Forest Ecosystems

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Geospatial analysis of forest fragmentation in Uttara Kannada District, India

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Abstract

Background: Landscapes consist of heterogeneous interacting dynamic elements with complex ecological, economic and cultural attributes. These complex interactions help in the sustenance of natural resources through bio-geochemical and hydrological cycling. The ecosystem functions are altered with changes in the landscape structure. Fragmentation of large contiguous forests to small and isolated forest patches either by natural phenomena or anthropogenic activities leads to drastic changes in forest patch sizes, shape, connectivity and internal heterogeneity, which restrict the movement leading to inbreeding among Meta populations with extirpation of species.

Methods: Landscape dynamics are assessed through land use analysis by way of remote sensing data acquired at different time periods. Forest fragmentation is assessed at the pixel level through computation of two indicators, i.e., P_f (the ratio of pixels that are forested to the total non-water pixels in the window) and P_{ff} (the proportion of all adjacent (cardinal directions only) pixel pairs that include at least one forest pixel, for which both pixels are forested).

Results: Uttara Kannada District has the distinction of having the highest forest cover in Karnataka State, India. This region has been experiencing changes in its forest cover and consequent alterations in functional abilities of its ecosystem. Temporal land use analyses show the trend of deforestation, evident from the reduction of evergreen - semi evergreen forest cover from 57.31 % (1979) to 32.08 % (2013) Forest fragmentation at the landscape level shows a decline of interior forests 64.42 % (1979) to 25.62 % (2013) and transition of non-forest categories such as crop land, plantations and built-up areas, amounting now to 47.29 %. PCA prioritized geophysical and socio variables responsible for changes in the landscape structure at local levels.

Conclusion: Terrestrial forest ecosystems in Uttara Kannada District of Central Western Ghats have been experiencing threats due to deforestation with land use changes and fragmentation of contiguous forests, as is evident from the decline of interior forests and consequent increases in patch, transitional, edge and perforated forests. Interior or intact forest cover in this ecologically fragile region is now 25.62 %. Considering the accelerating rates of forest fragmentation in recent times, the focus should be on reforestation and regeneration of natural vegetation to sustain food and water security and the livelihood of local populations. This requires innovation with holistic approaches in the management of forests by involving all local stakeholders to minimize the encroachment of forests, and improvements in regeneration.

Keywords: Land use dynamics, Forest fragmentation, Interior forests, Biodiversity, Geophysical variables

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Background

Any landscape is a mosaic of heterogeneous interacting dynamic elements, i.e., manifestations of natural and anthropogenic processes. The structure of a landscape (size, shape and configuration) affects its functional aspects such as bio-geo chemical cycling and hydrologic regimes. The interactions among the landscape elements result in the flow of nutrients, minerals and energy, which contribute to the functioning of the landscape. Forest ecosystems constitute a key component of the global carbon cycle that account for over two-thirds of net primary production on land through photosynthesis converting solar energy into biomass (Roy et al. 2001; MEA 2005; Ramachandra et al. 2013). Forest ecosystems offer timber and non-timber forest products (NTFP), such as medicinal resources, fuel wood and as well provide recreational values (Kindstrand et al. 2008). They aid as biodiversity repositories (Li et al. 2009), restrain soil erosion (Nandy et al. 2011), prevent landslides given that tree roots bind soil, regulate air humidity, temperature and mitigate global warming (Cabral et al. 2010) by absorbing 30 % of fossil fuel CO_2 emissions (Pan et al. 2011). The goods and services provided by forested landscapes are vital to the socioeconomic development of human populations (DeFries et al. 2004) and their survival (Ramachandra et al. 2013). At a large-scale land use, more recent land cover changes (LULC) are altering the ecosystem structure, affecting the goods and services of the ecosystem. These disturbances have resulted in fragmentation of forests with a mosaic of natural patches surrounded by other land uses (Ramachandra and Kumar 2011). A host of anthropogenic activities, such as tree logging, conversion of forest land to agriculture, intense agricultural practices, forest fire and unplanned infrastructural development have contributed to the disruption of the contiguity of forests in predominantly natural landscapes (Buskirk et al. 2000; Boogaert et al. 2004). An alteration in forest structure through fragmentation of forests has affected its functional abilities, as is evident from the decline in water yield, carbon sequestration potential and biodiversity. (Diaz et al. 2006; Ramachandra and Kumar 2011).

Fragmentation processes involve alterations in the structure and composition of native forests through the division of contiguous forest into smaller non-contiguous fragments with a sharp increase in edges (Riitters et al. 2002; Broadbent et al. 2008). This will have detrimental effects such as disruption in bio-geo chemical cycling, nutrient and water cycling, ecological processes (Fahrig 2003; Holway 2005), easier access and further land use changes (Holway 2005; Bennett and Saunders 2010; Ramachandra et al. 2012a). The edge effect may even destroy large trees within 300 m of the forest edge which are then replaced by densely spaced short-lived pioneers (Laurance 1999), resulting in the decline of forest biomass (Harper et al. 2005). The negative impact of edges include alterations in plant and animal community compositions with subsequent changes in diversity (Cagnolo et al. 2006), seed dispersion, pollination, predation, fire susceptibility, altered microclimate and increased carbon emissions (Laurance et al. 2002). Consequences of edge effects (Carolina 1995; Asner et al. 2006) also include abiotic changes such as in its micro climate (Kampichler et al. 2012) and water availability. Figure 1 explains the process of fragmentation with drivers. The earlier stages of forest fragmentation lead to changes in forest composition due to the transition of evergreen forests to a mix of semi evergreen and scrub forest patches leading to alterations in micro climate and habitat (Ramachandra et al. 2013). During the succession stage, edges will become more prominent with higher light availability and loss of soil moisture. This will directly affect seed dispersal, seed viability, species distribution and propagation of invasive species (Ramachandra and Kumar 2011). These cascading effects have the potential to disrupt seriously many basic ecological processes over large areas. The changes in forest structure will result in abrupt effects and disturbing the productivity of goods and services from the natural ecosystem. Analyses of the extent of forest fragmentation will provide insights of complex dynamic interactions, which help in adopting appropriate location specific

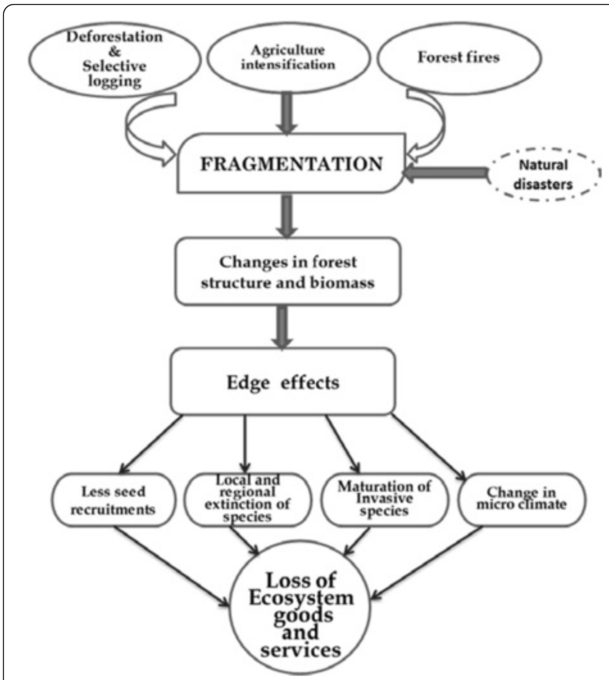

Fig. 1 A theoretical frame work of Fragmentation and its consequence

conservation measures to mitigate disruptions in ecological processes.

Quantification of forest fragmentation

Land use (LU) changes driven by anthropogenic activities alter the structure of a landscape, which adversely affect the functional aspects of an ecosystem. Land use patterns are the collective result of interactions among local geophysical indicators, such as elevation, slope and rainfall and agro-climatic indicators, demographic variation, market forces and related development policies (Munroe et al. 2004; Ameztegui et al. 2010). Numerous studies focusing on deforestation at the landscape level have explored the spatial patterns and interactions among the geophysical elements of the landscape and its dynamics (Nelson and Geoghegan 2002; Alix-Garcia et al. 2005; Echeverria et al. 2008; Ramachandra and Kumar 2011; Ramachandra et al. 2013). These changes, measured at temporal scales, help in monitoring ecosystems and aid in the implementation of location specific mitigation measures. Spatial data acquired remotely through space-borne sensors (remote sensing data) at regular intervals help in assessing the temporal changes in spatial patterns (Ramachandra et al. 2014a). Remote sensing data (RS) with geographic information systems (GIS) have made significant contributions to the examination of spatial-temporal patterns and processes of forest ecosystems (Nandy et al. 2011; Ramachandra et al. 2012a) in criteria based decision-making and selection of the optimal alternative. The availability of remote sensing data, with improvements in resolutions (spatial, spectral and temporal resolutions), enables the creation of land use and land cover maps (Chen et al. 2015), as well as that of innovative analytical techniques and helps to monitor changes in cost-effective ways (Bharath et al. 2012a). Changes in forested landscapes of the Western Ghats have been more sudden since the middle of the last century due to the impetus of industrialization policies as a consequence of globalization. Quantification of forest fragmentation in an ecologically fragile region, such as the Western Ghats will help in formulating appropriate mitigation measures towards the conservation of biodiversity.

Objectives

The objectives of this assessment of land use dynamics and forest fragmentation are to:

1. Understand the prevailing forest cover dynamics from 1979 to 2013 and evaluate the causal factors contributing to forest changes;
2. Explore the spatial-temporal patterns of forest fragmentation and quantification of the extent of fragmentation;
3. Evaluate the role of geophysical variables in forest cover changes and assess the effects of such variables on the patterns of forest loss at a temporal scale and
4. Suggest management options to mitigate forest loss and fragmentation to restore and sustain the ecosystem.

Method

Study area

Uttara Kannada (13.92 to 15.53° North and 74.09 to 75.09° East) is the fifth largest district of Karnataka State in India with abundant natural resources, perennial (water flows throughout the year) rivers, abundant flora, fauna and a long coastal line (about 140 km). The district consists of three distinct agro-climatic zones covering 11 taluks (local administrative divisions), i.e., the coastal taluks Karwar, Ankola, Kumta, Honnavar and Bhatkal, the Sahyadri Interior taluks Supa, Yellapura, Sirsi and Siddapur and two eastern plains (connected to Deccan plateau) Haliyal and Mundgod. The total population of the district is 1,437,169 (as per 2011 census) with a density of 140 persons per km^2. The district covers about 15,055 km of road length, ranging from national and state highways to village roads. The four forest types (Fig. 2) are dry deciduous, moist deciduous, evergreen to semi evergreen and coastal mixed deciduous forests, the result of its varied geographical features. Recent changes in the forest cover and associated habitat fragmentations are due to unplanned developmental activities. The implementation of hydroelectric and nuclear power projects with the consequent submergence of large tracts of evergreen forests and croplands has displaced thousands of families affecting their livelihood as well as the sustainability of natural resources. This necessitates a better understanding of forest dynamics with disturbance regimes, including the extent of fragmentations.

Quantification of spatial-temporal forest changes and extent of fragmentation

Land use (LU) changes in Uttara Kannada District were assessed using temporal remote sensing (RS) data with ancillary data and information obtained from the field. Figure 3 outlines the method adopted for the analysis of spatial patterns of forest changes. RS data used in the study are Landsat MSS (1979), TM (1989, 1999), Landsat ETM+ (2013) (downloaded from the archive - http://glovis.usgs.gov/) and Google Earth (http://earth.google.com). Slope maps were generated by using ASTER DEM (30 m) (http://gdem.ersdac.jspacesystems.or.jp/). Rainfall data was procured from the Directorate of Economics and Statistics, Government of Karnataka (http://des.kar.nic.in). Population data was procured from the Directorate of

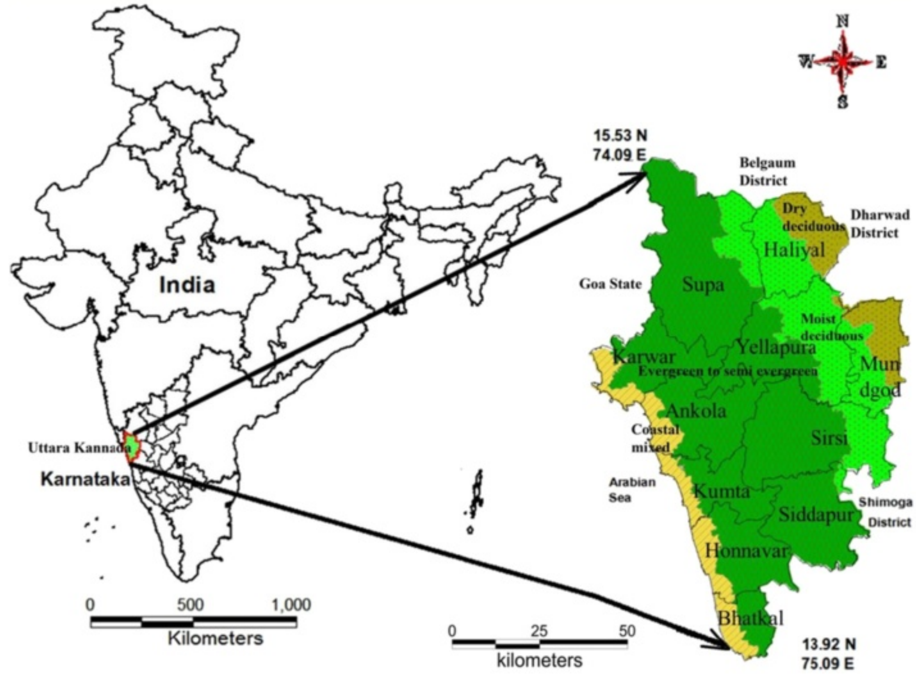

Fig. 2 Study area and forest type description

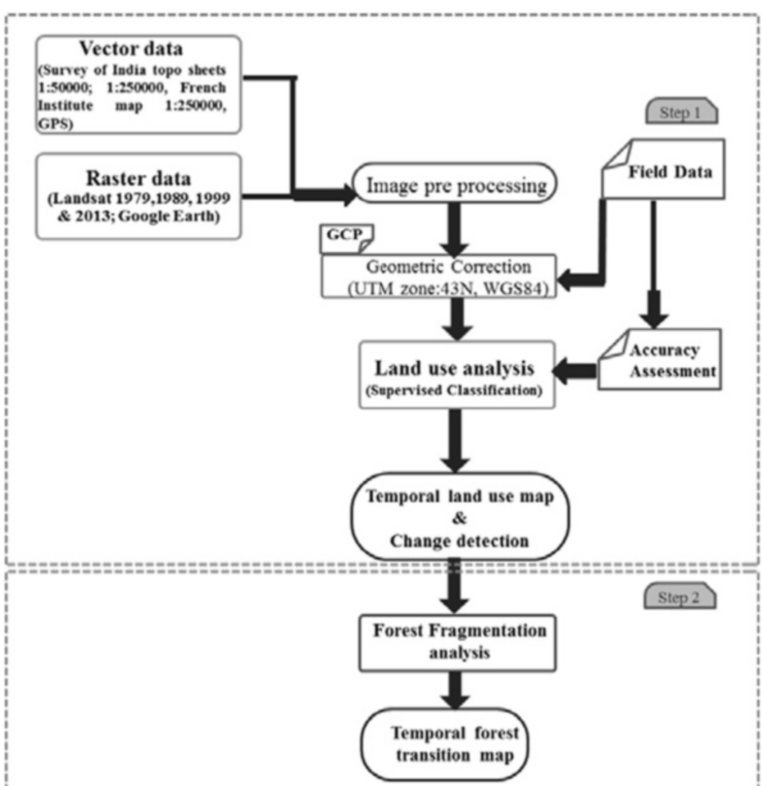

Fig. 3 Method for LULC and fragmentation analysis

Census Operations, Karnataka (http://censuskarnataka.gov.in). Ancillary spatial data include cadastral revenue maps (1:6000), the Survey of India (SOI) topographic maps (1:50,000 and 1:250,000 scales) were procured from the Survey of India (http://surveyofindia.gov.in), etc. Ground control points (GCP's) used to geo-rectify remote sensing data were digitized from the topographic maps and from field observations. Various forest cover types to classify RS data from the 1980's were obtained from the vegetation map of South India at a scale of 1:250,000 (Pascal 1986). Training data required for classification and validation of the latest remote sensing data were compiled from field observations using a pre-calibrated hand-held GPS (Global Positioning System). GPS calibration was carried out from known ground coordinates (benchmarks, intersection of roads and other landmarks) as per the most commonly adopted protocol (Yuan 2008). FCC (false color composites) helped in identifying heterogeneous land use patches. Select land use patches (uniformly distributed in the study region covering at least 10 % of the study region), were digitized and loaded to the GPS. Attribute information are collected (land use type, vegetation details) for these patches (training polygons) from the field.

Land use analysis and detection of change

Changes in land use during the last four decades were assessed using temporal RS data. This helped in determining the extent and causes of transitions in the landscape. Spatial data analyses involved (i) pre-processing, (ii) vegetation cover and (iii) land use analyses. Preprocessing involved geo-referencing, rectification and cropping of data pertaining to the study region. Georeferencing was carried out through ground control points collected from the field using pre calibrated GPS and from known points, such as road intersections, collected from geo-referenced topographic maps published by the Survey of India. The Landsat data of 1979, with a spatial resolution of 57.5 m × 57.5 m, was resampled to 30 m comparable to the 1989–2013 data, which are 30 m × 30 m (nominal resolution). The Landsat ETM+ bands of 2013 were corrected for the SLC-off (Scan Line Corrector failed) by using image enhancement techniques and nearest-neighbor interpolation.

Land use analysis involved (i) the generation of False Color Composites (FCC) of remote sensing data (bands–green, red and NIR), which helped in locating heterogeneous patches in the landscape, (ii) selection of training polygons by covering 15 % of the study area (polygons are uniformly distributed over the entire study area), (iii) loading the co-ordinates of these training polygons into GPS, (vi) the collection of corresponding attribute data (land use types) for these polygons from the field, where the GPS helped in locating respective training polygons in the field, (iv) supplementing this information with Google Earth. In the end, 60 % of the training data was used for classification, with the balance going for validation or accuracy assessment (Ramachandra et al. 2012c). The land use analysis was performed using a supervised classification technique based on the Gaussian maximum likelihood (GML) algorithm with training data (collected from the field using GPS). This evaluated quantitatively the variance and covariance of spectral response patterns of land uses based on a GML estimator (Atkinson and Lewis 2000; Ramachandra et al. 2012c). Land use classifications using temporal data was carried out through the open source program GRASS - Geographical Resources Analysis Support System (http://ces.iisc.ernet.in/grass). Accuracy assessments of the classified information have been performed (Lillesand and Keifer 1987; Liu et al. 2007) to evaluate the performance of classifiers through the computation of an error matrix, kappa (κ) statistics and overall accuracies.

Forest fragmentation model implementation

Fragmentation of forests at the pixel level are estimated through the computation of P_f (the ratio of the number of pixels that are forested to the total number of non-water pixels in the window) and P_{ff} (the proportion of all adjacent (in cardinal directions) pixel pairs that include at least one forest pixel, for which both pixels are forested) as given in equations 1 and 2 (Riitters et al. 2002; Kuèas et al. 2011; Ramachandra and Kumar 2011).

$$P_f = \text{Proportion of number of forest pixels} / \text{Total number of non-water pixels in window} \quad (1)$$

$$P_{ff} = \text{Proportion of number of forest pixel pairs} / \text{Total number of adjacent pairs of at least one forest pixel} \quad (2)$$

P_{ff} estimates the conditional probability that, given a pixel of forest its neighbor is also forest based, the proportion of all adjacent (cardinal directions) pixel pairs. P_f and P_{ff} were computed through a moving window of 5 × 5 pixels (Fig. 4), given that the results of the model are scale-dependent and threshold dependent. A kernel of size 5 × 5 is selected for spatial data of 30 m, based on earlier work (Riitters et al. 2002; Wickham et al. 2007; Kuèas et al. 2011; Prasad et al. 2009; Ramachandra and Kumar 2011), which maintain a fair representation of the proportion (P_f) of pixels and also interior forest at an appropriate level (Riitters et al. 2000; 2002; Wickham et al. 2007; Kuèas et al. 2011). Riitters et al. (2004) demonstrated the appropriateness of 5 × 5 kernels. Kernel sizes smaller than 5 × 5 have an effect of decreasing the average inter patch distance,

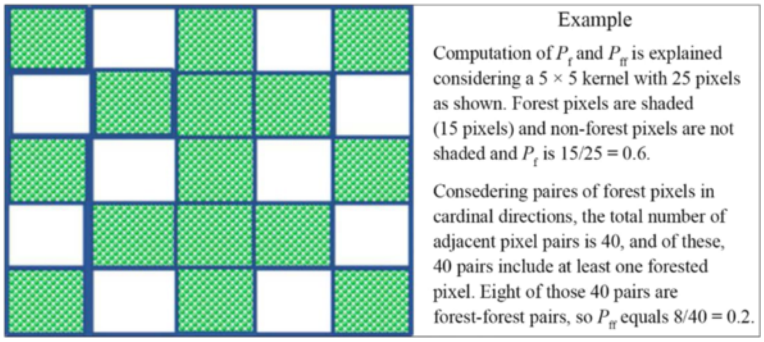

Fig. 4 KERNEL (5 × 5) for computation of P_f, P_{ff} values

indicating less fragmentation, even though disintegration of interior forests might be evident (Boogaert et al. 2004; Lindenmayer et al. 2008). Similarly, an increase of kernel size decreases the core area and this process may transform small core areas to form a discontinuous landmass (Ostapowicz et al. 2008; Kuèas et al. 2011). Depending on the indices P_f and P_{ff}, spatial extent of forest fragmentation were mapped and details are presented in Table 1. Water bodies or river courses are considered non-fragmenting features, for these constitute natural corridors in a forested landscape, while anthropogenic landscape elements (such as buildings, roads, agricultural field and barren land) are drivers of forest fragmentation.

Principal Component Analysis (PCA)

Unplanned urbanization, geography, industrialization, government policies, economic reforms and population growth are the major factors driving landscape changes (Gong et al. 2013). Socio-economic and bio-geophysical variables elucidate the role of anthropogenic forces in forest transitions, altering landscape structures and their composition (Ramachandra et al. 2014a). These geophysical variables and socio-economic factors aid as drivers of land use changes in the landscape (Nelson et al. 1999; Barbier 2001; Timar 2011; Cho et al. 2015).

The primary objective of geospatial statistical analysis is to quantify the correlation between socio-economic and bio-geophysical variables with the fragmentation of forests over a set of non-water pixels in a landscape through multiple linear regression (MLR). But, MLR explains the output data as a weighted sum of individual correlations with the assumption that any individual variable/feature in the input set is linearly independent. A high level of interdependence among input variables imply that forest fragmentation correlations do not have an independent biological interpretation. To reduce redundancy in multivariate data, a decomposition of eigen values is used in Principal Component Analysis (PCA). It helps in noise reduction and also in prioritizing variables, responsible for the variation in spatial landscape processes (Morris et al. 2009). Prioritizing these variables

Table 1 Fragmentation components and their description

Fragmentation component	Description	Computation
Interior	Forest pixels are far away from the forest-non forest boundary. Interior forested areas are surrounded by thicker forested areas.	($P_f = 1$). All pixels surrounding the center pixel are forest.
Patch	Forest pixels comprising small forested areas surrounded by non-forested land cover.	($P_f < 0.4$). A pixel is part of a forest patch on a non-forest background, such as a small wooded lot within a built-up area.
Perforated	Forest pixels forming the boundary between an interior forest and relatively small clearings (perforations) within the forested landscape.	($P_f > 0.6$ and $P_f – P_{ff} > 0$). Most pixels in the surrounding area are forested, but the center pixel appears to be part of the inside edge of a forest patch. This would occur if small clearings were made within a patch of forest.
Edge	Forest pixels that define the boundary between interior forest and large non forested land cover features.	($P_f > 0.6$ and $P_f – P_{ff} < 0$). Most pixels in the surrounding area are forested, but the center pixel appears to be part of the outside edge of a forest. This would occur along the boundary of a large built-up area, or agricultural field.
Transitional	Areas between edge type and non-forest types. If higher pixels are non-forest then they will be tending to non-forest cover with higher degree of edge.	($0.4 < P_f < 0.6$). About half of the cells in the surrounding area are forested and the center forest pixel may appear to be part of a patch, edge, or perforation depending on the local forest pattern.

based on their role in land use changes will help to evolve management strategies and sustain landscape elements with their interactions (Todd and Kerr 2009).

PCA explores multivariate patterns of all forest patch types versus spatial processes based on correlation matrices and frames clusters and relates spatial heterogeneity among variables correlated with one another and responsive to multiple principal components (PC). These derived components are linear function of the original data set. The components derived are ordered by decreases in variance, i.e., PC1 will have the largest variance among n components and PCn will have the smallest variance. After the extraction of the PCA eigenvalues, Scree plot is generated to prioritize the number of significant principal components (Jackson 1993). Finally, a series of ordinations were created to interpret the PCs visually and determine their fragmentation patterns. The sum of the eigenvalues is equal to the variance of the original data set, which preserves the original variation. The table of factor loadings explains the contribution of each variable to the derived components. A component is oriented towards that variable which has the maximum loading on it.

PCA with geo-physical variables aid in understanding the causal factors of environmental vulnerability. The positively correlated spatial parameters with geophysical and socio-economic variables serve as key descriptors of land use transitions (Salvati et al. 2008). PCA analyzes the variance of variables and reorganizes it into a new set of uncorrelated independent components (principal components) equal to the number of original variables as linear combinations of the measured variables (Swan and Sandilands 1995). These combinations are based on weights (eigenvectors) and the loading for each item/variable is the correlation between components, which serve to demarcate clusters of similar patterns (Colson et al. 2011). PCA aided in prioritizing bio-geophysical and socio variables that act as agents of changes in vegetation cover. The variables used in PCA were normalized (Abdi and Williams 2010; Bell et al. 2015) by computing Z-scores (Normalized (X)).

Results

Temporal land use analyses (Fig. 5) show a decrease in the evergreen forest cover from 57.31 % (1979) to 32.08 % (2013). Enhanced agricultural activities are evident from the increase in agricultural land use (Table 2) from 10.02 (1979) to 14.13 % (2013) and areas under human habitation have increased during the last four decades from 0.95 % (1979) to 3.07 % (2013). In addition to these, various on-going unplanned developmental projects have contributed to the decline in forest cover. The increase in plantations of exotic species such as *Acacia auriculiformis*, *Casuarina equisetifolia*, various *Eucalyptus* spp. and *Tectona grandis* serve mainly to meet the demand by forest-based industries. These plantations now (2013) constitute 12.04 % (*Acacia auriculiformis*, *Casuarina equisetifolia*, various *Eucalyptus* spp) and 6.60 % (*Tectona grandis*) respectively in the district. Degradation of vegetation cover in the coastal zone had triggered a series of landslides in 2009 at 21 locations along a national highway, i.e., NH-17, leading to the loss of property and human life (Ramachandra et al. 2012b). The dry deciduous forest cover is has declined considerably from 2.83 to 0.96 % (during 1973 to 2013) and is found mainly in the northeastern part of the district in Mundgod and Haliyal taluks. Accuracy of the classification ranges from 87 to 92 % indicating consistent classification results.

Land use changes during the past four decades were estimated using temporal remote sensing data from 1979 to 2013 and are shown in Fig. 5a, b, c, d. Natural

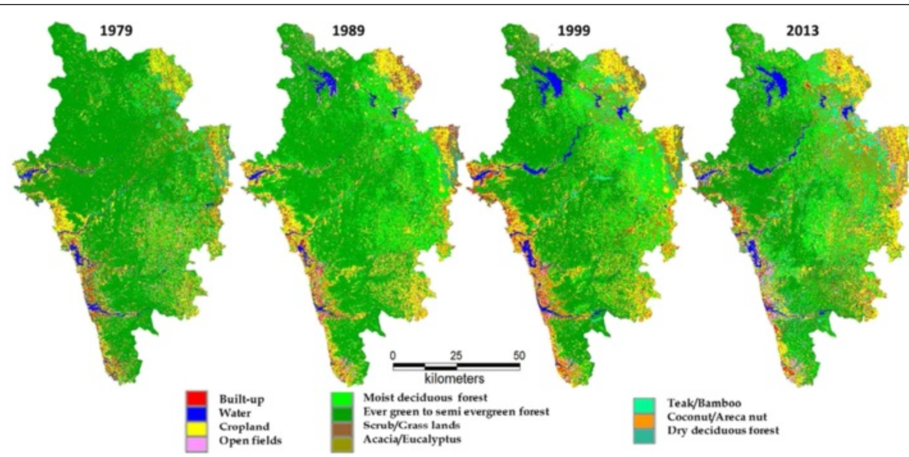

Fig. 5 (**a**, **b**, **c**, **d**): Landuse analysis from 1979–2013

Table 2 Temporal land use changes from 1979 to 2013 and accuracy assessment

Category	1979		1989		1999		2013	
	ha	%	ha	%	ha	%	ha	%
Built-up	9738	0.95	12,982	1.26	21,635	2.1	31,589	3.07
Water	18,527	1.8	16,604	1.61	32,983	3.21	28,113	2.73
Crop land	103,163	10.02	121,167	11.77	138,458	13.45	145,395	14.13
Open fields	15,988	1.55	34,783	3.38	21,945	2.13	37,660	3.66
Moist deciduous forest	102,967	10.01	143,849	13.98	179,075	17.4	161,996	15.74
Evergreen to semi evergreen forest	589,762	57.31	531,872	51.68	423,062	41.11	330,204	32.08
Scrub/Grass lands	58,936	5.73	44,123	4.29	47,366	4.6	40,402	3.93
Acacia/Eucalyptus plantations	50,321	4.89	55,694	5.41	73,977	7.19	122,927	11.94
Teak/Bamboo/plantations	20,896	2.03	21,937	2.13	38,588	3.75	67,111	6.52
Coconut/Areca nut/Cashew nut plantations	29,675	2.88	32,227	3.13	43,623	4.24	53,993	5.25
Dry deciduous forest	29,113	2.83	13,848	1.35	8374	0.81	9873	0.96
Total	1,029,086							
Overall accuracy (%)	84.29		92.22		90.71		91.51	
Kappa	0.81		0.89		0.87		0.89	

forest categories include moist deciduous, evergreen to semi evergreen, scrub/grass and dry deciduous forest types. Category-wise forest cover is extracted and depicted in Fig. 6a-d, which helped in assessing the impacts of unplanned developmental activities. Figure 6a illustrates the natural forest cover in 1979 (represented in green color) while Fig. 6d shows forest cover in 2013. Table 3 provides the spatial extent of forest cover loss during 1979 to 2013. The natural forest cover of 780,778 ha in 1979 was reduced to 733,692 ha by 1989 due to a large scale hydro-electric project at Supa, as well as by the conversion of native forests to monoculture plantations for forest based industries and cultivation. The forest changes during this ten year period was moderate, i.e., a 6.03 % reduction, whereas rapid losses were taken place during the period from 1989 to 1999 (forest cover 63.93 %) due to implementation of a large number of infrastructure projects, a series of hydroelectric projects, the construction of the Tattihalla and Bommanhalli reservoirs and other associated developments. The major disturbances noted in the forests of rural areas are due to unauthorized conversion of forest land into agriculture (encroachments), the diversion of forest lands for other purposes and logging of wood by forest based industries. Diversion of forestland under various schemes accounted for the loss of 66,443 ha (KFD 2010). The current area of forest cover is 542,475 ha (52.71 %) and forest losses amounted to about 35,021 ha (17.54 %) due to unauthorized land conversions and implementation of projects such as the Kodasalli reservoir, the Kadra dam, the Kaiga Nuclear Power plant, the Project Sea Bird, the Gerusoppa dam and others.

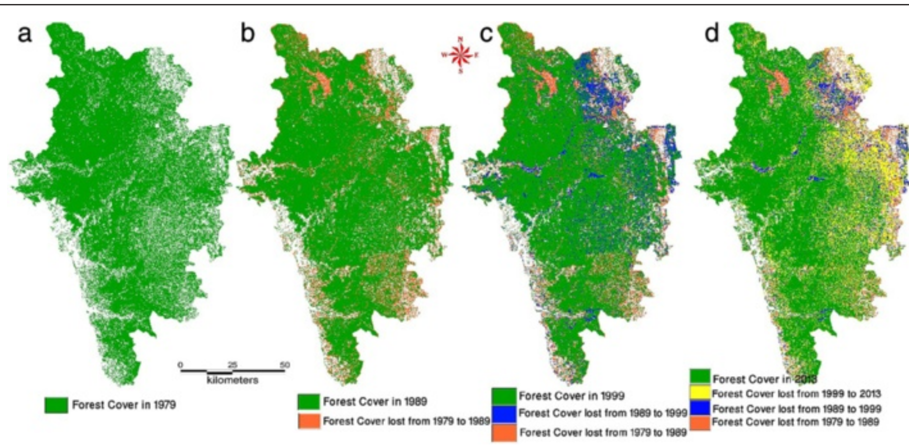

Fig. 6 (**a**, **b**): Forest cover in 1979, 1989 and its change; (**c**, **d**): Forest cover in 1999, 2013 and its change

Table 3 Forest cover change from 1979 to 2013

Year	Natural forest cover		Forest loss	
	ha	%	ha	%
1979	780,778	75.87		
1989	733,692	71.3	47,086	6.03
1999	657,877	63.93	75,815	10.33
2013	542,475	52.71	115,402	17.54
Total area (ha)	1,029,086			

Fragmentation of forests at the landscape level was assessed in order to understand the spatial-temporal patterns in forest degradation using temporal land use (1979 to 2013) information. Figures 7a, b, c, d and 8 depict the temporal pattern of the fragmentation process in Uttara Kannada District. Table 4 lists the spatial extent of various types of fragments (interior, perforated, edge, transitional and patch forests). Figure 7a depicts the domination of interior forests (64.42 %) in the district. Edge forests (7.32 %) are located along linear corridors, such as roads, rivers and boundary pixels of large forest patches. Patch forests are mainly located at the interfaces of forests, intermixed with agriculture and urban classes over small portions. The unscientific forest exploitation by the industrial sector peaked with the impetus of forest based industries during the period from 1960 to the 1980's leading to selective felling of trees in the evergreen forests (Gadgil and Chandran 1989). This has created canopy gaps and the spread of invasive exotic species, adversely affecting faunal species. Mining activities in the district leave significant ecological, economic and social footprints much beyond the physical boundaries of mines by disrupting continuous forest patches (Ramachandra et al. 2014b).

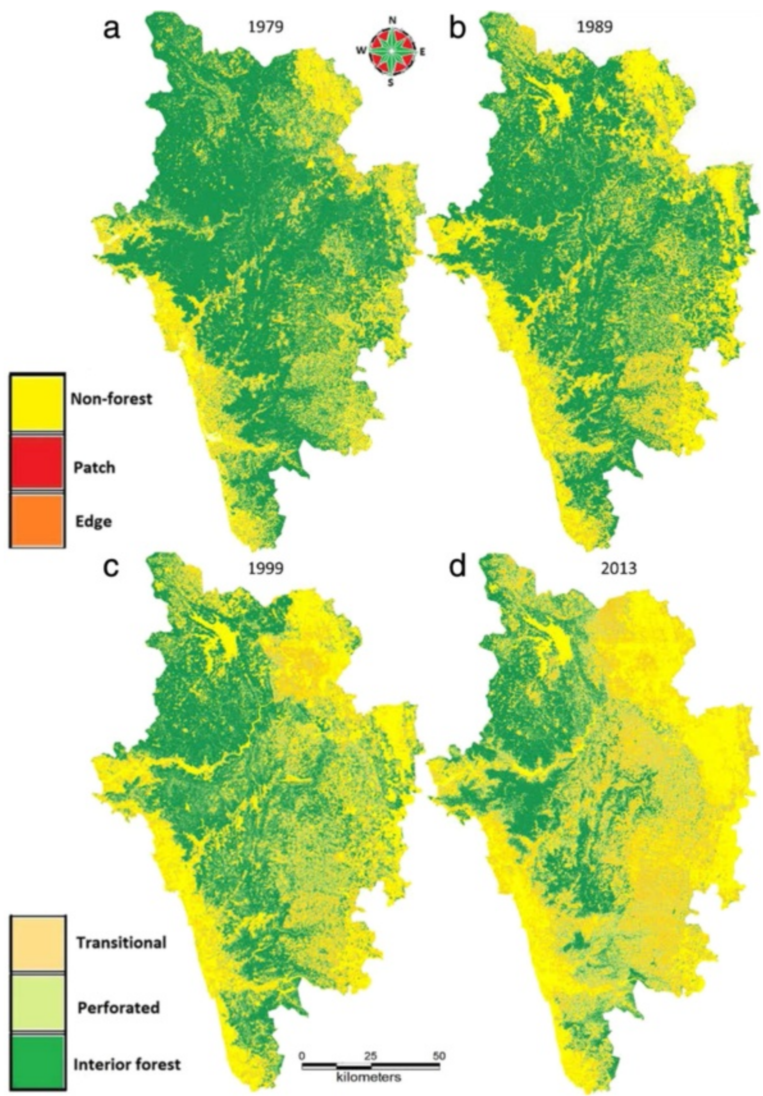

Fig. 7 (**a**, **b**, **c**, **d**): forest fragmentation at landscape from 1979 to 2013

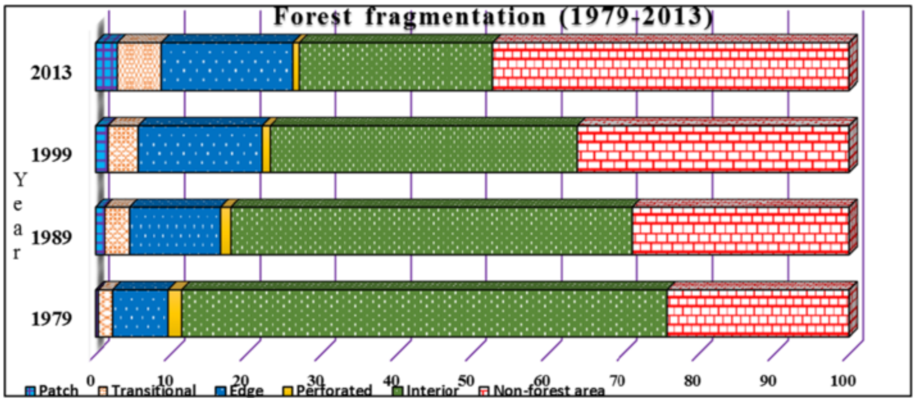

Fig. 8 Spatio temporal Pattern of fragmentation from 1979 to 2013 at landscape level

Figure 7b shows a decline in the area of interior forests from 64.42 % (1979) to 53.33 % (1989), with increase in edge forests (12 %). The major activities during this period were industrialization, infrastructure development, intensified agriculture, manganese mining, a ferromanganese plant, a paper mill and plantations. The provision of forest resources to industries at highly subsidized rates and permission to polluting industries in the ecologically sensitive regions have contributed to the decline of forests and contamination of natural resources. Unplanned developmental activities such as a series of large scale power projects, manganese mining, a ferromanganese plant, a paper mill and several irrigation projects have led to the retreat of forests, with their degradation evident in the form of barren hilltops. The mismanagement of Kans ('sacred forests' protected by local communities) and reserve forests also aggravated the situation towards the loss of interior, contiguous forests (Chandran 1989). Figure 7c shows the fragmentation status for the year 1999; the region lost a major portion of its interior forest and reached 40.74 % from 53.33 % (1989) with the increase in edge forests to 16.35 %. Drivers of these changes are the implementation of a series of hydroelectric projects, the construction of national routes NH-17, NH-63, NH-204, the Konkan railway line and other infrastructure projects. Figure 7d illustrates the status of forests (in 2013) with 25.62 % interior forests and 17.48 % of edge forests, as well as the loss of connectivity between interior forest patches. These interior forests exist now only in the form of protected areas - sanctuaries, protected areas, sacred groves or Kans. The area under non-forests has increased from 36.07 (1999) to 47.3 % (2013) with an increase of edge and perforated patches.

PCA aided in prioritizing bio-geophysical and socio-economic variables and explained the variation in spatial forest cover. Components PC1 and PC2 (for 1979 data) explain a large proportion of the variation (79.67 %) (Tables 5 and 6). Axis 1 represents the greater loading of variables such as evergreen to semi evergreen forest, dry deciduous forest, moist deciduous forest, slope, rainfall, and scrub/grass land. Axis 2 represents elevation, population density and other physical factors indicating that Supa, Siddapur and Ankola taluks with greater slopes had higher forest cover. Elevation as a variable had a partial effect on scrub/grass, while moist deciduous forest types in the Sirsi and Yellapura taluks formed clusters. Coastal taluks

Table 4 Temporal changes in forest fragmentation at landscape level from 1979 to 2013

Fragment type	1979		1989		1999		2013	
	ha	%	ha	%	ha	%	ha	%
Patch	3711.73	0.36	13368.35	1.30	18043.33	1.75	30,618	2.98
Transitional	20369.03	1.98	33833.24	3.29	40884.58	3.97	59,435	5.78
Edge	75281.05	7.32	123490.4	12.00	168266.32	16.35	179,870	17.48
Perforated	18517.00	1.80	14150.94	1.38	11434.67	1.11	8909	0.87
Interior	662909.2	64.42	548849.8	53.33	419248.5	40.74	263,643	25.62
Non-forest area	248297.99	24.13	295393.27	28.7	371208.6	36.07	486,611	47.3
Total area	1,029,086							

Table 5 Component loadings & variance for the year 1979

PC	Eigenvalue	% variance	Cumulative variance (%)
1	4.63	57.90	57.90
2	1.74	21.77	79.67
3	0.65	8.10	87.77
4	0.45	5.67	93.44
5	0.28	3.48	96.91
6	0.22	2.79	99.71
7	0.02	0.21	99.91
8	0.01	0.09	100.00

(Karwar, Kumta, Honnavar) suggest the effect of the variables slope and rainfall. Mundgod represents the effect of dry a deciduous and moist deciduous cover Fig. 9.

Together, PC1, PC2 and PC3 (based on 2013 data) explain a large proportion of the variation (88.04 %) presented in Tables 7 and 8. Axis 1 indicates the higher loadings of the variables evergreen, rainfall, slope, scrub/grass and dry deciduous forests. Axis 2 represents elevation, moist deciduous and population density. Supa and Ankola taluks have evergreen forests cover on slopes and edge effects are observed towards the periphery due to road network. Forest transitions in the Ankola, Kumta, Honnavar and Karwar (coastal) taluks have lost major forest cover towards the west side due to agriculture and aquaculture activities. The Bhatkal taluk has experienced loss of evergreen cover over the 1979 to 2013 period at its lower slopes due to intense activities of agriculture, plantations and other anthropogenic activities. Haliyal and Mundgod taluks have lost deciduous forest cover due to agricultural land expansions with the construction of reservoirs. Our analyses substantiate the role of geophysical variables in the changes of vegetation cover. However, further analyses are required in order to account for the nonlinear relationships among variables, since land transformations are often associated with nonlinear dimensions of human demand, government policies and socio-economic factors (Gong et al. 2011) Fig. 10.

Discussion

Forest clearing due to anthropogenic activities has been a major ecological problem (Laurance 1999; Etter et al. 2006), affecting biodiversity. Fragmentations of forests have resulted in habitat destruction and changes in the dispersal and migration processes (Armenteras et al. 2003; Etter et al. 2006; Eldegard et al. 2015). Shrinkages in animal habitat have led to inbreeding pressure, resulting in the extirpation of species, highlighting the intimate relationship between species and habitat. Edges contain communities different from interior forests due to an altered climate with higher light availability, loss of soil moisture, increased incursion of predators and competitors. As a consequence of fragmentation, changes in microclimatic near edges have favored the establishment of alien species such as *Lantana camara*, *Chromolaena odorata* and other species. This has caused a decline in the of native species, particularly in forests highly fragmented by transmission lines such as in the Haliyal and Mundgod taluks and at the lower slopes of Supa and Sirsi taluks. Forest patches shelter rare endemic species in human dominated landscapes. Studies have reported their role in pollination, maintenance of different life cycle phases of species, diversity and seed dispersal by harboring honey bees, small mammals, avifauna survival and many others (Bodin et al. 2006; Page et al. 2010). The Uttara Kannada District with relic forests (sacred forests/groves) and highly productive landscapes conserve local biodiversity and offer important ecological services, as well as improvement in the livelihood of local communities (Ray and Ramachandra 2010). These intact forests provide shelter for wild fauna and also benefit village communities with an array of forests goods and services such as hydrological functions, fuel wood and timber.

Forest fragmentation analyses provide vital insights to the potential effects of human disturbances (Hobbs and Yates 2003), through spatial descriptors of landscapes besides social and economic factors. The analysis of spatial patterns of forest changes should aid in formulating appropriate management strategies to conserve these

Table 6 Component variances for the year 1979

Variables	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8
Moist deciduous forest	−0.89	0.04	−0.19	−0.11	0.19	0.35	0.03	0.01
Evergreen to semi evergreen forest	0.93	0.27	−0.06	0.11	−0.17	0.08	0.06	0.05
Scrub/grass	−0.70	0.28	0.56	−0.33	−0.02	−0.06	0.02	0.02
Dry deciduous	−0.92	0.02	−0.29	0.12	0.10	−0.22	−0.03	0.05
Elevation	0.25	0.84	0.25	0.34	0.22	0.05	−0.03	0.00
Slope	0.88	−0.04	−0.10	−0.24	0.36	−0.15	0.04	0.00
Rainfall	0.87	−0.43	0.14	−0.13	0.07	0.14	−0.08	0.03
Population density	−0.24	−0.83	0.34	0.34	0.12	0.00	0.04	0.01

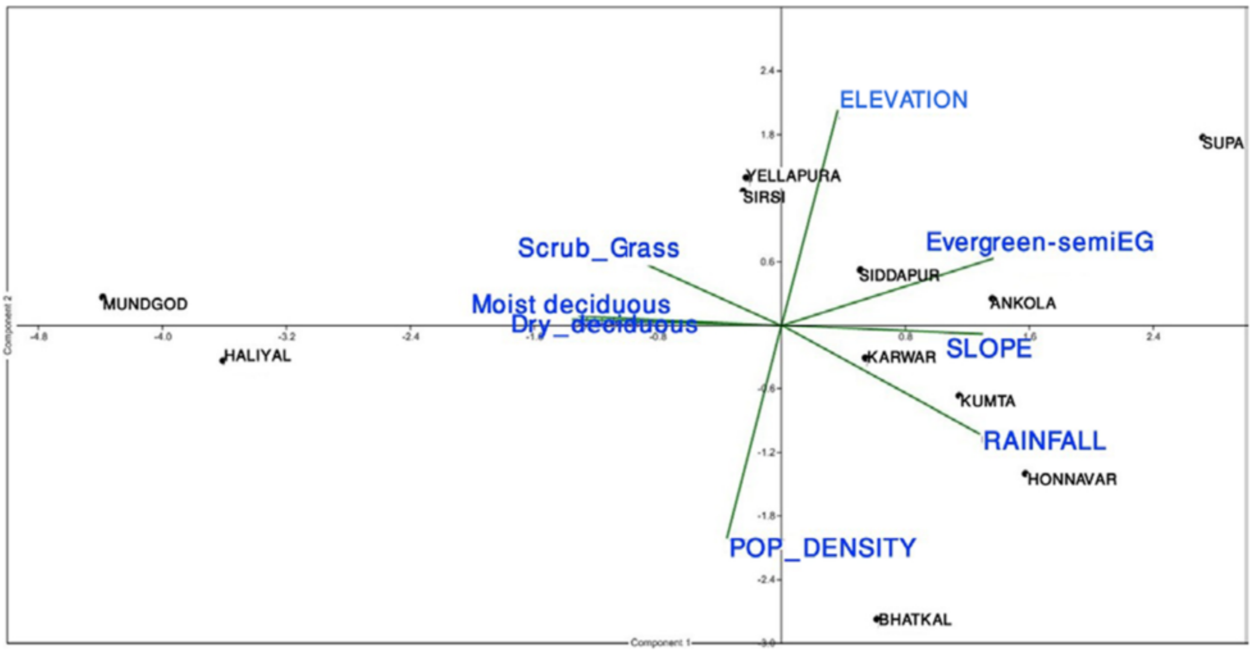

Fig. 9 Principle components analysis for 1979

threatened ecosystems. Analyses of forest changes are possible due to the availability of temporal remote sensing data. However, the spatial resolution of remote sensing data plays an important role in the analysis of spatial landscape patterns. Kernel sizes and resolution are intimately related in fragmentation analysis. Smaller kernel sizes have the effect of decreasing the average inter patch distance by considering smaller patches in the neighborhood, which also reduces the edge effect. Fragmentation analysis is also affected by up-scaling the resolution of remote sensing data as changes in spatial heterogeneity on a micro scale may not be detected using coarse spatial resolutions (Kitron et al. 2006). Bharath et al. (2012b) has elucidated the dependency of the role of spatial resolution on measuring landscape structures in order to understand the different landscape patterns. The results reveal that landscape metrics based on area or patch cover are sensitive to spatial resolution. Fragmentation indices are also explicit in sensitivity across various spatial resolutions of remote sensing data. Gupta et al. (2000) highlights the problem of upscaling data by comparing correlations among reflectance and areas of land use categories. Their results indicate the loss of land use information of about 40 % in proportion where upscaling was performed.

Table 7 Component loadings for the year 2013

PC	Eigenvalue	% variance	Cumulative variance (%)
1	3.748	46.852	46.85
2	2.159	26.991	73.84
3	1.135	14.193	88.04
4	0.572	7.149	95.19
5	0.255	3.192	98.38
6	0.094	1.178	99.55
7	0.024	0.299	99.85
8	0.012	0.145	100.00

Kernel sizes and resolution are intimately related in fragmentation analysis. The kernel or scale size can be consistent with respect to the pixel resolution and an increase of kernel size does not change the input data but increases the width of the non-interior classes, at the expense of interior forests, which maintain their overall proportion and the shapes of their features. Ostapowicz et al. (2008) explains the relationship between the resolution and kernel size by assessing and monitoring the structure of landscape patterns from multi-scale land-cover maps. Riitters et al. (2004) demonstrated the appropriateness of 5×5 kernel at a nominal resolution of 30 m. The scale effects on different forest composition and configuration were appraised by sensitivity analysis with various combinations of pixel size and kernel size parameters and comparing frequencies of pattern classes in the entire forest area under study.

Reforestation and afforestation practices have been helpful in partially addressing the negative consequences of forest loss, through carbon sequestration, erosion control and non-consumptive use of forest products. However, the introduction of exotic species would

Table 8 Component variances for the year 2013

Variables	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8
Moist deciduous forest	0.10	0.76	0.62	−0.08	−0.11	−0.06	0.03	0.06
Evergreen to semi evergreen forest	0.85	−0.01	−0.43	−0.05	0.23	−0.16	0.03	0.04
Scrub/grass	0.75	−0.40	0.14	−0.48	0.03	0.16	0.04	0.01
Dry deciduous forest	−0.92	−0.17	−0.28	0.11	0.08	0.12	0.00	0.07
Elevation	0.05	0.94	0.02	0.05	0.32	0.11	−0.01	−0.03
Slope	0.84	0.13	−0.16	0.46	−0.16	0.10	0.07	0.00
Rainfall	0.93	−0.22	0.20	0.18	0.02	0.04	−0.12	0.03
Population density	−0.17	−0.67	0.63	0.26	0.24	−0.02	0.04	−0.01

impact the native forest patches in the neighborhood (Shigesada and Kawasaki 1997; Ramachandra et al. 2013). The introduction of *Acacia auriculiformis*, *Tectona grandis* and other exotic species in the forested regions and grasslands of this district has appalling effects on biodiversity due to habitat destruction, decline in water resources and unavailability of food especially for grazing mammals, which in turn has affected the prey stock of wild carnivores (Rao et al. 2012). Many commercial plantations have come up in the valleys by removing the natural vegetation, even in places with ecologically important ecosystems such as the Myristica swamps (Chandran and Mesta 2001). In this context, the current conservation strategy needs to focus on the local regeneration of natural forests and maintain continuity of forests, which helps in sustaining the livelihood of dependent populations. This requires motivation, conviction and commitment among major stakeholders, i.e., the forest fringe dwellers as well as forest officials. Restoration of forests with native species at watershed levels will help in mitigating the impact of forest fragmentations and improve hydrological services and biodiversity. The existing village grazing lands needs to be demarcated and managed by involving local stakeholders. This would help in mitigating grazing impacts in natural forests and also improves the prospects of forest regeneration. Prohibition of clear felling in the intact primeval forests would aid in preserving the structure of this ecosystem while enhancing its functional aspects. Joint management of forests by involving all stakeholders - local communities and others, would help in curtailing illegal logging, encroachments, wildlife protection and sustainable management of forests.

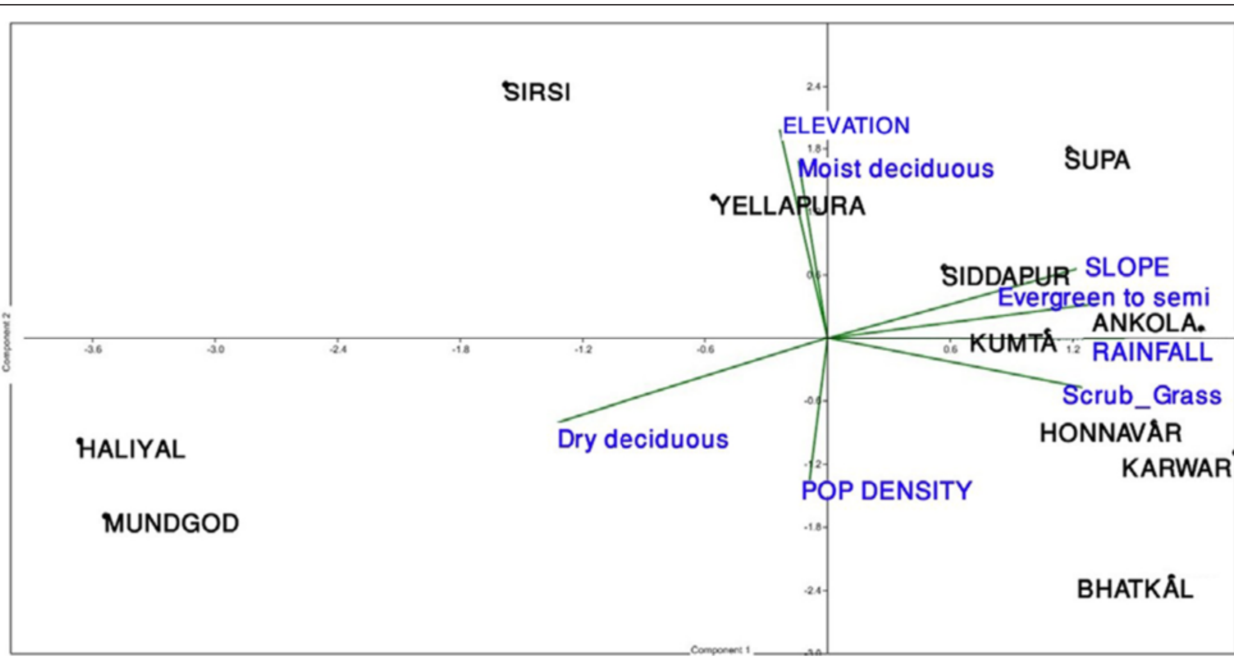

Fig. 10 Principle components analysis for 2013

Conclusions

The Western Ghats, the repository of diverse biological organisms is one among 35 global hotspots of biodiversity. This region has been experiencing large-scale land cover changes with the fragmentation of primeval forests. Current research is attempting to quantify spatial-temporal patterns of land use dynamics and fragmentation of forests using temporal remote sensing data. The analyses would be useful in evolving appropriate forest management strategies to mitigate impacts of adverse land use dynamics. Temporal land use analyses show a decrease in the evergreen forest cover from 57.31 % (1979) to 32.08 % (2013). Forest fragmentation analysis based on remote sensing data of the 1979–2013 period helped in assessing the spatial patterns of forests changes under patch, transitional, edge, perforated and interior cover. The study region, as an ecologically fragile area, is now left with only 25.62 % of interior forests and the spatial extent of non-forests is 47.3 % (2013), which highlights the need to restore forests. The district has 18.5 % of its area under monoculture plantations in the Haliyal and Mundgod taluks. Conservation planning of forest ecosystems needs to be holistic at watershed levels involving all stakeholders. Restoration of forests with native species would enhance hydrological services and biodiversity. By active participation in forest restoration initiatives and micro-level planning, stakeholders of the Western Ghats are likely to gain as promoters and guardians of biodiversity and hydrology. Rendering such service would help in mitigating global climatic change and serve the cause of forest ecosystems in global biodiversity hotspots.

Competing interests
The authors declare that they have no competing interests.

Authors' contribution
All authors read and approved the final manuscript. BS carried our remote sensing data analysis, MDS participated in the discussion and field investigations and TVR worked on the manuscript, data interpretation and language editing.

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