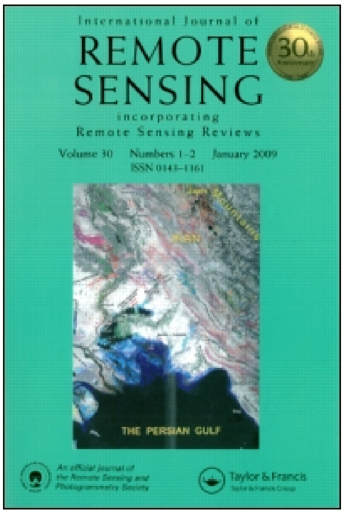


International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713722504

Assessment of tsunami and anthropogenic impacts on the forest of the North Andaman Islands, India

P. Rama Chandra Prasad [a]; C. Sudhakar Reddy [b]; K. Sundara Rajan [a]; S. Hazan Raza [c]; C. Bala Subrahmanya Dutt [d]
[a] Laboratory for Spatial Informatics, International Institute of Information Technology, Gachibowli, Hyderabad - 500 082, India [b] Forestry and Ecology Division, National Remote Sensing Agency, Department of Space, Balanagar, Hyderabad, India - 500037 [c] Department of Environmental Sciences, Osmania University, Hyderabad, India [d] Indian Space Research Organization, Dept of space, Bangalore, 560094, India

Online Publication Date: 01 January 2009

To cite this Article Prasad, P. Rama Chandra, Reddy, C. Sudhakar, Rajan, K. Sundara, Raza, S. Hazan and Dutt, C. Bala Subrahmanya(2009)'Assessment of tsunami and anthropogenic impacts on the forest of the North Andaman Islands, India',International Journal of Remote Sensing,30:5,1235 — 1249

To link to this Article: DOI: 10.1080/01431160802460070

URL: http://dx.doi.org/10.1080/01431160802460070

International Journal of Remote Sensing
Vol. 30, No. 5, 10 March 2009, 1235–1249

Assessment of tsunami and anthropogenic impacts on the forest of the North Andaman Islands, India

P. RAMA CHANDRA PRASAD*†, C. SUDHAKAR REDDY‡, K. SUNDARA RAJAN†, S. HAZAN RAZA§ and C. BALA SUBRAHMANYA DUTT¶

†Laboratory for Spatial Informatics, International Institute of Information Technology, Gachibowli, Hyderabad – 500 082, India

‡Forestry and Ecology Division, National Remote Sensing Agency, Department of Space, Balanagar, Hyderabad, India – 500037

§Department of Environmental Sciences, Osmania University, Hyderabad, India

¶Indian Space Research Organization, Dept of space, Anthariksh Bhavan, Bangalore, 560094, India

(*Received 19 October 2006; in final form 23 December 2007*)

Forests are being depleted drastically at higher rates to cater to the needs of growing population. In this context, an attempt was made to identify the drivers of forest changes on the vegetation of the North Andaman islands by broadly categorising the changes as anthropogenic and natural disturbances (tsunami) using satellite images of 1976, 1999 and 2005. The images were classified using visual interpretation technique to generate land cover maps of the area under study. A detailed change analysis of the 1976, 1999 and 2005 images showed that a high proportion of the natural vegetation has been converted into agriculture, settlement, sand and water. The overall forest change from 1976 to 2005 is 11,670 ha with a deforestation rate of 389 ha yr^{-1}. The tsunami of 26 December, 2004 was found to be a major cause of deforestation of coastal forests in the North Andaman Islands, deforesting an area of 3292.5 ha. Simulation of forest cover in the next 25 and 50 years predicted a deforestation of 13,100 and 22,700 ha with a corresponding increase in non-forest land cover to 19,600 and 29,600 ha respectively. It is predicted that after 50 years the forest area of 131,200 ha, estimated from the 1999 satellite data, may reduce to 108,500 ha, if proper conservation measures are not taken.

1. Introduction

Forests transform energy in an ecosystem for the sustainability and survivability of diversified living organisms. In many countries, forests are being depleted drastically at high rates to cater for the needs of growing population. In some cases also, forests are destroyed by natural calamities. Many studies pertaining to the deforestation/forest changes also predict the future status of the forest and suggest that timely conservative measures are required to preserve the remains of the forest that harbor rich biological diversity (Walter *et al.* 1989, Shukla *et al.* 1990, Uhl and Kauffman, 1990, Thomas *et al.* 1993, Achard *et al.* 1997, Kaimowitz *et al.* 1999, Carr David 2001, Naughton *et al.* 2006). Ground survey methods are inadequate and time consuming in assessing deforestation/forest changes over extended periods of time

*Corresponding author. Email: rcprasad@iiit.ac.in; rcp_ncmsl@yahoo.co.in

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160802460070

and over large regions. Remote sensing provides valuable tools for efficient detection, monitoring, mapping, and modeling of forest changes over broad spatial scales. Many researchers have applied remote sensing and geographic information system (GIS) techniques for detection and analysis of change to identify the structural changes in landscape by different disturbance factors like hurricanes, cyclones (Cablk *et al.* 1994, Kushwaha 1997), tsunami (Belward *et al.* 2007, Francesca and Lorenzo 2007), floods (Blasco *et al.* 1992, Nagarajan and Marthe 1993), fire (Suga *et al.* 1999, Takeuchi 2001), insects (Ciesla *et al.* 1989, Vogelmann and Rock 1989) and more prominently by human land use (Stibig *et al.* 2004, Sudhakar *et al.* 2007). In this context the present study was carried out to investigate the rate of deforestation of the tropical rain forest of the Andaman Islands using remote sensing satellite data.

1.1 *Objectives*

Both natural and anthropogenic disturbances play an important role in causing increasing deforestation rates of the vegetation of the Andaman Islands. The population structure analysis within North Andaman Islands, the present study site (see figure 1), shows that the major settlement areas – for examples Diglipur, Radhanagar, Aerial Bay, Kalighat and Mohanpur - have expanded rapidly owing to the influx of people from mainland. This influx of population has caused great damage to the virgin forest of the islands. Coupled with this, natural disturbances, notably earthquakes, cyclones and tsunami have also contributed to deforestation in these islands. The present study was carried out to assess the impact of both anthropogenic and natural disturbances (notably the tsunami of 26 December, 2004) on the vegetation of North Andaman Islands during the last three decades. The study uses three satellite images of 1976, 1999 and 2005 and the post classification

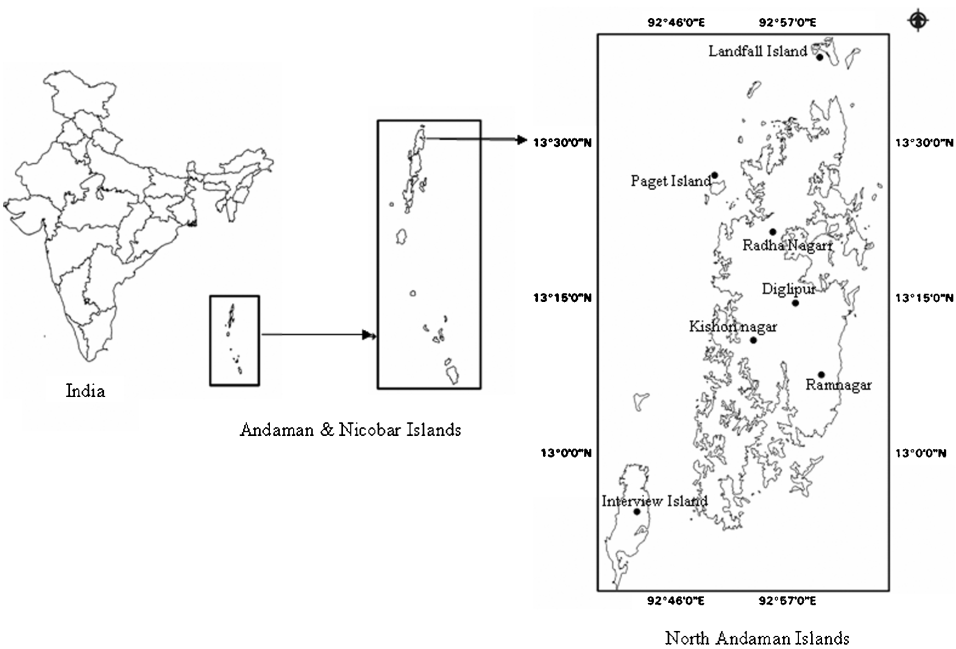


Figure 1. Location map of North Andaman Islands.

change detection method. This paper attempts to identify the drivers/causes of the forest changes by broadly categorising these changes as anthropogenic (human induced) and natural. A study of the impact of tsunami (on 26 December 2004) – a natural disaster, on forests of these islands, especially on coastal vegetation, also an important part of this research work.

2. Study area

The Andaman and Nicobar Islands are located in amidst Bay of Bengal, on southeastern side of Indian subcontinent. Geographically these islands are categorised into two groups, namely the Andaman group covering an area of 640 800 ha, and the Nicobar group with an area of 184 100 ha. The Andaman group comprises 204 islands of varying sizes and is popularly known as Great Andaman, consisting of North, Middle and South Andaman separated from one another by narrow straits. North Andaman Islands lie between $12^{\circ}45''$ to $13^{\circ}40''$ N latitude - 92° to 93° E longitudes and cover a distance of 102 km from north to south with an area of 145 800 ha. Champion and Seth (1968) classified the forest of these islands into Andaman evergreen (1A/C2), Andaman semi evergreen (2A/C1), Andaman moist deciduous (3A/C1), Littoral (4A/L1) and Mangrove forest (4B/TS2) (Table 1). Most

Table 1. Vegetation types of North Andaman Islands.

Serial. number	Champion & Seth classes	Code	Vegetation types in study area	Dominant species
1	Andaman Tropical Evergreen	1A/C2	Evergreen Forest	*Dipterocarpus gracilis* *Myristica glaucescens* *Artocarpus chaplasha* *Myristica andamanica* *Celitis wightii*
2	Southern Hill Top Evergreen	1A/C3	Evergreen Forest	*Eugenia Kurzii* *Parishia insignis* *Anacolosa frutescens* *Canarium manii* *Dipterocarpus gracilis*
3	Andaman Semi evergreen	2A/C1	Semi evergreen Forest	*Pterocarpus dalbergoides* *Celitis wightii* *Dipterocarpus gracilis* *Artocarpus chaplasha* *Pterygota alata*
4	Andaman Moist Deciduous	3A/C1	Moist Deciduous Forest	*Pterocarpus dalbergoides* *Diospyros oocarpa* *Aglaia oligophylla* *Mitragyna rotundifolia* *Terminalia bialata*
5	Littoral/Beach	4A/L1	Littoral Forest	*Manilkara littoralis* *Pongamia pinnata* *Morinda citrifolia* *Heritiera littoralis* *Hibiscus tiliaceous*
6	Mangroves	4B/TS2	Mangrove Forest	*Rhizophora mucronata* *Bruguiera gymnorhiza* *Sonneratia alba* *Aegiceras corniculatum* *Nypa fruticans*

of the area is covered with semi evergreen forest, which is scattered throughout the study area at different terrain levels.

3. Materials and methods

3.1 *Satellite data*

Multi temporal satellite datasets were used for the study. Initially an IRS 1D Linear Imaging Self Scanner (LISS) III image of 1 March 1999 was procured from National Remote Sensing Agency data center and geometrically rectified with reference to Survey of India topographic maps on 1 : 50 000 scale. For image registration, ground control points (GCPs) were well distributed throughout the scene and a first order polynomial transformation with nearest neighbour resampling technique was applied. This image was used as a master for georeferencing other two-satellite data i.e., Landsat Multi Spectral Scanner (MSS) image of 29 February, 1976, (downloaded at 57 m resolution from http://www.glcf.umiacs.umd.edu and resampled to 30m) and a SPOT Image of 2 January, 2005 (http://www.crisp.nus.edu.sg/tsunami/tsunami.html). The details regarding the sensor spatial and spectral resolution are shown in table 2.

3.2 *Processing*

On-screen visual interpretation was used to classify the satellite data into different themes representing the ground features. The interpretation classes are agriculture, settlements, barren lands, mud flats, sand, interior forest types (evergreen, semi evergreen, moist deciduous) and coastal forest types (mangrove and littoral). Within the mangrove ecosystem, differentiation was based on the canopy density levels and classified into dense (>40%), open (10–40%) and degraded (<10%). The field inventory carried out from October 2001 to January 2002 as part of biodiversity characterisation project at landscape level, using GPS at various locations of North Andaman Islands, aided in identifying and interpreting different classes on the MSS and LISS III images. Using stratified random sampling method, a total of 200 sample points (each plot $32\,m \times 32\,m$) were established in different forests types to

Table 2. Sensor parameters.

Satellite	Sensor	Band	Wavelength range (μm)	Spatial resolution (m)
LANDSAT-2	Multi spectral scanner (MSS)	4	0.5–0.6	57
		5	0.6–0.7	
		6	0.7–0.8	
		7	0.8–1.1	
IRS 1D	Linear imaging self scanner (LISSIII)	2	0.52–0.59 μm	23.5
		3	0.62–0.68 μm	
		4	0.77–0.86	
SPOT	High resolution visible (HRV)	1	0.50–0.59 μm	20
		2	0.61–0.68 μm	
		3	0.79–0.89	

collect phytosociological data. In addition to this, ground truth data for delineation of agricultural lands, barren areas, mud flats and sandy areas was also collected using GPS at 174 locations. For interpretation of tsunami-affected areas, a field survey was carried out during January 2005 as a special study (Prasad 2006).

Various image enhancement processes were applied to increase the quality and contrast of the images for proper delineation of different vegetation types and land cover classes, based on tone and texture. The image processing, interpretation and delineation of polygons was done using ERDAS 8.5 and Arc-view 3.2.1.software. The classified land cover map produced from the IRS 1D LISS III image was used as a template for classifying other two images (MSS and SPOT) by on-screen visual interpretation of change for forest and other-land cover classes. Polygons were then drawn around areas of change on the image and the corresponding areas were reclassified on the classified map. 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 atmospheric and environmental variability. The SPOT data interpretation was confined to interior forest, coastal forest and non-forest classes because of the low clarity of the image to distinguish other classes.

4. Results and discussions

On the SPOT image it was not possible to distinguish mudflats from mangroves so they were merged with mangrove class, because mudflats act as platform for the vegetation regeneration. Similarly the littoral class was also grouped with mangroves forming a single class named coastal vegetation. Out of 145 800 ha (including inland water bodies), the forest area (along with plantations) existing in 1976, 1999 and 2005 was 137 810, 131 220 and 126 140 ha respectively. The estimated forest loss between 1976 and 1999 was 6590 ha, i.e. about 274 ha yr^{-1}. From 1999 to 2005 the deforestation level was 5080 ha with the forest depletion rate of 725 ha yr^{-1} which is a very high transformation rate. The overall forest change from 1976 to 2005 is 11,670 ha, with forest loss at the rate of 389 ha yr^{-1} (see tables 3 and 4).

4.1 *Changes from 1976–1999*

In detail, analysis of the 1976 (MSS) and 1999 (LISS III) images showed a loss of 12.5% (5.0% interior and 7.5% coastal) of forest with a corresponding increase in non-forest area. A variety of inter transformations of land cover classes was

Table 3. Changes in Vegetation and Land cover classes during 1976, 1999 and 2005.

Satellite data	MSS (1976)	LISS (1999)	SPOT (2005)	1976–1999	1999–2005
Vegetation types/land cover		Area (ha)		Change in Area (ha)	
Interior vegetation types (including plantations)	104,810	99,720	98,370	−5,090	−1,350
Coastal vegetation types (including mud flats)	33,000	31,500	27,770	−1,500	−3,730
Total	**137,810**	**131,220**	**126,140**	**6590**	**5,080**
Non forest classes (Agriculture, settlement, barren)	6,360	12,430	16,230	6,070	3,800
Sand	1,450	1,990	3,240	540	1,250
Total	**7,810**	**14,420**	**19,470**	**6,610**	**5,050**

Table 4. Forest and land cover classes change detection during 1976 and 1999.

Sensor	MSS (1976)		LISS III (1999)*		Change	
Vegetation types/land cover	Area (ha)	Total land cover (%)	Area (ha)	Total land cover (%)	Area (ha)	Area (%)
Interior vegetation type						
Evergreen	31,360	21.5	31,010	21.3	−350	−1.1
Semi-evergreen	47,900	32.9	45,130	31	−2,770	−5.8
Moist deciduous	24,680	16.9	22,620	15.5	−2,060	−8.3
Sub total	**103,940**	**71.4**	**98,760**	**67.8**	**−5,180**	**−5.0**
Coastal vegetation types						
Littoral	5,460	3.7	4,820	3.3	−640	−11.7
Dense mangrove	14,820	10.2	9,580	6.6	−5,240	−35.4
Open mangrove	7,370	5.1	12,160	8.4	4,790	65.0
Degraded mangrove	3,200	2.2	1,980	1.4	−1,220	−38.1
Sub total	**30,850**	**21.2**	**28,540**	**19.6**	**−2,310**	**−7.5**
Non-forest classes						
Agriculture/settlement	6,320	4.3	12,400	8.5	6,080	96.2
Plantations	870	0.6	960	0.7	90	10.3
Mud flats	2,160	1.5	2,950	2	800	36.6
Barren land	40	0.0	30	0	−10	−25.0
Sand	1,450	1.0	1,990	1.4	540	37.2
Sub total	**10,840**	**7.4**	**18,330**	**12.6**	**7,490**	**69.0**
Total	**145,630**		**145,630**			

*Prasad *et al.* 2007.

observed and a positive change (548 ha) was seen in the mangrove vegetation owing to regeneration in mudflats and barren lands (see tables 5(*a*) and 5(*b*) and figure 2(*b*)). Comparatively, a decrease trend was observed in the areas of interior,

Table 5(*a*). Conversion of forest cover types and other land cover classes during 1976 to 1999.

Negative	**Area (ha)**
All classes to barren	2,059
Evergreen to agriculture/settlement	344
Semi-evergreen to agriculture/settlement	2,334
Moist deciduous to plantation & agriculture/settlement	1,709
Dense mangroves to open mangroves and agriculture	5,722
Open mangroves to agriculture	387
Degraded mangroves to agriculture	83
Littoral to agriculture	294
Degraded mangroves to mud flats	646
Dense mangroves to mud flats, sand and water	20
Open mangroves to mud flats, sand and water	140
Degraded mangroves to sand and water	58
Littoral to mudflats and sand	294
Mudflats to agriculture, sand and water	153
Barren land to Sand	209
	14,452
Positive	
Open mangroves to dense mangroves	232
Degraded to dense and open mangroves	219
Barren to open and dense mangroves	31
Mud flats to dense and open mangroves	66
	548

Table 5(*b*). Matrix showing change in forest cover types and other land cover classes during 1976 to 1999.

Classes	Evergreen	Semi-evergreen	Moist deciduous	Littoral	Dense mangrove	Open mangrove	Degraded mangrove	Agriculture/ Settlement	Plantations	Mud flats	Barren land	Sand	Water
Evergreen								Negative			Negative		
Semi-evergreen								Negative			Negative		
Moist deciduous								Negative	Negative		Negative		
Littoral								Negative		Negative	Negative	Negative	
Dense mangrove						Negative		Negative		Negative	Negative	Negative	Negative
Open mangrove					Positive			Negative		Negative	Negative	Negative	Negative
Degraded mangrove					Positive	Positive		Negative		Negative	Negative	Negative	Negative
Agriculture/ Settlement											Negative		
Plantations											Negative		
Mud flats					Positive	Positive					Negative		
Barren land					Positive	Positive					Negative	Negative	
Sand											Negative		
Water													

Negative change (dark shading) Positive change (light shading) No change (unshaded) littoral, dense mangrove classes and an increase in open and degraded mangroves along with agriculture/settlement areas. The influx of people from the mainland to these islands has modified the forest to non-forest areas to satisfy their needs and to provide them with livelihood. Forests nearer to the settlements have been more prone to deforestation because of the collection of firewood, timber and other non-timber products by the island inhabitants and the rate of destruction has increased with the increasing immigrant population. In some isolated islands, destruction was caused by the animals introduced like elephants (Interview Island) that damaged large trees, and deer (Paget and Point Islands) that feed on the saplings, thus effecting the regeneration of many species (Alirauf 2004).

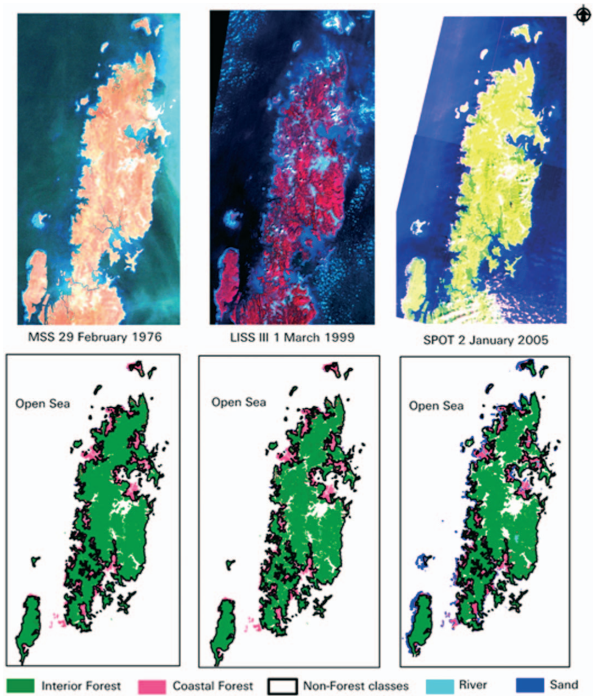
4.2 *Changes from 1999–2005*

Natural calamities are one of the factors that have caused great loss of forest resources. The entire island chain was susceptible to tsunamis, both from large local quakes as well as from massive distant shocks. Unfortunately there are no records of the extent of damage caused to the vegetation in prior to 2000. The earthquake of 14 September 2002 centered 23.6 km from Diglipur on North Andaman caused serious damage and the eastern and northern coasts of islands experienced tsunami events. However, the tsunami that occurred on 26 December 2004 adversely impacted the entire stretch of the Andaman and Nicobar Islands. Being nearer to the epicentric region of the earthquake, a lot of damage occurred to the island's coastal vegetation. The near shore bathymetry significantly increased the wave height, resulting in inundation of mangrove and littoral vegetation that lie along the coast resulting in mass coastal forest destruction (Curran *et al.* 2007). About 3730 ha of coastal vegetation was destroyed mainly by the tsunami (table 3) and to a lesser extent by human logging activities. It is viewed from the satellite images that most of the vegetation and coral reefs were affected and transformed into sand, barren and water (see figure 2(*a*)). The 1,350 ha (193 ha yr^{-1}) change in the interior forest types that was detected (see table 3) could be attributed to the anthropogenic influences because the chance of tsunami waves penetrating the deep forests is slight. This rate is similar to the pre-1999 rate of change in the interior forest, which is 212 ha yr^{-1} (see table 3). Coastal forests in most islands consists of mangrove and littoral vegetation, while in a few smaller islands such as Paget, Point and Plastic, it consists of exclusively evergreen and/or moist deciduous forest. Irrespective of the type of the forest, the vegetation along the coast was damaged by tsunami. Mangroves act as protection shield for the interior forest similar to the sand spread that protects the coastal forests from the high tides of sea. If disasters like tsunami damage the coastal vegetation then ultimately the threat extends to the interior forest too. The image of the North Andaman Islands viewed after the tsunami, reveals that isolated islands such as Interview, North Reef, Paget, Point, Landfall islands, all suffered more than the long continuous islands which remained relatively intact.

5. Future forest scenario

5.1 *Developmental plans*

The state government of Andaman and Nicobar Islands proposed development plans for the next 25 years (http://www.and.nic.in/plan1/apwd.pdf) for the construction of roads and bridges, housing, urban development, minor irrigation, civil aviation etc., to cater to the necessities of the growing population in these



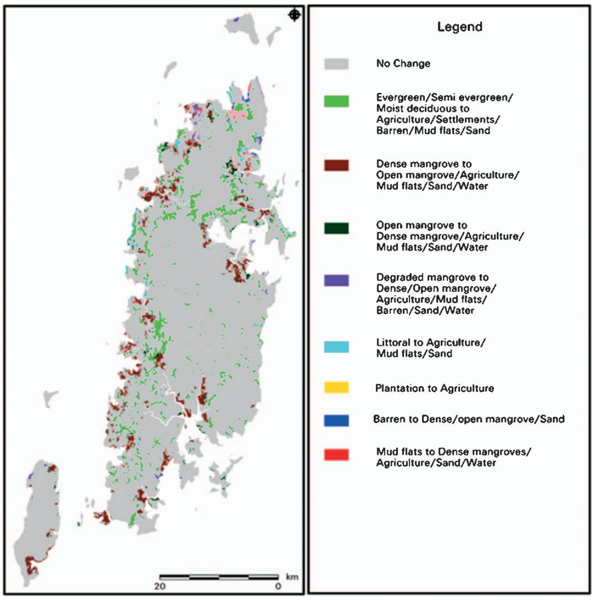
(*a*)

Figure 2(*a*). Impact of anthropogenic and natural factors on forest of north Andaman observed during 1976–2005.

islands. But at the same time it is necessary to see the impact of these developmental activities on the forest structure and ecology, particularly with reference to construction of roads, houses and increasing urban sprawl. Though the proposals are for entire Andaman and Nicobar Islands, it will also show an impact on North Andaman Islands as they form one of the major parts of Great Andaman. In the report they have proposed

(*a*) To widen the existing roads of 3.6 m to 5.50 m (between Port Blair on south and Aerial Bay on north) and to increase it to 7.0 m depending on the traffic situation.
(*b*) Construction of 900 km of new rural roads to connect each and every village as well as intra village point-to-point accessibility.
(*c*) Construction of residential accommodation for government servants using locally produced treated timber, bamboo and cane, which will have impact both on forest and forest goods.
(*d*) Preparation of master plan for Diglipur (North Andaman) urban development by various public construction works.

A simulation study was carried out based on the above proposed developmental activities and results of satellite data analysis to predict the forest scenario for the next 25 and 50 years (see figure 3). For this we have considered only the changes in MSS and LISS III for conversion of forest to non-forest categories, which was



(*b*)

Figure 2(*b*). Forest and other land cover changes observed during 1976–1999.

estimated to be about 6,590 ha for a period of 24 years *i.e*. 1976–1999 (figure 4), at a time when the transportation and communication means were not well developed. But in the present situation where different modes of transport are available and many people are migrating to these islands to overcome the struggle for employment on the mainland, the rate could be even more than estimated. The forest census report of 2001 estimated a loss of 200 ha of forest during their 1997 (1995–1997) assessment for the entire Andaman and Nicobar Islands and reported that the occurred loss was exclusively observed in North Andaman islands, which is similar to the 1976–1999 (212 ha yr^{-1}) anthropogenic rates of change in interior forests (see table 3 and figure 4).

5.2 *Assumptions*

Based on satellite (274 ha yr^{-1}, 1976–1999) data as well as the proposals of the Andaman and Nicobar state government developmental plans, we hypothesised the lowest deforestation rate to be 200 ha yr^{-1} for the simulation study (assuming a slight positive increase in forest area may be owing to afforestation programmes). Observations of data of past 24 years (1976–1999) showed that within the large settlements of North Andaman there was an increase in area of 1230 ha which translates to an overall boundary increase of about 100 km (table 6).

Relating the above forest conversion rate with the increasing human habitation along with other developmental activities and assuming that the future increase in all the settlements will be of similar size, we estimated that on an average there will be an increase in the radius around each major settlement area of 0.5 km for every 25 years. In other words, with the increasing population, for every 25 years the settlement area expands by a distance of 0.5 km around the existing area. This concept was used in simulation to predict the changing forest cover for next 25 and

Table 6. Showing area and perimeter of major and important settlements used for the simulation study.

Settlement Name	1976		1999		Change
	Area (ha)	Perimeter (km)	Area (ha)	Perimeter (km)	Perimeter (km)
Diglipur	2778.59	147.69	3132.96	160.16	12.47
Ramnagar	491.37	31.92	522.64	35.84	3.92
Kalighat	622.92	69.13	851.60	91.03	21.91
Kishorinagar	351.52	31.58	574.79	46.26	14.68
Radhanagar	312.74	36.43	708.58	77.85	41.41
Total					**94.40**

50 years owing to the effect of increasing urban sprawl. The main residential centers like Diglipur and its surrounding cities, Radhanagar, Kishori nagar, Ramnagar, Kalighat were used in the model, because these are the major and established settlements in North Andaman Islands.

5.3 *Simulated results*

Using GIS, incremental multi buffer zones, each of width 0.5 km, were generated around the major settlements. These buffer zones were used to model the forest

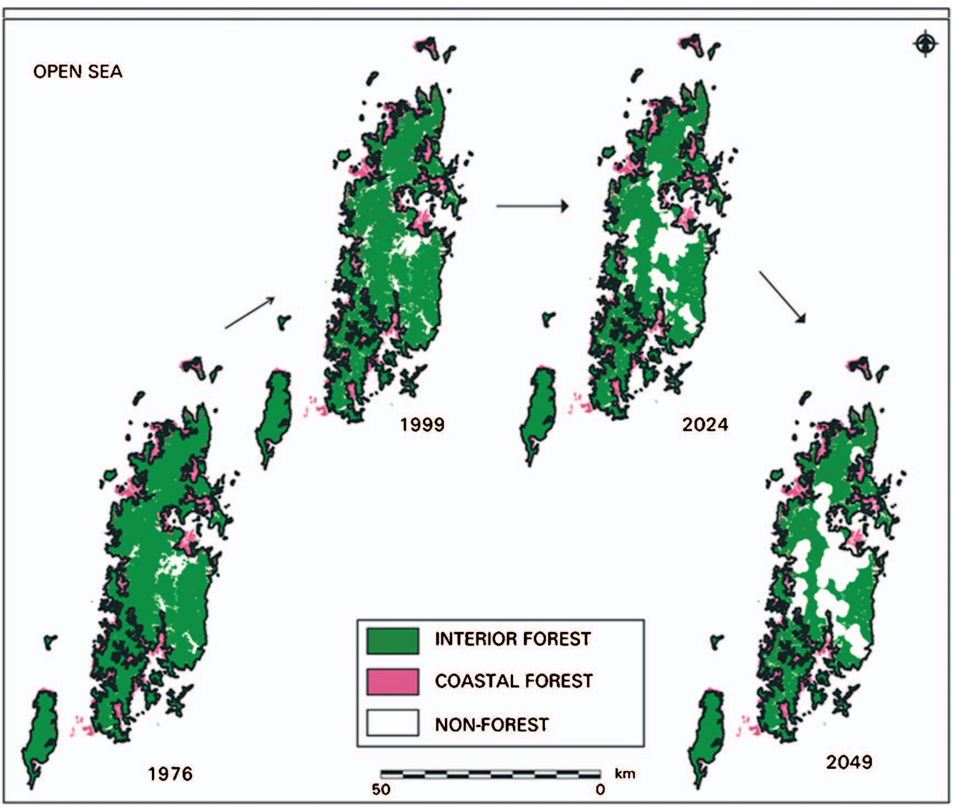


Figure 3. Simulated map showing the changing forest scenario with increasing anthropogenic impacts.

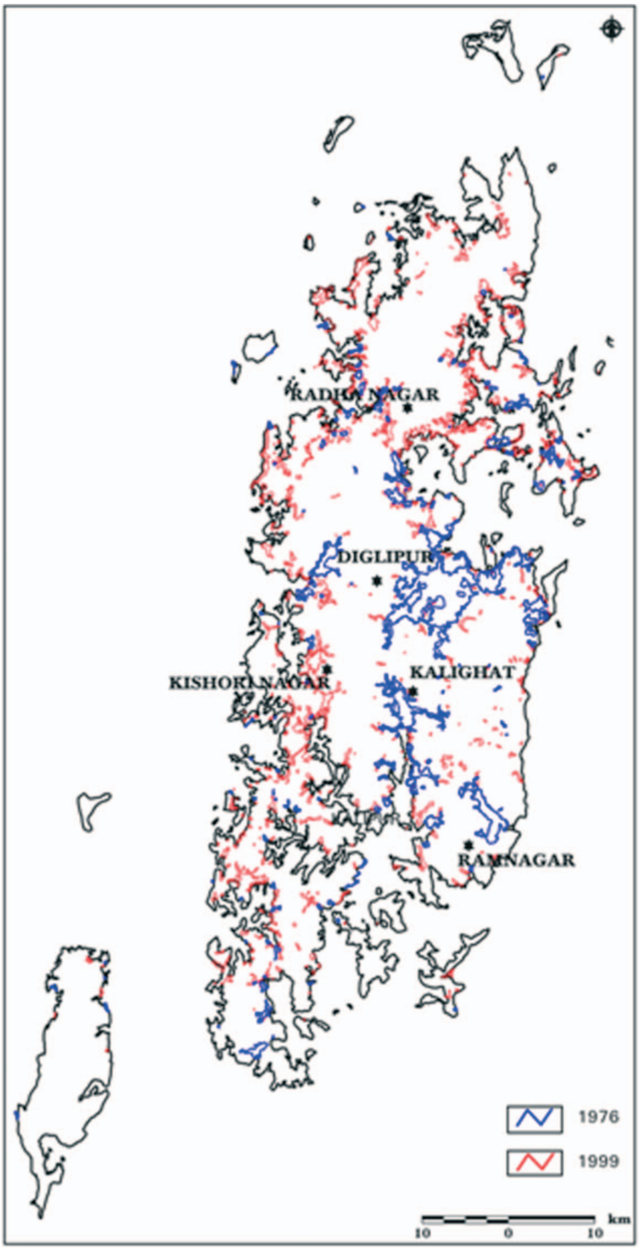


Figure 4. Increase in agriculture/settlement scenario during 1976–99 owing to anthropogenic interferences.

conversion rates to analyse the extent of forest area decreased at the expense of urbanisation over the next 25 and 50 years. Simulation predicted an increase in area of non forest landuse to 19,600 and 29,600 ha for the next 25 and 50 years respectively, resulting in the loss of 13,100 and 22,700 ha of forest. Finally, by the end of 50 years the estimated forest area of 131,200 ha (as per1999 satellite data) may reduce to 108,500 ha. This is the case when we consider only the main urban areas or settlements, but still there are numerous small hamlets, which are under the process of expansion and are not used in this simulation along with the new road construction and expansion. In addition to these anthropogenic changes, if any disaster such as tsunami repeats within a period of next 100 years then most of the coastal vegetation will be damaged. If this is also considered, then the forest area may reduce drastically to about half (50%) of the original. The forests of North Andaman are open to attack on both fronts, while interior (hinterland) forests may be destroyed by the increasing anthropogenic impacts, the outer coastal forests are exposed to disasters (sudden and severe in extent) that might reduce its ability to protect the interior forests from the vagaries of sea.

6. Conclusions

The application of remote sensing and GIS technique has proved beneficial in assessing the forest change scenario within North Andaman Islands. This study on forest change detection using different satellite images gives an idea of deforestation rates caused by both anthropogenic and natural factors. If the deforestation rates of approximately 389 ha yr^{-1} (both anthropogenic and natural) continue in the same trend, then these pristine islands will loose their vegetation to encroachment by human beings on one hand and, much more, to the disasters like tsunami on the other hand. Added to this, it was reported (Deccan Herald, 16 January. 2005) that the tsunami of 2004 also led to considerable increase in mean sea level (1.5 m). The increase in the mean sea level may shrink the islands, which are at low altitudes, as the maximum elevation found in North Andaman Islands is 732 m and many islands are located at an altitude of less than 20m.

In case of the coastal forests, the impact of tsunami is about 50 times greater than anthropogenic causes in the removal of forest cover: 3292.5 ha and 62.5 ha yr^{-1} respectively. This is observed based on the fact that the anthropogenic rates of deforestation in the interior forests during the entire period of study (1976 to 1999–212 ha $yr^{-1}$and 1999 to 2005–192 ha yr^{-1}; see table 3) were of similar order, and we assume that the effect on the coastal forests are also of similar extent (i.e., 62.5 ha yr^{-1}). Loss owing to natural calamities cannot be predicted or prevented, but it can be minimised if proper conservation measures to protect the island vegetation are carried out. As these islands harbor a great amount of species richness and endemicity, apart from *ex-situ* and *in-situ* conservation measures, it is recommended to collect the germplasm of rare and endemic plants, which are unique to these islands for future preservation and propagation.

Acknowledgements

This study was carried out as part of Jai-Vigyan Science and Technology mission project on 'Biodiversity Characterisation at Landscape Level in Andaman Nicobar Islands using remote sensing and GIS'. We are thankful to the Global Land cover facility programme, University of Maryland (for MSS data), Centre for Remote Imaging, Sensing and Processing (CRISP) of the National University of Singapore, Geoinformation PhD Programme of the Tor Vergata University, Rome, Italy (SPOT data), for making available pre- and post-tsunami satellite data of the study area.

References

ACHARD, F., EVA, H., GLINNI, A., MAYAUX, P., RICHARDS, T. and STIBIG, H.J., 1997, Identification of deforestation hot spot areas in the humid Tropics, TREES publication series B, Research report no 4, EUR 18079 EN, European Commission, Luxembourg, p. 100.

ALI RAUF, 2004, The effect of introduced herbivores on vegetation in the Andaman Islands. *Current Science*, **86**, pp. 1103–1112.

BELWARD, A.S., STIBIG, H-J., EVA, H., REMBOLD, F., BUCHA, T., HARTLEY, A., BEUCHLE, R., AL-KHUDHAIRY, D., MICHIELON, M. and MOLLICONE, D., 2007, Mapping severe damage to land cover following the 2004 Indian Ocean Tsunami using moderate spatial resolution satellite imagery. *International Journal of Remote Sensing*, **28**, pp. 2977–2994.

BLASCO, F., BELLAN, M.F. and CHAUDHURY, M.U., 1992, Estimating the extent of floods in Bangladesh using SPOT data. *Remote Sensing of Environment*, **39**, pp. 167–178.

CABLK, M.E., KJERFVE, B., MICHENER, W.K. and JENSEN, J.R., 1994, Impacts of Hurricane Higo on a coastal forest: Assessment using Landsat TM data. *Geocarto International*, **2**, pp. 15–24.

CARR, D.L., 2001, Colonization, clear-cutting, and cornfields: Rural migration and deforestation in the Sierra de Lacandón National Park (SLNP), Guatemala. *Proceedings of the Conference of the Latin American Studies Association of America*, March, 2000, Miami, FL.

CHAMPION, H.G. and SETH, S.K., 1968, 'A revised Survey of the Forest Types of India'. Govt. of India Press, Reprint. Dehra Dun, Natraj Pub., 2005, xxviii, 404 p., tables, figs.

CHANG, S.E., ADAMS, B.J., ALDER, J., BERKE, P.R., CHUENPAGDEE, R., GHOSH, S. and WABNITZ, C., 2006, Coastal Ecosystems and Tsunami Protection. *Earthquake Spectra*, **22**, pp. S863–S887.

CIESLA, W.M., DULL, C.W. and ACCIAVATTI, R.E., 1989, Interpretation of SPOT-1 color composites for mapping defoliation of hardwood forests by gypsy moth. *Photogrammetric Engineering and Remote Sensing*, **55**, pp. 1465–1470.

CURRAN, P.J., DASH, J. and LLEWELLYN, G.M., 2007, Indian Ocean tsunami: The use of MERIS (MTCI) data to infer salt stress in coastal vegetation. *International Journal of Remote Sensing*, **28**, pp. 729–735.

FRANCESCA, B. and LORENZO, B., 2007, A split-based approach to unsupervised change detection in large-size multi temporal images: application to tsunami damage assessment. *IEEE transactions on Geoscience and Remote Sensing*, **45**, pp. 1658–1670.

ISHII, M., SHEARER, P.M., HOUSTON, H. and VIDALE, J.E., 2005, Extent, duration and speed of the 2004 Sumatra-Andaman earthquake imaged by the Hi-Net array. *Nature*, **435**, pp. 933–936.

KAIMOWITZ, D., THIELE, G. and PACHECO, P., 1999, The effects of structural adjustment on deforestation and forest degradation in lowland Bolivia. *World Development*, **27**, pp. 505–520.

KUSHWAHA, S.P.S., 1997, Environmental monitoring and cyclone impact analysis on Sriharikota Island, India. *Geocarto International*, **12**, pp. 55–62.

NAUGHTON-TREVES, L., ALVARES-BERRIOS, N., BRANDON, K., BRUNER, A., HOLLAND, M., PONCE, C., SAENZ, M., SUAREX, L. and TREVES, A., 2006, Expanding protected areas and incorporating human resource use: a study of 15 forest parks in Ecuador and Peru. *Sustainability: Science, Practice, and Policy*, **2**, pp. 32–44.

NAGARAJAN, R. and MARATHE, G.T., 1993, Identification of flood prone regions of Rapti River using temporal remotely-sensed data. *International Journal of Remote Sensing*, **14**, pp. 1297–1303.

PRASAD RAMA CHANDRA, P., 2006, Phytodiversity assessment of tropical rainforest of North Andaman islands using remote sensing and GIS. PhD thesis, Osmania University, India. Unpublished.

PRASAD RAMA CHANDRA, P., SUDHAKAR REDDY, C.H., RAJASEKHAR, G. and DUTT, C.B.S., 2007, Mapping and analysing vegetation types of North Andaman Islands, India. *GIS Development*, **3**, pp. 1–3. Available online at: http://www.gisdevelopment.net/application/nrm/overview/over004_1.htm (accessed 12 December 2008).

SHUKLA, J., NOBRE, C. and SELLERS, P., 1990, Amazon deforestation and climate change. *Science*, **247**, pp. 1322–1325.

STIBIG, H.J., ACHARD, F. and FRITZ, S., 2004, A new forest cover map of continental Southeast Asia derived from SPOT-VEGETATION satellite imagery. *Applied Vegetation Science*, **7**, pp. 153–162.

SUDHAKAR REDDY, C., CHIRANJIBI PATTANAIK and MURTHY, M.S.R., 2007, Assessment and monitoring of mangroves of Bhitarkanika Wildlife Sanctuary, Orissa, India using remote sensing and GIS. *Current Science*, **92**, pp. 1409–1415.

SUGA, Y., OGURO, Y., TAKEUCHI, S. and KONISHI, T., 1999, Detection of forest fire devastation using optical and synthetic aperture radar data (in Japanese with English abstract). *Proceedings of the 27th Conference of Remote Sensing Society of Japan*, Vol. 27, pp. 225–226.

TAKEUCHI, S., 2001, A Comparative study of coherence information by L-band and C-band SAR for detecting deforestation in tropical rain forest. *Proceedings of IGARSS 2001*, Sydney, Australia, 9–13 July.

THOMAS, M., ROLLER, N., COLWELL, J. and KOTTAK, C., 1993, Integrating regional studies of deforestation into a global change context. In *Proceedings of the 25th International Symposium on Remote Sensing and Global Environmental Change*, pp. 559–570. Vol. 1. Ann Arbor, MI: Environmental Research Institute of Michigan.

UHL, C. and KAUFFMAN, J.B., 1990, Deforestation, fire susceptibility, and potential tree responses to fire in the eastern Amazon. *Ecology*, **71**, pp. 437–449.

VOGELMANN, J.E. and ROCK, B.N., 1989, Use of Thematic Mapper data for the detection of forest damage caused by the pear thrips. *Remote Sensing of Environment*, **30**, pp. 217–225.

WESTMAN, W.E., STRONG, L.L. and WILCOX, B.A., 1989, Tropical deforestation and species endangerment: the role of remote sensing. *Landscape Ecology*, **3**, pp. 97–109.

http://www.and.nic.in (accessed 5 October 2005).

http://www.andaman.org.in(accessed 5 October 2005).

http://www.asc-india.org/seismi/seis-andaman-nicobar.htm (accessed19 July 2005).

http://www.crisp.nus.edu.sg/tsunami/tsunami.html (accessed 7 August 2005).

Deccan Herald, 16 January 2005.

http://www.deccanherald.com/deccanherald/jan162005/n9.asp(accessed 5 August 2005).

http://www.esa.int/esa (accessed 6 August 2005).

http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake (accessed 6 August 2005).

http://www.glcf.umiacs.umd.edu (accessed 3 August 2005).

www.gsi.gov.in/sumatra.pdf (accessed 5 August 2005).

http://www.rapidfire.sci.gsfc.nasa.gov/gallery/(accessed 25 July 2005).

http://www.webindia123.com/territories/ANDAMAN/land/land.htm(accessed 5 October 2005).