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ORIGINAL ARTICLE

Salient Ecological Sensitive Regions of Central Western Ghats, India

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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

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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 geo-climatic 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

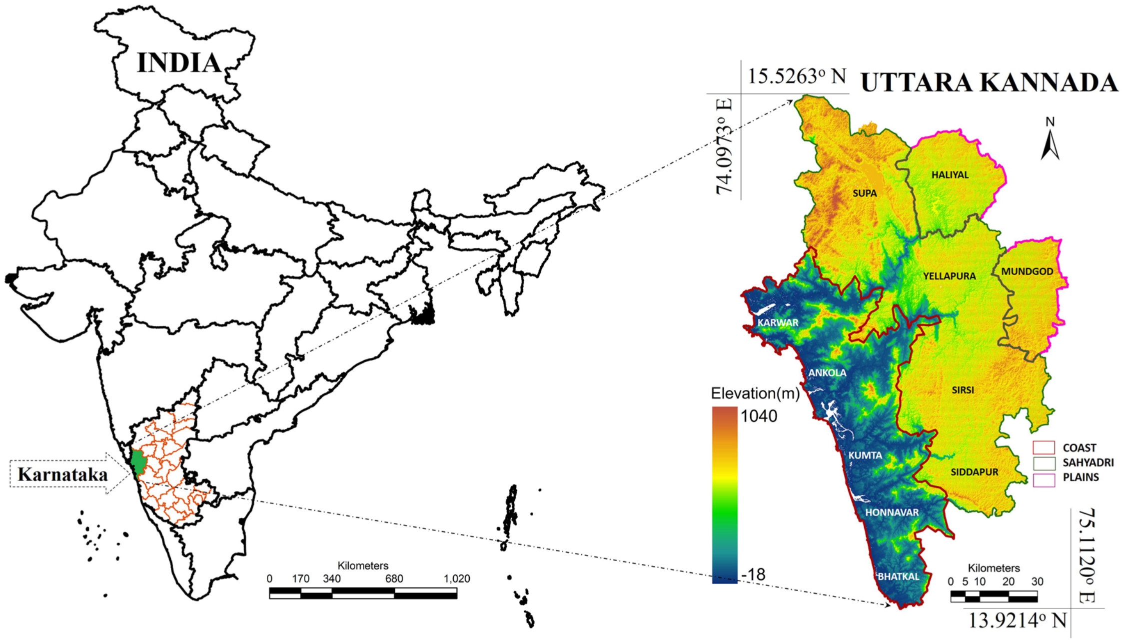


Fig. 1 Study area and its agro-climatic zones

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,

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

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

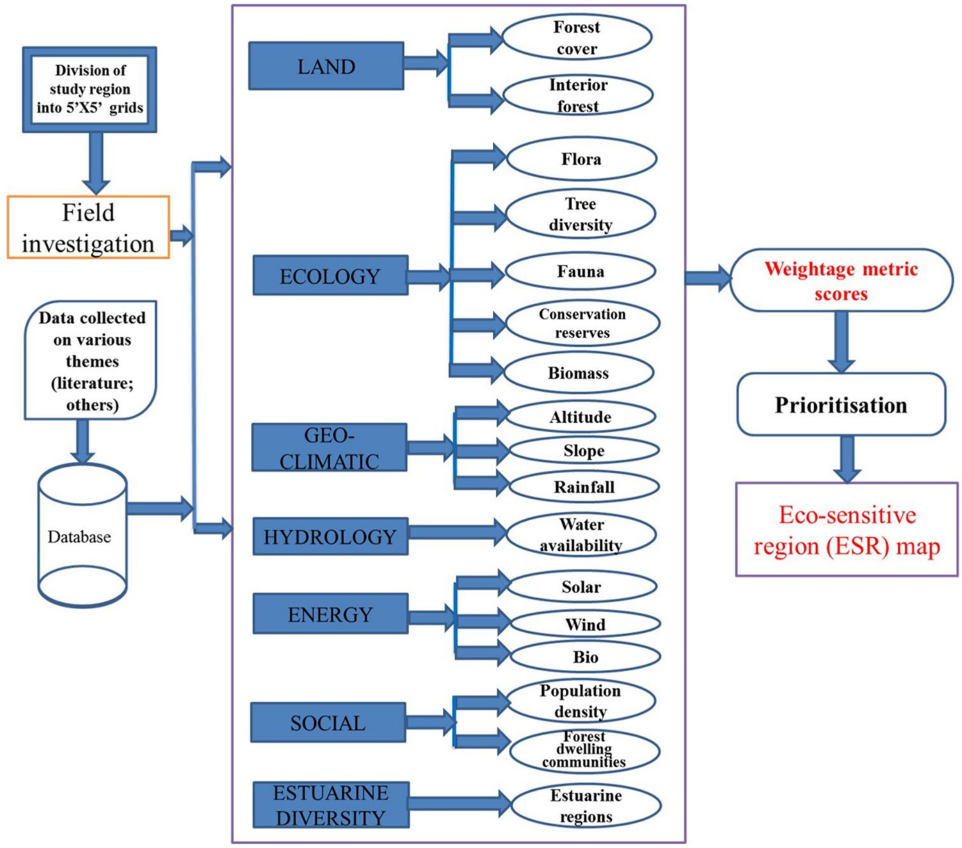


Fig. 2 Weightage metric criteria for prioritizing ESR

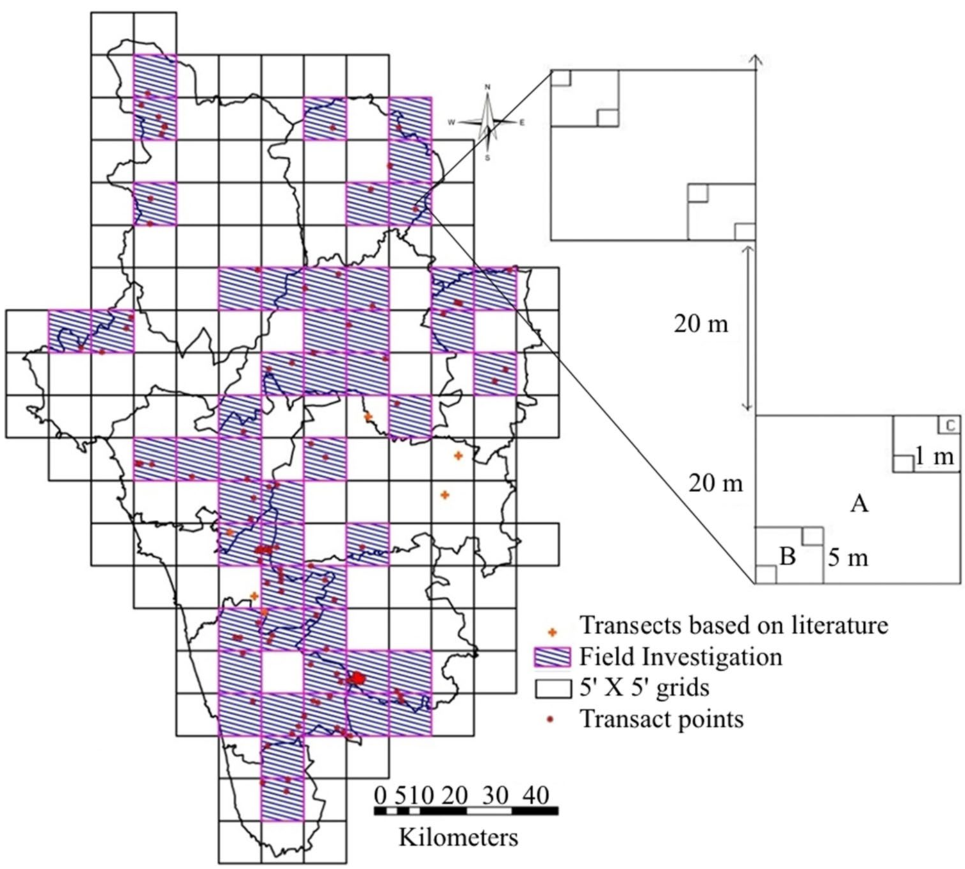


Fig. 3 Grids with the distribution of transects and transect cum quadrats (2 of 5 quadrats of 20 × 20 m only shown)

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,

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

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 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

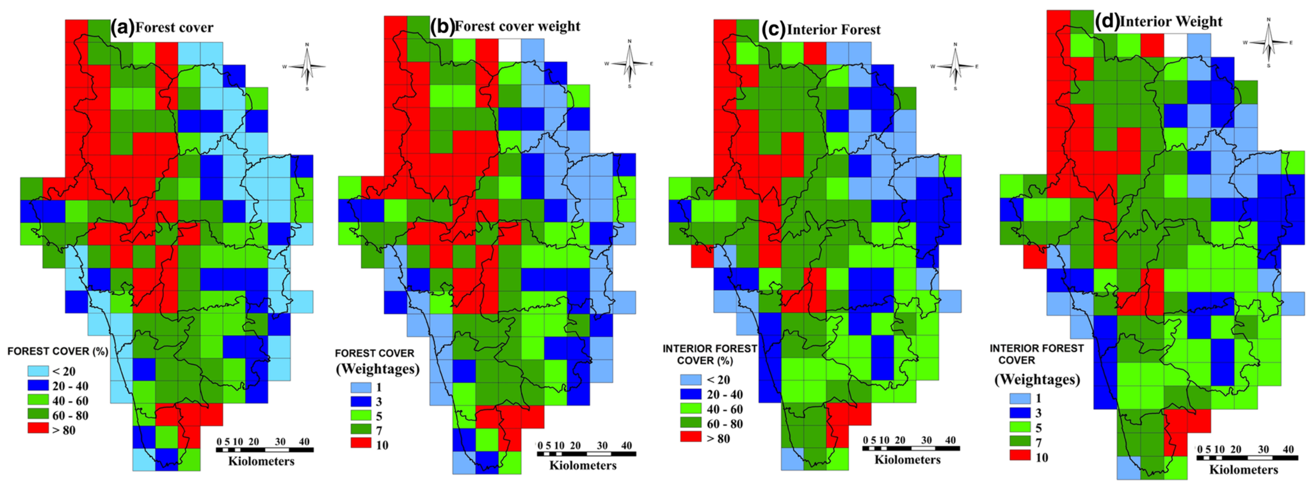


Fig. 4 Forest cover and interior forest cover status of Uttara Kannada district and their weights/rank

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

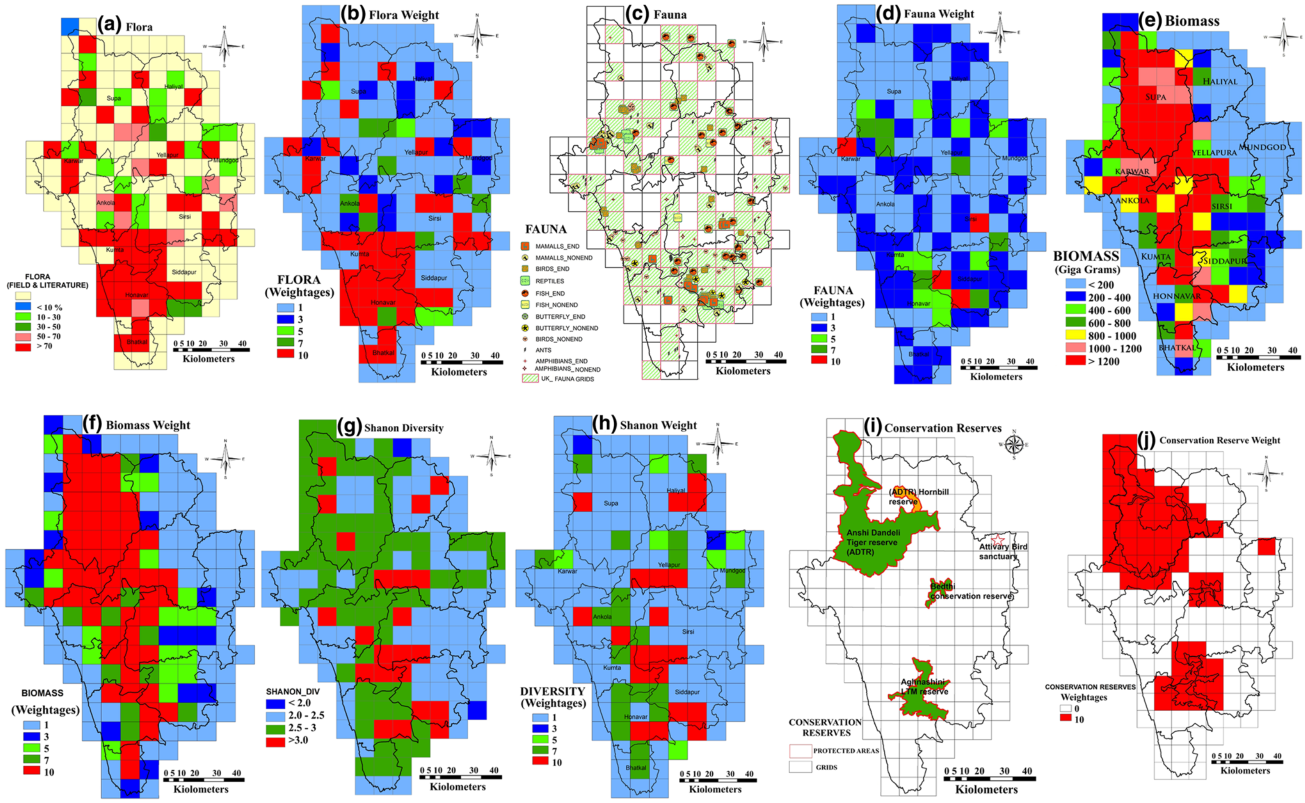


Fig. 5 Variables of ecology theme and their weights

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

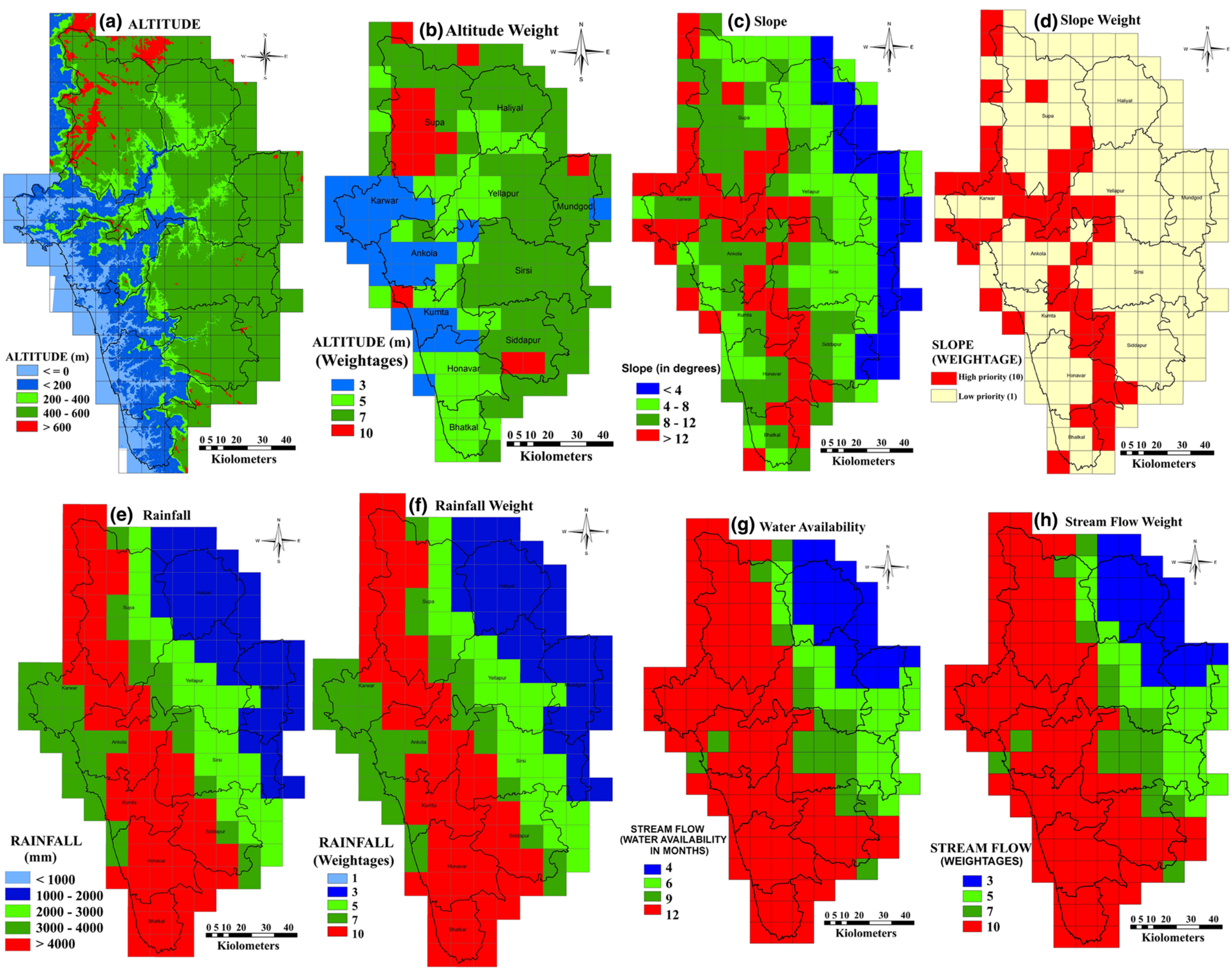


Fig. 6 Geo-climatic variables and weight

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

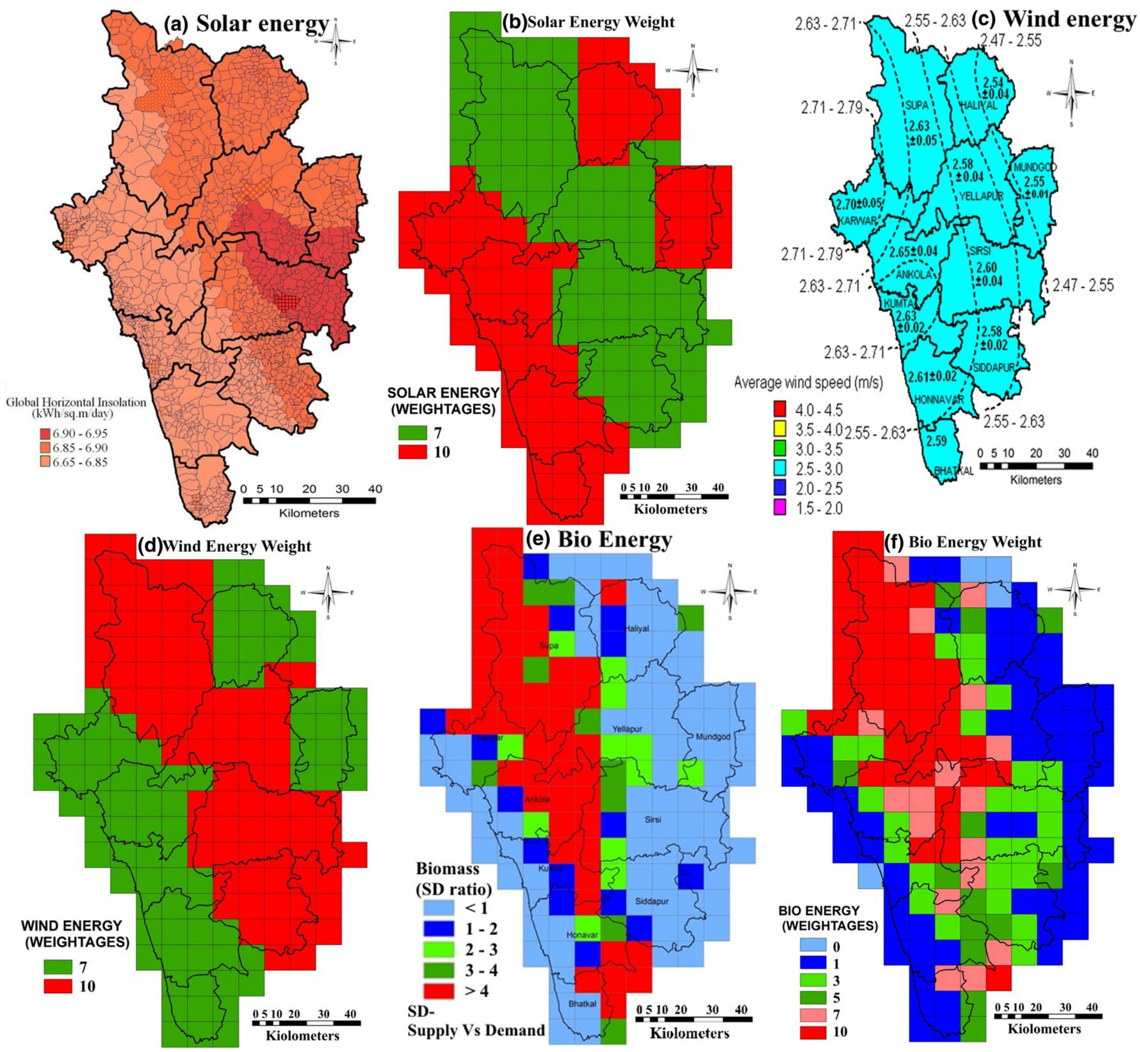


Fig. 7 Energy prospects and its weight

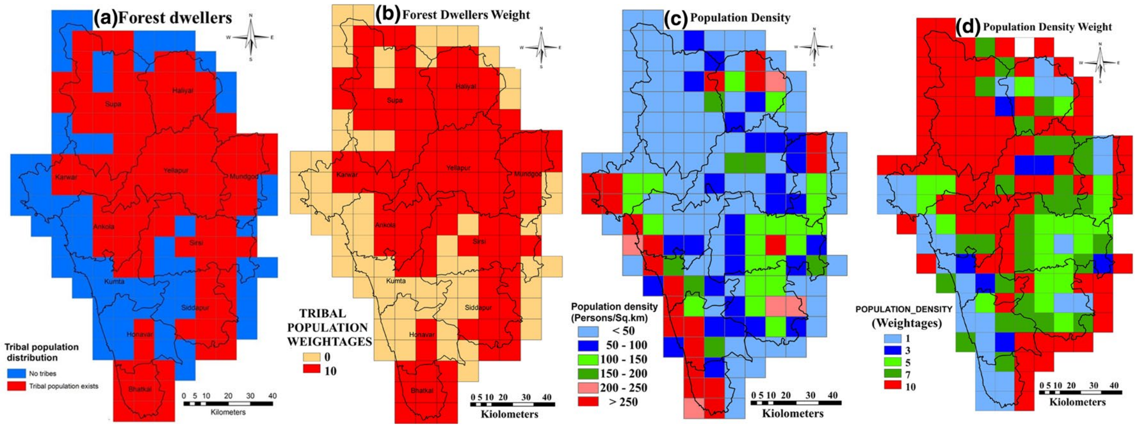


Fig. 8 Socio variables and weight

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

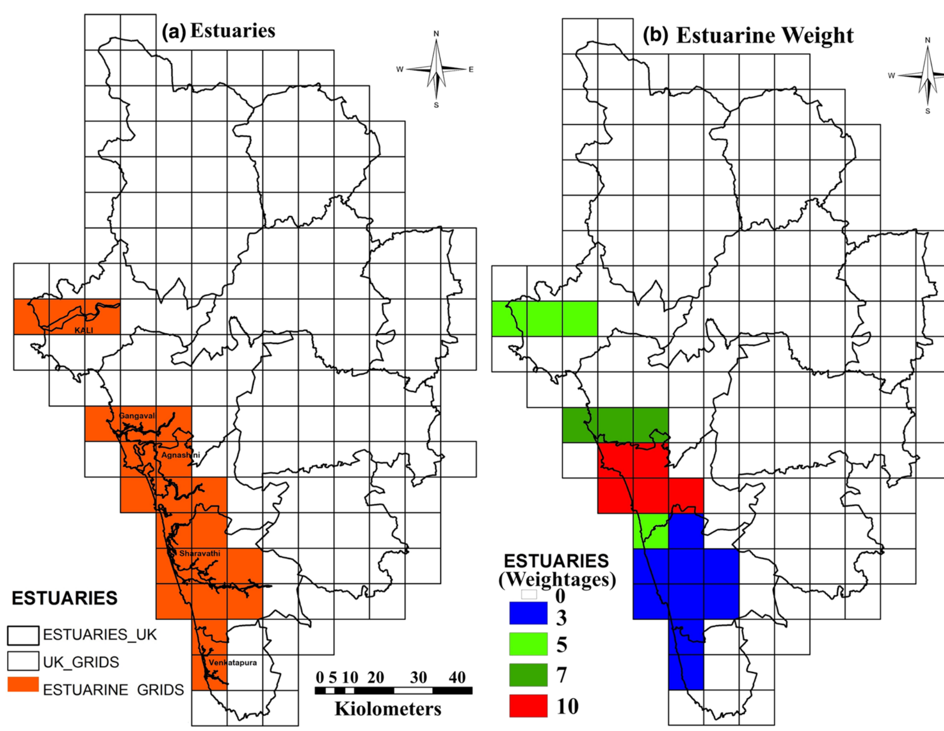
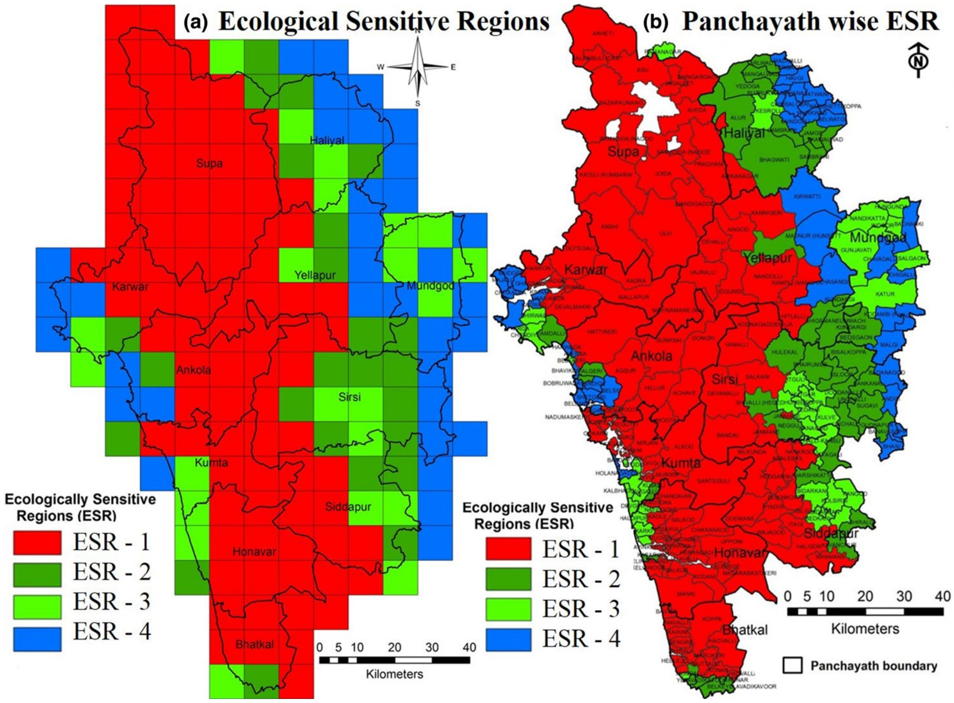


Fig. 10 Ecological sensitive regions of Uttara Kannada at panchayath level



(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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