SPATIAL DYNAMICS OF DEFORESTATION AND FOREST FRAGMENTATION (1930-2013) IN EASTERN GHATS, INDIA

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ABSTRACT

The tropical forests are the most unique ecosystems for their potential economic value. Eastern Ghats, a phytogeographical region of India has rugged hilly terrain distributed in parts of five states, viz. Odisha, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. The present study is mainly aimed to analyse the trends in deforestation and its role in forest fragmentation of Eastern Ghats. The long term changes in forest cover with its spatial pattern over time has been assessed by analyzing a set of topographical maps and satellite remote sensing datasets. The multi-source and multi-date mapping has been carried out using survey of India topographical maps (1930's), Landsat MSS (1975 and 1985), IRS 1B LISS-I (1995), IRS P6 AWiFS (2005) and Resourcesat-2 AWiFS (2013) satellite images. The classified spatial data for 1930, 1975, 1985, 1995, 2005 and 2013 showed that the forest cover for the mentioned years are 102213 km^2 (45.6%), 76630 (34.2%), 73416 km^2 (32.7%), 71730 km^2 (32%), 71305 km^2 (31.8%) and 71186 km^2 (31.7%) of the geographical area of Eastern Ghats respectively. A spatial statistical analysis of the deforestation rates and forest cover change were carried out based on distinctive time phases, i.e. 1930-1975, 1975-1985, 1985-1995, 1995-2005 and 2005-2013. The spatial analysis was carried out first by segmenting the study area into grid cells of 5 km x 5 km for time series assessment and determining spatial changes in forests. The distribution of loss and gain of forest was calculated across six classes i.e. <1 km^2, 1-5 km^2, 5-10 km^2, 10-15 km^2, 15-20 km^2 and >20 km^2. Landscape metrics were used to quantify spatial variability of landscape structure and composition. The results of study on net rate of deforestation was found to be 0.64 during 1935 to 1975, 0.43 during 1975-1985, 0.23 during 1985-1995, 0.06 during 1995-2005 and 0.02 during 2005-2013. The number of forest patches increased from 2688 (1930) to 13009 (2013). The largest forest patch in 1930 represents area of 41669 km^2 that has reduced to 27800 km^2 by 2013. Thus, it is evident that there is a substantial reduction in the size of the very large forest patches due to deforestation. According to spatial analysis, among the different land use change drivers, agriculture occupies highest area, followed by degradation to scrub and conversion to orchards. The dominant forest type was dry deciduous which comprises 37192 km^2 (52.2%) of the total forest area of Eastern Ghats, followed by moist deciduous forest (39.2%) and semi-evergreen forest (4.8%) in 2013. The change analysis showed that the large scale negative changes occurred in deciduous forests and semi-evergreen forests compared to wet evergreen forests due to high economic potential and accessibility. This study has quantified the deforestation that has taken place over the last eight decades in the Eastern Ghats. The decline in overall rate of deforestation in recent years indicates increased measures of conservation. The change analysis of deforestation and forest fragmentation provides a decisive component for conservation and helpful in long term management of forests of Eastern Ghats.

1. INTRODUCTION

Changes in forest cover have impacts on biodiversity, carbon stock, soil, global climatic systems and livelihoods of dependent people. The tropical forests are the most unique ecosystems for their immense value for timber, fuel wood, food and medicine. Now, there is a consensus that most of the tropical forest ecosystems are experiencing threat due to disturbances driven by deforestation, forest degradation and fragmentation. The global gross forest cover loss was reported to be 0.6% per year during 2000 to 2005 (Hansen et al. 2010). The rate of deforestation was reported as 3 Mha per year between 1990 and 2000 and of 6 Mha per year between 2000 and 2005 (FAO, 2012).

Satellite remote sensing has established its use to study historical forest cover changes and relate such changes to environmental and human factors (Reddy et al. 2013a). The application of satellite imagery for forest cover mapping has increased greatly over the past decade for various purposes at local to global levels (Fearnside & Barbosa, 2004). The review analysed the gross and net deforestation rates and sum up the Government initiatives for conservation of forests in India (Reddy et al., 2013a). Reddy et al., (2013b) studied long term forest cover change over Odisha, India and observed that information on historical changes in Indian forests is scarce. Harikrishna et al. (2014) has spatially explicitly mapped the forest cover change in Andhra Pradesh and found large scale deforestation during 1930-1975 period. The study based on long term forest cover change analysis in Nilgiri biosphere reserve has indicated conservation effectiveness under the ongoing forest management practices (Satish et al. 2014). In contrast to short period forest change, long term datasets need to integrate data from large scale historical topographical maps and recent remote sensing datasets.

A recent study defined forests as tree cover and included plantations in the quantification of forest loss (Hansen et al. 2013). It is critically important to know the context of forest loss, whether of a natural forest or a plantation (Margano 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). Thus forest cover as reported by FSI does not make any distinction between natural or manmade forests, thereby including all plantations and orchards. India could be potentially under-reporting deforestation by reporting only the gross forest changes at the national and state levels (Ravindranath et al. 2014). Thus, there is need for a new approach for monitoring and reporting of forest area, to meet the challenges of biodiversity and forest conservation. In the present study forest is a 'land spanning more than 1 ha, dominated with natural tree vegetation with an overstorey canopy cover greater than 10%'. The present study considers deforestation as replacement of natural forest by other land use and/or depletion of natural forest crown cover to less than 10%.

The main objective of this study is to map and analyse the deforestation in the Eastern Ghats of India. The study also aims to quantify patterns of forest fragmentation in the study area using landscape metrics.

2. MATERIALS AND METHODS

2.1 Study area

The *Eastern Ghats*, a phytogeographical region of India forming a chain of isolated hill ranges along the east coast harbour tropical forests. The Eastern Ghats extending over 1750 km with average width of about 100 km and extends from 10°05' to 22°30'N latitude and 76°23' to 86°50'E longitude. The physical feature of the Eastern Ghats, provided by the hills raising from almost 100 m mean seal level to about 1572 m altitude. The Eastern Ghats are geologically older than Himalayas and Western Ghats. Several large rivers like Mahanadi, Godavari, Krishna, Pennar and Kauveri cut the Eastern Ghats into discontinuous blocks of hills. It covers parts of five states, viz. Odisha, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu (Figure 1).

Eastern Ghats of Odisha are found in Phulbani, Boudh, Gajapati, Rayagada, Malkangiri and parts of Mayurbhanj, Keonjhar, Balasore, Jajpur, Angul, Dhenkanal, Cuttack, Khurda, Nayagarh, Ganjam, Nawarangpur, Koraput and Kalahandi districts. The north region of the Mahanadi river covering Mayurbhanj (Similipal) and the adjoining territory with the Malayagiri peak (1277m) and Meghasani peak (1165m) forms the northern most section of Eastern Ghats (Meher-Homji, 2001).

Eastern Ghats of Andhra Pradesh spreads over the parts of Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Guntur, Krishna, Nellore, Prakasam, Anantapur, Chittoor, Cuddapah, Kurnool districts. Eastern Ghats of Telangana are distributed in parts of Khammam, Mahabubnagar and Nalgonda districts. Eastern Ghats of Karnataka are found in parts of Chamrajnagar and Kolar districts. Eastern Ghats of Tamil Nadu are found in parts of Vellore, Erode, Salem, Namakkal, Dharmapuri, Tiruvanamalai, Tiruchirapalli, Pudukkottai, Villupuram districts. The forests are broadly classified into wet evergreen, semi-evergreen, moist deciduous, dry deciduous and thorn types (Champion & Seth, 1968).

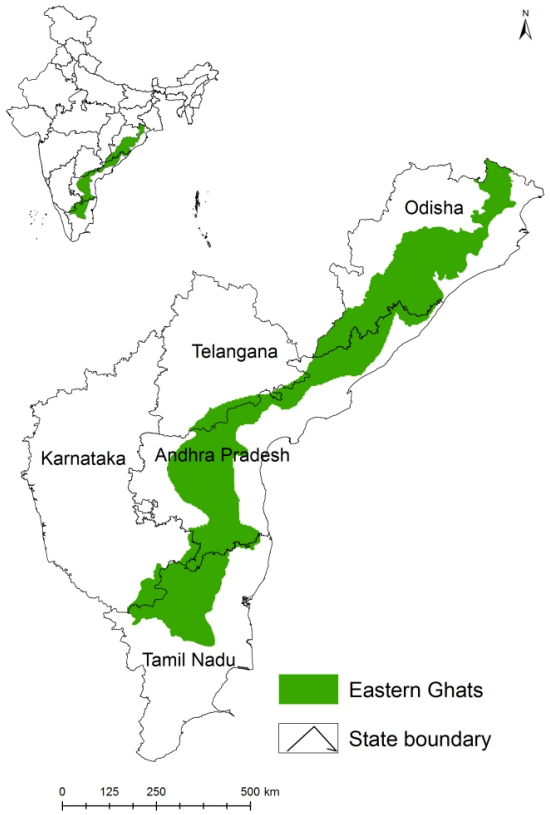

Figure 1. Location map of Eastern Ghats, India

2.2. Spatial Data

In the study, we attempted to create spatial database of forest cover from the topographical map records and satellite remote sensing data. This will be achieved by conducting a time series analysis based on multi-source and multi-temporal data for 1930, 1975, 1985, 1995, 2005 and 2013. The IRS data have been acquired from NRSC Data Centre, Hyderabad, India. Data sources have been summarised in Table 1. Survey of India Topographical maps pertains to 1950-1960's period was used in the gap areas of survey for the 1930's period. Visual interpretation technique was used to map forest cover from topographical maps. The images were georeferenced to the WGS84 datum. The contrast enhancement and vegetation index techniques are being used in image processing. Hybrid classification technique was used in mapping of forest cover and forest types using remote sensing data of 2013. The forest cover map produced from the Resourcesat-2 AWiFS image of 2013 was used as a template for classifying the other four periods (1975, 1985, 1995 and 2005) by visual interpretation for change between forest and non forest cover. Change areas were added to the spatial data of the corresponding period. The main advantage of using this technique, rather than classifying all images independently, is to minimise the changes that are associated with sensor differences as well as with phenological, atmospheric and topographic variability.

Type	Period	Scale/ Resolution*	Source
SOI Topographical maps	1917-1938	1:250,000	US Army Map Service[1]
Landsat MSS	1973-1977	80m	GLCF
Landsat MSS	1985	80m	GLCF
IRS 1A LISS-I	1995	72.5m	ISRO
IRS P6 AWiFS	2005	56m	ISRO
Resourcesat-2 AWiFS	2013	56m	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

Table 1. Historical maps and satellite datasets used in the study

2.3. 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), a_1 and a_2 are the forest cover estimates at time t_1 and t_2 respectively.

2.4. Change Analysis

National level grid of 5 km x 5 km was generated to analyse the trends in distribution of forest cover of Eastern Ghats. On each spatial database, the area covered by forest was estimated and the change (1930-1975, 1975-1985, 1985-1995, 1995-2005, 2005-2013) was evaluated. Spatial change in forest cover was quantified across the six classes i.e. <1 km^2, 1-5 km^2, 5-10 km^2, 10-15 km^2, 15-20 km^2 and >20 km^2.

2.5. Forest fragmentation

Forest patches were grouped under nine classes i.e. <1 km^2, 1-10 km^2, 10-50 km^2, 50-100 km^2, 100-500 km^2, 500-1000 km^2, 1000-2000 km^2, 2000-5000 km^2 and >5000 km^2. Landscape metrics have been used to analyse spatial variation and pattern of landscape level fragmentation. For this purpose, six landscape metrics were selected and calculated using Fragstats, ArcGIS and Excel (McGarigal et al., 2002; Reddy et al. 2013c).

2.6. Accuracy assessment

Field data comprising of 1500 sample points was used to assess the accuracy of thematic map of 2013. Validation of forest cover maps for 1930, 1975, 1985,

1995, 2005 was done based on visual assessment and the temporal consistency of ground control points.

3. RESULTS AND DISCUSSION

The results provide quantitative account of spatial distribution of forest cover, rates of deforestation and trend of forest fragmentation in Eastern Ghats.

3.1 Major changes in forest cover

The spatial database for 1930, 1975, 1985, 1995, 2005 and 2013 showed that the forest cover for the mentioned years are 102213 km^2 (45.6%), 76630 (34.2%), 73416 km^2 (32.7%), 71730 km^2 (32%), 71305 km^2 (31.8%) and 71186 km^2 (31.7%) of the geographical area of Eastern Ghats respectively. The net forest cover decline in Eastern Ghats was found to be 31027 km^2 (30.4% of the total forest) during 1930 to 2013. The forest cover loss during 1930 to 1975 is estimated as 25584 km^2 followed by 3213 km^2 during 1975 to 1985 and 1686 km^2 during 1985 to 1995. The average annual forest loss was estimated as 569 km^2 yr^{-1} during 1930-1975, 321 km^2 yr^{-1} during 1975-1985, 169 km^2 yr^{-1} during 1985-1995, 43 km^2 yr^{-1} during 1995-2005 and 15 km^2 yr^{-1} during 2005-2013. Among the five states (1930-2013), historical loss of forest area was very high in Eastern Ghats of Telangana with forest cover loss of 62.4% of area, followed by 36.9% in Eastern Ghats of Andhra Pradesh, 28.2% in Eastern Ghats of Odisha, 26.3% in Eastern Ghats of Karnataka and 10.3% in Eastern Ghats of Tamil Nadu. The Eastern Ghats of Odisha represents highest forest cover (44.1%), followed by Eastern Ghats of Andhra Pradesh (33.3%) in 2013 (Table 2).

State/ Region	1930	1975	1985	1995	2005	2013
Odisha	43682	34759	32690	31556	31492	31383
Andhra Pradesh	37607	25643	24637	24105	23749	23739
Telangana	3844	1490	1455	1445	1444	1444
Karnataka	4423	3336	3263	3263	3261	3261
Tamil Nadu	12658	11402	11371	11360	11359	11359
Eastern Ghats	102213	76630	73416	71730	71305	71186

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

3.2 Rate of deforestation

The results of study has brought out net rate of deforestation found to be 0.64 during 1935-1975, 0.43 during 1975-1985 and 0.23 during 1985-1995 and 0.06 during 1995-2005.The annual deforestation rate was very least (0.02) during recent period (2005-2013) indicate management intervention in protection of forests (Table 3). Analysis of rate of deforestation in different parts of Eastern Ghats indicates Telangana, Karnataka and Tamil Nadu are successful in protection of forests since 1995 (Figure 2). But, in the past (1930-1975) rate of deforestation was very high in Eastern Ghats of Telangana (Table 4).

Period	1975	1985	1995	2005	2013
1930	0.64	0.60	0.54	0.48	0.44
1975	-	0.43	0.33	0.24	0.19
1985	-	-	0.23	0.15	0.11
1995	-	-	-	0.06	0.04
2005	-	-	-	-	0.02

Table 3. Trend of annual net rate of deforestation in Eastern Ghats

Period	Odisha	Andhra Pradesh	Telangana	Karnataka	Tamil Nadu
1930-1975	0.51	0.85	2.11	0.63	0.23
1975-1985	0.61	0.40	0.24	0.22	0.03
1985-1995	0.35	0.22	0.07	0.00	0.01
1995-2005	0.02	0.15	0.00	0.01	0.00
2005-2013	0.04	0.00	0.00	0.00	0.00
1930-2013	-0.40	0.55	1.18	0.37	0.13

Table 4. Trend of annual net rate of deforestation in different parts of Eastern Ghats

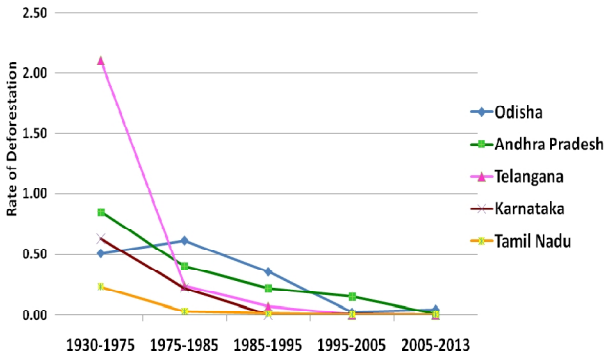

Figure 2. Annual net rate of deforestation in different parts of Eastern Ghats

4.3. Grid wise analysis of forest cover distribution

There are total 8411 grids identified in Eastern Ghats. The number of forest grids varies across the periods ranging from 7050 in 1930, 6097 in 1975, 6041 in 1985, 6005 in 1995 and 6003 in 2013 (Table 5). The spatial data for 1930, 1975, 1995 and 2013 were displayed along with grid wise representation of forest cover in Figures 3,4,5,6. The number of forest grids which are representing more than >20 km^2 have shown major difference due to large scale forest loss.

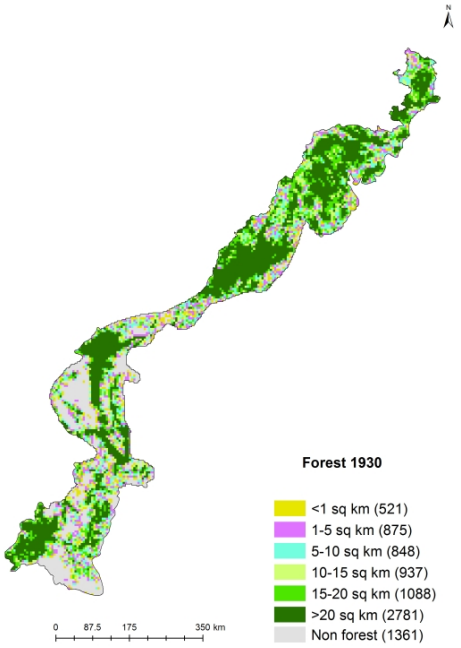

Figure 3. Forest cover map of Eastern Ghats: 1930

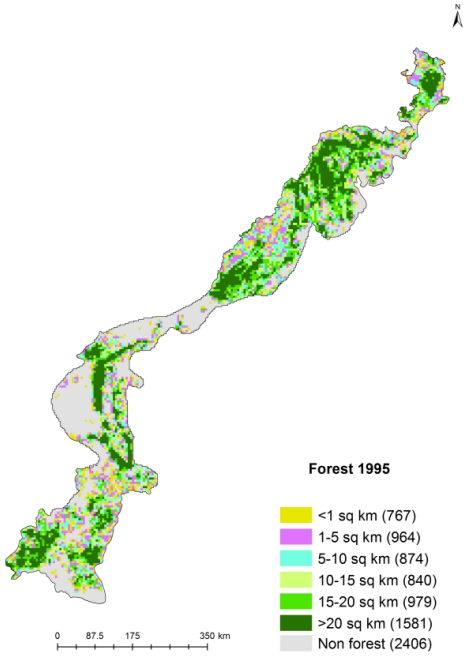

Figure 5. Forest cover map of Eastern Ghats: 1995

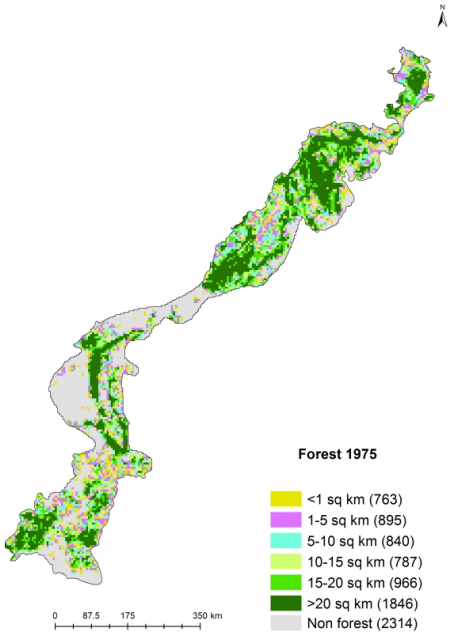

Figure 4. Forest cover map of Eastern Ghats: 1975

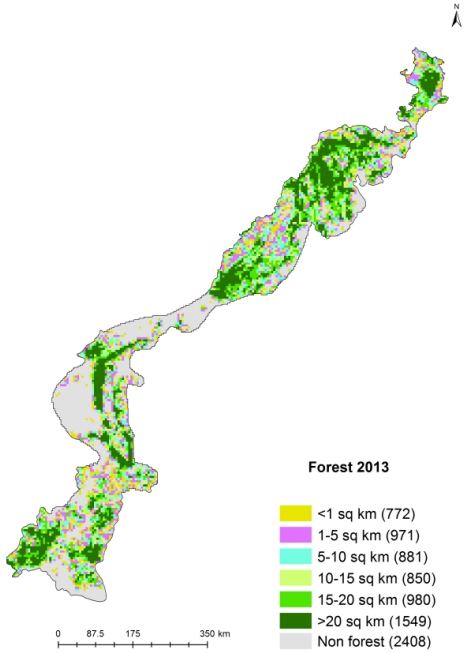

Figure 6. Forest cover map of Eastern Ghats: 2013

Size class (km^2)	1930	1975	1985	1995	2005	2013
<1	521	763	765	767	770	772
1-5	875	895	944	964	971	971
5-10	848	840	863	874	877	881
10-15	937	787	813	840	849	850
15-20	1088	966	979	979	984	980
>20	2781	1846	1677	1581	1552	1549
Total	7050	6097	6041	6005	6003	6003

Table 5. Grid wise distribution of forest cover in Eastern Ghats

4.4. Grid wise analysis of forest cover change

Spatial analysis indicates that highest number of grids has undergone negative changes during 1930-1975, 1975-1985 and 1985-1995 (Table 6). Forest cover change map of 1930-2013 is presented in Figure 7. Total 182 grids have shown gain of forest cover during 1930-2013. The unchanged grids increased from 1930-1975 to 2005-2013. About 5903 grids have not undergone any change in forest cover during 2005-2013, while only 1771 grids are showing indication of unchanged during 1930-1975. Overall 5215 grids have shown negative change during 1930-1975, 1720 grids during 1975-1985, 1396 grids during 1985-1995, 192 grids during 1995-2005 and 100 grids during 2005-2013.

Size class (km^2)	1930-1975	1975-1985	1985-1995	1995-2005	2005-2013
<1	763	792	898	76	100
1-5	2160	779	471	95	0
5-10	1260	126	25	20	0
10-15	585	22	1	1	0
15-20	300	1	1	0	0
>20	147	0	0	0	0
Total	5215	1720	1396	192	100

Table 6. Analysis of grid-wise negative changes in Eastern Ghats

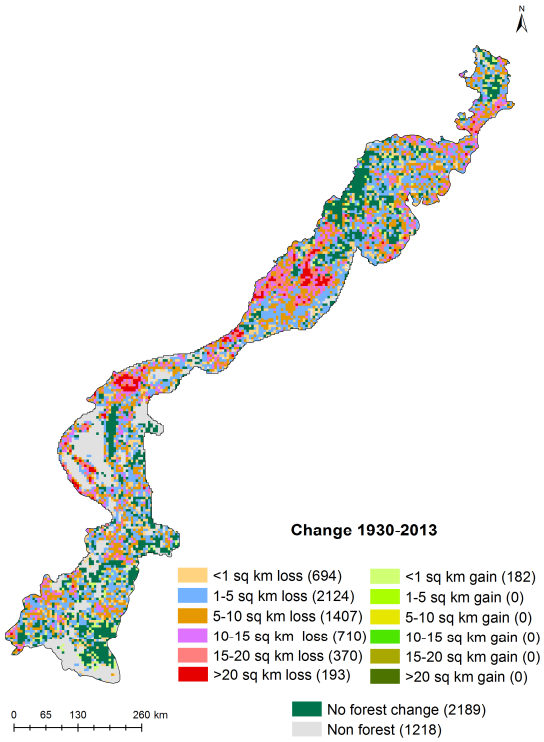

Figure 7. Forest cover change map of Eastern Ghats: 1930 to 2013

4.5. Major changes in forest types

Eastern Ghats has tropical wet evergreen, semi-evergreen, moist deciduous, dry deciduous, dry evergreen and thorn forests. The dominant forest type was dry deciduous which comprises 37192 km^2 (52.2%) of the total forest area of Eastern Ghats, followed by moist deciduous forest (39.2%) and semi-evergreen forest (4.8%) in 2013. A comparison based on spatial extent revealed that significant changes were occurred during 1975-2013. The statistics showed that the large scale negative changes occurred in deciduous forests and semi-evergreen forests compared to wet evergreen forests due to high economic potential and accessibility. About 9.2% of semi-evergreen forests, 7.8% of dry evergreen forests, 7.6% of dry deciduous forests and 6.5% of moist deciduous forests have reduced in spatial extent during 1975-2013 (table 7). The forest type distribution for the year 2013 is presented in Figure 8. Eastern Ghats of Andhra Pradesh has highest area (17044 km^2) under dry deciduous forests, while in Odisha, moist deciduous forests (20894 km^2) are dominant. Wet evergreen forests are found only in Eastern Ghats of Karnataka and Tamil Nadu. Semi-evergreen forests represent an area of 1651 km^2 in Andhra Pradesh followed by Odisha (1355 km^2). Thorn forests cover an area of 1264 km^2 in Tamil Nadu followed by an area of 436 km^2 in Andhra Pradesh. Eastern Ghats of Telangana predominantly consists of dry deciduous forests with an area of 1315 km^2 in 2013.

Forest type	1975	2013	Change area	% of Change
Wet evergreen	370	367	-3	-0.8
Semi-evergreen	3761	3414	-347	-9.2
Moist Deciduous	29850	27908	-1942	-6.5
Dry Deciduous	40256	37192	-3064	-7.6
Dry Evergreen	467	431	-36	-7.8
Thorn	1926	1874	-52	-2.7
Total	76630	71186	-5444	-7.1

Table 7. Areal extent of forest types in Eastern Ghats (area in km^2)

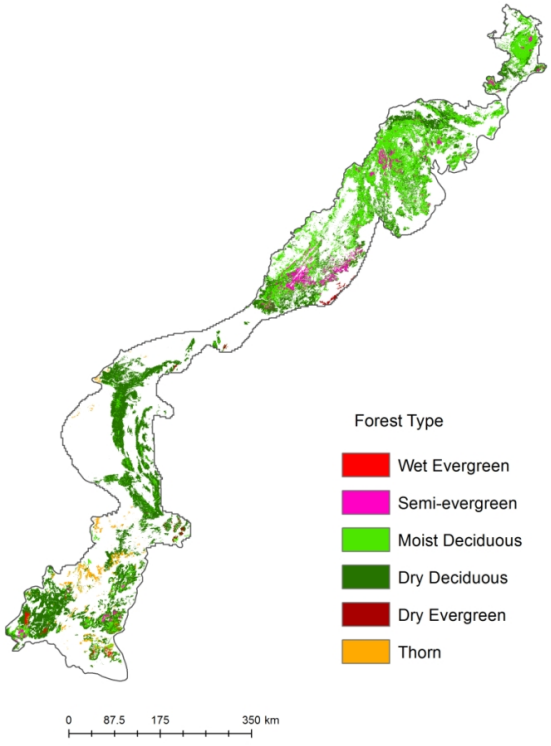

Figure 8. Forest type map of Eastern Ghats: 2013

4.6. Land use in deforested areas

Agriculture occupies highest deforested area, followed by degradation to scrub and conversion to orchards. About 17443 km^2 of agricultural area increased over a period of eight decades due to deforestation (Table 8). An area of 677 km^2 of forest was submerged due to construction of dams during the study period.

Land use	1930-2013	1975-2013	1985-2013	1995-2013	2005-2013
Agriculture	17443	2274	532	147	46
Scrub	16161	3577	1640	668	362
Barren	1412	122	31	9	5
Orchards/ Plantations	893	133	64	14	0
Water	677	56	15	4	1
Grasslands	317	68	27	5	2
Settlements	214	17	6	1	0
Total	37117	6248	2313	848	417

Table 8. Land use in deforested areas (area in km^2)

4.7. Variation in Forest patches

The number of forest patches increased from 2688 (1930) to 13009 (2013). The very largest forest patch in 1930 represents area of 41669 km^2 has reduced to 27800 km^2 by 2013. Thus it is evident that there is a substantial reduction in the size of the very large forest patches due to deforestation. The number of <1 km^2 patches are 1856 in 1930, 12846 in 1975, 11628 in 1985, 11927 in 1995, 11989 in 2005 and 12066 in 2013. It was determining extinction of 1218 small forest fragments (<1 km^2) during 1975 to 1985 due to severe anthropogenic pressure (Table 9).

Patch class (km^2)	1930	1975	1985	1995	2005	2013
<1	1850	12846	11628	11927	11989	12066
1-10	591	641	718	739	742	740
10-50	169	130	132	139	139	141
50-100	30	21	27	26	27	27
100-500	24	14	11	13	13	13
500-1000	11	9	8	6	6	6
1000-2000	2	4	4	5	5	5
2000-5000	4	5	5	5	5	5
>5000	7	6	6	6	6	6
Total	2688	13676	12539	12866	12932	13009

Table 9. Size class distribution of forest patches

4.8. Spatial configuration of forest

The mean patch size confirms severe change in area of 38 km^2 in 1930 to 5.5 km^2 by 2013. Largest patch index of forest landscape has been estimated as 18.6 and 12.4 in 1930 and 2013 respectively (Table 10).

Landscape metrics	1930	1975	1985	1995	2013
No. of forest patches	2688	13676	12539	12866	13009
Patch density index (per 100 ha)	0.01	0.1	0.1	0.1	0.1
Mean Patch size (km^2)	38.0	5.6	5.9	5.6	5.5
Largest patch index (%)	18.6	14.3	13.2	12.7	12.4
Edge Density	2541.2	1175.5	1133.5	1152.7	1132.2
Landscape shape index	219.1	292.3	305.1	312.3	314.7

Table 10. Change in spatial pattern of forest in 1930, 1960, 1975, 1985, 1995 and 2013

4.9. Accuracy assessment

Accuracy assessment was made for the classified map of 2013. The overall classification accuracy of the forest cover map of 2013 was 92.8% and kappa value was 0.89. The accuracy of previous years has been evaluated visually based on the temporal consistency of field sample points.

5. Conclusions

The results exhibit a large scale forest loss between 1930 to 1975 and 1975 to 1985 in the Eastern Ghats. The decline in overall rate of deforestation in recent years indicates increased measures of conservation. However, forest degradation and small-scale deforestation still continue for the need of fuel wood, fodder, timber products and shifting cultivation in parts of Eastern Ghats. The geospatial database generated will prove to be a comprehensive baseline for the long term conservation planning and management of natural resources of Eastern Ghats.

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