Earth Observation based Forest Monitoring and Conservation in Biodiversity Hotspots of South Asia

C. Sudhakar Reddy[1*], K.V. Satish[1], S. Vazeed Pasha[1], K.R.L. Saranya[1], C.S. Jha[1], P.G. Diwakar[1,2], V.K. Dadhwal[1,3], P.V.N. Rao[1] and Y.V.N. Krishna Murthy[1]

[1]National Remote Sensing Centre, Indian Space Research Organisation, Balanagar, Hyderabad, Telangana - 500 037, India

[2]Indian Space Research Organisation, Antariksh Bhavan, New BEL Road, Bengaluru, Karnataka - 560 231, India

[3]Indian Institute of Space Science and Technology, Valiamala, Thiruvananthapuram, Kerala - 695 547, India

*Email: drsudhakarreddy@gmail.com

KEYWORDS: Forest type, Deforestation, Fragmentation, Fire, Hotspots.

ABSTRACT: Biodiversity hotspots are large regions where an exceptional concentration of biodiversity and endemism exists. Biodiversity hotspots were first proposed set of global priority regions for conservation. The role of earth observation data in biodiversity monitoring was recognized in international biodiversity targets. Earth observation data provides unique information on biodiversity with reference to composition, structure and function across the scales. This study presents state of art earth observation based analysis for forest biodiversity and conservation in 'biodiversity hotspots' of seven South Asian countries. The spatial indicators of biodiversity have been derived from multi-temporal satellite data in terms of land cover, forest cover, forest type, forest fragmentation and fire occurrences. Forest cover change analysis indicates highest loss (35.8%) of forest area in the Western Ghats-Sri Lanka hotspot followed by Indo-Burma (parts of Bangladesh, Andaman and North East), Himalayas (parts of India, Nepal, Bhutan, Pakistan and Afghanistan) and Sundaland (Nicobar) over last eight decades. Forest fragmentation had major spatial variation across the biodiversity hotspots. Fire monitoring specifies the widespread occurrence of fires in deciduous forests of the Indo-Burma and the Western Ghats from 2005 to 2016. Analysis of forest cover change from 2005 to 2014 indicates increasing conservation effectiveness in the Himalayas and Western Ghats-Sri Lanka. Currently, Indo-Burma hotspot is undergoing a significant rate of deforestation and degradation with higher extents of perforated forests and annual fires. The results demonstrate ensured continuity of earth observations as a key requirement for an understanding of biodiversity change and to achieve sustainable development goals.

1. INTRODUCTION

The sustainable forest management necessitates resource data that are accurate and continuously updated (Running & Bauer, 1996). The term 'biodiversity hotspot' was coined by Myers (1989) and identified 18 geographical regions as conservation priorities because they contain a large number of endemic species that were facing significant threats of habitat loss. The term hotspot is applied to a geographical area that ranks, particularly rich in species, levels of endemism, threatened species and intensity of a threat or some combination of these attributes. Myers and Conservation International, later revised estimates of remaining primary habitat and defined the hotspots formally as biogeographic regions with >1500 endemic vascular plant species and ≤30% of original primary habitat (Myers et al., 2000). But this criterion is ambiguous, both for the number of species and for the historical extent of the original vegetation cover. Currently Conservation International has identified 36 areas as global biodiversity hotspots. Precisely biodiversity hotspots maintain 77% of all endemic plant species and 43% of endemic vertebrate species (Marchese, 2015; http://www.conservation.org). Even though biodiversity hotspots are key conservation areas, information on their vegetation diversity, long-term changes in forests, fragmentation and disturbances is currently scanty. 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 on the biodiversity hotspots of South Asia.

Earth Observations provides globally consistent, repetitive measurements of earth surface conditions relevant to land cover monitoring. There is an increasing use of remote sensing data sources for land cover change detection in the recent decades. Information generated through satellite remote sensing useful to measure conservation interventions across spatial scales (Pettorelli et al. 2014). It is important to know the clearing of a natural forest or a plantation which has very different implications on the native biodiversity (Margano et al. 2014). Park et al. (1983) suggested a one-year interval to detect forest to non-forest changes, a three to five-year interval to monitor non-forest to the successional shrub stage and another five to ten years to detect the consecutive establishment of a forest cover. Landscape

composition is primarily concerned with land cover types whereas configuration refers to fragmentation of habitats. In fragmentation of forests the patch reduces in size, changes in shape, increases edges and leads to increases in isolation. Since biodiversity hotspots are closely associated with the loss of the original habitats, use of multi-temporal remote sensing data and GIS can provide accurate information on land cover, fragmentation and habitat suitability which can be used for estimating the extent of damage to the original vegetation of the region (Roy, 2016). In this context, monitoring and quantification of forests are essential for the conservation prioritization in biodiversity hotspots.

Roy et al. (2012) carried out landscape level characterization of fragmentation, disturbance and biological richness for the Western Ghats, Andaman & Nicobar Islands and Indian part of the Himalayas. Studies on long-term forest cover change have quantified deforestation in the Western Ghats, Sri Lanka, Andaman & Nicobar Islands, Himalayan part of India, Nepal, Bhutan and Afghanistan (Reddy et al. 2016a,b,c,d,e,f; Reddy & Saranya, 2017; Reddy et al. 2017). South Asia is one of the regions at the forefront of global population and economic growth. The South Asian Association for Regional Cooperation (SAARC) is the regional intergovernmental organization and the geopolitical union of countries in South Asia. It comprises the eight countries, i.e. India, Bangladesh, Bhutan, Nepal, Pakistan, Afghanistan, Sri Lanka and Maldives. South Asia represents five world's biodiversity hotspots, i.e. Himalayas (parts of India, Bhutan, Nepal, Pakistan, Afghanistan), Indo-Burma (parts of Andaman Islands, North East India, Eastern parts of Bangladesh), Western Ghats-Sri Lanka, Sundaland (Nicobar Islands) and mountains of Central Asia (northernmost alpine zone of Afghanistan).

The main objective of this study is to generate consistent information on the extent of the past and actual forest cover which exists in the 'biodiversity hotspots' of South Asia. The present study has analysed forest types, land cover, current levels of forest fragmentation and historical fire occurrences. This study covers entire Western Ghats-Sri Lanka, major Himalayan range (excluding parts of China and Myanmar), part of Indo-Burma and Nicobar Islands of Sundaland. Even though the Andaman, North East India, Eastern parts of Bangladesh are not representative of the entire Indo-Burma, the results may provide an important perception into conservation planning of the whole region.

2. MATERIAL AND METHODS

The spatial datasets were sourced from national carbon project of India. Forest cover was mapped based on topographical maps and satellite remote sensing data to quantify the changes in South Asia's natural forests over the last eight decades (Reddy et al. 2015; Reddy et al. 2016a,b,c,d,e,f; Reddy & Saranya, 2017; Reddy et al. 2017). This database was prepared using topographical maps based on survey during 1920-1940 (http://www.lib.utexas.edu/maps/ams/) and multi-temporal data from the sensors, Landsat Multispectral Scanner (MSS) (1972-1977), Resourcesat-1 Advanced Wide Field Sensor (AWiFS) (2005-2006), Resourcesat-1 Linear Imaging Self-Scanning Sensor III (LISS III) (2005-2006), Resourcesat-2 AWiFS (2013-2014) and Landsat 8 Operational Land Imager data (OLI) (2014). Landsat data were downloaded from the USGS archives (http://earthexplorer.usgs.gov). Indian remote sensing data was procured from National Remote Sensing Centre, Indian Space Research Organisation. Multi-source datasets belonging to 1920-1940, 1972-1977, 2005-2006 and 2013-2014 has been referred to as 1930, 1975, 2005 and 2014 periods respectively. These datasets have been homogenized to facilitate comparisons across their land cover and forest type classes for South Asian countries. The visual interpretation technique was used to determine the forest cover changes. In this study forest is defined as 'land spanning more than 1 ha, dominated by indigenous tree species with an overstorey canopy cover of greater than 10%'.

This study has analysed compositional indicators of biodiversity, i.e. land cover, forest types and forest area change. The annual rate of forest cover change was calculated using compound interest formula (Puyravaud, 2003). Forest fragmentation is related to a structural indicator which determines forest spatial pattern. In this study, forest cover maps of 1930, 1975, 2005 and 2014 were used to analyse the trends in forest fragmentation. Landscape fragmentation analysis tool (LFT v2) was used for calculating the intensity of forest fragmentation (Vogt et al. 2007). The fragmentation classes identified in increasing order of fragmentation are; Core 3/large core, Core 2/medium core, Core 1/ small core, Perforated, Edge and Patch. To account the historical fire incidences, MODIS (both Aqua and Terra) active fire products were downloaded from the NASA Fire Information for Resource Management System data (https://firms.modaps.eosdis.nasa.gov/download/request.php). Fire location points with a brightness temperature value of >320 K and confidence level of >70% were retained. Fire location points of 2005-2016 were clipped with forest cover map.

3. RESULTS AND DISCUSSION

The present study has resulted in the assessment of the forest types, land cover distribution, forest cover changes, deforestation rates, the spatial pattern of forest fragmentation and identifying locations of historical fire occurrences. The indicators measured for forest resources, i.e. forest types and land cover, deforestation, forest fragmentation and forest fires have relevance to biodiversity conservation.

Forest type and land cover

Land cover is the basis for understanding the extent and type of forest species information across the landscape. Of the total hotspot area within the South Asia, forest constitutes 43% of the geographical area (Figure 1). Countrywide distribution of forest area within biodiversity hotspots is shown in Figure 2. The classification results for forest type and other land cover distribution for 2014 are summarized with the consistent classification scheme (Table 1). Among the four hotspots, the Himalayas are home to the world's highest mountains and represents high land cover diversity (Figure 3). The Nicobar Islands have the highest forest cover with reference to its geographical area, followed by Indo-Burma, Western Ghats-Sri Lanka and Himalayas. The predominant forest type in the Himalayas is Himalayan moist temperate forest followed by subtropical broad-leaved hill forest and subtropical Pine forest. Temperate forests and subalpine forests occur in the high-altitude parts of the Himalayas, where the upper forest limit usually lies between 3500m and 4200m. The tropical moist deciduous forest is the dominant forest type of Western Ghats-Sri Lanka followed by tropical semi evergreen forest and tropical wet evergreen forest (Figure 4).

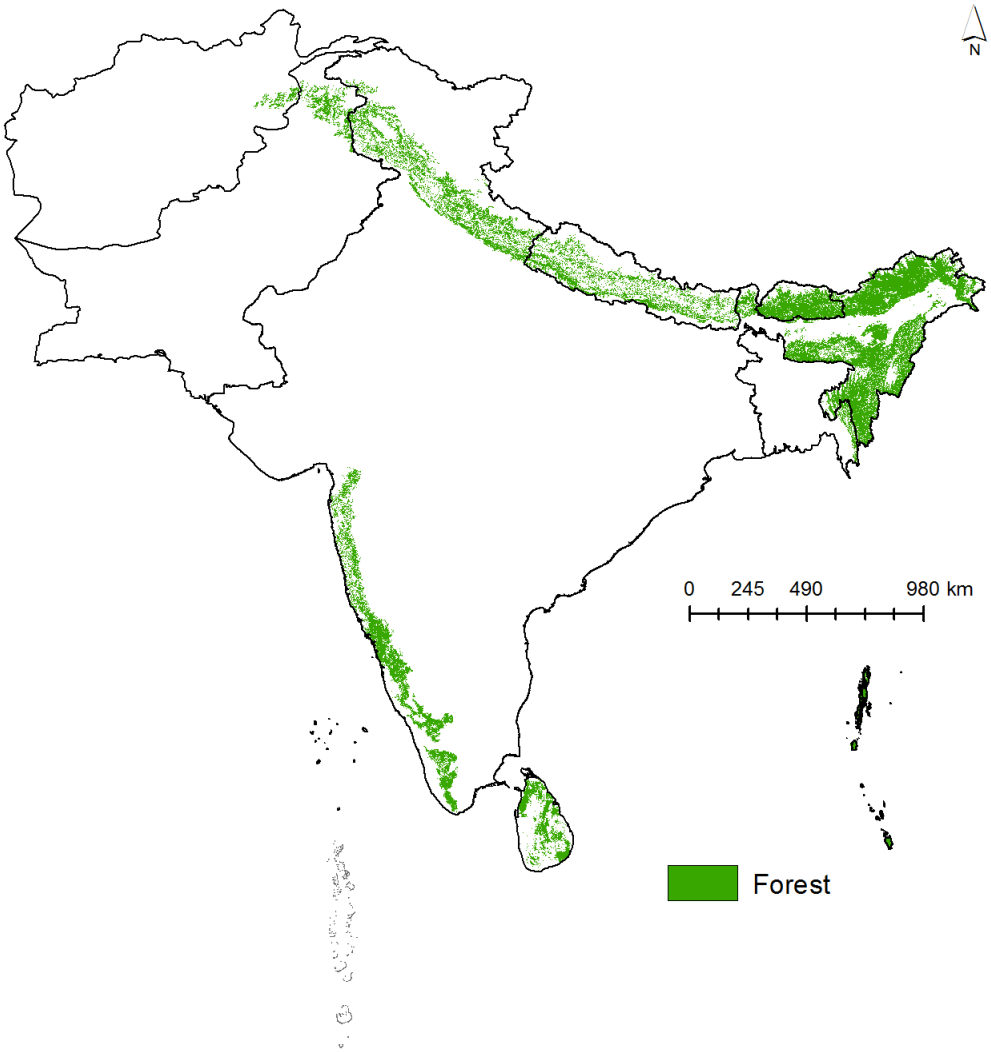

Figure 1. Forest cover map of Biodiversity hotspots - 2014

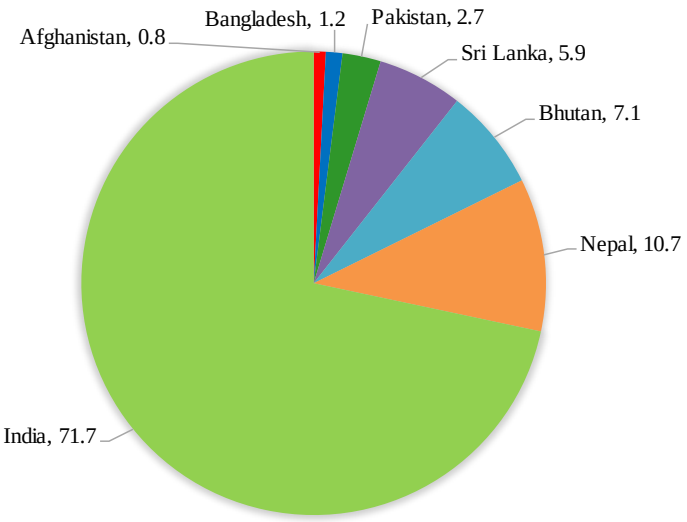

Figure 2. Country level distribution of forest area within biodiversity hotspots

Table 1. Forest type and other land cover distribution within South Asia (area in km^2)

Sl.no.	Biodiversity Hotspot	Part of Himalayas		Western Ghats-Sri Lanka		Part of Indo-Burma		Part of Sundaland (Nicobar)		Total Hotspots area	
	Class	Total	% of area	Total	% of area	Total	% of area	Total	% of area	% of area	Total
I	Forest										
1	Tropical Wet evergreen forest	8529	1.8	22875	11.7	16392	9.2	1358	73.8	49154	5.7
2	Tropical Dry evergreen forest			451	0.2					451	0.1
3	Subtropical Broad-leaved hill forest	33880	7.0			4896	2.8			38776	4.5
4	Subtropical Dry evergreen forest	2754	0.6							2754	0.3
5	Montane Wet Temperate forest	13556	2.8	1540	0.8	1480	0.8			16576	1.9
6	Tropical Semi evergreen forest	4018	0.8	24406	12.4	16111	9.1			44537	5.2
7	Tropical Moist deciduous forest	26836	5.5	29030	14.8	53130	29.9	2	0.1	108998	12.7
8	Tropical Dry deciduous forest	1621	0.3	5002	2.6	2482	1.4			9104	1.1
9	Tropical Thorn forest	253	0.1							253	0.03
10	Subtropical Pine forest	31487	6.5			640	0.4			32127	3.7
11	Himalayan Moist Temperate forest	40391	8.3			17				40408	4.7
12	Himalayan Dry Temperate forest	17558	3.6							17557	2.0
13	Subalpine forest	8128	1.7							8129	0.9
14	Littoral and swamp forest			143	0.1	675	0.4	3	0.2	821	0.1
	Sub total	189011	39.1	83447	42.6	95823	53.9	1363	74.0	369645	43.0

II	Non-forest										
15	Scrub	54989	11.4	11140	5.7	17744	10.0	136	7.4	84009	9.8
16	Grasslands	39115	8.1	2084	1.1	1561	0.9	121	6.6	42880	5.0
17	Agriculture	73117	15.1	43518	22.2	33312	18.7	5	0.3	149953	17.4
18	Plantations / Orchards	12287	2.5	46286	23.6	18188	10.2	65	3.5	76827	8.9
19	Barren land	68790	14.2	2194	1.1	2284	1.3	60	3.3	73328	8.5
20	Water bodies / Wetlands	3747	0.8	4004	2.0	7296	4.1	43	2.3	15090	1.8
21	Snow	41271	8.5							41271	4.8
22	Settlements	1516	0.3	3436	1.8	1571	0.9	48	2.6	6571	0.8
	Sub total	294833	60.9	112663	57.4	81956	46.1	478	26.0	489929	57.0
	Grand total	483845	100.0	196110	100.0	177778	100.0	1841	100.0	859574	100.0

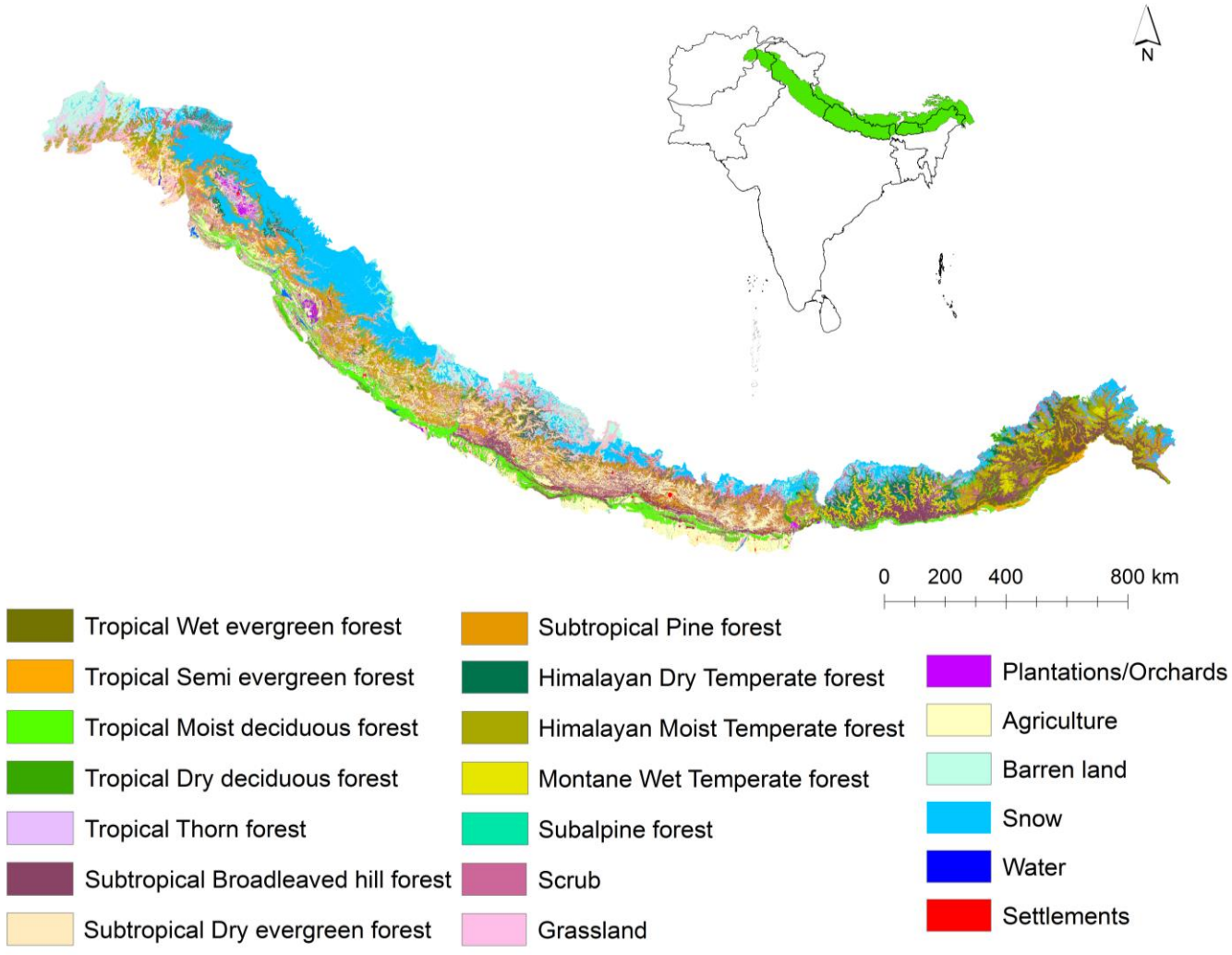

Figure 3. Forest type and land cover map of Himalayas

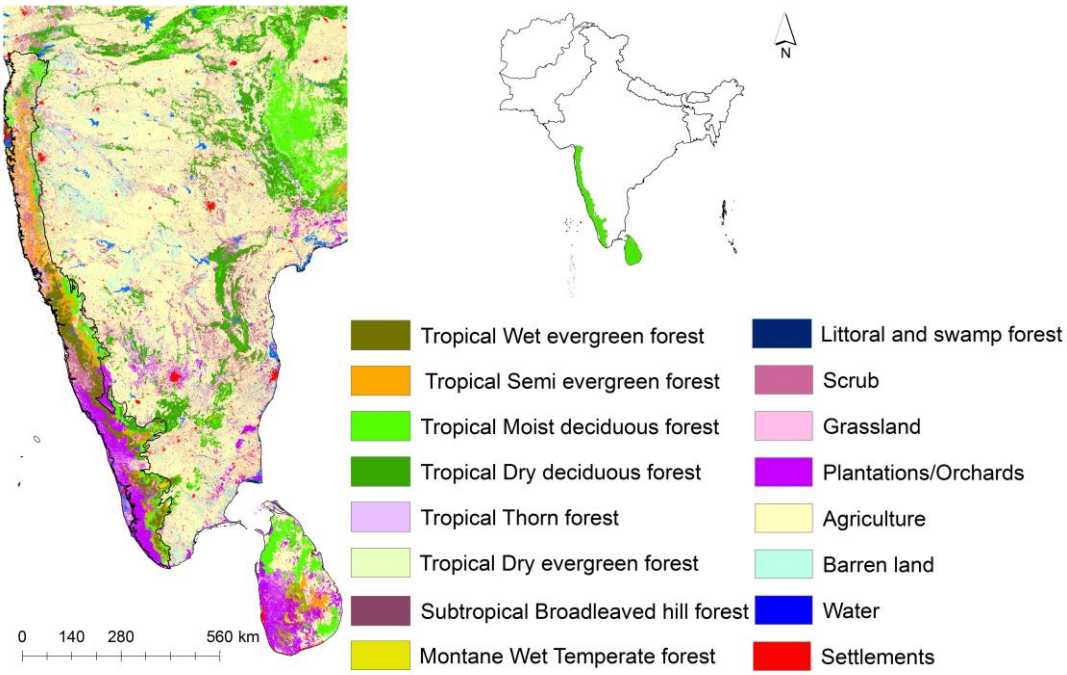

Figure 4. Forest type and land cover map of Western Ghats-Sri Lanka and surroundings

Monitoring of deforestation

Based on the forest classification data of the four periods in the South Asian region, the forest area is shown in Table 2. The forest cover change was very low during 2005-2014 indicates increased conservation measures. In the period of 1930–1975, the deforestation trend was different from that of the recent period. Between 1930 and 2014, the area coverage of forests had been reduced from 502264 km^2 to 369644 km^2. The loss of total forest over the course of eight decades was about 26.4% (132620 km^2) for the entire hotspot area of South Asia. Total net forest cover loss in the Western Ghats-Sri Lanka was highest and calculated as 35.8% from 1930 to 2014, followed by part of Indo-Burma (24.7%), Himalayas (22.3%) and part of Sundaland (18.8%). The majority of deforestation was attributed to the expansion of agricultural fields, shifting cultivation, plantations and degradation to scrub. The overall rate of deforestation from 1930-1975 was high in the South Asian hotspot area followed by 1975-2005 and 2005-2014. The annual net rate of deforestation was 0.51% for the Himalayas during 1930-1975, followed by 0.08% during 1975-2005. The annual net rate of deforestation for Western Ghats-Sri Lanka was about 0.91% from 1930-1975 and 0.11% from 1975-2005. The annual net rate of deforestation from 2005-2014 is almost nil for the Himalayas and Western Ghats-Sri Lanka. The calculated annual rate of forest cover loss for Indo-Burma from 1930-1975 was 0.49%. The annual net rate of deforestation was estimated as 0.16% for the three-decade period (1975-2005). The rate of forest loss was 0.18% between 2005-2013 higher to the rate of 1975-2005. The annual rate of deforestation was very high (0.55%) in Nicobar from 1975-2005 due to anthropogenic pressures and tsunami of 2004 which was declined to 0.05% from 2005-2014.

Table 2. Distribution of Forest cover (area in km^2)

Sl.no.	Hotspot/Country	1930	1975	2005	2014
I	Himalayas				
1	Afghanistan	3472	3106	3098	3094
2	Pakistan	11526	9885	9868	9865
3	India	124746	111547	110460	110453
4	Nepal	76710	42487	39426	39392
5	Bhutan	26896	26269	26137	26207
	Sub total	243350	193294	188989	189011

II	Western Ghats-Sri Lanka				
1	Western Ghats	95090	63123	61511	61511
2	Sri Lanka	34958	23217	21954	21936
	Sub total	130048	86340	83465	83447
III	Indo-Burma				
1	Bangladesh	7262	5284	4555	4251
2	North East	114074	91366	87562	86528
3	Andaman	5851	5471	5249	5044
	Sub total	127187	102121	97366	95823
IV	Sundaland				
1	Nicobar	1679	1615	1369	1363
	Grand total	502264	383370	371189	369644

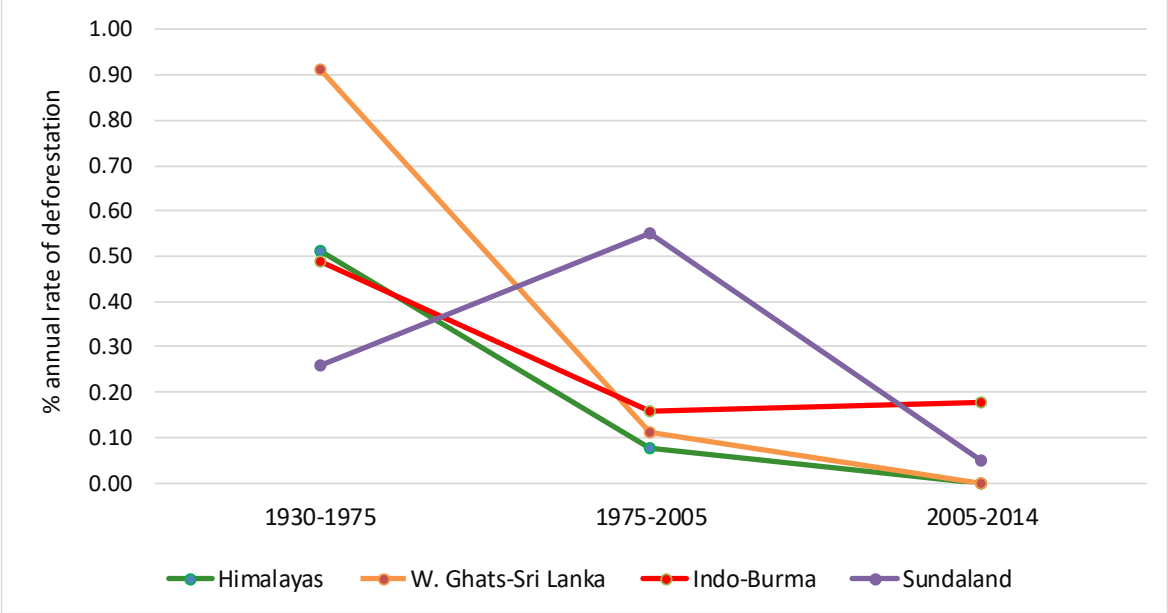

Figure 4. Trend of annual net rate of deforestation in Biodiversity hotspots

Fragmentation analysis

Among the four hotspots, Nicobar part of Sundaland has highest large core forest (86.7%), followed by Western Ghats-Sri Lanka (77.3%), Indo-Burma, (73.6%) and Himalayas (69.1%). As compared to other hotspots Himalayas highest fragmentation with more edge forests (15.3%) and patch (1.6%) forests. Whereas, Western Ghats-Sri Lanka have 14.4% of the area under edge forests and 0.5% under patch forests. Indo-Burma has 11.6% of the area under the edge and 1.3% of the area under patch forest. Indo-Burma has a highest perforated forest area (11.4%), followed by 6% in the Himalayas, 5.1% in the Western Ghats-Sri Lanka and 0.8% in Sundaland. Table 3 shows the results of the landscape level forest fragmentation in different parts of hotspots. The percentages of the total area of each fragmentation category have been provided. It can be found that 88.1% and 40.2% of the forest area belongs to the large core forest in Bhutan and Nepal respectively. Compared to Sri Lanka, Western Ghats represents highest large core forest. Within the Indo-Burma, Andaman had 86.4% of the area under large core, while Bangladesh had 6.3% of the area only. The presence of more perforated forests is a potential indicator of prevailing shifting cultivation. Increasing levels of habitat fragmentation create barriers to wildlife movement and complicate the ecosystem management at the regional and landscape levels. Fragmentation is also served an indicator of changes in carbon stocks of forests.

Table 3. Forest fragmentation analysis across Biodiversity hotspots: 2014

Sl.no.	Hotspot/Country	Patch	Edge	Perforated	Small Core	Medium Core	Large Core
I	Himalayas						
1	Afghanistan	1.0	17.4	9.6	6.4	1.7	63.8
2	Pakistan	0.6	16.9	1.8	3.0	1.2	76.5
3	India	1.1	12.9	4.0	2.0	0.9	79.1
4	Nepal	4.0	30.5	14.7	7.9	2.6	40.2
5	Bhutan	0.2	8.6	2.6	0.5	0.1	88.1
II	Western Ghats-Sri Lanka						
1	Western Ghats	0.4	14.7	3.6	1.7	0.8	78.8
2	Sri Lanka	0.6	13.5	9.2	2.6	0.9	73.3
III	Indo-Burma						
1	Bangladesh	1.1	28.2	56.8	6.6	0.9	6.3
2	North East	1.4	10.9	9.9	1.5	0.4	75.9
3	Andaman	0.3	9.9	2.2	0.8	0.4	86.4
IV	Sundaland						
1	Nicobar	0.6	9.9	0.8	1.3	0.7	86.7

Monitoring of Forest fires

Hotspot wise analysis indicates Indo-Burma has the highest number of fire incidences, followed by the Himalayas and Western Ghats-Sri Lanka. There are no fire incidences in Nicobar due to the predominance of wet evergreen forests. Fire monitoring indicates the ubiquitous occurrence of fires in tropical moist and dry deciduous forests of the Indo-Burma and the Western Ghats from 2005 to 2016. Distribution of forest fire locations was shown in figure 5. A number of fire incidences in the forests of the hotspots were higher during 2009. Annual count of forest fire incidences across hotspots for 2005 to 2016 is presented in table 3. Fire disturbances can directly result in carbon emissions and affect fire-sensitive species, regeneration and may lead to invasion by alien species and insect infestation.

Table 4. Fire incidences in Biodiversity hotspots of South Asia: 2005-2016

Year	Himalayas	W. Ghats-Sri Lanka	Indo-Burma	Total fires in Hotspots area	% of fire incidences
2005	1747	734	10813	13294	8.2
2006	1990	549	15063	17602	10.8
2007	1913	704	12300	14917	9.2
2008	2261	449	8379	11089	6.8
2009	3716	938	14336	18990	11.7
2010	2130	519	12543	15192	9.3
2011	1239	614	7775	9628	5.9
2012	3430	980	11090	15500	9.5
2013	1596	688	9131	11415	7.0
2014	2079	637	10269	12985	8.0
2015	1124	372	8821	10317	6.3
2016	3676	743	7220	11639	7.2
Grand total	26901	7927	127740	162568	100.0

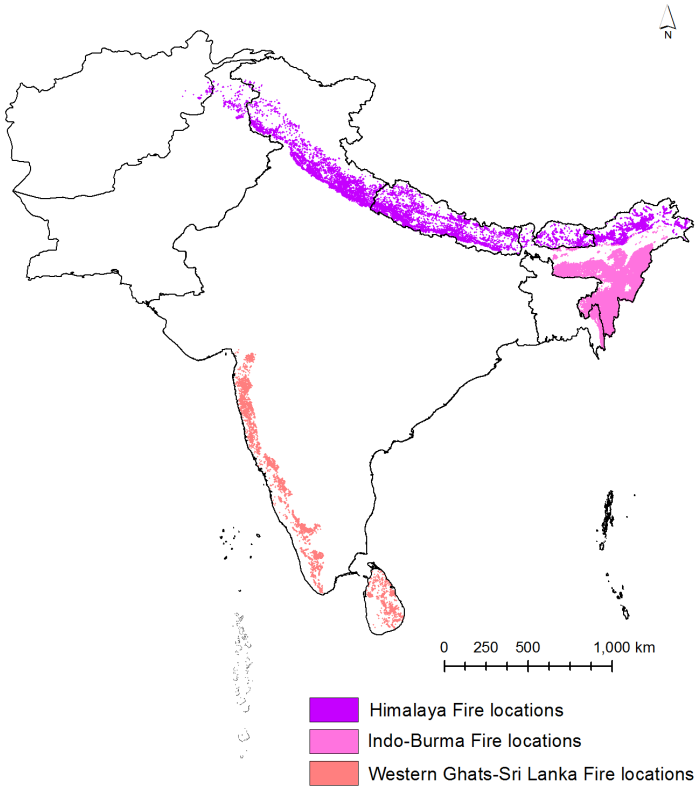

Figure 5. Distribution of forest fire locations in Biodiversity hotspots: 2005-2016

Conclusions

On the basis of earth observation data, we have analyzed the historical changes in forests, the pattern of forest fragmentation and fire occurrences in the biodiversity hotspot regions of South Asia. Trends over the South Asian biodiversity hotspots indicate a significant decrease in forest area over last eight decades. The comparison revealed that the extent of the forest loss was highest in the Western Ghats-Sri Lanka hotspot during the study period. At the country level, Himalayas of Nepal is having more fragmentation level due to a higher extent of edge forests. On the contrary, Indo-Burma part of the study area has high perforated forest and undergoing significant forest loss associated with a very high number of fire incidences. Currently, Himalayan and Western Ghats-Sri Lankan hotspots show conservation effectiveness for controlling deforestation. Earth observation has great potential to generate continuous measures of natural resources over the biodiversity hotspots which will support strategic conservation planning.

Acknowledgments

The present study has been carried out as part of ISRO's National Carbon Project. We gratefully acknowledge ISRO-DOS Geosphere-Biosphere Programme for supporting this research.

REFERENCES

http://www.conservation.org

http://earthexplorer.usgs.gov

https://firms.modaps.eosdis.nasa.gov/download/request.php.

http://www.lib.utexas.edu/maps/ams/

Marchese, C., 2015. Biodiversity hotspots: a shortcut for a more complicated concept. Global Ecology and Conservation, 3, pp 297e309.

Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F., Hansen, M.C., 2014. Primary forest cover loss in Indonesia over 2000–2012. Nature Climate change, DOI: 10.1038/NCLIMATE2277.

Myers, N., 1989. Threatened biotas: “Hotspots” in tropical forests, Environmentalist 8, pp 1-20.

Myers, N. et al., 2000. Biodiversity hotspots for conservation priorities. Nature 403, pp. 853-858.

Park, A.B., Houghton, R.A., Hicks, G.M., Peterson, C.J., 1983. Multitemporal change detection techniques for the identification and monitoring of forest disturbances. Proc. 17th Int. Symp. on Remote Sensing of Environment, Michigan, pp. 77-97.

Pettorelli N, Safi K, Turner, W., 2014. Satellite remote sensing, biodiversity research and conservation of the future. Phil. Trans. R. Soc. B 369: 20130190. http://dx.doi.org/10.1098/rstb.2013.0190

Puyravaud, J.P., 2003. Standardizing the calculation of the annual rate of deforestation. Forest Ecology and Management 177, pp. 593-596.

Reddy, C.S., Jha, C.S., Diwakar, P.G., Dadhwal, V.K., 2015. Nationwide classification of forest types of India using remote sensing and GIS. Environmental Monitoring and Assessment, 187(12), pp. 777.

Reddy, C.S., Jha, C.S., Dadhwal, V.K., Harikrishna, P., Pasha, S.V., Satish, K.V., Dutta, K., Saranya, K.R.L., Rakesh, F., Rajashekar, G., Diwakar, P.G., 2016a. Quantification and monitoring of deforestation in India over eight decades (1930-2013). Biodiversity and Conservation 25, pp. 93-116.

Reddy, C.S., Pasha, S.V., Jha, C.S., Diwakar, P.G., Dadhwal, V.K., 2016b. Development of national database on long-term deforestation (1930-2014) in Bangladesh. Global and Planetary Change 139, pp. 173-182.

Reddy, C.S., Satish, K.V., Jha, C.S., Diwakar, P.G., Krishna Murthy, Y.V.N., Dadhwal, V.K., 2016c. Development of deforestation and land cover database for Bhutan (1930-2014). Environmental Monitoring and Assessment 188, pp. 658. DOI: 10.1007/s10661-016-5676-6.

Reddy, C.S., Manaswini, G., Jha, C.S., Diwakar, P.G., Dadhwal, V.K., 2016d. Development of national database on long-term deforestation in Sri Lanka. Journal of Indian Society of Remote Sensing DOI :10.1007/s12524-016-0636-8.

Reddy, C.S., Jha, C.S., Dadhwal, V.K., 2016e. Assessment and monitoring of long-term forest cover changes (1920-2013) in Western Ghats biodiversity hotspot. Journal of Earth System Science 125(1), pp. 103-114.

Reddy, C.S., Satish, K.V., Pasha, S.V., Jha, C.S., Dadhwal, V.K., 2016f. Assessment and monitoring of deforestation and land-use changes (1976-2014) in Andaman and Nicobar Islands, India using remote sensing and GIS. Current Science 111(9), pp. 1492-1499.

Reddy, C.S., Saranya, K.R.L., 2017. Earth observation data for assessment of nationwide land cover and long-term deforestation in Afghanistan. Global and Planetary Change 155, pp. 155-164.

Reddy, C.S., Pasha, S.V., Satish, K.V., Saranya, K.R.L., Jha, C.S., Krishna Murthy, Y.V.N., 2017. Quantifying nationwide land cover and historical changes in forests of Nepal (1930-2014): Implications on forest fragmentation. Biodiversity and Conservation. DOI 10.1007/s10531-017-1423-8.

Roy, A., 2016. Identification and protection of terrestrial global biodiversity hotspots: progress and challenges. Research and Reports in Biodiversity Studies 5, pp. 15-27.

Roy, P.S., Kushwaha, S.P.S., Murthy, M.S.R., Roy, A., Kushwaha, D., Reddy, C.S. et al., 2012. Biodiversity characterisation at landscape level: national assessment. Indian Institute of Remote Sensing, Dehra Dun. pp. 1-254.

Running, T., Bauer, M. E., 1996. Change detection in forest ecosystems with remote sensing digital imagery. Remote sensing Reviews, 13, pp. 207-234.

Vogt, P. et al. (2007). Mapping spatial patterns with morphological image processing. Landscape Ecology 22(2), 171-177.