Assessment and monitoring of long-term forest cover changes (1920–2013) in Western Ghats biodiversity hotspot

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Western Ghats are considered as one of the global biodiversity hotspots. There is an information gap on conservation status of the biodiversity hotspots. This study has quantified estimates of deforestation in the Western Ghats over a period of past nine decades. The classified forest cover maps for 1920, 1975, 1985, 1995, 2005 and 2013 indicates 95,446 (73.1%), 63,123 (48.4%), 62,286 (47.7%), 61,551 (47.2%), 61,511 (47.1%) and 61,511 km^2 (47.1%) of the forest area, respectively. The rates of deforestation have been analyzed in different time phases, i.e., 1920–1975, 1975–1985, 1985–1995, 1995–2005 and 2005–2013. The grid cells of 1 km^2 have been generated for time series analysis and describing spatial changes in forests. The net rate of deforestation was found to be 0.75 during 1920–1975, 0.13 during 1975–1985, 0.12 during 1985–1995 and 0.01 during 1995–2005. Overall forest loss in Western Ghats was estimated as 33,579 km^2 (35.3% of the total forest) from 1920's to 2013. Land use change analysis indicates highest transformation of forest to plantations, followed by agriculture and degradation to scrub. The dominant forest type is tropical semi-evergreen which comprises 21,678 km^2 (35.2%) of the total forest area of Western Ghats, followed by wet evergreen forest (30.6%), moist deciduous forest (24.8%) and dry deciduous forest (8.1%) in 2013. Even though it has the highest population density among the hotspots, there is no quantifiable net rate of deforestation from 2005 to 2013 which indicates increased measures of conservation.

1. Introduction

Deforestation in tropical forests represents one of the primary threats to biodiversity (Sodhi and Brook 2008). There is a global level focus on policy approaches to strengthen conservation initiatives to reduce emissions from deforestation and degradation (Linkie *et al.* 2010). The global annual forest cover loss was 0.6% during 2000–2005 (Hansen *et al.* 2010). The annual rate of deforestation was estimated as 3 Mha per year between 1990 and 2000 and as 6 Mha per year between 2000 and 2005 (FAO 2012). India is contributing 6.8% of share in carbon dioxide emissions in 2012, making it, the fourth largest global emitter of carbon dioxide (Oliver *et al.* 2013). It has been more than a decade since *Nature* published the highly cited article on 'Global Biodiversity Hotspots' (Myers *et al.* 2000). Yet there are no comprehensive studies particularly on the biodiversity hotspots of India: Western Ghats, Himalayas, Indo-Burma and Sundaland (http://www.natureasia.com).

Mapping of forest cover is an important measure of natural resource inventory and management for any area. Satellite remote sensing as 'state-of-the-art technology' has gained vital importance in quantification and monitoring of deforestation. Geographical Information System along with remote sensing

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is useful in collection, processing and interpretation of data in quantifying the nature and rates of forest cover change. Since up-to-date land cover information is required and the change in land cover over periods of decades is of interest, remotely-sensed data provides a better source for derivations of land cover due to internal consistency, reproducibility and coverage in locations where ground-based knowledge is sparse (Roy and Joshi 2002).

The recent review has analysed studies of deforestation in India (Reddy *et al.* 2013a). Reddy *et al.* (2013b) studied long-term forest cover change in Odisha and observed that understanding of historical changes in Indian forests is inadequate. The present understanding of forest cover change within Western Ghats is limited due to paucity of comprehensive study covering the whole of Western Ghats. Ramesh *et al.* (1997) have estimated rate of deforestation as 0.19 in Agasthyamala part of Western Ghats from 1920 to 1960. Menon and Bawa (1998) reported the rate of deforestation as 0.57 in the part of Western Ghats from 1920 to 1990. Study in part of Kerala indicated that the deforestation between 1961 and 1988 was at an average annual rate of 0.28 (Prasad 1998). A study has showed annual rate of deforestation as 1.34 in the southern part of the Western Ghats from 1973 to 1995 (Jha *et al.* 2000). Annual deforestation rate of 0.33 was reported in Western Ghats of Kerala during 1960–1990 (Ramesh *et al.* 1997). Joseph *et al.* (2009) have reported rate of deforestation as 0.04 in Anamalai during 1973–2006. Panigrahy *et al.* (2010) have calculated the net rate of deforestation as 0.15 in Western Ghats and the west coast of Maharashtra during 1987–2005. The study on forest cover change analysis (1920–2012) in Nilgiris has indicated conservation effectiveness after declaration as a biosphere reserve (Satish *et al.* 2014). There is a need for more studies on classifying tropical forest types which provide valuable inputs for conservation (Ramesh *et al.* 1997). The process of forest fragmentation has three components: an overall loss of forest, a progressive fragmentation of surviving forest stands into smaller blocks and an increasing spatial isolation of fragments through time (Bennett 1999).

In the perspective of biodiversity and climate change, it is important to know that the clearing of a natural forest or a plantation has different implications on the biodiversity (Margono *et al.* 2014). The Forest Survey of India defines forest cover as all lands more than one hectare in area, with a tree canopy density of more than 10%, irrespective of ownership and legal status (FSI 2011). A recent study defined forests as tree cover and included plantations in the quantification of forest loss (Hansen *et al.* 2013). Forest cover as mapped by FSI and Hansen *et al.* (2013) does not make any distinction between natural or man-made forests, thereby including all plantations and orchards. According to Ravindranath *et al.* (2014), India could be under-reporting deforestation. In the present study, forest is defined as 'land spanning >1 ha, dominated by indigenous tree species with an over-storey canopy cover of greater than 10%'. The present study considers deforestation as replacement of natural forest by other land use and/or depletion of natural forest canopy cover to less than 10%.

Thus, the objective of present study is to quantify and characterize the long-term forest cover changes in Western Ghats over a period of nine decades. The study is also aimed to quantify spatial extent of forest types and land use and to estimate rate of deforestation in Western Ghats.

2. Study area

Western Ghats of India stretches from a latitudinal extent of 8°–22°N along a 1500 km in length from river Tapti in north to Kanyakumari in south. The mean elevation of the Western Ghats is higher than 600 m and exceeds 2000 m at some places. It covers parts of six states, viz., Gujarat, Maharashtra, Karnataka, Goa, Kerala and Tamil Nadu and one union territory (Dadra & Nagar Haveli) (figure 1). Among the hotspots under India, the Western Ghats account for 64.95%, Indo-Burma for 5.13%, Himalaya for 44.37% and Sundaland for 1.28%. Western Ghats along with Sri Lanka, is one of the hottest hotspots of biological diversity in the old world tropics (Myers *et al.* 2000). It contains more than 30% of all plant and vertebrate species found in India, in less than 6% of the country's landmass. There are 8080 taxa of flowering plants known from the Western Ghats including 5588 indigenous species (Nayar *et al.* 2014). The Anaimudi peak in the high ranges of Kerala rises to the height of 2695 m, is the highest peak south of the Himalayas. There is a major discontinuity in this otherwise continuous hill tract, stretching from the north to south and is known as the Palghat gap which is about 30 km long and 100 m high above mean sea level. The variability in precipitation and topographic diversity generates a wide variety of vegetation types ranging from wet evergreen and semi-evergreen forests on the western side and at high altitudes to dry deciduous forests on the eastern slopes and lowlands (Champion and Seth 1968).

The resource value of this mega-biodiversity centre spanned from timber–non-timber category through wilderness–ecotourism to medicinal–aromatic–food–industrial gene pools. This kind of luxuriant vegetation compositions evolved over geologic time scale has witnessed various land use practices depending upon the resource demand and access of human dimension. This has induced considerable alteration in the Western Ghats biogeography bringing in commercial agriculture, commercial forestry, hydropower, mining and biotic pressures within the forest ecosystems (IIRS 2002). The commercial plantations of coffee, cardamom, tea, *Acacia* and *Eucalyptus*, cashew, rubber, bananas, arecanut, coconut, etc., occupy large area and also make the forest landscape highly mosaic. The Western Ghats accommodated the highest human population density (>300 persons/km^2) among all global hotspots (Cincotta *et al.* 2000).

The exact total area under Western Ghats varies due to lack of well-defined boundaries of Western Ghats. According to Western Ghats ecology expert panel (WGEEP), the total area under Western Ghats is 129,037 km^2, but as per High Level Working Group (HLWG)'s definition, Western Ghats spreads over an area of 164,280 km^2. Biogeographic classification of India was done by Rodgers and Panwar (1988), describing 10 biogeographic zones in India. The maps were further revised by Rodgers *et al.* (2002) using GIS techniques into 10 zones and 26 provinces. The classification was done using various factors such as altitude, moisture, topography and rainfall. The spatial boundary generated from a revised biogeographic zone map of India by Rodgers *et al.* (2002) has total area of about 130,500 km^2 used in the present study.

3. Materials and methods

3.1 *Data used and methods*

We have generated spatial database on forest cover and forest types from the multi-source data. Time series analysis has been carried out using multitemporal data of 1920, 1975, 1985, 1995, 2005 and 2013. The time period prior to the availability of remote sensing data were mapped using Survey of India topographical maps, surveyed during 1909–1930 (Series – U.S. Army Map Service, 1:250,000 scale from the Perry Castaneda map collection (http://www.lib.utexas.edu/maps/ams/india/). Data sources have been summarized in table 1. On screen visual interpretation technique was used to map forest cover from topographical maps. Image-to-image registration was performed using ground control points selected from orthorectified Landsat ETM + data (http://glcf.umd.edu/research/portal/geocover/) using a first order polynomial transformation. Datasets were corrected with a root mean square error of <1 pixels for all data. The images were georeferenced to the WGS84 datum. All images were normalized using Top-of-Atmosphere (TOA) reflectance programme (Chavez 1996). The various image enhancement techniques are being used in image processing. Major forest types described by Champion and Seth (1968) were classified.

Hybrid classification method was used in mapping of forest cover and forest types using multiseason IRS Resourcesat-2 AWiFS data of 2013. The present study has used natural forest definition which is being dominated by a composition of indigenous tree species. In hybrid classification method, conjunctive use of visual interpretation, normalized difference vegetation index and supervised classification techniques were used, in view of phenological variations, topography and field information to be incorporated in terms of context, association and texture to delineate different forest type classes (Reddy *et al.* 2015). Field information has been collected from each of the forest type using GPS. The classified forest cover map of 2013 was used as a master for classifying the other four periods (1975, 1985, 1995 and 2005). The change map was prepared by visual interpretation to delineate forest and non-forest areas from the different periods. Forest type classification from the 2013 data was applied to the 1975's forest cover data. Forest type of an area does not change within a span of 30–40 yrs (Reddy *et al.* 2015). All

Table 1. *Datasets used in the study.*

Type	Period	Scale/resolution*	Source
SOI topographical maps	1909–1930	1:250,000	US Army Map Service[1]
Landsat MSS	1973–1976	80 m	GLCF
Landsat MSS	1985	80 m	GLCF
IRS 1A LISS-I	1995	72.5 m	ISRO
IRS P6 AWiFS	2005	56 m	ISRO
Resourcesat-2 AWiFS	2013	56 m	ISRO

*Scale for topographical maps; spatial resolution for satellite datasets.
[1]http://www.lib.utexas.edu/maps/ams/india/.
SOI: Survey of India; ISRO: Indian Space Research Organisation; GLCF; http://glcfapp.umiacs.umd.edu:8080/esdi.

multi-temporal datasets have been resampled to 56 m to reduce false change detection. The forest types mapped in the study area are wet evergreen forest, semi-evergreen forest, moist deciduous forest, dry deciduous forest and shola.

3.2 *Rate of deforestation*

The annual rate of forest cover change was calculated using compound interest formula (Puyravaud 2003).

$$r = \frac{1}{(t_2 - t_1)} \times \ln \frac{a_2}{a_1},$$

where r is the annual rate of change (percentage per year) and a_1 and a_2 are the forest cover estimates at time t_1 and t_2, respectively.

3.3 *Change analysis*

A grid of 1 km^2 was generated to analyse the trends in distribution of forest cover of Western Ghats. The area covered by forest was estimated and the change (1920–1975, 1975–1985, 1985–1995, 1995–2005, 2005–2013) was evaluated. Spatial change in forest cover was quantified across the six classes, i.e., <20 ha, 20–40 ha, 40–60 ha, 60–80 ha and >80 ha.

3.4 *Landscape analysis*

For the spatial analysis of forest fragmentation and to quantify the changes in landscape pattern, the landscape indices such as number of patches, mean patch size, patch density, edge density and largest patch index have been computed using customized FRAGSTATS software (McGarigal *et al.* 2012).

3.5 *Accuracy assessment*

The error matrix compares the reference points to the classified points. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Random sample points were generated to assess the accuracy of classified map of 2013. Validation of classified maps for 1975, 1985, 1995, 2005 was done based on the consistency of ground control points. Land use/land cover map of 1:250,000 scale (2012) available at National Remote Sensing Centre were consulted for corroboration of spatial distribution of forest cover. Post-classification refinement was done visually on the basis of very high resolution open access images available in Bhuvan (http://bhuvan.nrsc.gov.in/bhuvan_links.php) and Google Earth (http://earth.google.com).

4. Results and discussion

The results provided spatial information on distribution of land use/land cover in 2013, forest cover in 1920, 1975, 1985, 1995, 2005 and 2013, rates and trend of deforestation, change in forest types (1975 and 2013) and quantitative account of spatial patterns of forest landscape in Western Ghats.

4.1 *Land use/land cover*

In the present study, 13 land use/land cover classes have been mapped. Western Ghats is predominantly covered by forests accounted for 47.1% of geographical area in 2013. Among the land use classes, agriculture and plantations/orchards occupy 20.2% and 18.3% of the area, respectively. Of the scrub types, dry scrub represents 5.8% of geographical area followed by 2.7% under moist scrub. The area covered under each of the land use/land cover classes is given in table 2.

4.2 *Major changes in forest cover*

Over the past nine decades, Western Ghats has experienced large scale changes in forest cover. The classified forest cover maps for 1920, 1975, 1985, 1995, 2005 and 2013 showed that the forest area as 95,446 (73.1%), 63,123 (48.4%), 62,286 (47.7%), 61,551 (47.2%), 61,511 (47.1%) and 61,511 km^2 (47.1%) of the geographical area of

Table 2. *Land use/land cover classes and their areas for 2013.*

Class	Area (km^2)	% of area
Forest		
Wet evergreen forest	18821	14.4
Semi-evergreen forest	21678	16.6
Moist deciduous forest	15235	11.7
Dry deciduous forest	5002	3.8
Shola	775	0.6
Sub-total	61511	47.1
Scrub		
Dry scrub	7618	5.8
Moist scrub	3522	2.7
Sub-total	11140	8.5
Other land use		
Plantations/orchards	23857	18.3
Agriculture	26365	20.2
Barren land/fallow	1726	1.3
Grasslands	1816	1.4
Settlements	1820	1.4
Water	2264	1.7
Sub-total	57849	44.3
Total	130500	100

Table 3. *Distribution of forest cover in different parts of Western Ghats (area in km^2).*

State	1920	1975	1985	1995	2005	2013
Goa	1700	1328	1262	1253	1253	1253
Gujarat	3707	2425	2417	2412	2412	2412
Karnataka	31530	23472	23056	22995	22975	22975
Kerala	28043	11251	11018	10468	10450	10450
Maharashtra	20323	16033	16031	15925	15924	15924
Tamil Nadu	9895	8395	8391	8389	8388	8388
Dadra & Nagar Haveli	249	218	110	110	110	110
Grand total	95446	63123	62286	61551	61511	61511

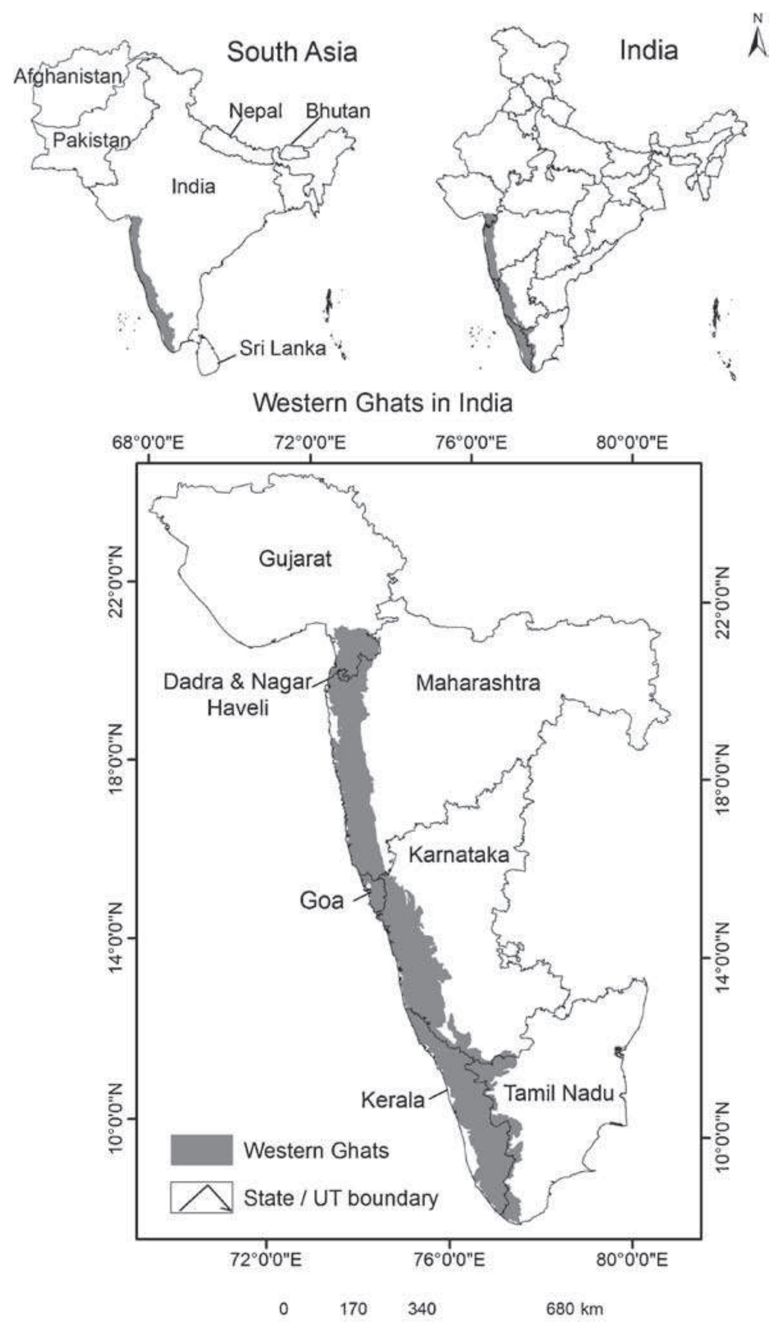

Figure 1. Location map of Western Ghats.

Western Ghats, respectively (table 3). Overall forest cover loss was found to be 33,579 km^2 (35.3% of the total forest) during 1920–2013 which indicates Western Ghats representing vulnerable ecosystems. The deforested area during 1920–1975 was estimated as 21,845 km^2 followed by 837 km^2 during 1975–1985 and 735 km^2 during 1985–1995. The average annual deforested area was estimated as 581 $km^2\ yr^{-1}$ during 1920–1975, 84 $km^2\ yr^{-1}$ during 1975–1985, 74 $km^2\ yr^{-1}$ during 1985–1995 and 4 $km^2\ yr^{-1}$ during 1995–2005.

The Western Ghats of Karnataka represents highest forest cover (37.4%), followed by Maharashtra (25.9%), Kerala (17%), Tamil Nadu (13.6%), Gujarat (3.9%) and Goa (2%) (table 3). Among the six states (1920–2013), historical loss of forest area was very high in Western Ghats of Kerala with forest cover loss of 62.7% of area, followed by 34.9% in Gujarat, 27.1% in Karnataka, 26.3% in Goa, 21.6% in Maharashtra and 15.2% in Tamil Nadu.

Table 4. *Trend of annual rate of deforestation in Western Ghats.*

Period	1975	1985	1995	2005	2013
1920	0.75	0.66	0.58	0.52	0.47
1975		0.13	0.13	0.09	0.07
1985			0.12	0.06	0.04
1995				0.01	0.07
2005					0.00

4.3 *Rate of deforestation*

As per compound interest formula, annual net rate of deforestation was calculated as 0.75 during 1920–1975, 0.13 during 1975–1985, 0.12 during 1985–1995 and 0.01 during 1995–2005. The annual net deforestation rate was nil during recent period (2005–2013) which indicates management effectiveness in Western Ghats (table 4). Analysis of rate of deforestation in different parts of Western Ghats indicates Goa, Gujarat, Maharashtra and Tamil Nadu are successful in the protection of forests since 1995 (figure 2). But in the past (1920–1975), rate of deforestation was very high in Western Ghats of Kerala (table 5). In 1940s due to 'Grow More Food' campaign, substantial areas of forests were opened up for the cultivation of food crops. Colonization during the 1950s and 1960s, created

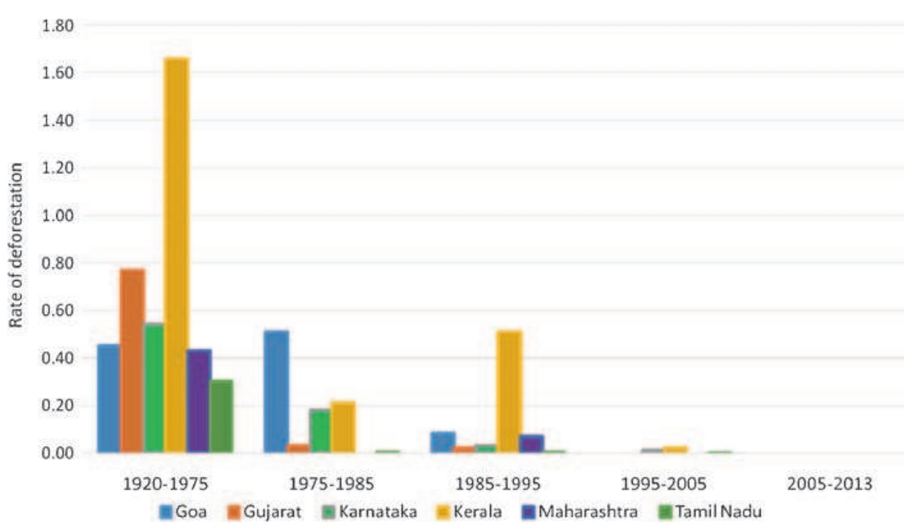

Figure 2. Annual net rate of deforestation in different parts of Western Ghats.

Table 5. *Trend of annual rate of deforestation in different parts of Western Ghats.*

State	1920–1975	1975–1985	1985–1995	1995–2005	2005–2013
Goa	0.45	0.51	0.08	0.00	0.00
Gujarat	0.77	0.03	0.02	0.00	0.00
Karnataka	0.54	0.18	0.03	0.01	0.00
Kerala	1.66	0.21	0.51	0.02	0.00
Maharashtra	0.43	0.00	0.07	0.00	0.00
Tamil Nadu	0.30	0.01	0.00	0.00	0.00
Dadra & Nagar Haveli	0.24	6.80	0.00	0.00	0.00

new settlements in the deforested areas and infrastructure development of the post-independence era, during which projects in power, irrigation and transportation sectors were set up on forest lands (George and Chattopadhyay 2001).

4.4 *Gridwise analysis of forest cover distribution*

There are total 135,586 grid cells identified in Western Ghats. The number of forest grid cells varies across the periods ranging from 117,508 in 1920,

Table 6. *Grid cellwise distribution of forest cover in Western Ghats.*

Class	1920	1975	1985	1995	2005	2013
<20 ha	8632	10895	11106	11239	11241	11241
20–40 ha	7821	9443	9626	9766	9780	9780
40–60 ha	8598	10123	10251	10364	10366	10366
60–80 ha	10286	11981	11957	12016	12021	12021
>80 ha	82171	47496	46511	45636	45586	45586
Grand total	117508	89938	89451	89021	88994	88994

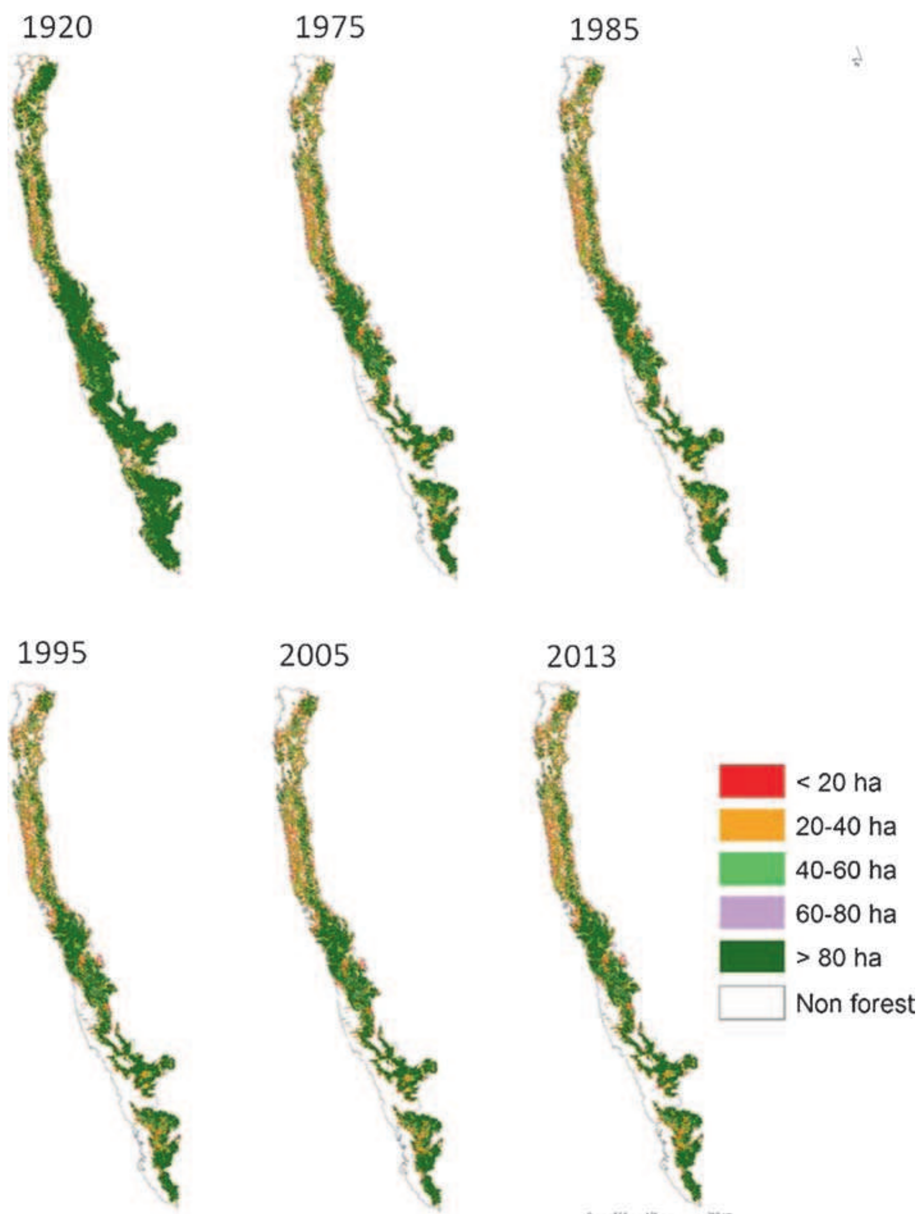

Figure 3. Spatial maps of forest cover in Western Ghats: 1920–2013.

89,938 in 1975, 89,451 in 1985, 89,021 in 1995 to 88,994 in 2005/2013 (table 6). The spatial data for 1920, 1975, 1995 and 2013 were displayed along with gridwise representation of forest cover in figure 3. The number of forest grids which are representing more than >80 ha are 82,171 in 1920 have shown major difference (negative change in 36,585 grids) due to large scale forest loss.

4.5 *Gridwise analysis of forest cover change*

Spatial analysis indicates that highest number of grid cells have undergone negative changes during 1920–1975, 1975–1985 and 1985–1995 (table 7). Forest cover change map of 1920–2013 is presented in figure 4. A total of 450 grids have shown gain of forest cover during 1920–2013. The unchanged grids from 1920 to 2013 are 45,683. Overall 73,714 grids have shown negative change during 1920–2013.

4.6 *Major changes in forest types*

Western Ghats represents tropical wet evergreen, semi-evergreen, moist deciduous, dry deciduous and shola forests. The dominant forest type was semi-evergreen, which occupies 21,678 km^2 (35.2%) of the total forest area of Western Ghats, followed by wet evergreen forest (30.6%), moist deciduous forest (24.8%) and dry deciduous forest (8.1%) in 2013. A comparison based on spatial extent revealed that significant changes occurred during 1975–2013. The statistics showed that the large scale negative changes occurred in moist deciduous forests and dry deciduous forests compared to wet evergreen forests. About 6.9% of dry deciduous forests, 6.1% of shola, 2.6% of moist deciduous forests, 2.3% of semi-evergreen forests, 1.4% of wet evergreen forests have reduced in spatial extent during 1975–2013 (table 8). The classified forest type map of 2013 is presented in figure 5.

4.7 *Replacement land use*

The calculation between classified maps of 1920 and 2013 revealed different kinds of changes in the forest cover and resulted in multiple transfers of land use/land cover. Patches which were identified in the change analysis as deforested were categorized under one of the existing replacement land use class following land use data of 2013. Among the dominant drivers of deforestation, expansion of plantations are responsible for 50.8% of forest cover

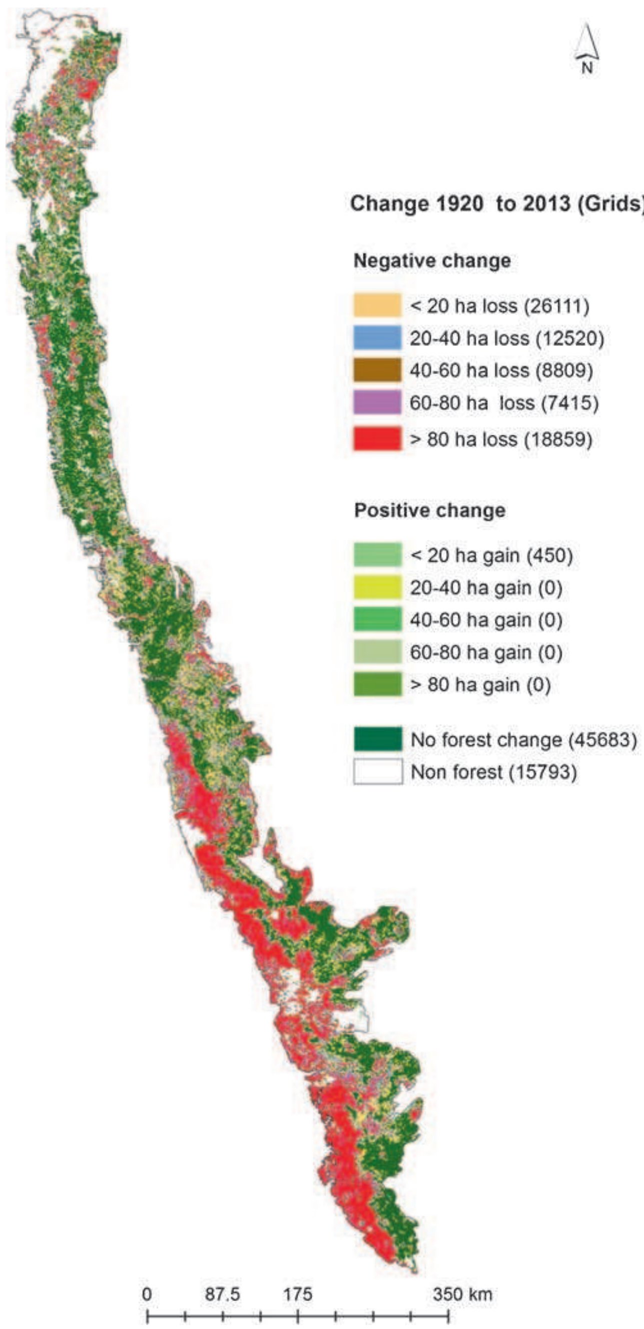

Figure 4. Forest cover change map of Western Ghats: 1920–2013.

Table 7. *Analysis of grid cellwise negative changes in Western Ghats.*

Change class	1920–1975	1975–1985	1985–1995	1995–2005	2005–2013
<20 ha	25636	6073	6234	199	0
20–40 ha	12032	487	444	40	0
40–60 ha	8393	298	199	13	0
60–80 ha	6990	179	91	8	0
>80 ha	17879	179	41	1	0

Table 8. *Areal extent of forest types in Western Ghats (area in km^2).*

Forest type	1975	2013	Change area	% of change
Wet evergreen	19083	18821	262	1.4
Semi-evergreen	22199	21678	521	2.3
Moist deciduous	15641	15235	406	2.6
Dry deciduous	5374	5002	372	6.9
Shola	826	775	51	6.1
Grand total	63123	61511	1612	2.6

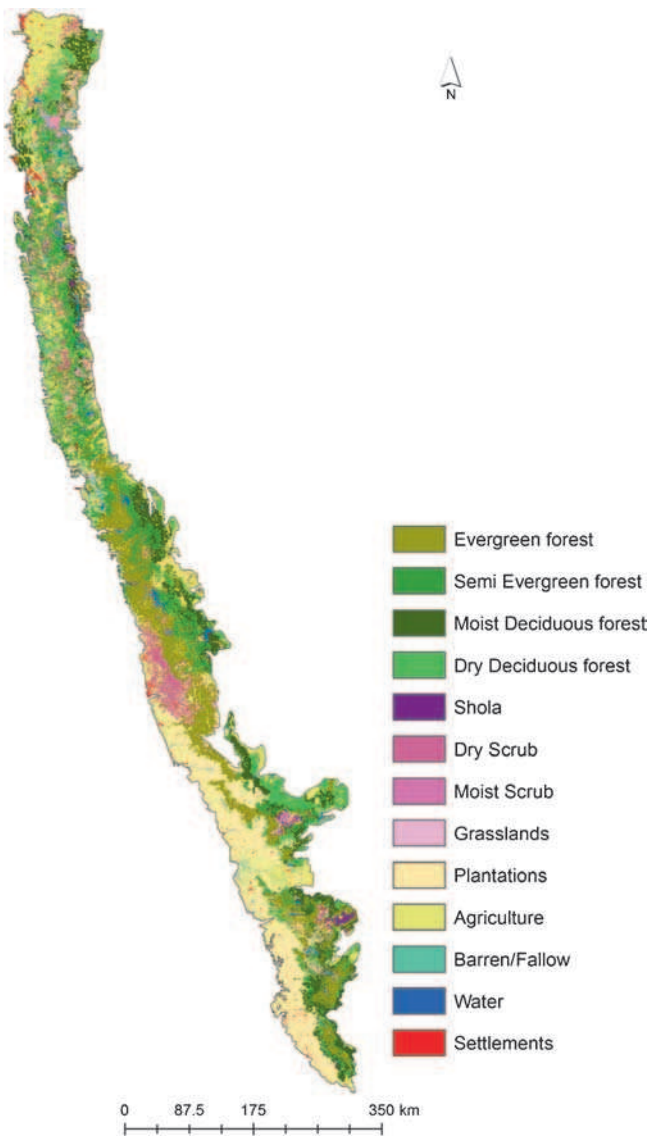

Figure 5. Forest type and land use/land cover map of Western Ghats: 2013.

loss, followed by agriculture and transformation to dry scrub. About an area of 17,239 km^2 of plantations increased over a period of nine decades due to deforestation (table 9). An area of 1057 km^2 of forest was submerged due to construction of dams during the study period. In recent decades, forest degradation has been the leading process affecting forest cover change. The areas converted to scrub and grasslands can be selected for restoration.

Table 9. *Land use in deforested areas (area in km^2).*

Land use	Area (km^2)	% of area
Plantations/orchards	17239	50.8
Agriculture	8380	24.7
Dry scrub	4111	12.1
Moist scrub	1568	4.6
Water	1057	3.1
Grasslands	794	2.3
Settlements	438	1.3
Barren/fallow	350	1.0
Grand total	33935	100

Table 10. *Spatio-temporal pattern of landscape indices in Western Ghats.*

Landscape indices	1920	1975	1985	1995	2013
No. of patches	4624	8673	8308	8787	8793
Mean patch (km^2)	20.6	7.3	7.5	7.0	7.0
Patch density/100 ha	0.04	0.07	0.06	0.07	0.07
Largest patch index	59.6	60.0	47.7	48.1	48.1
Edge density	1048.7	2132.6	2205.0	2280.1	2282.1

4.8 *Spatial variation in forest landscape*

Western Ghats has undergone spatial changes in landscape patterns over the period of nine decades. To provide ecologically meaningful quantification, fragmentation statistics have been estimated only on forest patches. Results indicated that large scale forest fragmentation has occurred during 1920–1975, doubling the number of forest patches. At the landscape level, the largest patch index which represented 56,903 km^2 (59.6%) in 1920 declined to 29,577 km^2 (48.1%) by 2013. Due to deforestation, the number of patches in 1920 increased from 4624 to 8793 in 2013 (table 10). Forest patches were categorized under seven classes, i.e., <1, 1–5, 5–10, 10–20, 20–50, 50–100 and >100 km^2 (table 11). Of the total 8793 forest patches, 7997 (90.9%) patches belonged to <1 km^2 patch size category in 1920. The number of <1 km^2 patches were 7946 in 1975, 7524 in 1985, 7991 in 1995 and 7997 in 2013. The patches of >100 km^2 are contributing to highest forest area of 90,517 km^2 in 1920, while it is 55,863 km^2 in 2013 (table 12). It is evident that there is extensive decline in the size of the largest forest patches due to deforestation. Nationwide study on fragmentation has reported moderate level of fragmentation in Western Ghats (Reddy *et al.* 2013c).

4.9 *Accuracy assessment*

The accuracy of the maps was validated independently of the mapping (tables 13–17). Validation of forest cover maps for 1975, 1985, 1995 and 2005 was done based on visual assessment of satellite images and the temporal consistency of ground control points. The inaccuracy in mapping was minimized by visual interpretation of forest cover in topographical maps. Overlay analysis has indicated all forest ground control points collected during 2014 matched with forest cover map of 1920. The mapping for the oldest data of 1975–1995 was carried out carefully considering ground control points that had not changed

Table 11. *Size class distribution of forest patches in Western Ghats.*

	1920		1975		1985		1995		2013	
Patch class	Count	Percentage	Count	Percentage	Count	Percentage	Count	Percentage	Count	Percentage
<1 km^2	3933	85.1	7946	91.6	7524	90.6	7991	90.9	7997	90.9
1–5 km^2	474	10.3	506	5.8	551	6.6	561	6.4	561	6.4
5–10 km^2	102	2.2	107	1.2	102	1.2	103	1.2	103	1.2
10–20 km^2	55	1.2	55	0.6	64	0.8	65	0.7	65	0.7
20–50 km^2	29	0.6	31	0.4	31	0.4	30	0.3	30	0.3
50–100 km^2	13	0.3	7	0.1	12	0.1	13	0.1	13	0.1
>100 km^2	18	0.4	21	0.2	24	0.3	24	0.3	24	0.3
Grand total	4624	100	8673	100	8308	100	8787	100	8793	100

Table 12. *Areal extent of forest patches in Western Ghats (area in km^2).*

Patch class	1920		1975		1985		1995		2013	
	Area	Percentage	Area	Percentage	Area	Percentage	Area	Percentage	Area	Percentage
<1 km^2	631	0.7	917	1.5	887	1.4	915	1.5	915	1.5
1–5 km^2	997	1.0	1092	1.7	1166	1.9	1186	1.9	1186	1.9
5–10 km^2	687	0.7	736	1.2	711	1.1	714	1.2	714	1.2
10–20 km^2	751	0.8	794	1.3	923	1.5	948	1.5	948	1.5
20–50 km^2	908	1.0	989	1.6	964	1.5	946	1.5	945	1.5
50–100 km^2	956	1.0	539	0.9	864	1.4	940	1.5	940	1.5
>100 km^2	90517	94.8	58056	92.0	56771	91.1	55902	90.8	55863	90.8
Grand total	95446	100	63123	100	62286	100	61551	100	61511	100

Table 13. *Error matrix generated for accuracy assessment: 1975.*

Class	Code	1	2	3	4	5	6	7	8	9	10	11	12	13	Row total	User's accuracy
Wet evergreen forest	1	51	4	2	0	0	0	0	0	0	0	0	0	0	57	89.47
Semi-evergreen forest	2	6	70	5	0	0	0	1	0	0	0	0	0	0	82	85.37
Moist deciduous forest	3	2	2	99	8	0	0	2	1	0	0	0	0	0	114	86.84
Dry deciduous forest	4	0	1	6	162	0	2	0	0	0	0	0	0	0	171	94.74
Shola	5	0	0	0	0	13	0	0	0	0	0	0	0	0	13	100.00
Dry scrub	6	0	0	0	1	0	16	0	0	2	1	1	0	0	21	76.19
Moist scrub	7	9	1	1	0	0	0	17	1	0	0	0	0	0	20	85.00
Plantations/orchards	8	0	0	1	0	0	0	2	21	1	0	0	0	0	25	84.00
Agriculture	9	0	0	0	0	0	0	0	1	21	1	1	1	0	25	84.00
Barren/fallow	10	0	0	0	0	0	1	0	0	0	11	0	1	0	13	84.62
Grasslands	11	0	0	0	0	0	1	0	0	2	2	16	0	0	21	76.19
Settlements	12	0	0	0	0	0	0	0	0	0	2	0	20	0	22	90.91
Water	13	0	0	0	0	0	0	0	0	0	0	2	0	14	16	87.50
Column total		59	78	114	171	13	20	22	24	26	17	20	22	14	600	
Producer's accuracy		86.44	89.74	86.84	94.74	100.0	80.0	77.27	87.50	80.77	64.71	80.0	90.91	100		

over time. In order to manage mapping errors propagated through the analyses of change, all the digital datasets were resampled to 56 m before proceeding for analysis. The land use/land cover map of 2013 yielded overall classification accuracy of 90.17%. Accuracy of plantations was computed as 88%. For forest types, user's accuracy ranges from 86.96% (moist deciduous forests) to 100% (shola). The accuracy of previous periods has been evaluated visually based on the consistency of ground control points. The overall accuracy of the classified maps derived for the years 1975, 1985, 1995 and 2005 was 88.50%, 89.33%, 89.50% and 90.17%, respectively. All the Kappa coefficient (K_{hat}) values were greater than 0.86. Kappa coefficient >0.80 represent strong agreement and good accuracy.

Table 14. *Error matrix generated for accuracy assessment: 1985.*

Class	Forest	Non-forest	Row total	User's accuracy
Forest	401	34	435	92.18
Non-forest	30	135	165	18.18
Column total	431	169	600	
Producer's accuracy	93.04	79.88		

Table 15. *Error matrix generated for accuracy assessment: 1995.*

Class	Forest	Non-forest	Row total	User's accuracy
Forest	401	34	435	92.18
Non-forest	29	136	165	17.58
Column total	430	170	600	
Producer's accuracy	93.26	80.00		

Table 16. *Error matrix generated for accuracy assessment: 2005.*

Class	Forest	Non-forest	Row total	User's accuracy
Forest	401	30	431	93.04
Non-forest	29	140	169	17.16
Column total	430	170	600	
Producer's accuracy	93.26	82.35		

5. Conclusions

The result of this study has provided an up-to-date account of the extent, distribution and changes in forests covering the whole of Western Ghats. Change analysis has revealed the net loss of 35.3% of forest area in the Western Ghats from 1920's to 2013. There is no quantifiable rate of deforestation in recent years which indicates conservation efficacy for protection of forests in Western Ghats. We hereby recommend for similar kind of historical analysis of forest cover change which could be used to analyse the conservation status of all global biodiversity hotspots. The limitations of our work are detailed analysis of forest types and change in forest canopy density, which are not addressed in this research.

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Table 17. *Error matrix generated for accuracy assessment: 2013.*

Class	Code	1	2	3	4	5	6	7	8	9	10	11	12	13	Row total	User's accuracy
Wet evergreen forest	1	51	3	2	0	0	0	0	0	0	0	0	0	0	56	91.07
Semi-evergreen forest	2	5	71	4	0	0	0	1	0	0	0	0	0	0	81	87.65
Moist deciduous forest	3	2	2	100	8	0	0	2	1	0	0	0	0	0	115	86.96
Dry deciduous forest	4		1	4	165	0	2	0	0	0	0	0	0	0	172	95.93
Shola	5					13	0	0	0	0	0	0	0	0	13	100.00
Dry scrub	6				1	0	18	0	0	1	1	1	0	0	22	81.82
Moist scrub	7		1	1	0	0	0	17	1	0	0	0	0	0	20	85.00
Plantations	8			1	0	0	0	1	22	1	0	0	0	0	25	88.00
Agriculture	9								1	22	1	1	1	0	26	84.62
Barren/fallow	10						1	0	0	1	9	0	1	0	12	75.00
Grasslands	11						1	0	0	1	1	18	0	0	21	85.71
Settlements	12										1	0	20	0	21	95.24
Water	13											1	0	15	16	93.75
Column total		58	78	112	174	13	22	21	25	26	13	21	22	15	600	
Producer's accuracy		87.93	91.03	89.29	94.83	100.00	81.82	80.95	88.00	84.62	69.23	85.71	90.91	100.0		

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