Assessment and monitoring of deforestation and land-use changes (1976–2014) in Andaman and Nicobar Islands, India using remote sensing and GIS

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Andaman and Nicobar Islands are part of Indo-Burma and Sundaland global biodiversity hotspots. This study provides spatial information on forest types, deforestation and associated land-use changes in Andaman and Nicobar Islands during 1976 to 2014. Satellite remote sensing and geographical information system (GIS) techniques have been used to analyse forest cover changes, rate of deforestation and to map patterns of forest cover distribution in Andaman and Nicobar Islands. Classified maps prepared for 1976, 1989, 1993, 2000, 2006 and 2014 indicate that the forest cover accounts for an area of 7086.1 (85.9%), 6969.2 (84.5%), 6941.1 (84.1%), 6934.6 (84.1%), 6617.8 (80.2%) and 6407.3 sq. km (77.7%) respectively. It was found that the area occupied by evergreen forests is very high, consisting of 3065.1 sq. km (32.2%) followed by semi-evergreen (1531.6 sq. km), moist deciduous (1133.4 sq. km) and mangrove forest (677.2 sq. km) in 2014. There is large-scale deforestation in Andaman and Nicobar Islands which has been estimated as 678.8 sq. km during the last four decades. The loss of forest cover is high in moist deciduous forests which has been estimated as 312.2 sq. km in Andaman Islands; whereas in Nicobar Islands, the highest loss was found in evergreen forests (244.6 sq. km). The rate of deforestation in Andaman and Nicobar Islands was high during 2000–2006 (0.78) indicating major influence of the tsunami of 26 December 2004. The annual rate of deforestation from 2006 to 2014 was 0.40. The geospatial analysis of areas of forest cover change provides baseline information for restoration and conservation planning.

Keywords: Andaman and Nicobar Islands, deforestation, forest, GIS, remote sensing, land use.

DEFORESTATION is a global environmental problem and has multifaceted links with other issues such as biodiversity, human population, air and water quality, the carbon cycle and climate change[1]. The significance of forests in earth's functioning is reflected in the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity[2]. The decline of natural forest resources advocates that conservation efforts should maintain a focus on sustainable forest management practices. The ever-growing human population is considered as a major threat to forests. Agricultural expansion, plantation development, logging, mining, industry, urbanization and road construction are primarily responsible for deforestation in tropical regions[3]. The total yearly uptake of carbon by terrestrial ecosystems is 2.9 Pg per year, but land-use and land-cover change acts as a source of 2.2 Pg carbon per year[4]. New simulations have shown that anthropogenic land-cover change should be considered a first-order climate forcing[1]. Islands which constitute less than 5% of earth's land mass are at risk due to natural disasters, unsustainable development and invasive alien species being compounded by the serious threat of climate change[5].

There is an increasing awareness that forest monitoring is required at national, regional and global levels. Satellite remote sensing data is useful because of its synoptic view, repetitive coverage and real-time data acquisition. The satellite imageries enable to accurately map various land use categories which is very essential for monitoring change. Remote sensing and geographical information system (GIS) approaches could form part of a conservation and decision support management system that informs management actions on the ground for prioritizing efforts and then quantifies whether these interventions have reduced deforestation. Remote sensing and GIS support advanced ecosystem management[6]. Remote sensing provides valuable tools for modelling of forest changes[7]. Global gross forest cover loss was accounted to be 0.6% per year from 2000 to 2005 (ref. 8). A historical spatial dataset on forest cover and land-use change is required to understand the trends and thereby to identify opportunities for management intervention and to analyse implications on carbon pools[9].

India is one of the top 12 mega-biodiversity nations and accounts for 6% of the world's forests. The net and gross rates of deforestation in different parts of India have been summarized by Reddy *et al.*[10]. Studies on biodiversity characterization have mapped vegetation types and assessed landscape-level fragmentation and biological richness in India[11,12]. As part of the national carbon project, a few studies have analysed long-term forest cover change over Odisha, Andhra Pradesh, Central India and Eastern Ghats of India[9,13–15]. We attempt to create such a spatial data for the Andaman and Nicobar Islands to assess land use/land cover, forest types, rate of deforestation and spatial changes in forests during 1976 to 2014.

Andaman and Nicobar Islands are located between lat. 6°40′N and 14°45′N and long. 92°8′E and 94°1′E with the total geographical area of 8249 sq. km. These islands are categorized into two groups; Andaman and Nicobar represent an area of 6408 and 1841 sq. km respectively. Andaman and Nicobar Islands rank first amongst union

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territories of India in terms of highest forest area, i.e. 6711 sq. km as per 2011 assessment, which includes forests and plantations as per definition of Forestry Survey of India (FSI). This accounts for 81.36% of the total geographical area of the island[16]. Andaman and Nicobar consist of fragile ecosystems, high biological diversity and endemism covering two global biodiversity hotspots, i.e. Indo-Burma and Sundaland. It represents over 2000 indigenous species of flowering plants including 353 endemic species[17]. These islands comprise 572 chains of islands or islets. A total of 9 national parks and 96 wildlife sanctuaries cover 18.5% of the total protected area network of India. The major islands in Andaman are North Andaman, Middle Andaman, South Andaman, Baratang and Little Andaman. Nicobar Islands consisting of Car Nicobar, Chowra, Teresa, Nancowry, Katchal, Little Nicobar and Great Nicobar (Figure 1). The soil types of this archipelago range from sandy clay to sandy loam. Saddle peak is the highest altitudinal point (730 m) which is located in North Andaman. The mean annual temperature is roughly 26.4°C, mean annual precipitation is around 3100 mm, the relative humidity varies from 65% to 89%. However, these landscapes consist of fascinating flora and fauna and show maximum affinity with Myanmar and Malaysia. The major forest types in this archipelago are tropical evergreen, semi-evergreen, moist deciduous forests along with littoral forests and mangroves. Common tree elements in Andaman evergreen forests are *Dipterocarpus grandiflorus*, *Dipterocarpus kerrii*, *Artocarpus chaplasha*, *Sideroxylon longepetiolatum* and *Calophyllum soulattri*. In the semi-evergreen forests, *Dipterocarpus alatus*, *Pterocymbium tinctorium*, *Pterygota alata* and *Lagerstroemia hypoleuca* are dominant species. Moist deciduous forests are mainly represented by *Pterocarpus dalbergioides*, *Terminalia bialata*, *Tetrameles nudiflora*, *Dillenia pentagyna* and *Semecarpus kurzii*. Mangroves consist of *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Sonneratia caseolaris*, *Xylocarpus molluccensis* and *Nipa fruticans*[18,19]. Human population statistics of Andaman and Nicobar Islands from 1931 to 2011 showed a continuous population increase from 19,223 to 381,000 and the population growth was more than 90% (ref. 20). The islands were exposed to agricultural activities in 1901 when forest land was cleared for cultivation[21].

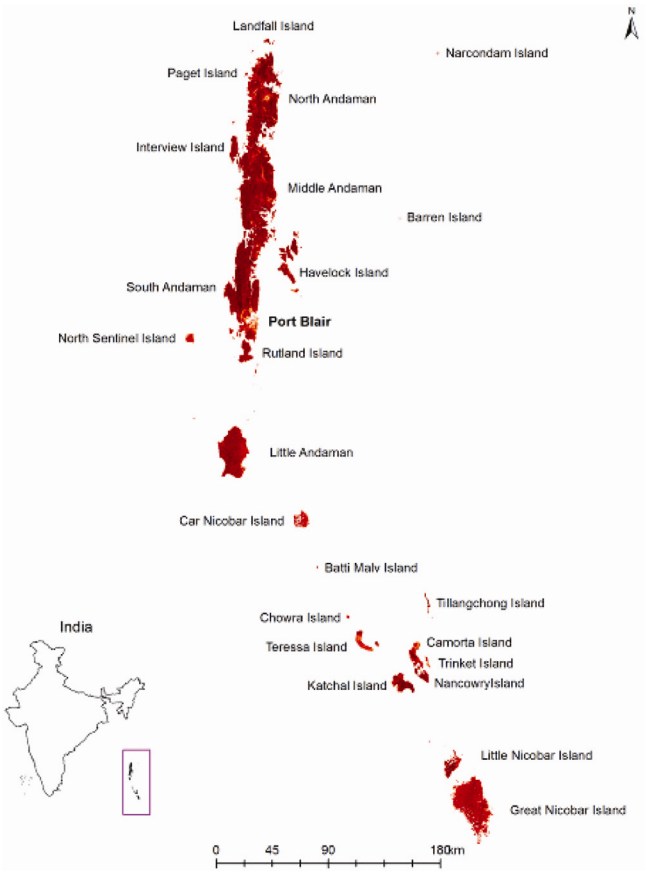

Figure 1. Landsat 8 OLI false colour composite image of Andaman and Nicobar Islands (2014).

Multi-temporal remote sensing datasets have been used. Landsat MSS (1976), Landsat TM (1989), Landsat ETM+ (2000) and Landsat OLI (2014) provided by Global Land Cover Facility Programme (http://glcfapp.umiacs.umd.edu) and United States Geological Survey (USGS) Earth explorer Programme was downloaded from the websites[22,23]. IRS 1A/1B LISS I (1993) and IRS P6 LISS III (2006) were procured from National Remote Sensing Centre. Hybrid classification techniques (combination of visual interpretation and supervised classification) were used to map land use/land cover classes based on Landsat data of 2014. This spatial data was used as a base for classifying the other four years (1976, 1989, 1993, 2006) through visual interpretation technique. The present study considers natural forest definition, i.e. forest is defined as land spanning more than 1 ha, dominated by composition of indigenous tree species having a minimum stand height of 5 m with an overstorey canopy cover of greater than 10%. The images were georeferenced to the Lambert Conformal Conic coordinate system and WGS84 datum. Image enhancement and vegetation ratio techniques are used in digital image processing as a first step after rectifying the scene. The present study has followed the classification scheme of Champion and Seth (1968) to map major forest types[18]. ERDAS Imagine 2013 and ArcGIS 10.1 were used for digital image processing and GIS analyses respectively. Figure 1 shows Landsat OLI False Colour Composite image of Andaman and Nicobar Islands.

To calculate annual rate of deforestation, the area under forest cover was compared in two different time periods, using compound interest formula[24].

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

Table 1. Distribution of forest cover in Andaman and Nicobar Islands (area in sq. km)

Period	Andaman Islands	% of TGA	Nicobar Islands	% of TGA	Andaman & Nicobar Islands	% of TGA
1976	5471.2	85.4	1614.9	87.7	7086.1	85.9
1989	5362.5	83.7	1606.7	87.3	6969.2	84.5
1993	5338.1	83.3	1603.0	87.1	6941.1	84.1
2000	5331.6	83.2	1603.0	87.1	6934.6	84.1
2006	5248.6	81.9	1369.2	74.4	6617.8	80.2
2014	5044.4	78.7	1362.9	74.0	6407.3	77.7

Table 2. Trend of annual net rate of deforestation in Andaman and Nicobar Islands

T1	T2	Andaman Islands	Nicobar Islands	Andaman & Nicobar Islands
1976	1989	–0.15	–0.04	–0.13
1989	1993	–0.11	–0.06	–0.10
1993	2000	–0.02	0.00	–0.01
2000	2006	–0.26	–2.63	–0.78
2006	2014	–0.50	–0.06	–0.40
1976	2014	–0.21	–0.45	–0.27
1989	2014	–0.24	–0.66	–0.34
1993	2014	–0.27	–0.77	–0.38
2000	2014	–0.40	–1.16	–0.56

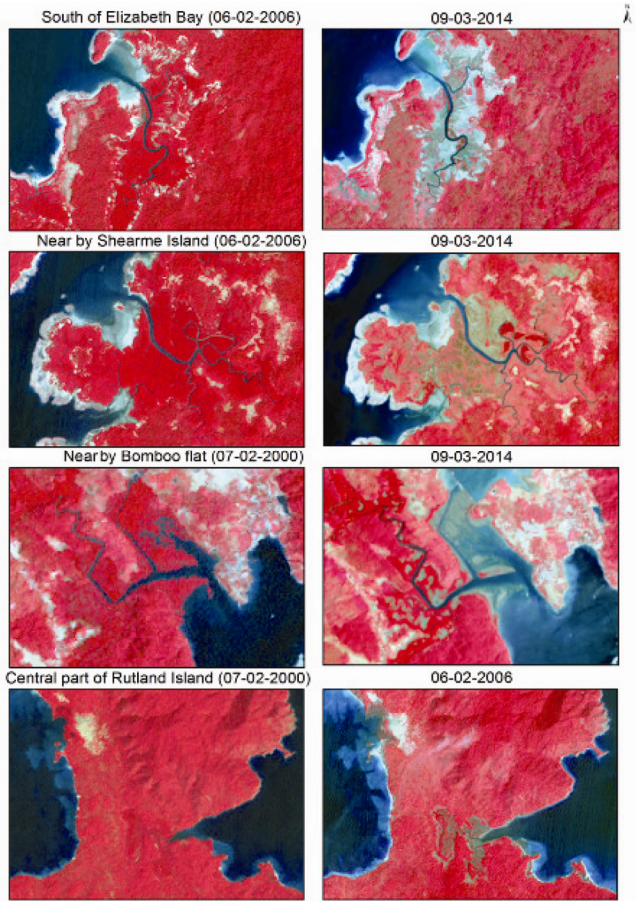

Figure 2. False colour composite satellite image chips showing forest cover change in Andaman Islands.

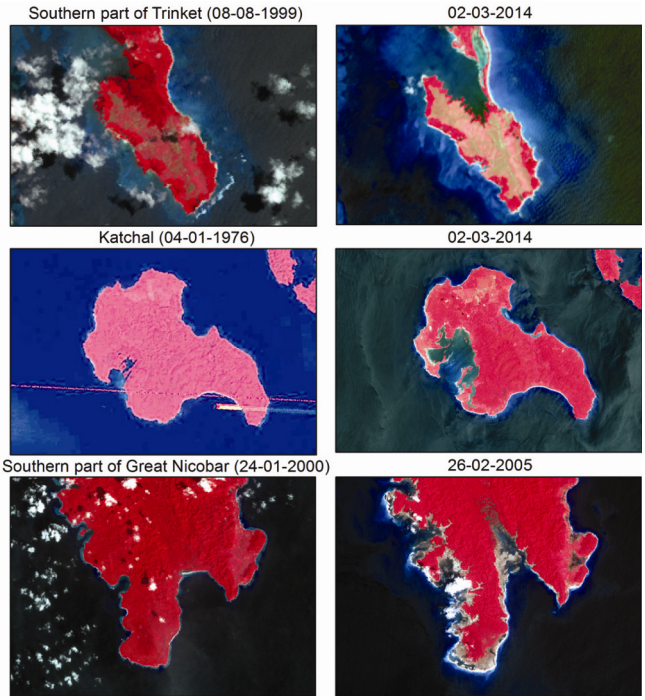

Figure 3. False colour composite satellite image chips showing forest cover change in Nicobar Islands.

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.

Spatial analysis of forest cover change has been carried out by generating grid cells of 5 km × 5 km (refs 9, 13–15). The areas of change have been evaluated across 1976–1989, 1989–1993, 1993–2000, 2000–2006 and 2006–2014. Grid cell wise change was carried out based on the six classes, i.e. <1, 1–5, 6–10, 11–15, 16–20 and >20 sq. km.

To evaluate the accuracy of classified maps of 2014, we have used 200 ground samples from different locations and high resolution images available on the web[25,26]. Validation of maps for 1976, 1989, 1993, 2000 and 2006 was done based on spatial consistency of sample points on high resolution images from Google Earth.

Land cover classification has discriminated 2 classes at level I (i.e. forest and non-forest) and 11 classes at level II. Forests were split into four classes to increase their

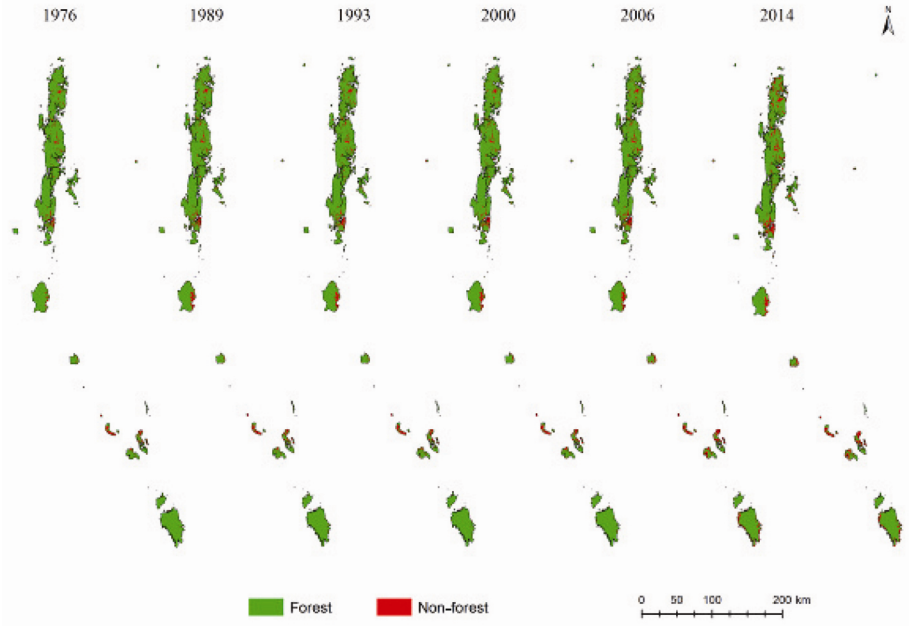

Figure 4. Spatial maps of forest cover: 1976 to 2014.

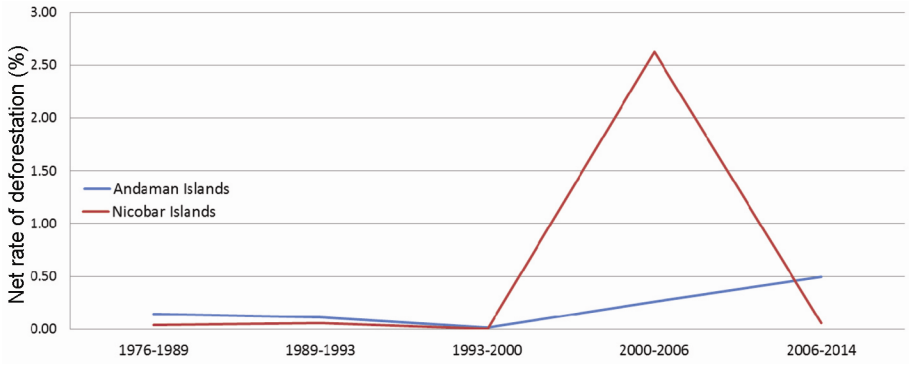

Figure 5. Graph showing annual rate of deforestation.

Table 3. Analysis of grid-cell-wise negative changes in Andaman and Nicobar Islands (no. of 5 × 5 km cells)

Size class (sq. km)	1976–1989	1989–1993	1993–2006	2006–2014
<1	65	18	103	67
1–5	20	5	55	56
6–10	2	1	5	5
11–15	0	1	1	0
16–20	1	0	0	1
21–25	0	0	0	0
Total	88	25	164	129

separability with other land cover classes (evergreen forest, semi-evergreen forest, moist deciduous forest and mangrove). The non-forest class includes plantations, scrub, grassland, agriculture, barren land, water and settlements.

Statistical analysis of forest cover indicates major changes that occurred during 1976 to 2014. The forest cover for 1976, 1989, 1993, 2000, 2006 and 2014 was estimated as 7086.1 (85.9%), 6969.2 (84.5%), 6941.1 (84.1%), 6934.6 (84.1%), 6617.8 (80.2%) and 6407.3 sq. km (77.7%) respectively. Selected image chips of multi-temporal satellite data showing deforestation is given in Figures 2 and 3. The percentage of forest cover with reference to total geographical area (TGA) of the Andaman

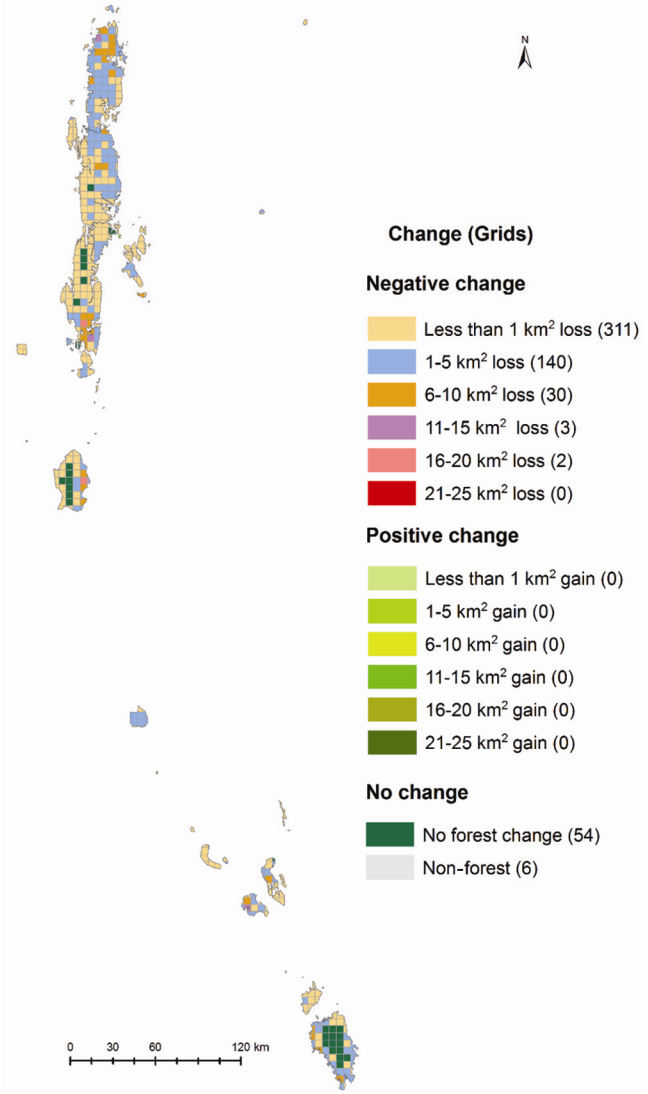

Figure 6. Grid-wise forest cover changes in Andaman and Nicobar Islands: 1976 to 2014.

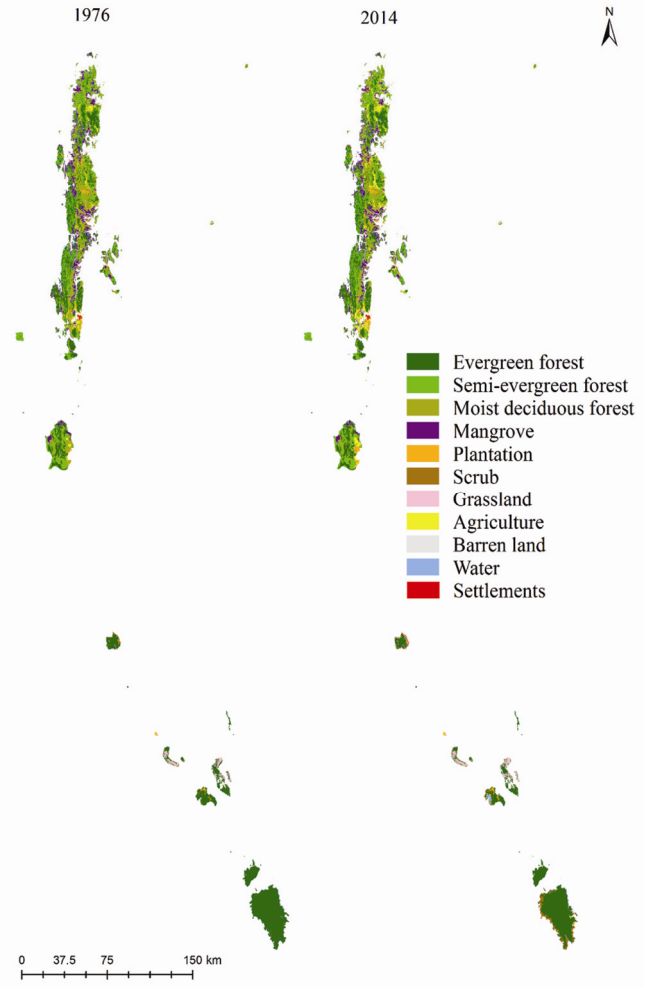

Figure 7. Forest type and land use/land cover map of Andaman and Nicobar Islands: 1976 and 2014.

and Nicobar Islands is shown in Table 1. Classified forest cover maps of 1976, 1989, 1993, 2000, 2006 and 2014 are presented in Figure 4.

The forest cover change analysis was based on the five time phases, viz. 1976–1989, 1989–1993, 1993–2000, 2000–2006 and 2006–2014. Within nearly four decades (1976–2014), the net forest cover decline in Andaman and Nicobar Islands was 678.8 sq. km (9.6% of the total forest area). The deforested area was very high during 2000 to 2006 and estimated as 316.8 sq. km. The 'tsunami' on 26 December 2004 caused severe damage to the forests of Andaman and Nicobar islands[7,27].

Area-wise analysis indicates overall deforestation was very high in Andaman Islands with forest cover loss of 426.8 sq. km, followed by 252 sq. km in Nicobar Islands from 1976 to 2014. In these islands, the major anthropogenic drivers of forest loss are expansion of agricultural activities.

The rate of deforestation was high during the recent time phases, i.e. 2000–2006 (0.78) and 2006–2014 (0.40) respectively. Analysis of annual net rate of deforestation from 2000 to 2006 indicates large-scale deforestation in Nicobar Islands, which was recorded as 2.63. The analysis supports that there was a strong footprint of natural calamities (tsunami) on forests of Nicobar Islands (Table 2). Annual rate of deforestation is shown in Figure 5.

The grid-cell-wise forest cover change data is presented in Figure 6. A total of 546 grids were identified in Andaman and Nicobar Islands. Grid-wise analysis records the highest number of negative change grids during 1993–2006 and 2006–2014 (Table 3). Results indicate small-scale negative changes were more throughout the study period.

The classification results revealed that the land use of the Andaman and Nicobar Islands has changed substantially. The historical changes in forest types and land use during 1976 and 2014 are shown in Tables 4 and 5. Four major forest types, i.e. evergreen, semi-evergreen, moist deciduous and mangroves were delineated.

Table 4. Areal extent of land use and land cover (LULC) in Andaman Islands (1976 to 2014) (area in sq. km)

LULC	1976	1989	1993	2000	2006	2014	Change (1976–2014)
Forest							
Evergreen	1710.5	1709.0	1709	1708.9	1707.1	1707.1	–3.4
Semi-evergreen	1553.5	1548.8	1547.3	1546.4	1540.1	1531.6	–21.9
Moist deciduous	1443.5	1352.1	1332.1	1326.7	1274.9	1131.2	–312.3
Mangrove	763.7	752.6	749.7	749.6	726.5	674.5	–89.2
Sub-total	5471.2	5362.5	5338.1	5331.6	5248.6	5044.4	–426.8
Non-forest							
Plantations	68.6	90.7	93.5	93.6	101.1	102.8	34.2
Scrub	6.7	12.5	14.7	14.8	20.9	54.7	48
Grassland	6.7	11.0	12.1	12.1	15.4	27.8	21.1
Agriculture	163.9	228.6	241.7	245.3	278.1	402.5	238.6
Barren land	83.5	98.2	100.2	100.2	113.1	125.9	42.4
Water	598.2	593.5	594.8	596.8	616.3	634.4	36.2
Settlements	9.2	11.1	13.0	13.6	14.5	15.5	6.3
Sub-total	936.9	1045.6	1069.9	1076.4	1159.3	1363.6	426.8
Grand total	6408	6408	6408	6408	6408	6408	

Table 5. LULC in Nicobar Islands (1976 to 2014) (area in sq. km)

LULC	1976	1989	1993	2000	2006	2014	Change (1976–2014)
Forest							
Evergreen	1602.6	1596.0	1592.3	1592.3	1364.3	1358	–244.6
Moist deciduous	2.2	2.2	2.2	2.2	2.2	2.2	0.0
Mangrove	10.1	8.4	8.4	8.4	2.7	2.7	–7.4
Sub-total	1614.9	1606.7	1603	1603.0	1369.2	1362.9	–252.0
Non-forest							
Plantations	39.6	40.5	42.9	42.9	62.3	64.5	24.9
Scrub	4.6	6.6	7.1	7.1	135.3	135.7	131.1
Grassland	91.7	92.8	93.5	93.5	119.8	120.6	28.9
Agriculture	1.2	1.2	1.2	1.2	4.9	4.9	3.7
Barren land	29.6	30.0	30	30.0	58.5	59.6	30.0
Water	55.1	58.7	58.8	58.7	81.7	83.3	28.2
Settlements	4.3	4.4	4.5	4.5	9.3	48.1	43.8
Sub-total	226.1	234.3	238	238.0	471.8	516.8	290.7
Grand total	1841	1841	1841	1841	1841	1841	

Figure 7 shows the classified forest types and land use/land cover maps for 1976 and 2014. In Andaman and Nicobar Islands, the dominance of evergreen forests is evident, comprising an area of 3065.1 sq. km (32.2%) followed by 1531.6 sq. km (18.6%) of semi-evergreen, 1133.4 sq. km (13.7%) of moist deciduous and mangrove forest occupies 677.2 sq. km (8.2%) of the forest cover in 2014. In Andaman Islands forest types, i.e. moist deciduous forests, mangroves, semi-evergreen forests and evergreen forests showed significant reduction of an area of 21.6%, 11.7%, 1.4% and 0.2% respectively. Whereas in Nicobar, mangroves and evergreen forest shows massive reduction accounted as 73.3% and 15.3% respectively, during 1976 to 2014. As per area analysis of change in Nicobar, the loss of evergreen forests is very high (244.6 sq. km) followed by mangroves (7.4 sq. km). Agricultural land use shows increasing trend in Andaman and Nicobar Islands during study period (Tables 4 and 5). The people still use the land for farming purposes.

Forest cover is mostly converted to agriculture in Andamans, while in Nicobars, it is converted to plantations. In Andamans, barren land increased from 83.5 to 125.9 sq. km, scrub from 6.7 to 54.7 sq. km and grasslands from 6.7 to 27.8 sq. km during 1976 to 2014. In Nicobar, changes are evident in increase of scrub from 4.6 to 135.7 sq. km, barren land from 29.6 to 59.6 sq. km and grasslands from 91.7 to 120.6 sq. km during 1976 to 2014.

The area under settlements indicated an increase of 50.1 sq. km from the actual area of 13.5 to 63.6 sq. km from 1976 to 2014. The maximum conversion gain to settlements was from forests and agriculture. Most of the

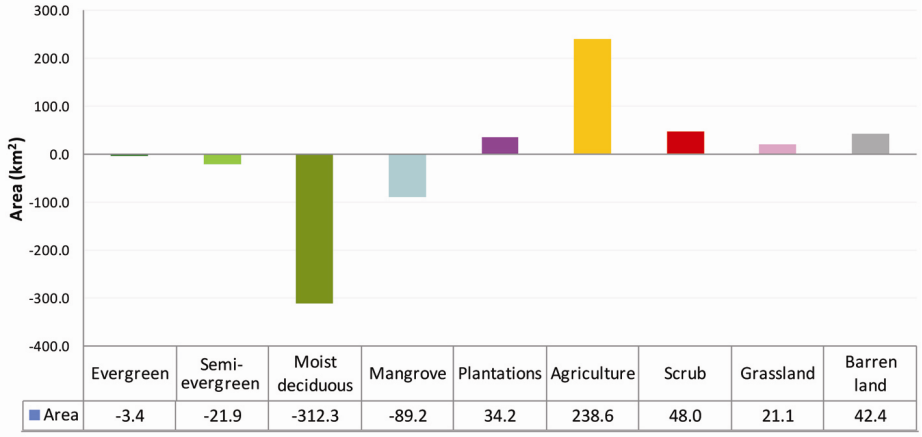

Figure 8. Major changes in forest types and land use/land cover of Andaman Islands (1976–2014).

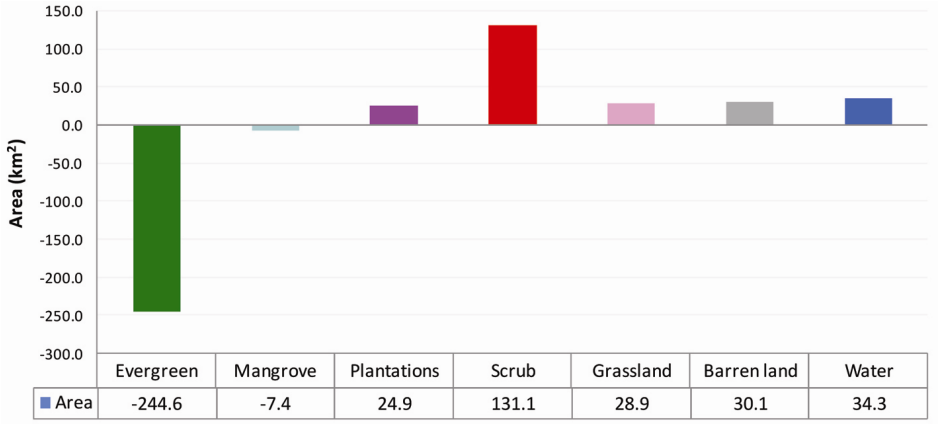

Figure 9. Major changes in forest types and land use/land cover of Nicobar Islands (1976–2014).

settlements are still small and scattered. It is very interesting to observe development of settlement area around Port Blair, capital city of Andaman and Nicobar Islands.

The massive increase of barren land, scrub and grasslands due to natural and anthropogenic factors indicates a need for restoration programmes in Andaman and Nicobar Islands.

In Andamans, Little Andaman shows 55.17 sq. km of loss of forest cover, followed by Havelock island (10.51 sq. km), Rutland island (6.55 sq. km) and Neil island (5.06 sq. km) during 1976 to 2014. In Nicobars, 92.76% of forest cover loss was recorded during 2000 and 2006. Great Nicobar island (biosphere reserve) has undergone large-scale deforestation during 1976 to 2014 which was estimated as 143.1 sq. km, followed by Katchal island (33.9 sq. km), Camorta island (26.6 sq. km), Car Nicobar (23.2 sq. km), Little Nicobar (8.6 sq. km), Trinket island (6 sq. km), Nancowry island (4.4 sq. km), Teressa island (3.7 sq. km) and Bompoka island (1.8 sq. km). In Andaman Islands, the primary economic resource is moist deciduous forests which have high timber value species and accounted for the greatest loss. Annual rate of deforestation of moist deciduous forests is high (0.64) followed by mangroves (0.35%), evergreen forest (0.20%) and semi-evergreen forests (0.04%). A net rate of deforestation of 0.09% accounted for the mangroves during 1976 to 2000, 0.65% during 2000 to 2006 and 0.92% during 2006 to 2014. The increased loss of mangroves during 2000 to 2006 was mainly due to natural calamity (tsunami). Figures 8 and 9 show major changes in forest types and land use/land cover of Andaman Islands and Nicobar Islands (1976–2014).

Despite the protection efforts of the forest department, forest cover change in islands is primarily attributed to natural disasters, clearance of forests for agriculture and plantations, logging, infrastructure development and construction of dams for irrigation and electricity needs. The earth quake (9.0 Richter scale) which struck Andaman and Nicobar Islands on 26 December 2004 and the consequent tsunami had caused considerable change on the mangrove stands of Andaman Islands. The mangroves of south Andaman was affected in various degrees based on their physiological response to the continuous inundation/exposure under the changed scenario; whereas, in the North Andaman due to the elevation of land, the sea water did not affect some of the mangrove stands[28]. The

tsunami found to be a major cause of deforestation of coastal forests in the North Andaman Islands, deforested an area of 32.9 sq. km (ref. 7). The study showed that mangroves were affected by tsunami to the extent of 335.70 ha in Camorta, 339.03 ha in Katchal, 152.53 ha in Nancowry and 240.06 ha in Trinket (ref. 29). In Central Nicobar and Car Nicobar, tsunami is responsible for loss of forest cover estimated as 24.8 and 23.2 sq. km respectively[27]. It has been established through peer-reviewed literature and the present study that Andaman and Nicobar Islands has a high level of deforestation. However, to address this issue, the present analysis provided grid-cell-wise changes to prioritise areas which need an immediate conservation action plan.

The overall classification accuracy of the forest types and land use/land cover map of 2014 was 90.01%. Kappa statistics value was 0.87. The errors that were observed during the accuracy evaluation were manually re-assigned to appropriate classes.

The study highlights the need of satellite remote sensing for monitoring and quantitative assessment of land-use/land-cover changes. The rate of deforestation is high in Andaman and Nicobar islands due to natural factors as well as anthropogenic disturbances. The spatial database generated in the present study provides baseline data for deforestation and facilitates conservation planning to undertake restoration programmes and appropriate management measures.

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