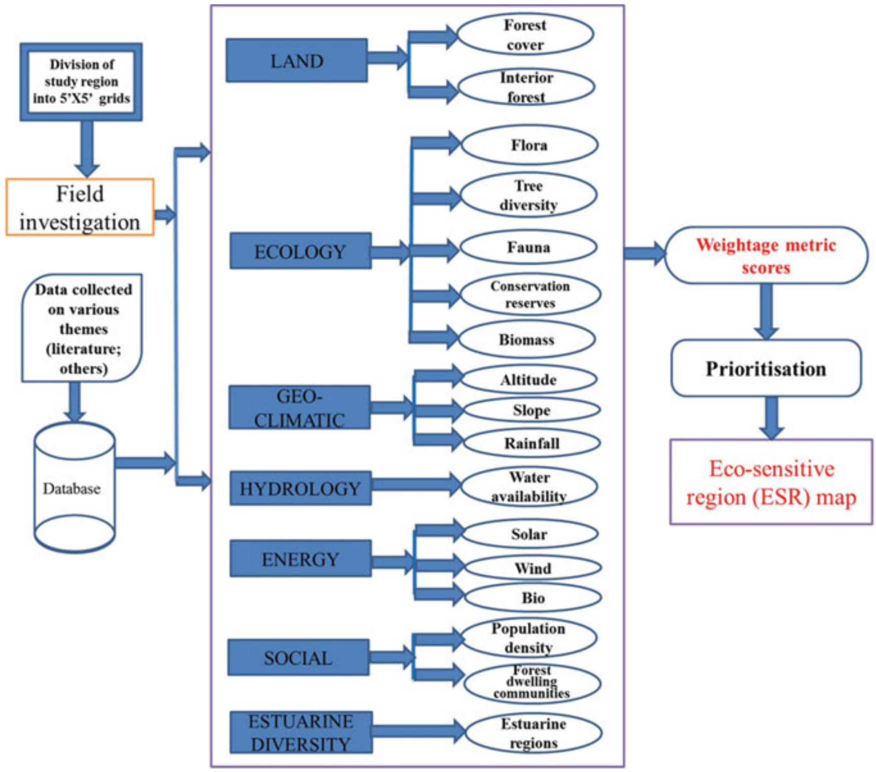


Fig. 2 Weightage metric criteria for prioritizing ESR

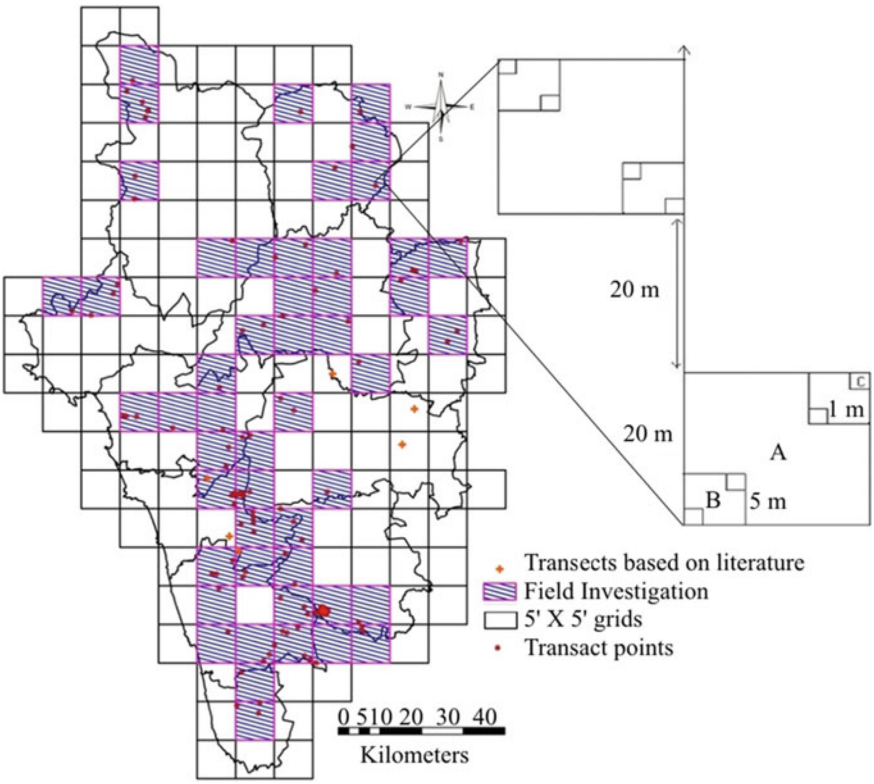


Fig. 3 Grids with the distribution of transects and transect cum quadrats (2 of 5 quadrats of 20 × 20 m only shown). Shaded grids are the representative grids chosen based on agro-climatic zones for field data collection

$$Weightage = \sum_{i=1}^{n} W_i V_i \tag{1}$$

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 prioritization. Assigning weightages based on individual proxy based extensively on GIS techniques has proved to be the most effective for prioritizing ESR. Visualization of levels of ESR helps 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 given below highlights the consideration of variables for study and their significance in conservation priority.

Table 1 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%	
2.	Flora	NEND	END < 30%	30 < END < 50%	50 < END < 70%	END > 70%	Ecology
	Tree diversity	SHD < 2	2 < SHD < 2.5	2.5 < SHD < 2.7	2.7 < SHD < 3	SHD > 3	
	Fauna	–	NEND	–	–	END	
	Conservation reserves (CR)	–	–	–	–	National parks, wildlife reserves, Myristica swamps, Sanctuaries	
	Biomass (Gg)	BM < 250	250 < BM < 500	500 < BM < 750	750 < BM < 1000	BM > 1000	
3.	Altitude slope	–	–	–	Slope > 20%	Slope > 30%	Geo-climatic
	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	
6.	Population density (PD)	PD > 200	100 < PD < 200	100 < PD < 150	50 < PD < 100	PD < 50	Social
	Forest-dwelling communities (tribes)	–		Tribes are present then assigned 10; if no tribal population exists, then assigned as 0			
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

2.2.1 Land

Land uses based on the analysis of remote sensing data were considered, and grids were prioritized based on the proportion forest cover [18]. Forest fragmentation statistics is computed as per the standard protocol [18, 19]. The interior forest cover refers to the undisturbed core forest patches that aid in preserving the structure of the ecosystem while enhancing its functional aspects.

2.2.2 Ecology

Field investigations were carried out in 116 sample transects (Fig. 4) 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 girth at breast height (GBH) 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 five 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 two herb layer quadrats, 1 m^2 area each was 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 [20].

The health of ecosystem and its significance is derived based on the key variables—endemism, floral diversity, evergreenness, etc., for evolving the composite conservation index. Tree species diversity is another measure calculated using Shannon's diversity index (H′). H′ is given by Eq. 2 [21, 22].

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

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

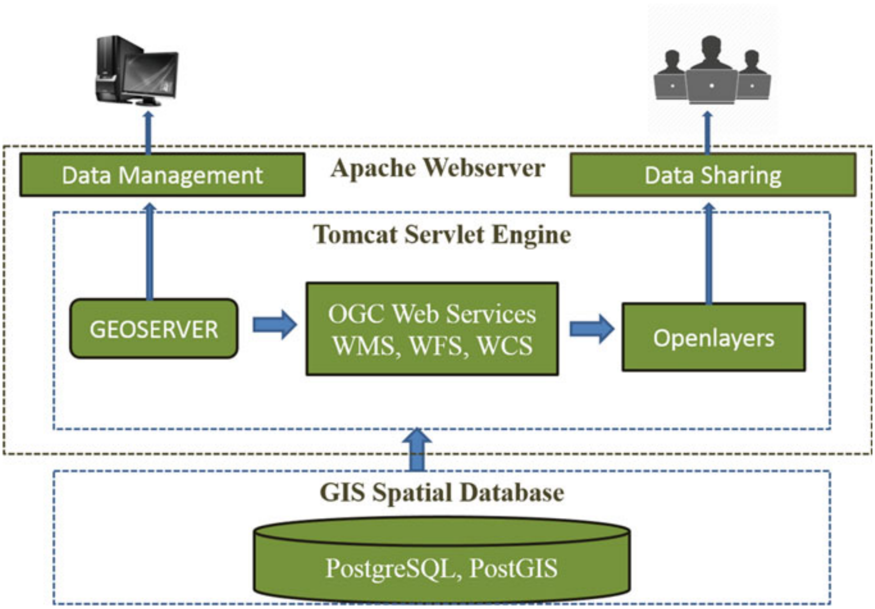


Fig. 4 Framework of the SDSS

multiplied by −1. The Shannon 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 increases 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 [4, 23]. 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 [24]. A set of criteria for prioritizing 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. 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. These reserves protect habitats that are under private ownership also, through active stakeholder participation. The biological diversity in these zones like National parks, Sanctuaries (Anshi Dandeli Tiger reserve (ADTR)), botanical gardens (Shalmala Riparian Ecosystem Conservation Reserve, Aghanashini LTM Conservation Reserve, Hornbill Conservation Reserve, Attiveri Bird Sanctuary), zoological gardens hosts threatened (rare, vulnerable, endangered) flora/fauna. Higher weightage is assigned for CRs.

2.2.3 Biomass

Biomass is another important indicator of forest health and reveals its role in a global carbon sink. Most of the Uttara Kannada district is located in the high rainfall zone, except Mundgod and eastern parts of Haliyal and Yellapura support trees with higher biomass. Details of biomass quantification, flora and fauna diversity are available in the literature [16, http://wgbis.ces.iisc.ernet.in/biodiversity/database_new/]. The analysis has calculated total standing biomass of forest's vegetation [25, 26] based on field data and remote sensing data. Transect-wise basal area per hectare was estimated using allometric equations.

2.2.4 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 a significant role in local ecology [27]. 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 [28, 29]. 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 Geographical Resources Analysis Support System (GRASS)—http://wgbis.ces.iisc.ernet.in/grass/index.html)—free and open-source tool.

Hydrology provides a fundamental basis for understanding material flows, environmental quality and stream ecosystem in a basin [30]. Conservation of high biodiversity forest landscapes is justified on the basis of hydrological benefits—in particular, reduction of flooding hazards for downstream floodplain populations [31]. 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 [20, 32]. 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. 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 run-off as compared to catchments with disturbed/altered forest covers. Run-off and thus erosion from monoculture plantation forests were 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. Streams with undisturbed forest cover (vegetation of native species) in the catchment showed a good amount of dry season flow. Native forests in the catchment aid as sponge retaining the water, while allowing infiltration during monsoon, which are steadily released during the lean season. Compared to this, streams in the catchment dominated by agricultural and monoculture plantations (of Eucalyptus sp. 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.

2.2.5 Energy

Dependence on the conventional energy resources for electricity generation is eroding the natural resources at faster rate by causing a 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 is assessed (Solar, Wind, Bioenergy) month-wise and captured the variations [33–35]. 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. The 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 which show that the coastal taluks such as Karwar, Ankola and Kumta have good wind potential [34]. The households' 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 show 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 [35]. The 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.

2.2.6 Social Aspects

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. Forest-dwelling communities (tribes) of the district are 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 [36]. 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 prioritization, and the grids with lower population density are assigned higher weightage. The need for combining nature conservation with social aspect is to emphasize receiving a livelihood from natural resources and participation in enriching biodiversity.

2.2.7 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 [37]. West coast estuaries of the district were assessed based on productivity, biodiversity and human pressure [38–40]. 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 [38] brings 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.

2.2.8 SDSS Framework

SDSS integrates the scientific data in addressing the problems and provides appropriate solutions for sustainable utilization of the resources. OGC provide standardized interface specifications to support geospatial data sharing and interoperability among Web-based GIS systems (Fig. 4). SDSS Server GIS framework (i) is used remotely as data management done by the researchers and administrators, (ii) provides access to functionality via Web protocols such as the OGC Web Processing Service and (iii) allows the users to access the data and enter input parameters. Web-mapping API such as Openstreet Maps which is one of the popular Web-mapping application programming interfaces (APIs) and Bhuvan (http://bhuvan.nrsc.gov.in), WMS layers are used in our framework, and other examples are Google Maps (http://maps.google.co.in), Yahoo! Maps (http://maps.yahoo.com) or Bing Maps (http://bing.com/maps). The online user will be able to access the graphical user interface (http://10.58.20.79/ol3/ukwms.html) and choose the different map layers [41]. When the request is received, the Web server communicates with the GeoServer to retrieve the map layers as a service which will be fetched from the database and a response is sent to the user through the GUI. The user will be able to visualize the information on the maps.

3 Results and Discussion

ESRs in the district are prioritized considering biological, ecological, geo-climatic, renewable energy and social prospects. Weightages are 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 is assessed using remote sensing data of Landsat ETM+ sensor 30 m resolution. Land-use analysis reveals that the region has about 32.08% under evergreen–semi-evergreen forests (Table 2), and higher forest cover (>80%) is confined to the grids in Sahyadri region (Supa, Yellapura, Ankola, Sirsi taluks). The coastal taluks are having forest cover in the range 60–80% towards eastern part, whereas western side totally degraded due to higher pressure. The plains show least cover (<20%) reflecting higher degradation, and the natural forest cover in the district is only 542,475 Ha. The land clearing and subsequent

Table 2 Land use and fragmentation of forests in Uttara Kannada

Category	Land-use analysis		Fragment type	Spatial extent	
	Ha	%		Ha	%
Built-up	31589	**3.07**	Transitional	59435	5.78
Water	28113	2.73	Perforated	8909	0.87
Cropland	145395	14.13			
Open fields	37660	3.66	Patch	30618	2.98
Moist deciduous forest	**161996**	**15.74**			
Evergreen to semi-evergreen forest	**330204**	**32.08**	Edge	179870	17.48
Scrub/grass	40402	3.93			
Acacia/Eucalyptus/hardwood plantations	122927	**11.94**	Interior	**263643**	**25.62**
Teak/bamboo/softwood plantations	67111	**6.52**			
Coconut/arecanut/cashew nut plantations	53993	**5.25**	Non-forest area	**486611**	**47.3**
Dry deciduous forest	9873	0.96			
Total area (Ha)	**1029086**				

agricultural expansion, exotic plantations resulted in the degradation of large forest patches at temporal scale. Weightages were assigned to the grids based on the extent of forest cover, and grids in Sahyadri region have highest ranking (10) compared to plains (1). Fragmentation analysis considering the spatial extent of forests reveals that contiguous forests (interior forests) cover only 25.62%, and land use under non-forest categories (cropland, plantations, built-up, etc.) covers 47.29% of the landscape across 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. Grids in Honnavar, Kumta, Sirsi, Bhatkal, Siddapur are with higher weights, and Mundgod and Haliyal show least endemism [29].

Analysis of faunal distribution shows that tiger (*Panthera tigris*), leopard, wild dog (dhole) and sloth bear are the main predators. The district is a paradise for birds; 272 birds are listed in the Dandeli, out of which 19 are considered to be endemic [36]. The distribution of freshwater fishes is highly correlated to terrestrial landscape elements, of which quantity and quality of evergreen forests are more important [2]. Higher weightages (10) are assigned to the grids with endemic species, and least (3) were assigned for grids with non-endemic fauna.

Biomass is estimated grid-wise, based on the spatial extent of forest and per hectare basal area. The total biomass of the district is **113823.58** Gg, with Sahyadrian taluks such as Supa, Sirsi and Yellapura having greater biomass (>1200 Gg) followed by the coastal taluks (Karwar, Ankola, Kumta, Honnavar). Grids with higher standing biomass regions were assigned higher weightages [26, 39], as these regions help in maintaining global carbon through sequestration. Tree diversity is computed through the Shannon diversity index which shows that most evergreen to semi-evergreen forests with diversity values ranging between 3 and 4. Uttara Kannada district has two important protected areas, namely Anshi National Park and Dandeli Wildlife Sanctuary, which are assigned higher weights as they are key eco-sensitive regions with diverse biodiversity [40].

Geo-climatic variables such as altitude, slope and rainfall are analysed to identify sensitive zones. Highest elevation is 758 m in Supa taluk. Grids with elevations >600 m as higher priority for conservation and > 400 m is moderate and rest is of least concern. Rainfall pattern shows that the 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 [40]. The sub-basin-wise field investigations were carried out to account perennial, seasonal flows of the region. 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 [32]. Grids in Sahyadri regions show 12-month water availability in the streams and were assigned higher weightages. Streams in Haliyal, Mundgod, eastern part of Yellapura have flow of only 4 months due to scarce rainfall and monoculture plantations.

Environmentally sound alternative sources of energy resources (solar, wind, io) potential were considered for prioritization [26, 33–36]. The region receives an average solar insolation of 5.42 kWh/m^2/day annually and has more than 300 clear sunny days. Wind resource assessment shows wind speed varies from 1.9 m/s (6.84 km/hr.) to 3.93 m/s (14.15 km/hr.) throughout the year with a minimum in October and maximum in June and July. Bioresource availability is computed based on the compilation of data on the area and productivity of agriculture and horticulture crops, forests and plantations. Sector-wise energy demand is computed based on a primary household survey of 2500 households, the National Sample Survey Organization (NSSO study) data and the information compiled from the 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 [33–36]. The location of forest-dwelling communities such as *Kunbis, Siddis, Goulis, Gondas* was spatially mapped, and the respective grids were assigned highest weights, because these people are directly and indirectly dependent on forest resources and have been protecting forests. Grid-wise population is computed by aggregating villages in the respective grid for 2011. Population density is computed for each grid and weightages were assigned. Grids with the lowest population density (<50 persons) were assigned higher weight (considering the likely lower anthropogenic stress) and vice versa [40, 41].

The four major estuaries, viz. Kali, Gangavali, Aghanashini, and Sharavathi, 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 [38, 39], which has affected the productivity of livelihood resources (fish, bivalves, etc.). Coastal grids were assigned weightages based on the biological diversity and productivity (considering provisional goods—fish, bivalves, sand and salt).

Aggregation of these spatial layers corresponding to biological, ecological, geo-climatic, renewable energy and social variables aided in prioritising the grids as ESR 1, ESR 2, ESR 3 and ESR 4, respectively, (Fig. 5a) 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 5b depicts ESR with taluk and gram panchayat (decentralized administrative units with a cluster of few villages) boundaries. Uttara Kannada district has 11 taluks and 209 panchayats. ESR analyses reveal that ESR 1 consists of mainly Supa, Yellapura, Ankola, Sirsi, Siddapura, Honnavar and Kumta taluks. Considering Panchayat-level analyses, 102 panchayats are in ESR 1, while 37 panchayats in ESR 2, 33 panchayats in ESR 3 and 37 panchayats in ESR 4. Sahyadri and eastern part of coastal regions represent highest ecological sensitiveness. 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.

The visualization is implemented through open layers by adding the WMS layer. Figure 6 visualizes layer of Western Ghats boundary, Western Ghats states and districts, Uttara Kannada Panchayats boundary on the backend layer of OpenStreetsMap and also the land-use WMS layer of Bhuvan. The user can choose different layers using the checkbox option and view accordingly. This information contributes to analyzing and utilizing the resources in an efficient way, which helps the decision-maker or the concerned citizen to use the data to make better plans and policies. SDSS aids users to visualize diverse themes of land, ecology, energy, socio, hydro and estuarine variables of rich biodiversity hotspots and also provides an opportunity to integrate ecological and socio-economic aspects in decision-making. The 73rd amendment to the constitution (1992) empowers local governing bodies to make relevant plans for the socio-economic development of a region. Inclusive growth enhances social capital for the public can be achieved by ensuring the active and effective participation of all sections of society at every level of governance. The implementation of SDSS at local levels would help in realizing the vision of Biodiversity act, 2002, which empowers Biodiversity Management Committees (BMC) at panchayat with the knowledge of local biodiversity richness with ecological status to take decisions towards the prudent use of natural resources.

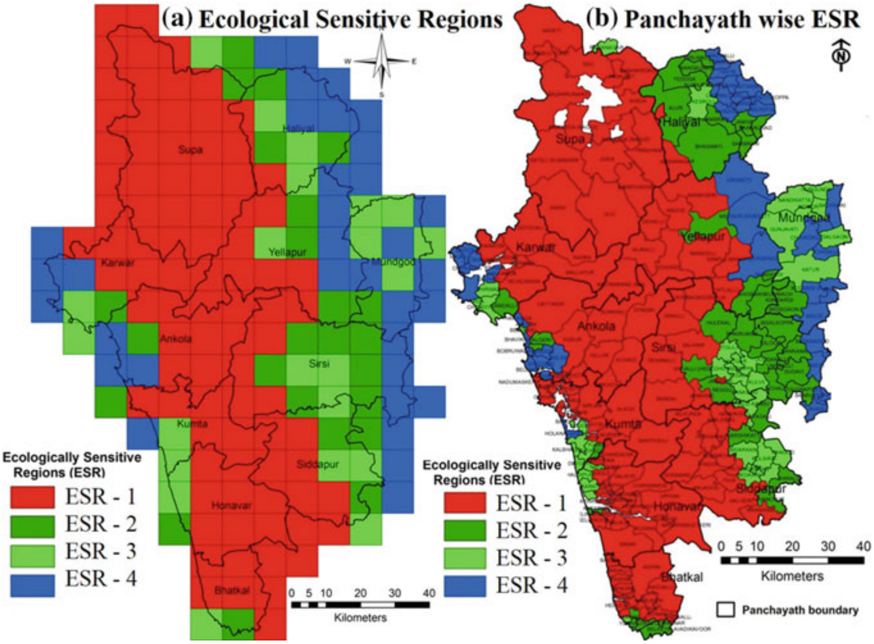
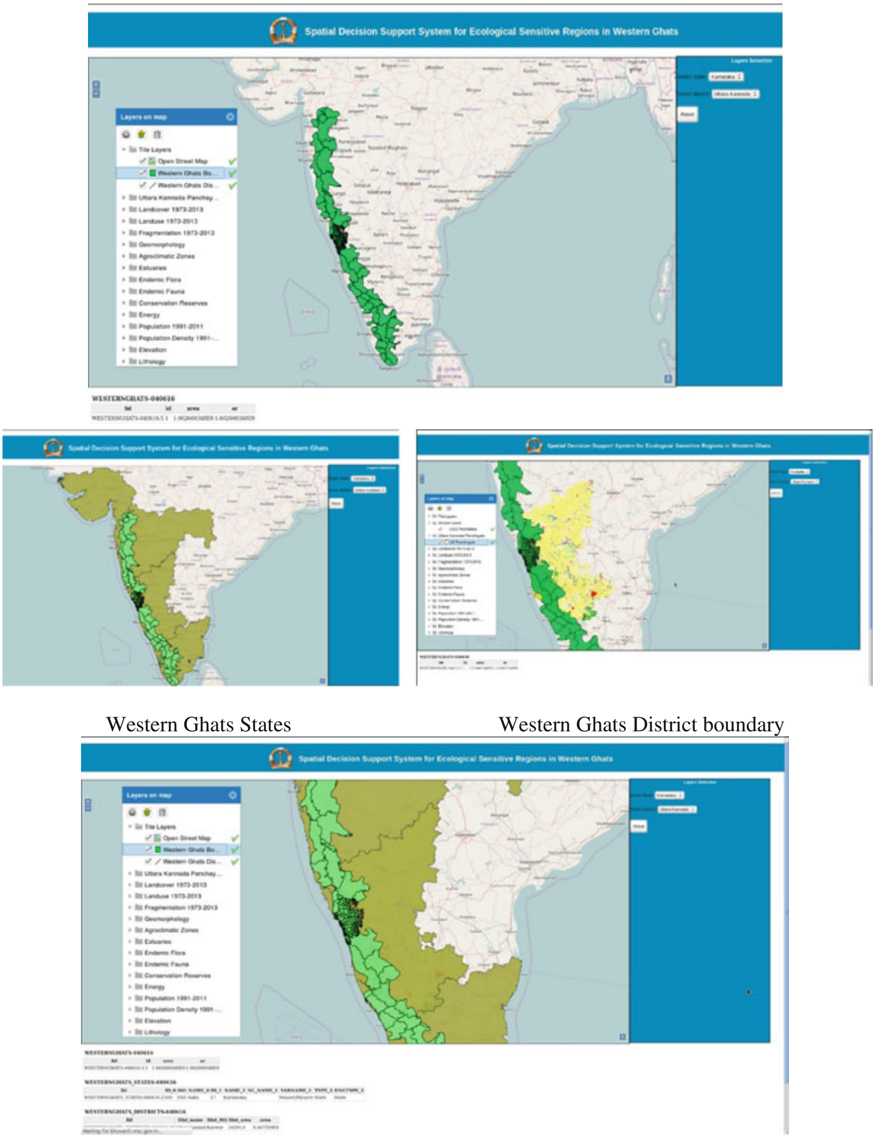


Fig. 5 Ecological sensitive regions of Uttara Kannada at panchayat level

4 Conclusion

ESRs are the eco-clusters or 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 panchayat level is a major step towards an ecological audit that eventually results 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 ESR 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 scope to attain the status of ESR 1 with eco-restoration measures. The persistence of the endemic (rare, threatened, etc.) species in ESR 1 and ESR 2 calls for serious attention from conservationists and decision-makers to initiate programs immediately for conservation. The fact that watercourse forests have not only rare species but also high biomass and greater carbon sequestration potential also calls for revision of forest management policies, as the innumerable stream courses of 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. Rendering such service for mitigating global climatic change can also, same time, serve well the cause of eco-sensitive



Western Ghats States

Western Ghats District boundary

Overlay of Western Ghats States, District Boundaries and Uttara Kannada Panchayats

Fig. 6 Visualization spatial layers of Western Ghats

regions in an otherwise much-impacted biodiversity hotspot. Conservation and sustainable management of natural resources in the Western Ghats will ensure food and water security in the peninsular India and intergeneration equity. Hence, 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. This 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. The outcomes visualize an ongoing process and integrate ecological and environmental considerations into administration in the biodiversity-rich regions. 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, eco-clusters 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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