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RESEARCH ARTICLE

Insights of Forest Dynamics for the Regional Ecological Fragility Assessment

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Abstract
Forest ecosystems play a vital role in sustaining various life forms on the earth. These ecosystems support society through the provision of goods (timber, fuelwood, etc.) and an array of ecological services (carbon sequestration, nutrient cycling, etc.). However, unplanned developmental activities have been affecting the ecological integrity evident from the fragmentation of forests, barren hilltops, conversion of perennial streams to intermittent or seasonal streams, etc. During the past three decades, forests have undergone major transitions with the breaking of contiguous native forests into small parcels of land, restricting the movement of species thereby limiting the potential of species for dispersal and colonization. This paper analyzes the landscape dynamics and spatial patterns of forests fragmentation of Shimoga District, Central Western Ghats and prioritizes ecologically fragile or Ecologically Sensitive regions (ESR) at village levels based on bio-geo-climatic-social variables with the land use dynamics considering temporal remote sensing data. Results revealed that there was a net loss of 10% in forest cover from 43.83% (1973) to 34.02% (2018), primarily caused by the expansion of agriculture, horticulture, and forest plantations. Forest fragmentation has increased, evident from the decline of the interior forest to an extent of 11% from 26% (1973–2018). ESR prioritization at village level in the Shimoga district considering the ecological, geo-climatic and social variables indicate that 11% villages are ESR 1 (highest sensitivity), 30% are in ESR 2 (higher sensitivity), 36% are in ESR 3 (high sensitivity) and the remaining 23% are in ESR 4 or moderate sensitivity category. The analysis illustrates the importance of understanding spatiotemporal patterns of landscape structure for sustainable management of tropical forests.

Keywords Landscape dynamics · Land use land cover (LULC) · Shimoga · Forest fragmentation · Ecological sensitive regions (ESR)

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Introduction

Landscape refers to a portion of heterogeneous terrain with the interacting ecosystems and is characterized by its dynamics, which are governed by human activities and natural processes (Ramachandra et al. 2012a). An ecosystem is characterized by several unique biotic and abiotic components and its interactions among them. Interactions of these components among themselves and with each other happen through processes of nutrient cycling and energy flows. The anthropogenic land use and land cover (LULC) changes have been the major driver of the landscape changes at local levels. Unplanned developmental activities with the uncontrolled exploitation of natural resources and accelerating rates of LULC changes have led to the degradation of the ecosystem, evident from barren hilltops

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(Ramachandra and Bharath 2018), conversion of perennial streams to seasonal ones (Vinay et al. 2013), loss of livelihood, reduction in productivity, alteration in temperature (Ramachandra et al. 2018), escalation in carbon footrpint (Ramachandra et al. 2019), etc. LULC change analyses using temporal remote sensing data aid in understanding the spatiotemporal patterns of land uses, which is useful in the regional planning with prudent management of natural resources and good governance (Bhatta et al. 2010; Jenson 1982; Ramachandra et al. 2012a, b; 2018).

Forests form an important component of a landscape and perform basic ecological and hydrologic functions, which help in sustaining water, conservation of biodiversity, regulating the air temperature, mitigate global warming (Ben-Zhi et al. 2005; Bharath et al. 2013; Naughton-Treves et al. 2005; Saxe et al. 2002), etc. Forests are the repository of natural resources, which support an array of biotic components, and cover only 30 percent of the land area of which only 20% are contiguous intact forests (WRI 1997; FAO 2010). Humans have been influencing the forested landscape through the clearing of native forests for various uses which in turn have degraded these ecosystems fragmenting it into patches. These biodiversity reserves are progressively being degraded or surrounded by urban environments or by agriculture and thus making them isolated fragments. Fragmentation is the breaking up of a landscape, habitat, ecosystems, or land use types into smaller parts (Forman and Wilson 1995), which results in the decreased size of the contiguous forests leading to the loss of connectivity between populations and the similar ecosystems (Griffiths and Lee 2000; Fahrig 2003; Ramachandra et al. 2016a). Fragmentation and consequent deforestation is a major issue for mitigating climate changes and conservation of forests. Anthropogenic pressures on forest landscapes result in a complex pattern of forest structure with devoid of connectivity (Reddy et al. 2013). Connectivity among patches places a major role in species survival and conservation. Establishing the connectivity between the forest fragments can aid in conserving the overall ecosystem. The patch size quantification also assists to analyze the relationship between the number of species occurring and the patch size and also narrates the probable loss in species due to loss of forest cover (Jha et al. 2005). Patch size information aid in the fragmentation assessment and helps in assessing their role in maintaining biodiversity (Mandal and Chatterjee 2020). Increase in bisecting edges, perforated areas, with the decline of core areas are the consequences of anthropogenic induced fragmentation across the globe, which can be addressed systematically through comparing different time series data (Sharma et al. 2017). The extent of forest fragmentation has been quantified (i.e., the degree to which the forest is broken) through the assessment of changes in spatial characteristics and configuration of remaining patches (Saunders et al. 1987; Ramachandra and Kumar 2011).

The consequences of forest fragmentation are increased instances of human–animal conflicts, microclimatic changes, extirpation of species, increased isolation of remnant populations, alteration in the regional hydrological cycle by impacting the amount of evapotranspiration, infiltration and surface water runoff, uncontrolled emission of greenhouse gases (GHG) with the loss of natural sink (Ramachandra et al. 2019), lowering of soil quality and inbreeding (Laurance et al. 1998; Boyle 2001; Ramachandra et al. 2018). Hence, it is necessary to understand the extent of forest fragmentation, in order to develop appropriate mitigation measures for conservation and prioritization. The numerous techniques of forest fragmentation and forest connectivity using spatial data are available for quantitative estimation of landscape health and the ecological functions of individual patches. Spatial metrics have been applied extensively to describe the structures of a landscape with diverse land use classes (Herold et al. 2002, 2003; Ramachandra et al. 2015), for explaining the interrelationship of intra- and inter-land uses (Ji et al. 2006; Huang et al. 2007; Ramachandra et al. 2012a) and to quantify temporal spatial heterogeneity (Lele et al. 2008). The average forest patches, size, forest patch density, number of forest patches, forest patchiness, forest continuity, edge density, shape measures and proportion of forest in the largest forest patch are the prime indices considered for assessment across the globe (Vogelmann 1995; Trani and Giles 1999). This information provides vital insights to the linkages between spatial patterns and ecological processes (Macleod and Congalton 1998; Madanian et al. 2018). Further, the analysis of forest fragments through the computation of 'P_f' and 'P_{ff}' are easily comprehendible and are effective in categorizing the forest status (Ritters et al. 2000, 2004; Ramachandra et al. 2016a). The ecosystem also has a certain capability of withstanding external disturbances and thrives up to a certain limit, which is referred as the sensitivity or capacity of the respective ecosystem. Ecologically Sensitive Region (ESR) or ecologically fragile region, refers to a region that has low resilience and if disturbed by external influences either anthropogenic or natural, will find it difficult to be restored to its natural state (Gadgil et al. 2011). Landform, vegetation, geology, climate, social, cultural, and evolutionary history aspects are prime considerate in assessing the sensitivity of a region (McMahon et al. 2004). Ecosystems are not only characterized by their sensitivity but they are also significant in terms of the services that they provide (Wilkinson 2006) as well as their economic importance. An understanding of the various components of the ecosystem, their values and services, their interactions, and the anthropogenic effects (Ramachandra et al.

2016b) on them is crucial to sustainably manage through an ecosystem approach to conserve biodiversity and sustain natural resources (Ramachandra et al. 2017). However, most of the earlier endeavor lacks scientific rigor as well as eliciting information from the stakeholders.

The biodiversity hotspot regions such as the Western Ghats is considered ecologically or economically significant and/or sensitive, necessitates to delineate regions of importance to formulate appropriate conservation measures through the integration of technologies coupled with multi-criteria analysis. In this regard, the current work focuses on understanding LULC dynamics and temporal fragmentation of forests in Shimoga, located in the heart of Central Western Ghats. An attempt is made to understand the agents of forest fragmentation through a compilation of forest encroachments. The research also aims to identify and prioritize Ecologically Sensitive Regions (ESR) of Shimoga at village level based on the collection and compilation of primary data of ecological, geo-climatic and social aspects to assist in decision making toward the prudent management of natural resources.

Materials and Method

Study Area

Shimoga or "Shivamogga" or "hiva-Mukha" district lies between 13° 27′ and 14° 39′ N latitude and 74° 37′ to 75° 53′ E longitude, with a spatial extent of 8495 km^2 spread across 1530 villages. Agriculture and animal husbandry are the major contributors to the economy of Shimoga district. The climate is tropical wet and dry and temperature ranges between 37 °C (Max) and 23.2 °C (Min). The district receives an average rainfall of 1813 mm. Shimoga district is divided into 2 sub-divisions (Sagara and Shimoga), 7 taluks (Shimoga, Bhadravathi, Thirthahalli), and 3 forest divisions (Sagara, Shimoga, Bhadra) (Fig. 1). As per the 2011 census, the population of the district is 17,55,512 with a density of 207 persons per sq.km. Shimoga is an ideal destination for tourism across the seasons due to dense forests, hills, splendidly diverging waterfalls, and religious places with diverse cultures. The region is home to rich diverse flora such as *Alangium salviifolium, Artocarpus heterophyllus, Artocarpus hirsutus, Holigarna grahamii, Holigarna nigra, Mangifera indica, Caryota urens, Canarium strictum, Garcinia gummi-gutta, Grewia tiliifolia, Hopea ponga, Hopea Jacobi, Cinnamomum malabatrum, Saraca asoca, Lagerstroemia microcarpa, Memecylon talbotianum, Ficus nervosa, Knema attenuate, Myristica malabarica, Syzygium travancoricum, Santalum album*, etc. The faunal species include *Bos gaurus, Macaca Silenus, Panthera pardus, Panthera tigris, Rusa unicolor, Sus scrofa, Indirana beddomii, Nyctibatrachus beddomii, Philautus leucorhinus, Ramanella montana, Apus affinis, Chalcophaps indica, Vanellus indicus, Halisatur indicus, Pavo cristatus, Ocyceros griseus, Dicrurus pradiseus, Catla catla, Garra mullya, Labeo rohita, Puntius carnaticus, Schistura nagodiensis, Schistura Sharavathyensis, Geckoella albofasciatus, Kaestlea beddomii, Naja naja, Trimeresurus malabaricus, Varanus bengalensis*, etc. Protected Areas such as the Sharavathy Wildlife Sanctuary, Someshwara Wildlife Sanctuary Shettihalli Wildlife Sanctuary, and Gudavi Bird Sanctuary are with diverse flora and faunal species.

Data

Multiresolution spatial data acquired from Landsat and IRS multispectral sensors for the period 1973 to 2018, listed in Table 1, were downloaded from the respective web portals. These data are resampled to 30 m to maintain common resolution across the datasets. The Landsat satellite 1972 images have a spatial resolution of 57.5 m × 57.5 m (nominal resolution) was resampled to 30 m comparable to other data which are 30 × 30 m (nominal resolution) as per the standard protocol reported earlier (Pohl, 1996; Gupta et al. 2000; Kumar et al. 2010; West et al. 2014). Radiometric corrections were implemented by transforming raw digital numbers (DN) to radiance or reflectance, considering band-specific additive or multiplicative rescaling factor from metadata with the quantized and calibrated standard product pixel values (DN). The Survey of India (SOI) topographic maps were used to generate base layers of administrative boundaries, ground control points (GCP's), etc. Ground control points to register and geo-correct remote sensing data were also collected using handheld pre-calibrated GPS (Global Positioning System). Collateral data used for geo-rectification and classification include geo-referenced topographic maps of the Survey of India, historical vegetation maps (from Karnataka Forest Department, Shimoga division), Vegetation map of South India (French Institute, Pondicherry), Annual Progress reports of the Karnataka Forest Department and other government agencies. In addition to these, the location-specific field data are being collected during the past three decades in the central Western Ghats as part of the ongoing ecological research pertaining to vegetation, monitoring of riverine ecosystems, etc. This aided in compiling training polygons (with attribute information) for remote sensing data classification and accuracy assessment.

Method

The spatiotemporal LULC changes were studied and ecological sensitive villages are demarcated as outlined in

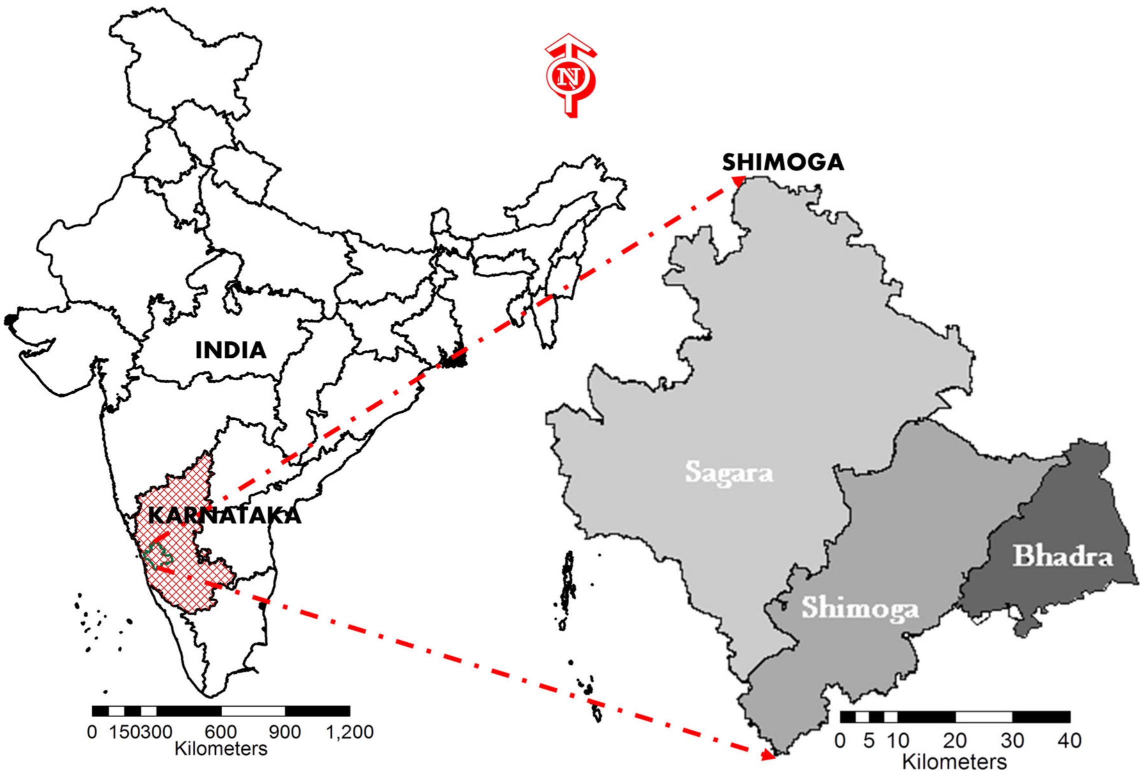


Fig. 1 Study area—Shimoga district in Karnataka with three forest divisions

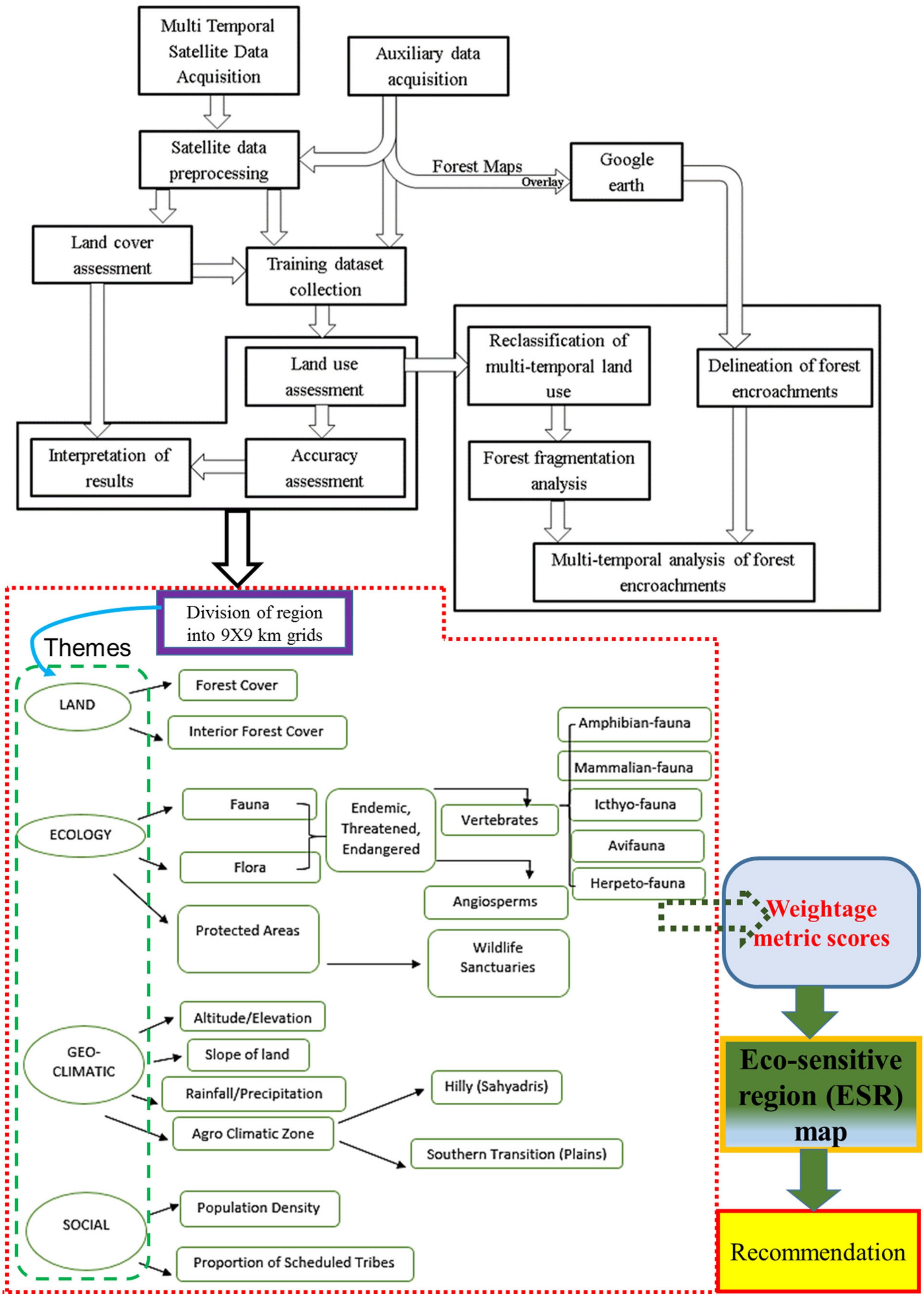
Table 1 Data used in the analyses of landscape dynamics

Data	Year	Source	Required for
MSS (Multispectral) Landsat (57.5 m)	1973	http://glcf.umiacs.umd.edu/data	LULC analysis, Fragmentation analysis and ESR prioritization
Landsat TM-Thematic mapper (28.5 m)	1990		
Landsat Operational Land Imager (30 m)	2018		
Indian Remote Sensing LISS III (23.5 m)	2002	http://nrsc.gov.in	
The Survey of India (SOI) topographic maps of scales 1:50,000 and 1:250,000	–	https://soinakshe.uk.gov.in/Home.aspx	To Generate boundary and Baselayer maps.
Field data collected using pre-calibrated GPS	2012–2018		Ground truthing, geo-rectification, classification and accuracy assessment
Google Earth and Bhuvan	2000–2018	http://earth.google.com; http://bhuvan.nrsc.gov.in	For digitizing various attribute data, creating encroachment layer and for validation of classification

Fig. 2. The analyses have been carried out in three stages namely (i) LULC change estimation, (ii) fragmentation analysis with casual factors estimation, and (iii) prioritization of region based on ecological sensitiveness.

Quantification of Land Use Land Cover dynamics

Spatiotemporal analyses involved determining the land use and land cover changes using geo-registered temporal remote sensing data. The monitoring of LC involves the computation of vegetation indices, which enables assessing the extent of vegetation cover over non-vegetation. Land cover was determined through the computation of NDVI (Normalized Difference Vegetation Index) as per Eq. 1 (Table 2), based on the spectral difference of vegetation absorbance in the red during photosynthesis and reflectance in the near-infrared wavelength of the spectrum. Among all techniques of vegetation mapping, NDVI is most widely accepted (Zhang and Zhang 2007; Jensen and Toll 1982; Nelson 1983) technique with a capability to bring out



Multi Temporal Satellite Data Acquisition
Auxiliary data acquisition
Satellite data preprocessing
Forest Maps
Overlay
Google earth
Land cover assessment
Training dataset collection
Land use assessment
Reclassification of multi-temporal land use
Delineation of forest encroachments
Interpretation of results
Accuracy assessment
Forest fragmentation analysis
Multi-temporal analysis of forest encroachments
Division of region into 9X9 km grids
Themes
LAND
Forest Cover
Interior Forest Cover
ECOLOGY
Fauna
Flora
Endemic, Threatened, Endangered
Vertebrates
Amphibian-fauna
Mammalian-fauna
Icthyo-fauna
Avifauna
Herpeto-fauna
Angiosperms
Protected Areas
Wildlife Sanctuaries
Weightage metric scores
GEO-CLIMATIC
Altitude/Elevation
Slope of land
Rainfall/Precipitation
Agro Climatic Zone
Hilly (Sahyadris)
Southern Transition (Plains)
Eco-sensitive region (ESR) map
SOCIAL
Population Density
Proportion of Scheduled Tribes
Recommendation

◀ **Fig. 2** Procedure followed in spatial data analysis

changes in LC and extract changes through automated change detection techniques from temporal remote sensing data (Roy et al. 2002; Ramachandra et al. 2014).

LU analyses involved (i) geo-rectification of remote sensing data; (ii) developing False Color Composite (FCC) using 3 bands (bands–green, red and NIR) of remote sensing data, which aided in locating heterogeneous patches; (iii) digitization of training polygons (corresponding to heterogeneous patches in FCC) uniformly distributed over the entire study area, covering 15% of the study area; and, (iv) collecting the attribute data (land use types) of these training polygons from the field using pre-calibrated GPS; (iv) collecting additional information from the latest spatial data available at virtual spatial portal-Google Earth and Bhuvan; and (v) using 60% of the training data for classification, and the balance during the post-classification for validation or accuracy assessment.

LU categories were derived from the remote sensing data, based on the Gaussian maximum likelihood algorithm using the supervised classification technique. This approach preserves the basic LU characteristics using a number of well-distributed training pixels. Gaussian Maximum Likelihood algorithm is an efficient method among supervised classification techniques based on training data or "ground truth" information. Geographical Analysis Support System (GRASS) GIS, a free and opensource software accessible at http://wgbis.ces.iisc.ernet.in/grass/index.php, with the robust processing capability of both vector and raster files. Accuracy assessments help in assessing the quality of the information derived from remotely sensed data by a set of reference pixels. These test samples are then used to create an error matrix (also

Table 2 Equations used for the analysis

Equation	Equation	Description
1	$\mathrm{NDVI} = \frac{(\mathrm{NIR} - R)}{(\mathrm{NIR} + R)}$	NDVI is calculated by using visible Red and NIR bands of the data reflected by vegetation. For a given pixel it always results in a number that ranges from − 1 to (+ 1)
2	$\mathrm{NP}_v = n$ NP indicates the number of patches in the landscape	NPU > 0, is a fragmentation Index and higher values indicate the fragmented landscape
3	$\mathrm{PD} = \left(\frac{\mathrm{NP}_v}{\mathrm{Area}}\right) \times 1000000$ Area = total landscape area	PD > 0 without limit; Patch density increases with a greater number of patches within a reference area
4	$\mathrm{TE} = \sum_{k=1}^{m} e_{ik}$ e_{ik} = total length (m) of edge in landscape involving patch type (class) i, k = patch type, m = number of patch type	TE ≥ 0, without limit; TE is an absolute measure of the total edge length of a particular patch type
5	$\mathrm{ED}_k = \frac{\sum_{i=1}^{n} e_{ik}}{\mathrm{Area}}(10000)$ n = number of edge segment of patch type k	ED ≥ 0, without limit; ED = 0 when there is no class edge. ED used to compare the landscape of varying sizes by measuring the total edge of urban boundary
6	$\mathrm{LSI} = \frac{e_i}{\mathrm{min}e_i}$ e_i = total length of edge of class i in terms of number of cell surfaces, min e_i = minimum total length of edge of class i	LSI ≥ 1, without limit; LSI = 1 when the landscape consists of a single square or maximally compact. LSI increases without limit as the patch type becomes more disaggregated
7	$\mathrm{AI} = \left[\sum_{i=1}^{n}\left[\frac{g_{ii}}{\max \to g_{ii}}\right]P_i\right](100)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method, max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type class i based on single count method, P_i = proportion of patch type (class) i	1 ≤ AI ≤ 100; AI = 1, patches are maximally disaggregated and AI = 100 patches are maximally aggregated or clustered into a single compact patch
8	$\mathrm{Pf} = \frac{(\text{Proportion of forest pixels})}{(\text{Total non-waterpixels in window})}$	Pf estimates proportion of forest pixels in a fixed-area kernels considering the current pixel and its neighborhood
9	$\mathrm{Pff} = \frac{(\text{Proportion of forest pixel pairs})}{(\text{Total adjacent pairs of forest pixel})}$	Pff estimates the conditional probability that given a pixel of forest, its neighbor is also forest based all adjacent pixel pairs at least on forest pixel (cardinal directions only)
10	$\mathrm{Weighatge} = \sum_{i=1}^{n} W_i V_i$ where n is the number of data sets, V_i is the value associated with criterion i, W_i is the weight associated with that criterion	Each criterion is described by an indicator mapped to a value normalized between 10 (higher priority for conservation) and 1 low conservation value). The value 7, 5 and 3 corresponds to high, moderate, low levels of conservation

referred as confusion matrix) kappa (κ) statistics and producer's and user's accuracies to assess the classification accuracies. Kappa is an accuracy statistic that permits us to compare two or more matrices and weighs cells in error matrix according to the magnitude of misclassification. The accuracy of pre-2002 images was assessed based on the collateral data (geo-referenced the survey of India toposheets of 1:50,000, vegetation map of South India of 1:250,000, published reports and the field data collected during the past three decades in the central Western Ghats pertaining to vegetation sampling, monitoring of riverine ecosystems, etc.). Availability virtual earth portals (such as Bhuvan, Google Earth) during post-2002 also helped in classification and accuracy assessment.

Fragmentation Analysis

Fragmentation of forests is assessed using spatial metrics such as Number of Patches (NP), Patch Density (PD), Total Edge (TE), Edge Density (ED), Landscape Shape Index (LSI) and Aggregation Index (AI) using Fragstats free software (Eq. 2–7, Table 2). These metrics were calculated with a moving window of 5×5 (Neel et al. 2004; McGarigal et al. 2005; Ramachandra et al. 2012b; Bharath et al. 2017) that aid in assessing the neighborhood alterations in its spatial quantity.

Fragmentation through Pf and *Pff* Further to understand the level of degradation/deforestation 'Pf and Pff' were computed to quantify the type of forest fragmentation as shown in Eq. 8 and 9, Table 2 (Ritters et al. 2000; Ramachandra and Kumar 2011; Ramachandra et al. 2016a). The result is stored at the location of the center pixel. Based on the knowledge of Pf and Pff, six fragmentation categories were derived as Interior (Pf = 1.0); patch ($Pf < 0.4$); transitional ($0.4 < Pf < 0.6$); edge ($Pf > 0.6$ and $Pf–Pff > 0$); perforated ($Pf > 0.6$ and $Pf–Pff < 0$), and non-forest.

Assessing the Causal Factors of Forest Degradation

Forests in Shimoga are administered through three divisions by the Karnataka Forest Department. The geo-registered administrative boundaries of forests in respective divisions were obtained from the Karnataka state forest department. These layers were overlaid on higher spatial resolution spatial data (Google Earth) to assess the forest changes within the respective boundaries. These regions are overlaid on classified land use layer to ascertain the type of land conversions (for example forest to agriculture/plantations).

Identification of Ecologically Sensitive Regions (ESR)

The study area is divided into $5' \times 5'$ equal area grids (74) to account for the changes at microscale for assessing ecological sensitiveness. The data of various themes were compiled from field surveys, published literature, unpublished datasets, etc. A detailed database is created considering various themes covering geo-climatic, ecological, and social variables (Table 3). The weightage metric score is computed using Eq. 10 (Tables 2 and Table 3) to reflect the priorities/significance associated with the respective theme. Developing a weightage metric score requires knowledge from a wide array of disciplines (Termorshuizen and Opdam 2009), planning should acknowledge and actively integrate present and future landscape needs. In particular, the weightages, which is based on an individual proxy and draws extensively on GIS techniques, stands out as the most effective method. The aggregated weightage (Eq. 10, Table 3) for each grid (region) is generated and grouped based on mean and standard deviation to determine the various levels of sensitivities. The final ESR map will aid in decision making toward the conservation of ecologically sensitive regions through effective natural resource planning (Ramachandra et al. 2017).

Results

Assessment of LULC Change

LC computation through NDVI reflects the percentage of area under vegetation and non-vegetation. Figure 3 illustrates the spatiotemporal changes in vegetation cover of the study area. The vegetation cover of 96.57% (1973) has decreased to 86.55% by 2018. Spatial patterns of LU of the study area are depicted in Fig. 4 and category wise LU details during 1973 to 2018 are listed in Table 4, which highlights of the forest cover decline from 43.83% (1973) to 34% (2018) with the increase in built-up from 0.63% (1973) to 2.35% (2018), plantations (9 to 30%), industrial and cascaded developmental activities. The incidence of human-induced forest fires and over-exploitation of forest produce (NTFP, timber, etc.) are the causal factors of deforestation and resource degradation. Rampant conversions of forests to other land uses, cropland to plantations (rubber, etc.) and water intense crops (zinger, etc.), etc., are threatening the productivity of the ecosystem. The unplanned developmental projects such as dams and widening of roads in the ecologically sensitive habitats have aggravated forest loss apart from other pressures such as grazing, firewood collection, and weed infestation (Eupatorium, Parthenium, *Chromolaena odorata*), illegal hunting, poaching (elephant poaching for ivory), etc.

Table 3 Variables considered for ESR mapping

SNO	Theme	Variable	Weightage				
			1	3	5	7	10
1	Land	Forest Cover	< 20%	20–40%	40–60%	60–80%	>80%
2		Interior Forest Cover	< 20%	20–40%	40–60%	60–80%	>80%
3	Ecology	Flora	Non-endemic	–			Endemic/ Threatened flora
4		Fauna	–	Non-endemic	–		Endemic/ Threatened fauna
5		Protected Area(PA)	0 was assigned to grids outside PA				10 if grids are within PA
6	Geo-climatic	Altitude	–	< 250 m	250–500 m	500–750 m	>750 m
7		Slope	–	N.A	N.A	>15%	>30%
8		Rainfall	< 1250 mm	1250–2500 mm	2500–3750 mm	3750–5000 mm	>5000 mm
9		Agro-Climatic Zone	–	–	Southern Transition zone/Plains	–	Hilly Zone/ Sahyadris
10	Social	Population Density(persons per sq.km)	>200	150–200	100–150	50–100	< 50
11		Scheduled Tribe	0 weightage was assigned to the grids with less than 20% ST population				More than 20% ST population

Kappa statistics and overall accuracy were calculated to estimate the level of accuracy of spatial data classification.

Fragmentation Analysis

Temporal LU data were used as input for the fragmentation analysis and computation of the spatial metrics. Prioritized metrics based on the earlier work (Ramachandra et al. 2012a b) were considered. Intact forests were prevalent in the 1970s, but post-1990, there was a sharp increase in the number of patches as evident from Fig. 5. This has also contributed to higher patch density (> 1 in 2012) indicating enhanced forest fragmentations. Further investigation of total edges in the landscape proved that the number of edges which were less in 1973 and phenomenally increased highlighting that the forest continuity or intactness has been lost resulting in the discontinuous animal habitats. Landscape shape based on forest LU showed a complex and convoluted pattern (since the value of LSI is very high (> 330) during post-2002 compared to 1973 (< 235). Forest area was of simple shape in 1973 indicating contiguity and intactness of forests. AI shows the forested area was more aggregated till 2002 and has become disaggregated due to uneven LU. The more non-forest patch types resulted in AI value reduction from 78 to 65 (from 1973 to 2018).

Forest status of Shimoga district is assessed through the computation of Pf and Pff and the results are depicted in Fig. 6 and Table 5 lists category wise spatial extent of forests over a different time period. The 26.41% of forest cover was under interior cover in 1973 which is reduced to 11% in 2018 due to anthropogenic interventions. The interior cover was disrupted by non- forest LU categories through conversion into agriculture and horticulture plantations. The large tracts of forests were de-notified for other purposes (for short term political gains). Market-based cropping pattern has been threatening hydrologic regime due to over-exploitation of water coupled with the declined water retention capability with the removal of vast tracts of native vegetation. The common grassy blank areas under the revenue department are being mismanaged, rampant grazing inside core forest areas are impacting the regeneration. The non-forest area covers 79% of the landscape (2018).

Agents of Forest Fragmentation in Shimoga

Geo-registered and verified forest boundaries of the district were overlaid on high resolution classified remote sensing data and verified with the Google earth and Bhuvan data to assess the extent of forest land conversion to other categories. Figure 7 illustrates the spatial estimate of the land conversions in the reserve forest area. The estimate shows the conversion of forest to agriculture and horticulture is to the tune of 36,105 hectares. Verification of these LU in the field revealed most of these changes are unauthorized or encroachments. Eighteen percent of the reserved forest area

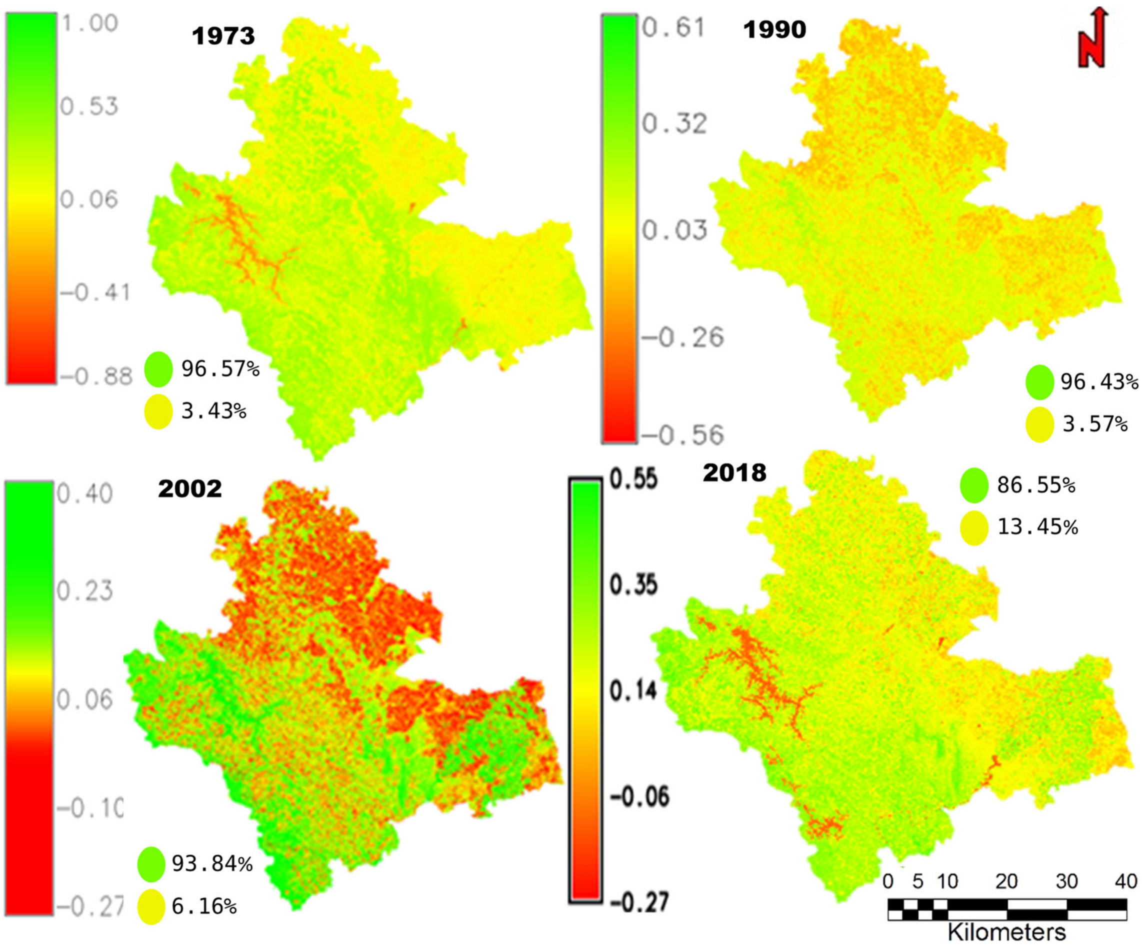


Fig. 3 Land cover analysis of Shimoga

is encroached in the Bhadravathi division, followed by 14% in Shimoga and 13% in the Sagara forest division.

ESR Prioritization

The ecologically sensitive regions or ESR in the Shimoga district are delineated at grid levels considering diverse (geo-climatic, ecological, hydrologic, social) themes. A total of 114 grids covering the study were considered and weightages were assigned to the analyzed variables, which were aggregated and grids are prioritized (Fig. 8a–t) based on the relative scores into four categories as ESR1 (highest sensitivity), ESR2 (higher sensitivity), ESR3 (high sensitivity) and ESR4 (moderate sensitivity).

LULC analysis of the district revealed that the district has a forest cover of 33.9%. The villages situated in the western part of the district (Western Ghats) have good forest cover. The grids of Agumbe rainforest, Thirthahalli taluk, Sharavathy Wildlife Sanctuary had the highest forest cover of greater than 80 percent as compared to the grids on the eastern side of Soraba, Shimoga and Shikaripura taluk (< 20–40%). The weightages are assigned based on forest cover across the district (Fig. 8a, b). Forest fragmentation analysis of the district revealed an interior forest cover of 11.32%. The grids on the western side of the district showed the highest percentages of interior forest cover > 80 percent, while the eastern and northern grids of the district had < 20 percent of interior forest (Fig. 8c, d).

The spatial distribution of the flora and faunal species across the district was compiled through field sampling and literature review. The distribution of the species endemic to the Western Ghats as well as the threatened species (according to the IUCN Conservation Status) has been analyzed, which are concentrated in the grids in and around Sharavathy Wildlife Sanctuary, Sagar taluk, Agumbe Rainforest, Thirthahalli taluk and toward the Bhadra Wildlife Sanctuary in Shimoga taluk (Fig. 8e–h). There are about 209 unique flora species under 60 different families distributed across the district. Dominant flora families of the district are Euphorbiaceae (19 species), Rubiaceae (16), Moraceae (13), Anacardiaceae (10), Fabaceae (10), Lauraceae (9), Ebenaceae (8), etc. As per IUCN conservation status, the number of species present in various categories are Critically Endangered (3 species), Vulnerable (17),

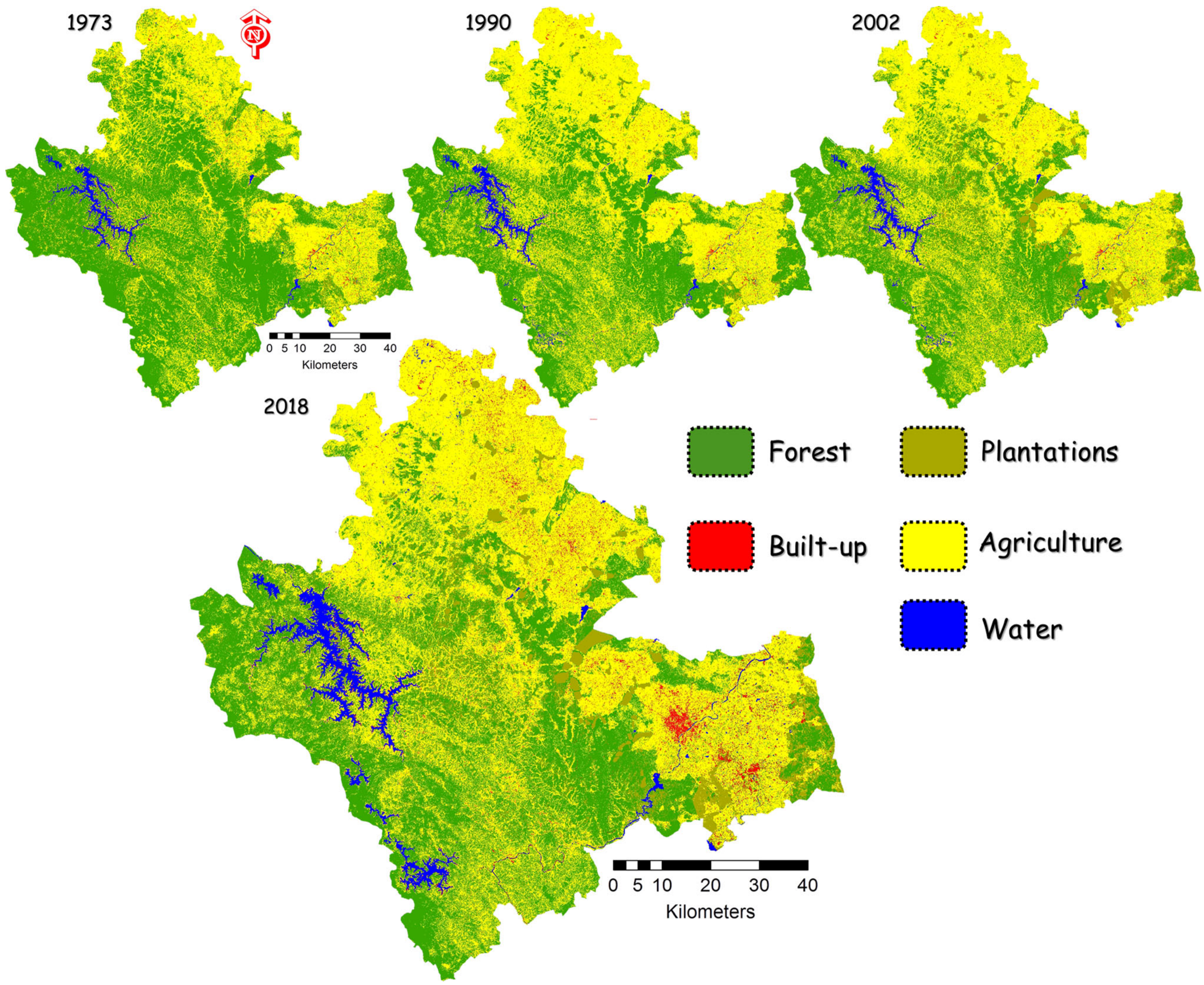


Fig. 4 Temporal Land use analysis of Shimoga

Table 4 Land use statistics

Year/category (%)	1973	1990	2002	2018
Forest	**43.83**	39.90	37.78	**34.02**
Water	1.91	4.53	4.57	4.29
Built-up	**0.63**	0.74	1.08	**2.35**
Plantation	9.46	25.15	26.36	**29.17**
Agriculture	44.14	29.68	30.21	30.17
Kappa coefficient	0.82	0.89	0.83	0.86
Overall accuracy	74.68	86.31	92.23	89.2

Bold values indicate the reduction in forest with an increase in plantations and built-up

Endangered (11), Near Threatened (6), Least Concern (11), Data Deficient (3), Not Evaluated (158). There are about 497 unique faunal species under various categories. Dominant fauna are amphibians (37 species), birds (206), fish (154), mammals (20), reptiles (80). As per IUCN category, the number of species identified under conservation groups are as follows Critically Endangered (3 species), Data Deficient (17), Endangered (29), Extinct (3), Least Concern (332), Near Threatened (23), Not Evaluated (160), Vulnerable (64).

Protected areas refer to a geographical space, that are significant in terms of their biological, ecological, or cultural values and hence are recognized, dedicated and managed, to achieve the long term conservation of nature, through appropriate environmental legislations. These regions are with the limited human occupation or the limited exploitation of resources. Protected areas constitute about 4.93% of the country's geographical area which includes national parks, sanctuaries, conservation reserves, and community reserves. Figure 8i and j depict protected areas in the district.

Geo-climatic variables such as the altitude or elevation, the percentage slope of the region, annual average

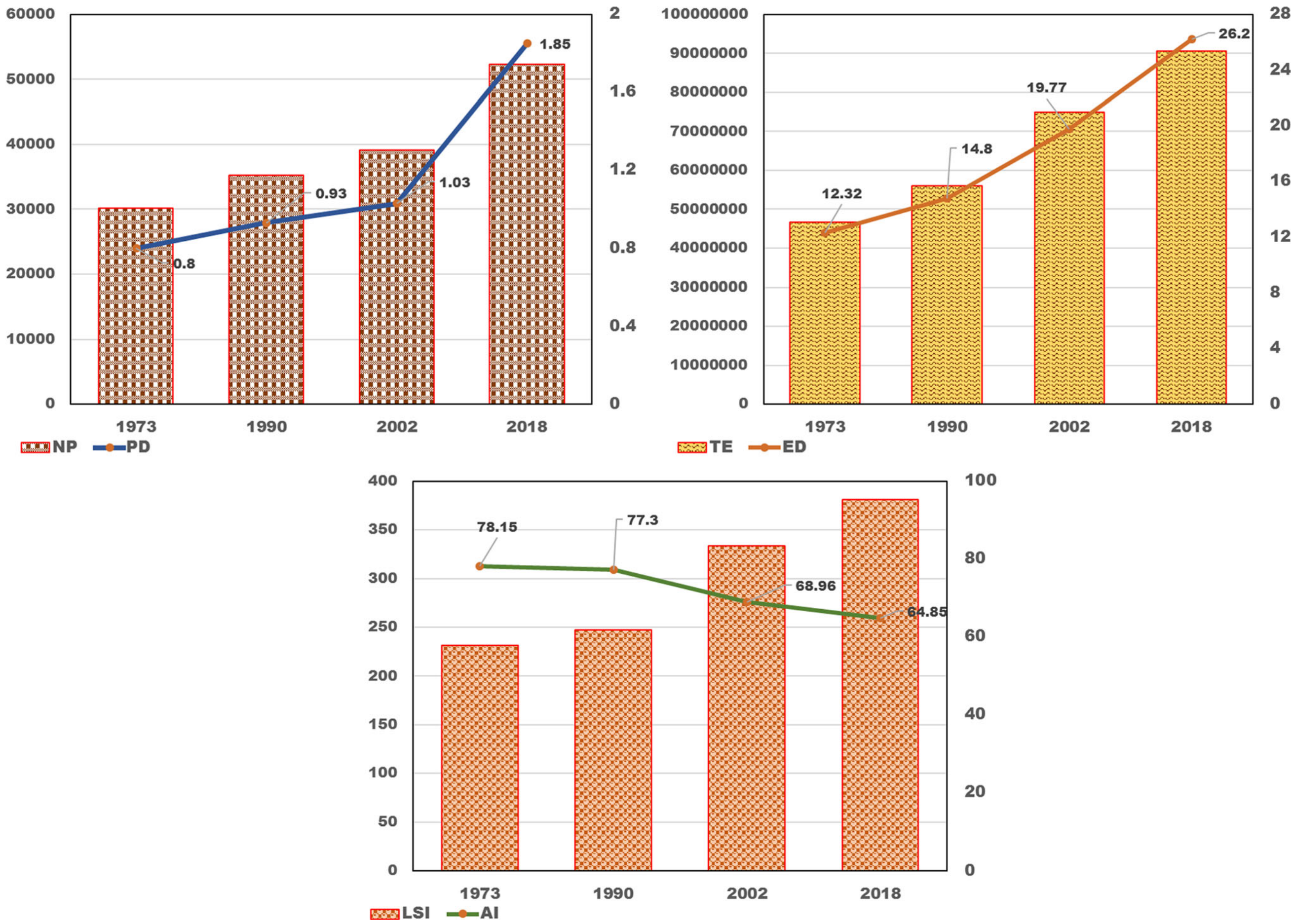


Fig. 5 Temporal pattern analysis through spatial metrics

precipitation or rainfall received by the region, and the agro-climatic zones were analyzed village wise, for the entire district. The altitude or elevation of the Shimoga district varies between 38 and 1335 meters above mean sea level and weightages assigned as per higher elevations (Fig. 8k, l). The regions on the western side of the district, toward the Ghats, had a higher slope of between 15 and 20 percent and more. The weightages are assigned based on slope values across each grid as the disturbing slope of the regions will aggravate instances of landslides.

Shimoga receives rainfall between the ranges of 592 and 7628 mm annually. Eastern sides of the taluks of Sagar, Hosanagara, and Thirthahalli receive the highest rainfall of more than 5000 mm as an annual average (Fig. 8m, n). Based on the agro-climatic zones, the district can be divided into 2 main zones, namely, the hilly zones comprising the Sahyadris and the southern transition zone comprising the plains, respective weightages were assigned (Fig. 8o, p).

The population density was analyzed at the village level and villages in Shimoga taluk have higher population density and Shimoga City Municipal Corporation (SCMC) has the highest population density of 4206 persons per square km. The villages of Sagar, Hosanagara, and Thirthahalli taluks have the lowest population densities, as the forests of Western Ghats are present here, as well as the Sharavathy Valley wildlife sanctuary (Fig. 8q, r). The proportion of Scheduled Tribe (ST) population was also analyzed village wise, which contributes to 3.7 percent of the whole population. Most of the villages have a scheduled tribe population of less than 25% (Figs. 8s, t). The aggregated weightages were analyzed and grids are prioritized based on the relative score that also the respective ecological sensitivity. The 27 grids are under ESR1, 27 under ESR2, 36 under ESR3, and 24 under ESR4 (Fig. 9a). Out of the 1585 villages, 184 were prioritized as ESR1, 472 as ESR2, 565 as ESR3, and 364 villages as ESR 4 (Fig. 9b). The ESR-1 represents a zone of highest conservation, no further degradation allowed. ESR-2 has the potentiality to become ESR-1 provided with strict regulations and improvement of forests and its environs by more protection. A small change in ESR-2 will have more adverse effects in ESR-1. It is recommended to impose a complete ban on illegal occupations, illegal NTFP

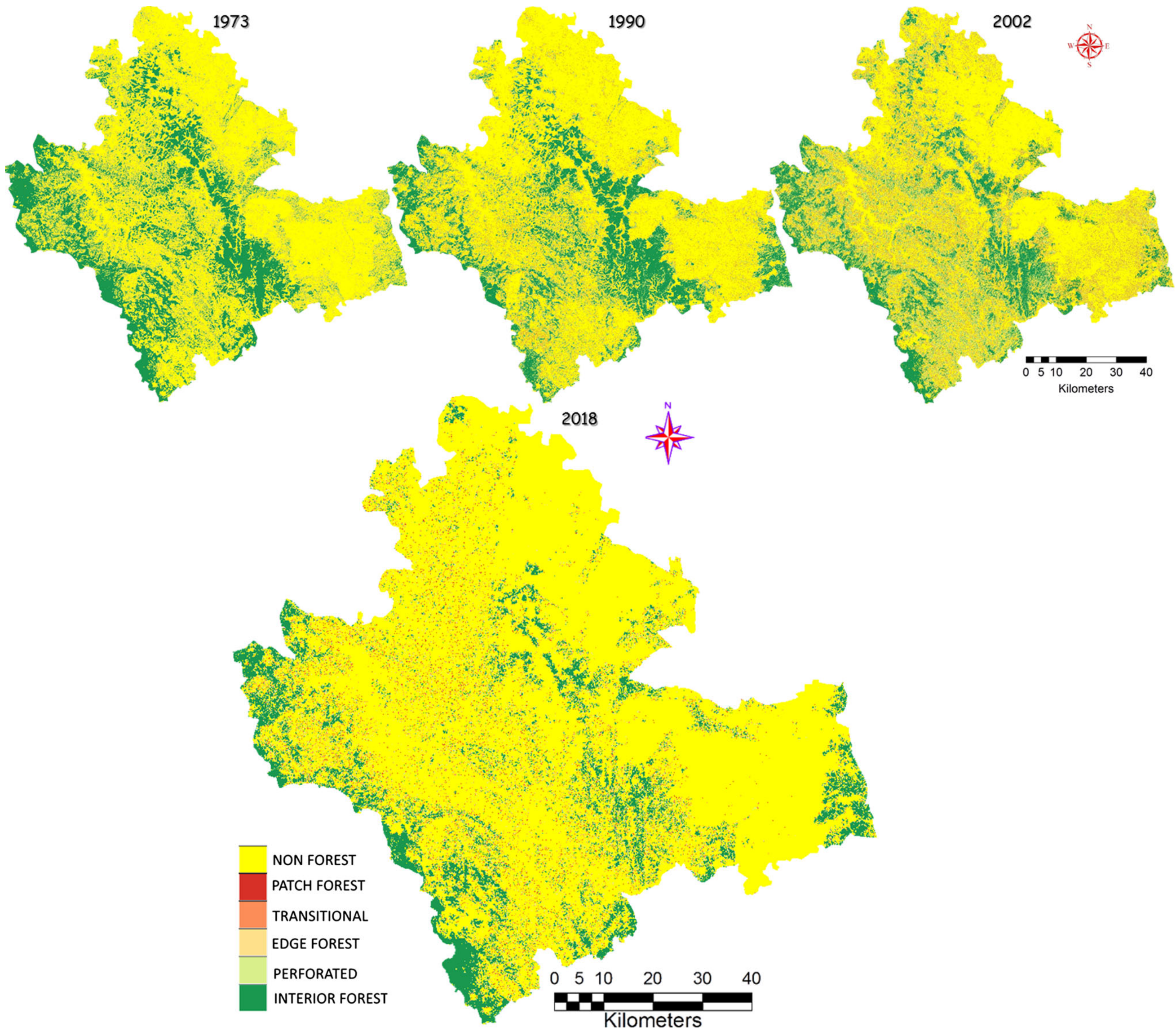


Fig. 6 Interior forest cover of Shimoga (1973–2018)

Table 5 Fragmentation analysis of Shimoga

SNO	Category (%)	1973	1990	2002	2018
1	Interior forest	**26.41**	21.04	17.02	**11.21**
2	Patch forest	0.00	2.52	3.93	1.21
3	Transitional forest	4.75	3.72	3.88	2.47
4	Edge forest	5.27	1.21	0.86	2.02
5	Perforated forest	7.61	9.33	11.00	4.19
6	Non-forest cover	**55.96**	62.17	63.31	**78.91**

Bold values indicate the significant reductions in interrior (or contiguous) forests with an increase in non-forest category in the district

collection, over-exploitation of forest resources. River diversion, stream alternations should not be allowed even for drinking water projects as the region is already facing a severe water crisis. Many river diversion projects are being pushed by the lobby (timber and power lobby) under the guise of drinking water projects (deliberately misleading judiciary). Diversion of the river should not be allowed to ensure the sustenance of biodiversity and the management of ecological flow. Forest conservation is possible only through active participation of local people and self-help women group through (i) development of nurseries of native forest trees and medicinal plants, (ii) NTFP collection (removal of contract system of middlemen) and (iii) value additions-developing bee-keeping in addition to the administrative mechanisms. Suggestions for prudent management of these ESR are given in Appendix A. Species suitable for reforestation in the degraded landscapes are also listed in the Appendix (Tables 6 and 7).

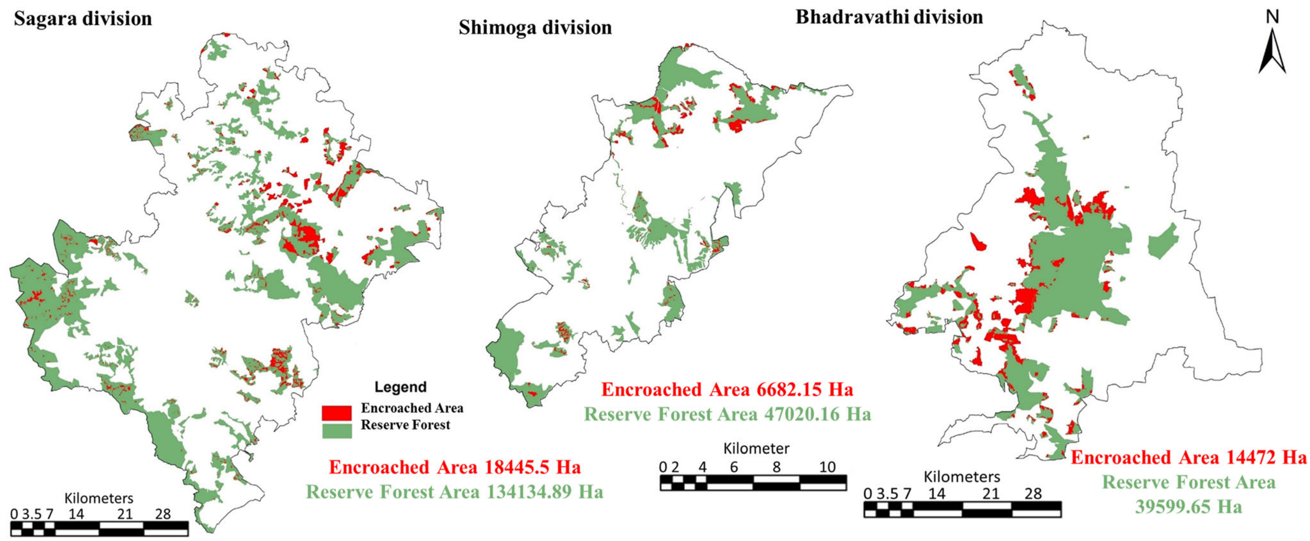


Fig. 7 Forest area encroachment across the divisions

Discussion

Forest ecosystems provide a rich habitat for diverse flora, fauna and the survival of the organism that depends on biotic and abiotic factors of its respective habitat. The fragmentation of contiguous forests into patches or islands surrounded by human habitations, leads to the decline of species richness and the equilibrium of dependence as trees lose its native area and fauna will lose its food. The rampant use of fire for clearing the evergreen vegetation for converting to cultivation areas or creating grassy area or plantations have caused the change of climax evergreen vegetation to savannas, scrub and secondary deciduous forests with diminished water flow in the streams and rivers, which can be detrimental to the livelihoods of people in Malnad and beyond-even the drier Deccan plains. Fragmentation of animal habitat leads to increased instances of human–animal conflicts, inbreeding, and ultimately the extirpation of species. Many parts of Shimoga have been experiencing higher instances of crop raid by animals, human–animal conflicts during the last two decades. Further regionally the climate and the microclimate in the patch and surrounding the patch will differ and will increase the temperature in the human habitat surrounding the patch (Bharath et al. 2013). These edges will also be exposed to high winds, and the incidence of fires will be higher since the forest edges are drier as the climate is higher than the moist interior this in turn might lead to natural disasters (Chen et al. 1993; Malhi et al. 2008). The edge effect may even perish large trees within 300 m of the forest edge and are replaced by densely spaced short-lived pioneers (Laurance 1999), resulting in the decline of forest biomass (Harper et al. 2005).

Mapping of land use changes in each forest division helps the decision makers and forest managers in the prudent management of forest habitats through an understanding of forest fragmentation, etc. Large-scale land use conversions alter the contiguous intact forests to perforated and edge fragments leading to the loss of connectivity. Mitigation of forest fragmentation provides better connectivity, which improves species richness and biogeographical environment while reducing their endangerment. The restoration of forest patches with native species would aid in improving the considerable share of endemic species in the large core fragments thereby reducing the influence of perforated and edge fragments (Paul and Banerjee 2020). The conservation of biodiversity is achieved through better connectivity with the restoration of fragmented landscapes. This helps in establishing the necessary habitat linkages, which minimizes inbreeding and consequent extirpation of species. This approach is referred as either habitat corridor, movement corridor, wildlife corridor, dispersal corridor, or biodiversity corridors, and fulfill the broader conservation needs (Kale et al. 2010). Prudent management of forest ecosystems entails maintaining forest habitat structural integrity, which will improve habitats of diverse organisms inhabiting forests, minimize ecological disturbances, reduces human–animal conflicts, species extinction, colonization of invasive species, etc. (Mandal et al. 2020). The designation of a region as 'Protected Area' based on the ecological significance of a region is an appropriate strategy to arrest deforestation and improve forest resources with biodiversity. These unique natural areas with sustainable management strategies, considering human communities as their integral component will lead to the conservation of characteristic ecosystems covering different biogeographic regions (Satish et al. 2014).

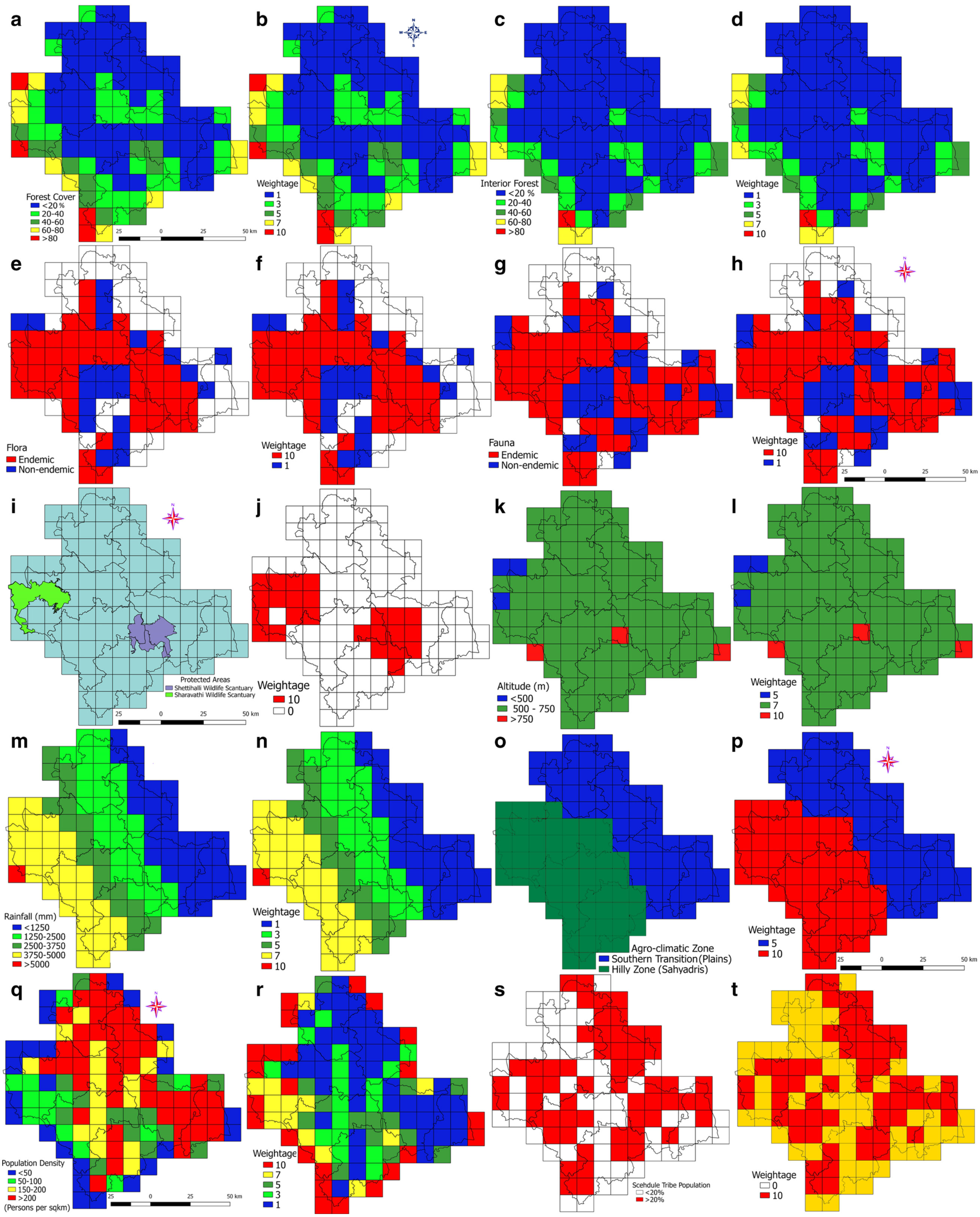


Fig. 8 variables considered and their respective weightages

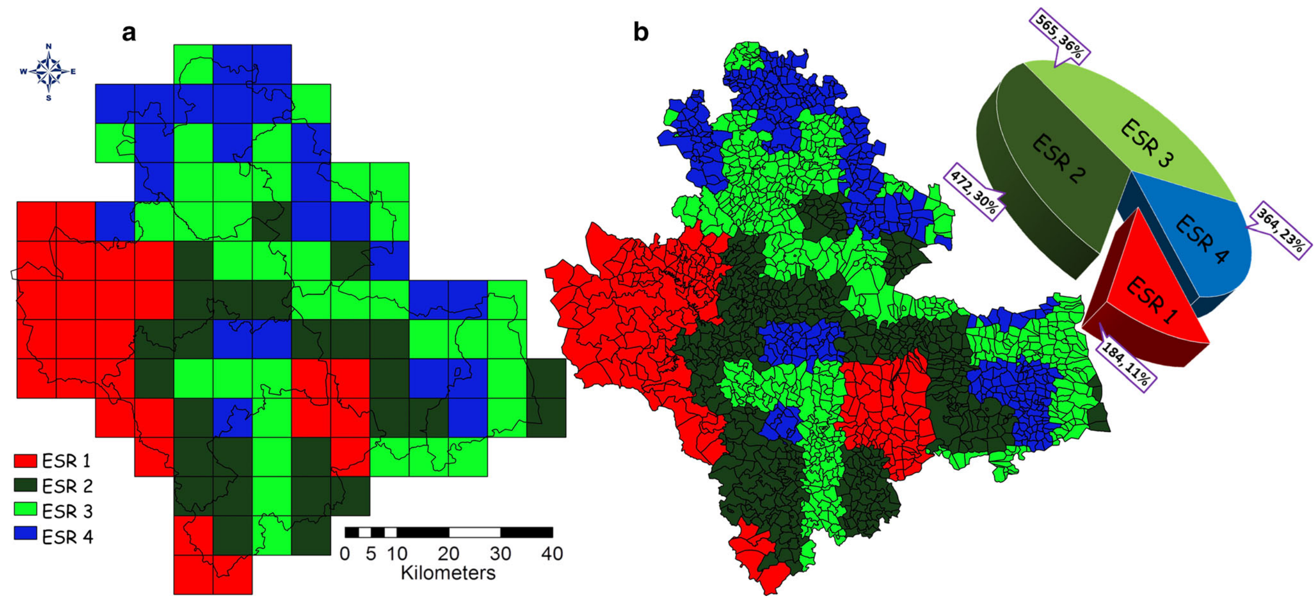


Fig. 9 ESR of Shimoga at village wise

Implementation of the national strategies such as National Action Plan on Climate Change (NAPCC), Reducing Emissions from Deforestation and forest Degradation (REDD +) through effective involvement of all stakeholders would aid in mitigating carbon dioxide (CO_2) through carbon sequestration. The success of these programs depends on the level of involvement of tribal (indigenous) and local people in conservation. As part of the United Nations agenda on sustainable development, several countries have adopted Sustainable Development Goals (SDGs) that emphasize the protection of the planet's ecosystems. In Canada, ecological regions have been used over the last few decades as the basis for a state of the environment and state of human activities on terrestrial and marine wildlife habitats. This was done to improve the capabilities of monitoring systems to track changes in an ecological context and to understand why these changes are taking place (Wiken and Gauthier 1997). In Sri Lanka, a five-year pilot project was initiated jointly by the Ministry of Mahaweli Development and Environment in collaboration with the United Nations Development Programme (UNDP), funded by the Global Environmental Facility and the Government of Sri Lanka to provide the capacity to manage Environmentally Sensitive Areas or ecologically sensitive regions (ESR). ESR denotes the region of lower resilience and difficult to be restored to its natural state if disturbed by external influences, which are either anthropogenic or natural. The demarcation of ecologically sensitive regions spatially is essential for effective conservation planning and management.

Conclusion

Spatiotemporal changes in land cover highlight the decline of vegetation cover from 96.57 (1973) to 86.55% (2012). Temporal land use analyses reveal that paved surfaces (built-up) have increased from 0.63% (1973) to 2.35% (2018) and forest cover has decreased from 43.83% (1973) to 34% (2012). The results highlight conversion of forests to commercial agriculture, industrial and cascaded developmental activities acted as major driving forces of degradation. Forest fragmentation analysis highlights that the domination of forests receded during the post-1990s with the formation of non-forest patches. The unauthorized land holdings are another major issue faced by the forests of Shimoga. The Total encroachment of reserve forest in the 3 divisions of Shimoga district accounts for 39,599 ha. The political, social, and religious pressures are threatening forests and troubling regulatory agencies in management. The results emphasize the need for an immediate eco-restoration measure to arrest fragmentation, human–animal conflicts, and consequent reduction in goods and services. ESR prioritization of Shimoga based on the collection and compilation of primary data of ecological, geo-climatic, and social aspects depict sensitive regions necessitates for conservation. The village wise ESR demarcation portraits 184 villages as ESR-1, 472 under ESR2, 565, and 364 under ESR 3,4, respectively. ESR1 and 2 depict the zone of highest sensitivity, absolutely no new developmental activities such as mining or dams are to be allowed in this zone. So, the majority of the villages fall under ESR 3 (high sensitivity category), where large-scale developmental activities, change in land use and forest

Table 6 Plant species suggested for afforestation

Sno	Species name	Common name
1	*Acacia concinna*	Seege
2	*Acacia ferruginea*	Banni
3	*Artocarpus heterophyllus*	Wild Jack; Hebbalasu
4	*Artocarpus integrifolia*	Jackfruit; Halasu
5	*Bombax ceiba*	Buraga, Silk cotton
6	*Careya arborea*	Kumbia, Kaul
7	*Caryota Urens*	Palm
8	*Cassia fistula*	Kakke
9	*Cordia myxa*	Challe
10	*Dendrocalamus giganteus*	Dragon bamboo
11	*Dillenia pentagyna*	Kanigala
12	*Dipterocarpus indicus*	Dhuma, Vaalee mara, Maradenne, New Guinea rosewood
13	*Diospyros ebenum*	Indian Ebony; Abanasi; Bale
14	*Emblica officinalis*	Nelli; Gooseberry
15	*Ficus bengalensis*	Banyan
16	*Ficus religiosa*	Pipal
17	*Ficus racemosa*	Atti; Cluster fig
18	*Garcinia indica*	Kokam; Goa butter tree; punarpuli
19	*Garcinia gummi-gutta*	*Garcinia cambogia; Malabar tamarind*
20	*Grewia tiliaefolia*	Dhaman; Dadaslu
21	*Gnetum edule*	Navuru katte, Kodkamballi
22	*Knema attenuata*	Wild Nutmeg; Kaadu pinde
23	*Litsea floribunda*	Pattuthali
24	*Madhuca indica*	Hippi mara
25	*Mallotus phillippensis*	Kumkumadamara
26	*Mangifera Indica*	Mango
27	*Meiogyne pannosa*	Malabar Fingersop
28	*Mimusops elengi*	Bakula
29	*Mucuna pruriens*	Nasagunni kai
30	*Myristica malabarica*	Malabar Nutmeg; Kanage
31	*Neolitsea cassia*	Grey Bollywood, smooth-barb bollygum
32	*Pongamia pinnata*	Pongamia; Honge
33	*Pterocarpus marsupium*	Netra Honne
34	*Saraca asoca*	Ashoka mara
35	*Spondias acuminata*	Kaadmate
36	*Syzygium Cumini*	Jamun; Nerle
37	*Tetrameles nudiflora*	Kadu bende
38	*Terminalia bellerica*	Tare mara
39	*Terminalia tomentosa*	Indian Laurel
40	*Tamarindus indica*	Hunase
41	*Vateria indica*	White Damar; Indian Copal; Ganapathi kayi mara
42	*Xylia Xylocarpa*	Jamba
43	Zanthoxylum rhetsa	Jummina mara
44	*Ziziphus rugosa*	Mulla hannu, Kaare
45	*Ziziphus oenoplia*	Wild jujube

encroachment should not be allowed; however small-scale industries like IT sectors, agro-processing industries are permitted. The integration and analysis of various heterogeneous data of several ecological, biological, geo-climatic, and social variables resulted in prioritizing sensitive regions will assist as a decision support system, for

Table 7 Grass species suggested for enriching barren lands for wildlife

Sno	Species Name	Suitable habitat	Common name
1	*Arundinella metzii*	Open slopes	
2	*Arundinella leptochloa*	Slopes	
3	*Brachiaria mutica*	Moist regions	Para grass (cultivated)
4	*Centotheca lappacea*	Slight shades	
5	*Chloris gayana*		Rhodes grass (cultivated)
6	*Chrysopogon hackelii*	Slopes	
7	*Chrysopogon fulvus*	Slopes	Ganjigorikahullu, Karada (Kan)
8	*Coix lacryma-jobi*	Wet, marshy areas	Job's tear grass
9	*Cymbopogon caesius*	Open dry slopes	
10	*Cymbopogon sp.*	Open dry slopes	
11	*Dichanthium annulatum*	Open moist	
12	*Digitaria ciliaris*	Moist shady	
14	*Eleusine coracana*	Open moist places, abandoned fields	Ragi
15	*Eulalia trispicata*	Slopes	
16	*Heteropogon contortus*	Open slopes	Spear grass
17	*Panicum maximum*	Moist regions	Guinea grass (cultivated)
18	*Panicum auritum*	River side, moist slopes	
19	*Pennisetum purpureum*	Banks of rivers, moist places	Napier grass (cultivated)
20	*Saccharum spontaneum*	Banks and wet places	Kan-kabbu
21	*Sporobolus indicus*	Dry regions	
22	*Themeda tremula*	Open slopes	
23	*Themeda triandra*	Open slopes	

management and conservation plans. Integration of these data with an appropriate spatial decision support system will benefit various stakeholders and managers to take rationale and formal decisions in the management and conservation-related plans.

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Data and Accessibility Data used in the analyses are compiled from the field. Data are analyzed and organized in the form of table, which are presented in the manuscript. Also, synthesized data are archived at http://wgbis.ces.iisc.ernet.in/energy/water/paper/researchpaper2.html#ce. http://wgbis.ces.iisc.ernet.in/biodiversity/.

Compliance with Ethical Standards

Conflict of interest We have conflict of interest either financial or non-financial.

Ethical Approval The publication is based on the original research and has not been submitted elsewhere for publication or web hosting.

Human and Animal Rights The research does not involve either humans, animals or tissues.

Permission to Carry Out Fieldwork Our research is commissioned by the Ministry of Environment and Forests (ENVIS Division), Government of India, and hence no further permission is required as the field work was carried out in the non-restricted areas/protected areas.

Appendix: Recommendations

The regions of high ecological sensitivity include regions having the dense forests of Western Ghats, such regions are rich with the presence of endemic and threatened biodiversity with high biomass and have great potential in carbon sequestration. Hence, it is recommended to implement forest policies, conservation plans, strict laws, and regulations with respect to developmental activities. The ESR-1 represents a zone of highest conservation, no further degradation allowed. ESR-2 has the potentiality to become

ESR-1 provided with strict regulations and improvement of forests and its environs by more protection. A small change in ESR-2 will have more adverse effects in ESR-1. The following recommendations are suggested for effective management and enrichment of forests in the region.

- Forest Rights Act to be implemented in its true spirit by reaching out to people. Impose a complete ban on illegal occupations, illegal NTFP collection, over-exploitation of forest resources.
- River diversion, stream alternations should not be allowed even in the name of drinking water projects as the region is already facing a severe water crisis. In the view of ecological flow measures, the diversion of water should not be allowed.
- In the case of fragmented forests (especially Soraba, Sagara, Bhadravathi taluks), connectivity between forest patches should be established by enriching native forest cover (biological corridors to ensure food and fodder) that allow species to move and genes to flow from one region to other. Improved connectivity with reduced fragmentation will aid in endemic species conservation.
- Monoculture plantations are not allowed, existing exotics should be replaced by planting native or endemic species (Table 6). The open fields and barren hilltops should be considered for grassy blocks creations with native varieties (Table 7).
- Promote decentralized electricity, use of renewable energy sources such as (solar, wind power).
- The local bio resource-based industry should be promoted. All should be strictly regulated and be subject to social audits.
- Adapt development projects which will have the least environmental impact by involving local community members in decision making and environmental monitoring.
- No new major roads, railway lines are allowed, except when highly essential and subject to EIA, by imposing strict regulations and social audits.
- Small-scale tourism should be encouraged by adopting benefit sharing with local communities such as home-stay, spice farms, eco-friendly boating, etc.
- Tourism Master Plan should be based on MoEFCC regulations (after taking into account social and environmental costs).
- The uncontrolled development should be discouraged in and around of pristine lakes, primeval forest patches, perennial water bodies. The site-specific (clustered base) sustainable developments can be taken up at each panchayat, which least affects the ecosystem.
- Controlled activities are permitted based on socio-economic importance and activities such as depriving wetlands, natural forests, the introduction of alien invasive species are not permitted.
- Enrich the grasslands, grassy patches by native grass varieties to improve herbivorous population in forest areas. Forests should be a healthy combination of different landscape elements, including the grasslands that provide a bulk of the fodder needs of the ungulates. The trailing habit of many grasses (e.g., *Cynodon dactylon, Oplismenus burmanii, Arundinella leptochloa, Panicum auritum*, etc.) helps them to withstand grazing pressure, trampling and even fires.
- Leguminous fodder herbs (*Cassia fistula, Desmodium triflorum, Entada scandens, Erythrina spp*, etc., may be planted in abandoned agricultural fields to promote wildlife, which would aid in enriching the soil while providing required nutrition to the dependent fauna. Herbaceous climbers of legumes, that provide forage for wildlife may be promoted experimentally in monoculture plantations.
- The task force under VFCs should be set up involving local stakeholders and forest departments to tackle and maintain harmony between the administration and people. The task force should also involve in demarcating borders, detecting and enforcing violations of regulations, and planning and implementing management activities.
- Creation of fodder reserves: It is very necessary to enrich the forests impoverished of wild animal fodder plants, using the land resources of poor-grade monoculture plantations, degraded forests, abandoned mine areas, underneath high tension power lines and such identified stretches.
- The fencing of small blocks of land for three to five years from human impact and grazing by domestic cattle will have a very positive impact on forest succession and healthy growth of grasses in overgrazed areas. Once tall saplings are naturally established, the forest will flourish on its own. The protection may be shifted to other unprotected areas after the three to five-year period. The forest lands thus protected may be named “Regeneration Blocks”. The vegetation succession in such blocks to be monitored and recorded, preferably by local volunteers. Seeds of suitable tree and shrub species may be disseminated in such areas to promote diversity.
- Creation/maintenance of water bodies: Water bodies are to be created intermittently in the forest areas so that the movement of animals in dry months could be minimized. Several old village ponds and tanks need desilting and maintenance. Watershed-based forest management is critical for creating healthy habitats for elephants and other wildlife.

- Development of nurseries involving local people and self-help women groups. People be encouraged and guided to make nurseries of native forest trees and medicinal plants.
- NTFP collection (removal of the contract system of middlemen) and value addition, developing bee-keeping involving forests. As bee-keeping is recommended as an important activity for almost all clusters, roadsides, common lands, under-stocked, or degraded forest patches around villages be planted with appropriate nectar plant species.
- The contract system for collection of NTFP from forests found to be highly detrimental to forests and biodiversity and economic well-being of local people be stopped forthwith and co-management system involving local people be adopted.
- Production of bamboo-based products by local craftsman and effective utilization of bamboo for local development is important.
- Regular conduct of training in bird-watching, wildlife studies, trekking trails, hygiene, and solid waste management involving VFCs, local youth in forest, and wildlife related tourism areas be arranged with the view of generating eco-friendly employment potential.
- Kan forests are the remnants of climax evergreen forests, preserved through generations by the village communities, the abode of endemic ecologically sensitive plant species, and also acting as a sustainable source for water resources for the villages located. The restoring these climax patches would be difficult if they are perturbed by an external influence. Hence, the Kan forests should be demarcated and fenced by protecting from further degradation.
- Recommended to consider for heritage sites status to 'kans' under Sect. 37(1) of Biological Diversity Act 2002, Government of India as kans are the repository of a biological wealth of rare kind, and the need for adoption of holistic ecosystem management for conservation of, particularly the rare and endemic flora of the Western Ghats.

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