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Assessment of Forest Dynamics in Chikkamagalur District, Central Western Ghats using Temporal Remote Sensing Data and Spatial Metrics

Forests in the ecologically fragile Western Ghats are undergoing changes in its structure and composition due to irrational policy decisions and mounting human pressure on forest services. Land-use changes in any form potentially result in fragmentation. The extent of the impact will depend on the type of change, the degree of fragmentation, and has effect in terms of patch size, patch shape, connectivity and isolation. This study investigates the spatial patterns of landscape fragmentation dynamics considering temporal data acquired through space borne sensors. Results revealed that forest vegetation has declined from 50.74% (1976) to 36.33% (2009) due to conversion of forests to agriculture, industrial and developmental activities. Encroachment of forest land (22055.59 ha) and conversion to agricultural land is the principal cause of degradation at local level apart from land releases for major developmental activities. Forest fragmentation analysis through spatial metrics shows decline in the interior forest and domination of isolated patches. This study illustrates importance of understanding spatiotemporal patterns of land use changes for sustainable management of tropical forests and help in formulating appropriate conservation measures for the region rich in forest resources.

Key words: Western Ghats, Chikkamagalur, LULC, Forest Dynamics, Forest Fragmentation, Landscape structure.

Investigation of the spatial patterns of land cover dynamics considering temporal data acquired through space borne sensors, reveal that forest vegetation has declined from 50.74% (1976) to 36.33% (2009) with the decline of contiguous interior forests and domination of edge and patch forests in Chikkamagalur district, Central Western Ghats.

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Introduction

The Western Ghats bioregion is rich with flora and fauna and is considered as one among the 36 biodiversity hotspots (also one among the eight hottest hotspots of biodiversity) of the world (http://www.conservation.org). The region with a wide range of forest types ranging from tropical wet evergreen forests to grasslands is a repository of rich flora and fauna (Daniels, 2003; Sreekantha *et al.*, 2007; Gururaja, 2004) evident from the occurrence of over 4,000 species of flowering plants (38% endemics), 330 butterflies (11% endemics), 156 reptiles (62% endemics), 508 birds (4% endemics), 120 mammals (12% endemics), 289fishes (41% endemics) and 135 amphibians (75% endemics). The forests of Western Ghats, in view of their floristic diversity and numerous multipurpose species, areconsidered a repository of economically important plants. Due to unplanned developmental activities, large blocks of contiguous native forests are being reduced to remnant patches of secondary habitats, affecting the ecology, hydrology and biodiversity. The impacts of these human induced changes are evident from extinction of species and increased population of exotic/invasive species (Daniels, 2003). Vast stretches of barren lands, barren hill tops, reduced water infiltration and water retention capability of the catchment has led to the conversion of perennial streams to intermittent streams and lowering of water table. Implications of the changes in ecosystem structure, function, and distribution, due to global climatic changes and land-use practices have raised serious concerns and also brought a paradigm shift in the approach towards ecosystem from human versus ecosystem to human and ecosystem along with the concept of 'sustainable development' in conservation and management of natural resources. Last few decades, have seen increased awareness on the need for conservation and sustainable use of the natural resources of Western Ghats (Chandran, 1998). Ban on timber extraction in 1988 from natural forests has kindled the hope of biological revival of the Western Ghats forests.

Landscape dynamics

Landscape refers to the heterogeneous land features composed of sets of interacting ecosystems and is characterized essentially by its dynamics that are partly governed by human activities (Ramachandra *et al.,* 2012). Human induced land cover and land use changes are considered as one of the pervasive sources of alteration on Earth's surface (Houet and Verburg, 2010). Consequences of land use changes such as forest fragmentation poses a serious threat to the ecological sustainability of a landscape (Ramachandra and Uttam Kumar, 2011).

Forest fragmentation is a process of isolation of forest patches which results in change of composition, structure, extent and spatial patterns through human induced activities (Roy *et al.,* 2002). Fragmentation implies division of landscape into smaller parts which results in uneven separation, size and dis-connectivity between population and similar ecosystems (Forman, 1995; Griffiths *et al.,* 2000). Fragmentations of landscape have been quantified by changes in spatial characteristics and configuration of remaining patches (Saunders *et al.*, 1987). Various ecological effects of forest fragmentations are loss of species populations, increased isolation of remnant populations, inbreeding (Laurance *et al.,* 1998; Boyle, 2001), enhanced human-animal conflicts, decline in ecosystem goods and services, etc. This necessitates understanding of the causes of forest and habitat fragmentations, in order to evolve effective management strategies for conservation.

Remote sensing (RS) data acquired through space borne sensors available since 70's at regular intervals can be used as one of the major tools to understand LULC dynamics and quantify the extent of forest fragmentation (Gustafson, 1998; Turner and Gardner, 1991; Jha *et al.,* 2005). Land use details derived from temporal RS data offer potential for assessing the changes in land uses, forest fragmentation and its impact on ecology and biodiversity (Ramachandra *et al.,* 2009). Categorization and understanding of forest fragmentation using spatial data (RS data) provides a picture of the degree and extent of fragmentation, which are useful for conservation of the affected habitat fragments (O'Neill *et al.,* 1997). Numerous measures of forest fragmentation and forest connectivity using spatial data include average forest patch size, mean forest patch density, number of forest patches, forest patchiness, forest continuity, and proportion of forest in the largest forest patch (Vogelmann, 1995; Wickham *et al.*, 1999). Quantification of Pf and Pff has effectively helped in assessing the process of fragmentation (Ramachandra *et al.,* 2009). This communication assesses the LULC dynamics in Chikkamagalur and examines the extent of forest fragmentation in Chikkamagalur landscape. The objectives of current study are:

i. To assess the present status of forests of Chikkamagalur;

ii. Land use and land cover [LULC] dynamics in the district considering temporal remote sensing data; and

iii. Assessment of the extent of fragmentation of forests and its impact on the ecosystem

Material and Method

Study area

Chikkamagalur district is situated in the south-western part of Karnataka state. District has large hilly regions that are forested with heavy rainfall. District is situated between 12°54'42" and 13°53'53" north latitude and between 75°04'46" and 76°21'50" east longitude (Fig. 1), bounded on the east by the Tumkur district, on the south by the Hassan district, on the west by the Western Ghats which separate it from the Dakshina Kannada district, on the north east by the Chitradurga district and on the north by the Shimoga district (Chikkamagalur District, 2018 - http://www.chickmagalur.nic.in/). Population in 2001 was 1.14 million with a population density of 158 persons per km^2 and current population in the district is 1.13 million, and there has been a decrease of 0.28% during the last decade (Census of India, 2011 - http://censusindia.gov.in). Large parts of Chikmagalur district are mountainous. The highest point in the district is Mullaiyanagiri at 1926 m amsl) (Karnataka State Gazetteer, Chikkamagalur District, 1981; http://gazateer.kar.nic.in). The principal rivers of the district are the twin streams - Tunga and Bhadra. Fig. 2 shows the location of major rivers in the district. This is the wettest district in the state having an annual average rainfall of 1772 mm. Mean Annual distribution of Rainfall in the district is as shown in Fig. 3.

Forests of Chikkamagalur district consists of evergreen and semi-evergreen climax forests and their degradation types and deciduous climax forests and their degradation types (Pascal, 1988). The evergreen and semi-evergreen climax forests and degradation type consists following categories: *Dipterocarpus indicus - Humboldia brunonis –Poeciloneuron indicum* type *Dipterocarpus indicus – Diospyrus candolleana -*

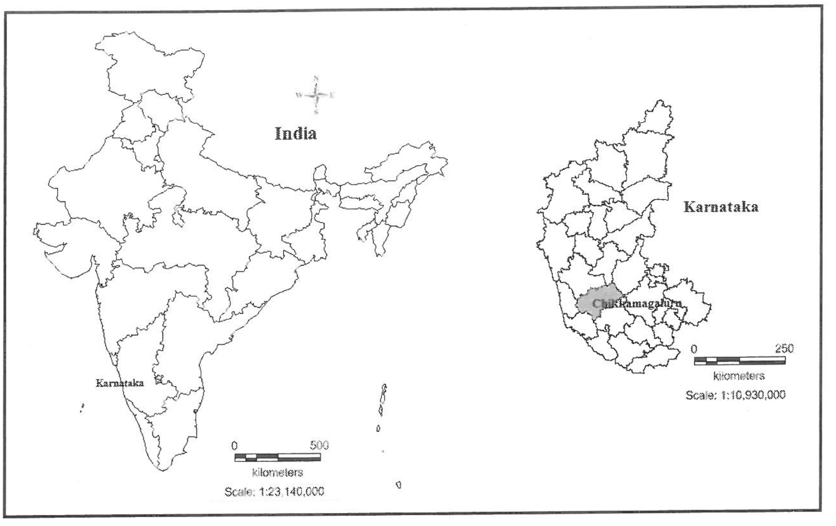

Fig. 1: Study region - Chikkamagalur district, Karnataka State, India.

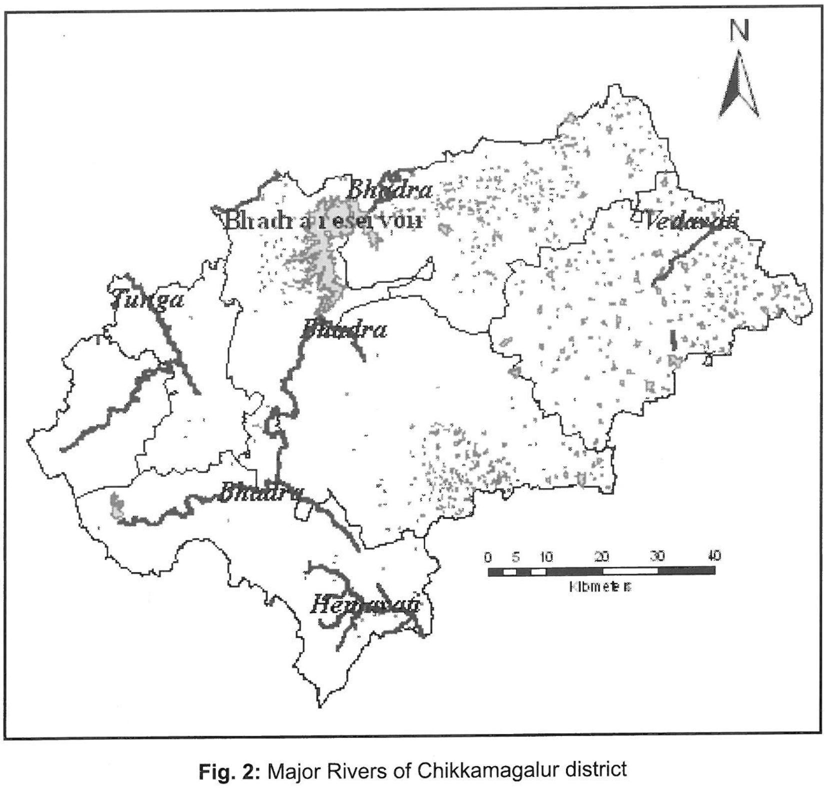

Fig. 2: Major Rivers of Chikkamagalur district

Diospyros oocarpa type, *Dipterocarpus indicus* - *Persea macrantha* type, *Persea macrantha* - *Diospyros* spp.- *Holigarna* spp. type, *Diospyros* spp.- *Dysoxylum malabaricum* - *Persea macrantha* Kan forest type of low elevation (0-850m) *Mesuaferrea* - *Palaquium ellipticum* type, *Palaquium ellipticum* - *Poeciloneuron indicum* - *Hopea canarensis* type of medium elevation (800-1400 m) and *Schefflera* spp. - *Gordonia obtuse* - *Meliosma arnottiana* type. The secondary or degraded type contains secondary Evergreen, Semi-evergreen and moist deciduous forests. Deciduous climax forests consist of moist deciduous type – *Lagerstoemia microcarpa* -*Tectona grandis* - *Dillenia pentagyne* type and dry deciduous - *Anogeissus latifolia* – *Tectona grandis* - *Terminalia tomentosa* type. The vegetation broadly falls into 4 types i). Dry deciduous hill type ii). Moist deciduous type, iii) the Evergreen type and iv). The Sholas and Grassland type (Fig. 4)

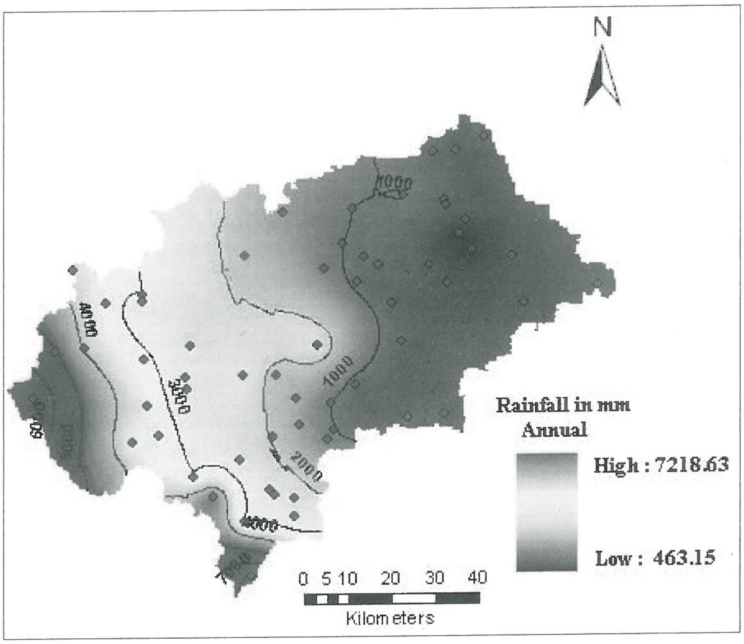

Fig. 3: Mean Annual rainfall distribution from 1901-2010 for Chikkamagalur district

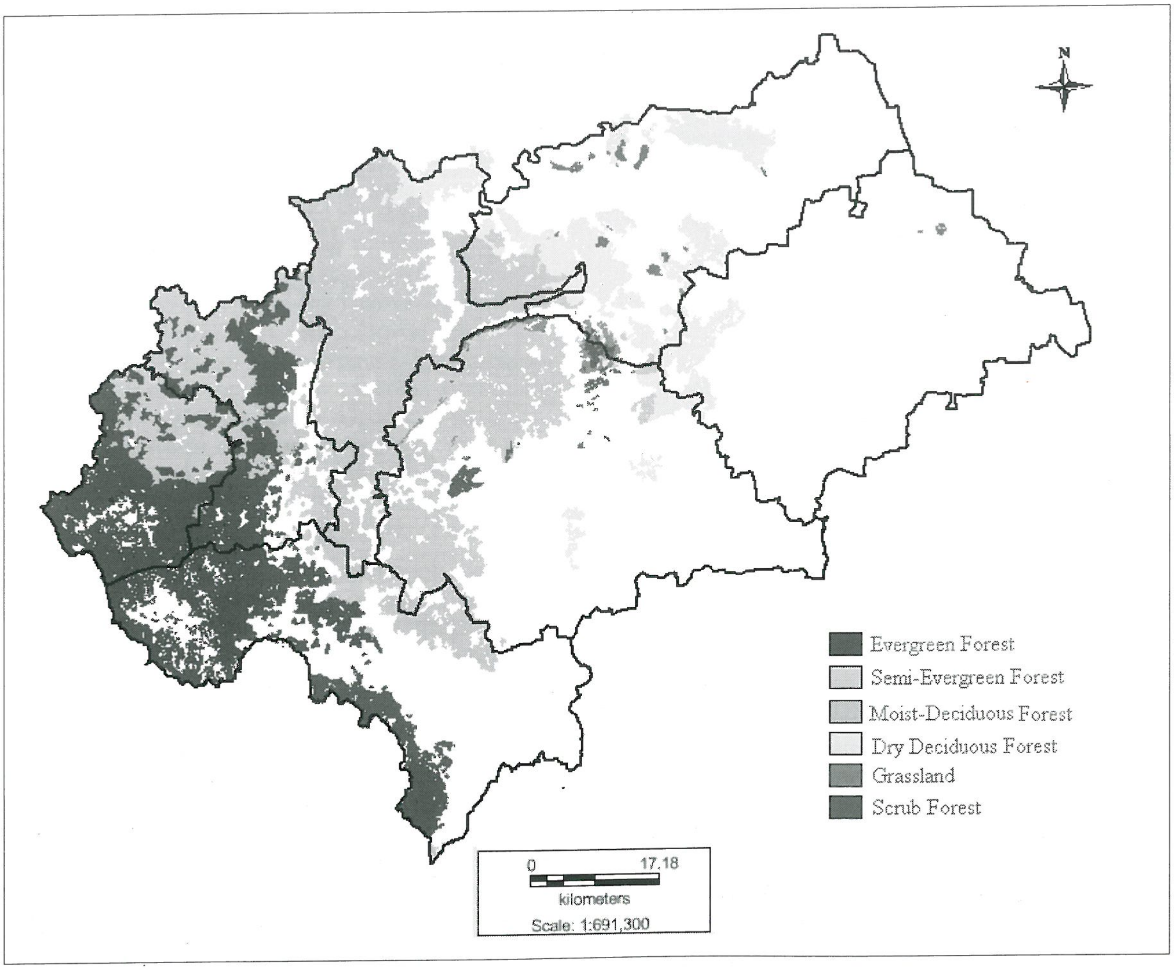

Fig. 4: Vegetation distribution (classification as per Champion and Seth, 1968).

Materials

The satellite data of Landsat series Multispectral sensor, thematic mapper and IRS LISS III sensors for four-decade period (1976 to 2009) were acquired from Global Land Cover Facility (GLCF), (United States Geological Survey (USGS)-Earth Explorer, GLOVIS and Bhuvan website as listed in Table 1.

Method

Assessment of landscape dynamics involved (i) temporal analysis of land cover and land use using remote sensing data, (ii) quantification of natural forests, (iii) assessment of extent of forest fragmentation (due to encroachment and subsequent changes in land uses). The procedure followed to assess landscape dynamics is outlined in Figure 5. Spatio-temporal changes of land cover and land use (LULC) were studied using temporal remote sensing data with geospatial techniques. The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using GPS and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. Ground control points (GCP's) were collected from the Survey of India (SOI) topographic maps as well as from field using hand held pre-calibrated GPS. This helped in geometrically correcting the distorted remote sensing data. Landsat satellite 1976 data have a spatial resolution of 57.5 X 57.5 m (nominal resolution) were resampled to 28.5 m comparable to the 1991-2009 data which are 28.5 X 28.5 m (nominal resolution).

Land cover analysis

Normalized Difference Vegetation Index (NDVI) was used to calculate the land cover types. The vegetation change analysis for multi-temporal data can be done using NDVI (Ramachandra *et al.*, 2009; Ramachandra and Uttam Kumar, 2011). NDVI is calculated using Near Infrared and Red Bands data using equation (1),

$$NDVI = \frac{NIR - IR}{NIR + IR} \quad ...1$$

Table1: Details of the data used in the analysis.

Data and source	Resolution	Purpose
Landsat Series Multispectral sensor	57.5m	Land cover, Land use analysis and Fragmentation analysis
Landsat Series Thematic mapper http://landsat.gsfc.nasa.gov	28.5m	
IRS LISS III http://nrsc.gov.in	23.5m	
Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales http://surveyofindia.gov.in		Generate boundary and Base layer maps
Field visit data -captured using pre-calibrated GPS		Geo-correcting and generating validation dataset
Google earth and Bhuvan http://bhuvan.nrsc.gov.in		For digitizing various attribute data and as validation input

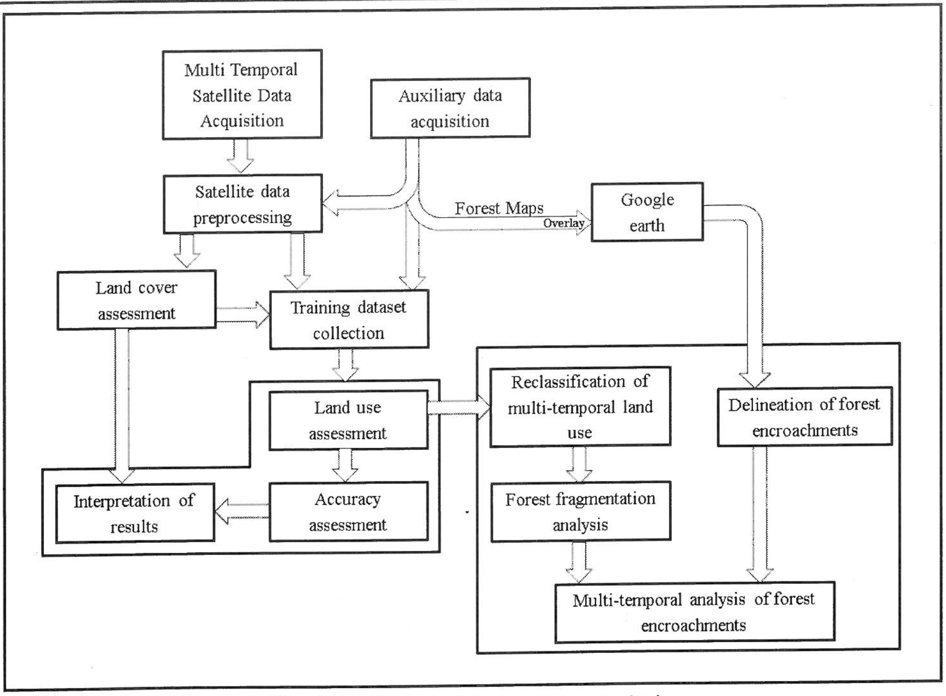

Fig. 5: Method used for Land use analysis.

NDVI values ranges from -1 to 1. The negative value indicates the non-vegetation and presence of built-up, water, sand etc. The increasing value from 0 indicates the presence of vegetation.

Land use analysis

Land use analysis was done for four-decade satellite data. The procedure involved (i) generation of False color composite (FCC) of the datasets using bands green, red and near infrared, mainly used in the identification of heterogeneous patches in the landscape, (ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, iv) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, v) supplementing this information with Google Earth vi) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.The land use analysis was carried out with training data using supervised classification technique based on Gaussian Maximum Likelihood algorithm. The supervised classification approach preserves the basic land use characteristics through statistical classification techniques using a number of well-distributed training pixels. Gaussian Maximum Likelihood classifier (GMLC) is appropriate and efficient technique based on "ground truth" information for classifier learning. Supervised training areas are located in regions of homogeneous cover type. All spectral classes in the scene are represented in the various subareas and then clustered independently to determine their identity. The following classes of land use were examined: built-up, water, cropland, open space or barren land, and forest. Such quantitative assessments, will lead to a deeper and more robust understanding of land-use changes for an appropriate policy intervention. *GRASS GIS (Geographical Analysis Support System)*, a free and open source software having the robust support for processing both vector and raster files is used for the analysis. Accuracy assessment of classified data has been done through the computation of kappa (κ) statistics and producer's and user's accuracies

Fragmentation analysis: Forest fragmentation analysis was performed to quantify the type of forest in the study area- patch, transitional, edge, perforated and interior based on the classified images of Chikkamagalur district. Forest fragmentation statistics and the total extent of forest (Pf) and its occurrence as adjacent pixels (Pff) is computed through fixed-area window (3x3) considering central pixel and its surrounding pixels (Ritters *et al.,* 2000, Ramachandra and Uttam Kumar, 2011, Ramachandra *et al.,* 2009; 2016). The result is stored at the location of the central pixel. Thus, a pixel value in the derived map refers to between-pixel fragmentation around the corresponding forest location. Forest fragmentation category at pixel level is computed through Pf (the ratio of pixels that are forested to the total non-water pixels in the window) and Pff (the proportion of all adjacent (cardinal directions only) pixel pairs that include at least one forest pixel, for which both pixels are forested). Pff estimates the conditional probability that given a pixel of forest, its neighbor is also forest. Based on the knowledge of Pf and Pff, six fragmentation categories derived (Fig. 6) are (i) interior, when Pf= 1.0; (ii) Patch, when Pf < 0.4; (iii) transitional, when 0.4 < Pf < 0.6; (iv) edge, when Pf > 0.6 and Pf – Pff> 0; (v) perforated, when Pf > 0.6 and Pf – Pff< 0, and (vi) undetermined, when Pf > 0.6 and Pf = Pff.

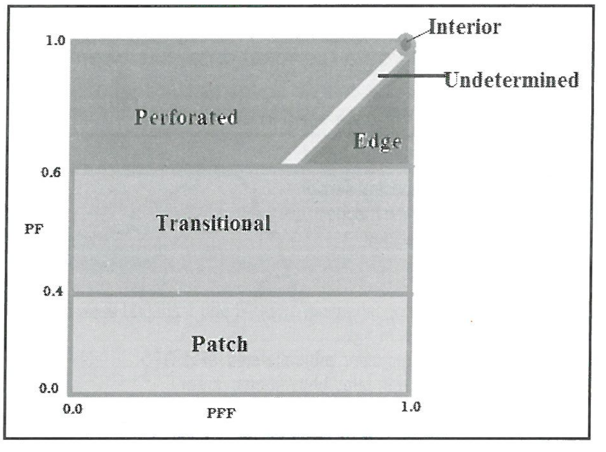

Fig. 6: Forest Fragmentation using PF and PFF (Source: Ramachandra *et al.*, 2016).

Results

Land cover analysis

Land cover analysis through NDVI shows the percentage of area under vegetation and non-vegetation. NDVI is based on the principle of spectral difference based on strong vegetation absorbance in the red and strong reflectance in the near-infrared part of the spectrum. Fig. 7 and Table 2 illustrates the spatio-temporal changes in the land cover of the region, which highlight the decline of vegetation cover from 96.62 (1976) to 93.6% (2009).

Table 2: Extent of vegetation cover during 1976, 1990, 2002 and 2009

	Land cover (%)	
	Vegetation	Non-vegetation
1976	96.62	3.38
1991	94.43	5.57
2000	94.28	5.72
2009	93.60	6.40

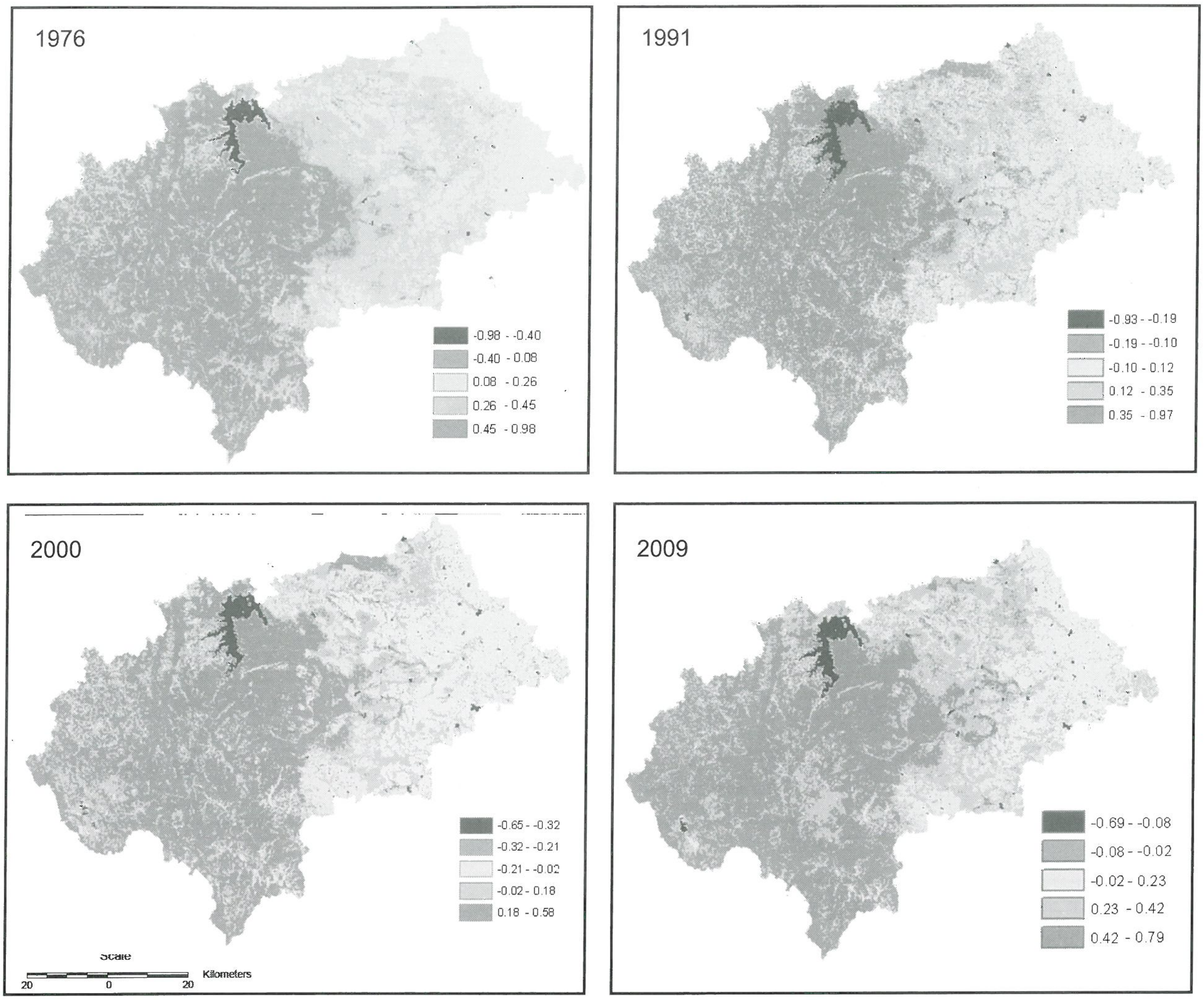

Fig. 7: NDVI reflecting vegetation dynamics in Chikkamagalur.

Land use analysis: The changes in the land uses at landscape level during 1976 to 2009 are highlighted in the Figure 8 and Table 3. This shows the decline of forests from 50.74% (1976) to 36.33% (2009). Table 4 lists category wise land uses in percentage and Table 5 provides the accuracy assessment details.

Fragmentation analysis

Land use data (classified data with 4 classes) were used as input to the fragmentation analysis and the analysis was done at district, division and taluk levels. Figure 9 illustrates the extent of forest fragmentation while Table 6 provides the summary statistics. Applying forest fragmentation analysis to a time series of land use data provided quantitative assessment of the spatial pattern and trends in forest fragmentation. The analysis indicated that domination of forests receded during 90's with the formation of patch and edge forest in all 5 divisions.

Forests in Chikkamagalur district are administered through five divisions – Chikkamagalur, Koppa, Bhadravathi, Kudremukh National park and Bhadra Wildlife Sanctuary. The quantification of extent of forest fragmentation has been done division-wise for the past four decades to enable the respective division administration to undertake appropriate forest restoration measures to minimize fragmentation of ecologically important ecosystems. Land use changes from forests to non-forests with intensified human interference had been very high especially in Bhadravathi, Chikkamagalur division. Interior forest decreased by 94.48 (1976) to 74.4 (2009). In Bhadravathi division interior forest decreased by 52.54 (1976) to 34.31 (2009) and patch increased by 5.73 (1976) to 13.52 (2009). Chikkamagalur division interior forest was about of 39.68 in 1976 which was

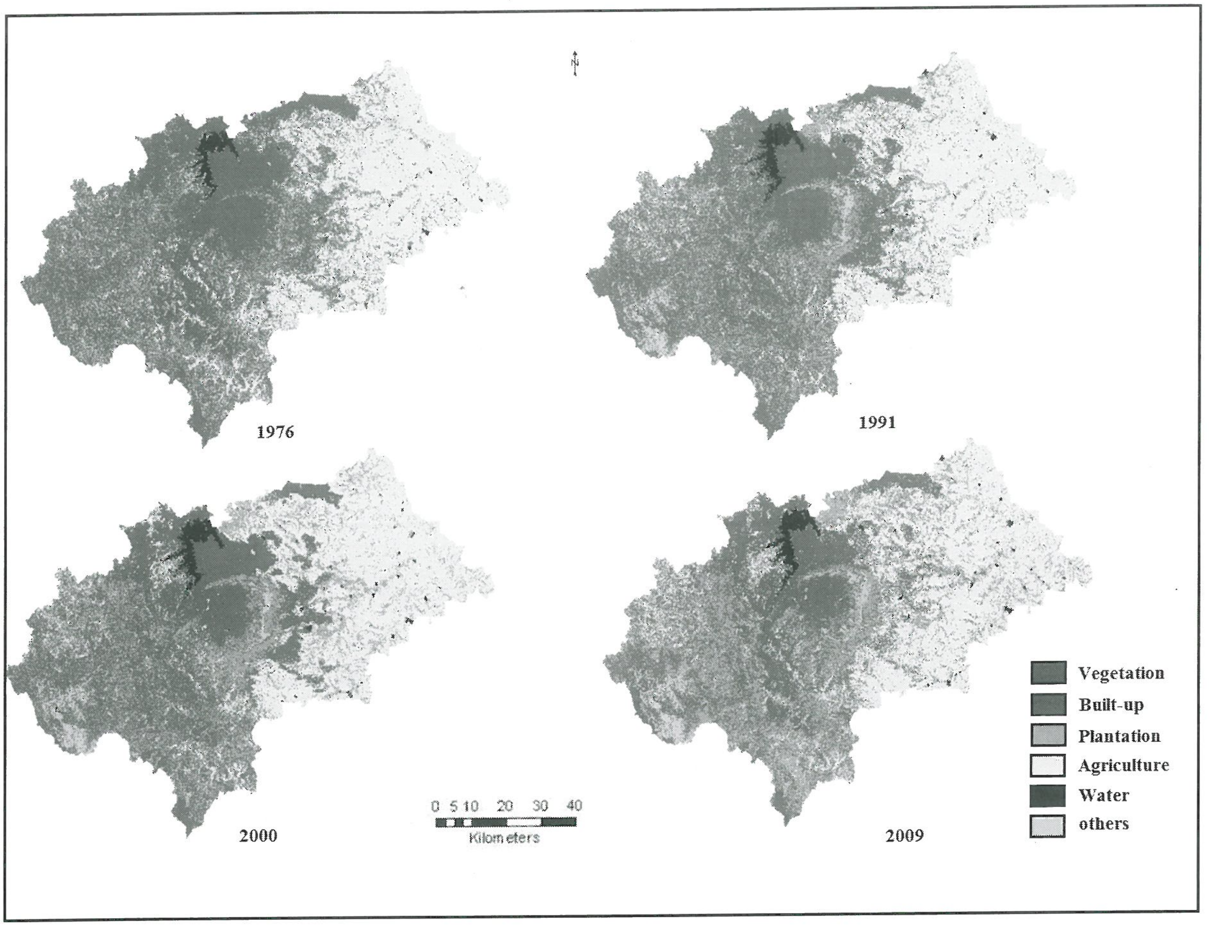

Fig. 8: Land use dynamics in Chikkamagalur district.

Table 3: Land use statistics in Hectares

	Land use categories (Ha)					
Years	**Forest**	**Urban**	**Plantation**	**Agriculture**	**Water bodies**	**Others**
1976	365,541.08	365.88	89,105.83	243,307.46	8781.52	14,894.00
1991	344,445.96	1228.60	102,724.69	231,948.04	12,534.45	26,889.70
2000	299,549.97	1548.91	150,583.68	228,137.15	14,240.50	25,790.61
2009	261,520.87	1783.18	171,558.74	238,985.04	13,339.59	32,486.38

Table 4: Land use statistics in Hectares

	Land use categories (percentage)					
Years	**Forest**	**Urban**	**Plantation**	**Agriculture**	**Water bodies**	**Others**
1976	50.74	0.05	12.35	33.61	1.21	2.06
1991	47.85	0.17	14.27	32.23	1.74	3.74
2000	41.61	0.21	20.09	31.69	1.98	3.58
2009	36.33	0.25	23.84	33.20	1.85	4.51

decreased to 23.75 in 2009. Interior forest in Koppa decreased by 52.82 (1976) to 32.27 (2009) and in Kudremukh interior forest decreased by 42.72 (1976) to 35.05 (2009).

Conclusion

Temporal Land cover analyses highlighted the decline of forest cover from 96.62 (1976) to 93.60% (2009). Spatio-temporal land use analysis indicated the increase of built-up patches from 0.05 to 0.25% (2009). The results also reveal the fragmentation of forest patches due to the conversion of forest areas for agricultural and development activities. Forest fragmentation analysis showed the decline in interior forests from 1976 to 2009 and domination of edge and patch forest in all divisions. Land use changes from

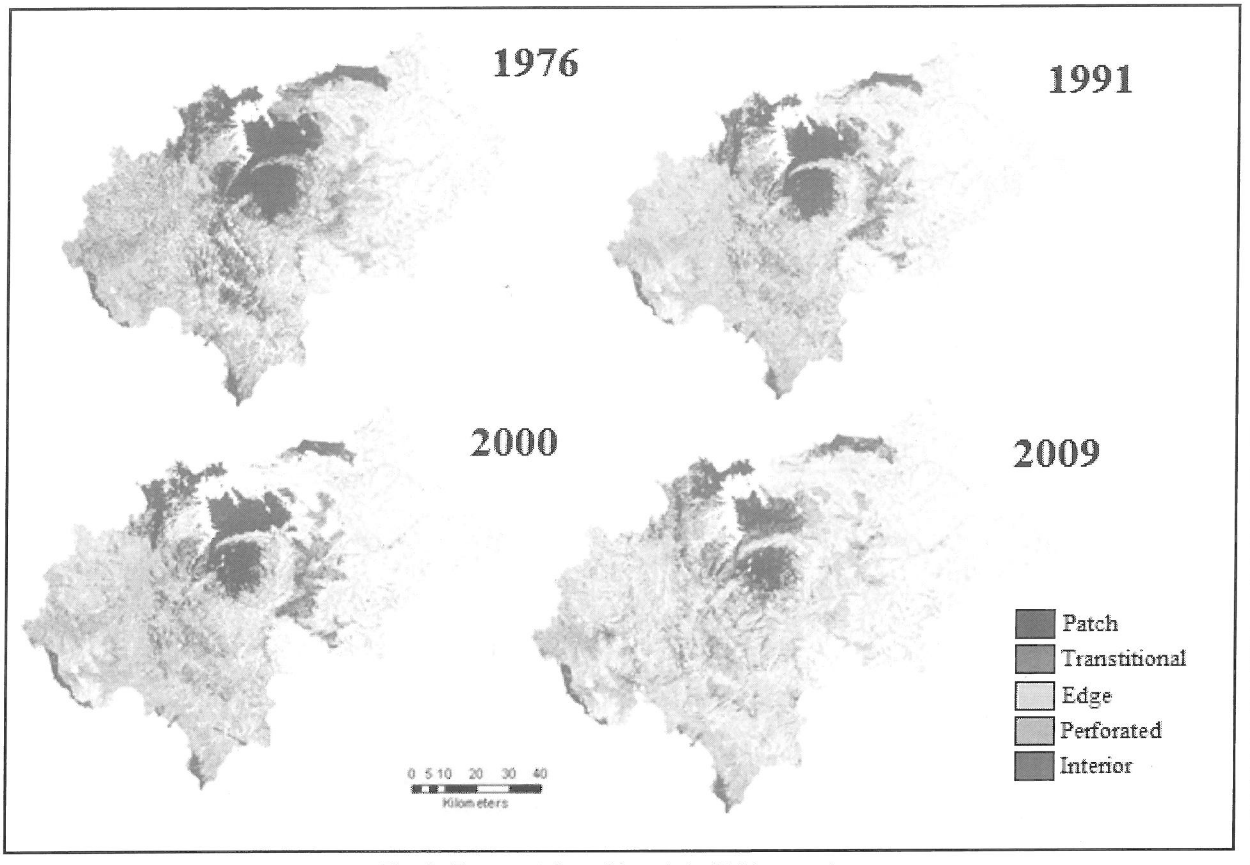

Fig. 9: Fragmentation of forests in Chikkamagalur.

Table 5: Kappa and overall accuracy

Year	Kappa Co-efficient	Overall accuracy (%)
1976	0.77	84.43
1991	0.78	86.06
2000	0.80	87.12
2009	0.91	93.43

Table 6: Extent (in percentages) of forest fragmentation during 1976 to 2009.

Types of fragmentation	1976	1991	2000	2009
Patch	3.51	5.71	5.93	8.74
Transitional	9.43	12.14	13.59	14.79
Edge	29.32	37.23	37.64	35.87
Perforated	5.35	2.35	3.32	3.22
Interior	52.39	42.56	40.40	37.38

forests to non-forests with intensified human interference had been very high especially in Bhadravati and Chikkamagalur division. Koppa forest division showed more fragmented forest patches with increased edge and patch forest. The extent of interior forest declined in last few years in Kudhremukh National Park due to mining/ quarrying activities. Bhadra wild life Sanctuary also showed decline in forest cover.

अल्पकालिक सूदूर संवेदी आँकड़ों एवं स्थानिक मैट्रिक्स का उपयोग करके चिकमगलूर जिला, मध्य पश्चिमी घाटों में वन गतिकी का मूल्यांकंन

टी.वी. रामचन्द्रा, सुदर्शन पी. भट, गौरी कुलकर्णी एवं भारथ एच. एथल

सारांश

पारिस्थितिकीय रूप से कमजोर पश्चिमी घाटों के वन अविवेकी नीति निर्णयों और वन सेवाओं पर भारी मानवीय दबावों के कारण अपनी संरचना और संयोजन में परिवर्तनों से गुजर रहे है। किसी भी रूप में भूमि उपयोग परिवर्तन सक्षम तौर पर विखण्डन पैदा करते है। प्रभाव की सीमा परिवर्तन की किस्म; विखण्डन की मात्रा पर निर्भर करेगी तथा पैच आकार, पैच रूप, संयोजकता और पृथक्करण के संदर्भ में प्रभाव डालेगी। इस अध्ययन में स्पेस जनित सेन्सरों के जरिए अर्जित अल्पकालिक आँकड़ों पर विचार करते हुए भूदृश्य विखण्डन गतिकी के स्थानिक पैटर्नों की जाँच की गई है। परिणामों ने दर्शाया कि कृषि, उद्योग एवं विकासात्मक गतिविधियों के लिए वनों के रूपान्तरण के कारण वन वनस्पति 50.74% (1976) से 36.33% (2009) तक घटी है। प्रमुख विकासात्मक कार्यकलापों के लिए भूमि निर्मुक्त करने के अलावा वन भूमि का अतिक्रमण (22055.59 हैक्टेयर) और कृषि भूमि में रूपान्तरण स्थानीय स्तर पर निम्नीकरण

के प्रधान कारक हैं। स्थानिक मैट्रिक्स के जरिए वन विखण्डन विश्लेषण ने भीतरी वनों में कमी और पृथक्कृत पैचों की प्रधानता को दर्शाया। इस अध्ययन में उष्णकटिबंधीय वनों के पोषणीय प्रबंधन के लिए भूमि उपयोग परिवर्तनों के स्थानिक- कालिक पैटर्नों को समझने के महत्व और वन संसाधनों में समृद्ध क्षेत्रों के लिए उपयुक्त संरक्षण उपायों को सूत्रित करने में सहायता को बताया गया है।

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