Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of islands with special reference to mangroves

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Sustainable use is a current theme of prime importance for better utilization of natural resources, through rational and responsible multiple-use management. Synoptic and repetitive coverage provided by orbiting satellites have opened up immense possibilities in terms of resource mapping, monitoring and management. The present study deals with the application of Remote Sensing and Geographic Information System (GIS) technologies in the study of coastal ecology with special reference to mangroves. The coastal wetland ecology of Muthupet and Pichavaram has been studied by considering the changes in wetlands. Wetland maps were prepared on 1 : 25,000 scale using high resolution SPOT (for the year 1989) and IRS LISS II data (for the years 1990 and 1996). Changes in coastal wetland ecology were studied by integrating remote sensing data with GIS. In Muthupet, about 86.77 m^2 of the mangrove forest have been reduced over a period of 7 years (1989 to 1996). Digital analysis of 1986 Landsat TM and 1993 IRS LISS II data showed that 0.36 km^2 area of mangrove in Pichavaram was lost over a period of 7 years. Ground-based spectral measurements of different mangrove species using field spectroradiometer showed highest spectral radiance between 0.7 and 1.1 μm using radiometer of MSS bands and highest spectral reflectance in 0.69–0.86 μm regions of IRS and TM band which could be used in identifying mangrove forest from other vegetation. In Andaman and Nicobar islands the total mangrove area is about 762 km^2 and degradation occurred only in very small pockets (up to 2.379 km^2).

WETLANDS are the areas that lie between aquatic and terrestrial ecosystems, dominated by the influence of water. By virtue of its geographical extent and varied terrain and climate, India supports a rich diversity of inland and coastal wetland habitats[1]. India's 7500 km coastline has numerous lagoons, estuaries and mangrove swamps[2]. One such habitat is the mangrove forest ecosystems that occur in the intertidal zone along tropical and subtropical coastlines.

The mangroves dominated by salt and flood-tolerant trees are among the most biologically productive areas of the estuarine ecosystem. At the ecosystem level, mangroves serve as nursery, feeding and spawning grounds for commercial fishes and shell fishes, provide detritus for the coastal ecosystem, reduce cyclone and wind damage and prevent soil erosion[3]. They also serve as a nesting and feeding ground for a variety of wildlife and as a sink or trap for coastal pollutants[4]. The allochthonous detritus produced by mangroves is an important food source for phytoplankton in the estuarine areas.

Understanding the status of mangroves including the degradation areas and its causes is important for decision making and also for creating public awareness to conserve these important coastal resources. In India, mangroves have not received the attention they deserve and they have been subjected to overexploitation and encroachment and hence there is a need for management of mangrove forests.

In this paper we address the application of remote sensing and GIS in studying the changes in the mangrove ecosystem between 1990 and 1996 at Muthupet and Pichavaram, Tamil Nadu and the Andaman and Nicobar islands. We discuss the changes in the mangrove wetlands in the light of the degradation caused by the human influence and emphasize the need for conserving the wetlands.

Description of the study areas

Muthupet (10°15′–10°22′N and 79°30′–80°00′E)

The coastal length of Tamil Nadu is about 1000 km of which 225 km belong to Thanjavur district, where an extensive mangrove swamp is located at the southern tip of the Cauvery delta. The Cauvery river is the main riverine system of Thanjavur district. The drainage arteries of Cauvery basin include the rivers Paminiyar, Korayar, Kilaithangai, Kanthaperichan and

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Marakakorayar. The arteries flowing through Muthupet and adjacent villages create mangrove swamp. Even though the swamp is situated 73 km away from Thanjavur, it is ideally placed for the study of the mangrove ecosystem because all along the 12 to 13 km of the riverine length which separates the village from sea, there is a gradual but noticeable change in the landscape. Muthupet mangrove swamp is in close association with the coastal wetlands of Vedaranyam.

Pichavaram (11°22′–11°30′N and 79°45′–79°52′E)

The Pichavaram mangrove realm near Parangipettai is situated on the south east coast of India and represents a heterogeneous mixture of mangrove elements. It lies in-between the northern Vellar and southern Coleroon estuary systems and along with Killai lagoon, is referred to as the Vellar Coleroon estuary complex. Covering an area of approximately 1100 ha, it is represented by 51 islands, waterways, channels, gullies and rivulets. About 40% of the total area is covered by mangrove vegetation; of this 50% is forest and the remaining part consists of mudflats and sandy plains. This ecosystem is well known for its luxuriant growth of mangrove plants with high productivity and diversity of fauna and is provided with rich detritus, nutrients, salts, trace elements, etc. Pichavaram mangrove is one of the typical mangrove swamps of India with high productivity of organic plant detritus.

Andaman and Nicobar group of islands (6°00′–14°00′N and 92°00′–94°00′E)

Andaman and Nicobar group of islands is an archipelago of 572 islands. The Andaman and Nicobar group of islands cover an area of about 8717.54 km^2. The altitudes vary from sea level to 732 m above m.s.l.

Methodology

For Muthupet and Andaman and Nicobar islands sites, the visual interpretation of satellite data combined with ground truth verifications were employed. For the Pichavaram site digital analysis of satellite data was carried out. In addition, ground-based spectral reflectance studies were carried out to see the changes in spectral signatures of different species of mangroves and the background soils.

Satellite data products were procured from National Remote Sensing Agency, Hyderabad. The base maps were prepared using Survey of India toposheets. Wetland maps for the years 1989, 1990 and 1996 were prepared using SPOT and IRS 1B LISS II data for Muthupet. For Andaman and Nicobar islands in addition to IRS 1B LISS II data, Landsat 5 TM data have also been used. The changes in the wetlands in Muthupet between the periods 1989 and 1996 were analysed and the change detection maps were prepared subsequently using GIS (PAMAP).

Base map preparation

It is very essential to incorporate the other related ground information on the manually interpreted map. For this purpose, the base map showing major rivers, water bodies, roads, railways, etc. was prepared using the Survey of India toposheet on 1 : 50,000 scale. To obtain a base map of 1 : 25,000 scale the toposheet was mounted on the planvariograph and enlarged. Since the scale is on 1 : 25,000, each toposheet (1 : 50,000) is divided into four parts, representing NE, NW, SE and SW. The maps prepared after interpretation were superimposed, over the base map using planvariograph.

Visual interpretation of satellite data and ground truth verification

IRS LISS II and SPOT transparencies of May 1989, January 1990 and August 1996 were used for the visual interpretation of Muthupet on 1 : 25,000 scale. In the case of Andaman and Nicobar islands IRS-1B and Landsat 5 TM transparencies were used. The visual interpretation was carried out by mounting the transparency on PROCOMM 2 and classified based on the procedure by Space Applications Centre, Ahmedabad, for the nation-wide wetland mapping (Table 1).

The low water line, forest boundary and village locations were transferred from Survey of India toposheets. The satellite imageries were interpreted on the basis of tone, texture, colour, pattern, location, etc. The various wetland categories like beach, mudflat, mangroves, marsh vegetation, scrub, plantation, salt pan, salt-affected area, etc. were identified. An image interpretation key indicating colour/tone, size and pattern for each category is given in Table 2.

The maps prepared from IRS LISS-II imagery were ground-truthed. Further, based on ground survey the mangrove degradation sites were verified and the general zonation pattern of Muthupet and Pichavaram mangroves was prepared. Ground truth verification was also carried out in Andaman and Nicobar islands and the mangrove degradation sites were checked. The accuracy of the interpretation after ground truth verification at both sites was 90%.

Digital analysis

Digital analysis was carried out in the VAX 11/780 computer system. The Pichavaram mangrove area was initially identified from the Survey of India toposheet. Digital data of IRS P2 were loaded for the exact path and row as noted from the reference chart. The entire area was initially displayed and later subscene was extracted using the image extraction program. Study area chosen is confined to a dimension of 512 × 512 pixel to obtain more accuracy. The false colour composite was created and training sets were given with the help of ground information. The training sets were checked for their pixel values in all the bands and accepted for classification if their values were not with much of change. As the study area comprises of wide variations within a small area, it required more number of training sets (75) so that the number of unclassified pixels is kept at minimum. Image statistics were obtained for the image and their values were analysed for standard deviation and variance. The individual class segments were obtained by running the classes option of VAX/VMS. Desired colour codes were given for the classes using the lookup table. Thus the classified output distinctly shows the different categories. Mangroves occur with other coastal elements categories such as mud/tidal flats, waterways, beach sand, etc. Accurate estimation of the area under mangroves requires a suitable classification method for the analysis of digital data. In the present study, classification accuracy of maximum likelihood classifier and fuzzy classification method was compared based on the number of pixels pertaining to each training set. The fuzzy classifier was observed to classify the training set classes with more than 95% classification accuracy, while maximum likelihood classifier classified only to 88%.

Table 1. Classification system followed for mangrove mapping

Level I	Level II	Level III
Non-vegetated wetland	Mud-flat sand	High-tide flats beach
Vegetated wetland	Mangroves	Dense Less dense Degraded
	Forest plantations	Interior
	Beach plantations	Coastal
Others	Agricultural lands	Presently cropping Current fallow

Ground-based spectral studies on mangroves

Spectral studies of individual mangrove species under different environmental conditions were made using ground-based spectroradiometer in MSS, TM and IRS bands. Exotech radiometer of MSS bands was used at Pichavaram and the spectral radiance of five major species, viz. *Avicennia marina* (Forsskal) Vierh, *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam., *Rhizophora x lamarckii* Mantrouz and *Suaeda maritima* (L.) Dumort were measured. For twelve species, viz. *Acanthus ilicifolius* L., *Aegiceras corniculatum* (L.) Blanco, *Avicennia marina* (Forsskal) Vierh., *Bruguiera cylindrica* (L.) Blume, *Ceriops decandra* (Griffith) Ding Hon, *Excoecaria agallocha* L., *Lumnitzera racemosa* Willd, *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam., *Salicornia brachiata* Roxb, *Sesuvium portulacastrum* (L) L. and *Suaeda monoica* (Forsskal) J. Gmelin spectral properties were studied using the multiband ground truth radiometer of TM and IRS bands at Pichavaram and Muthupet.

Spectral radiance (mw/cm^2-Sr-μ) was calculated as: $L = (O/P) \times (CL)/(G)$, where L is the spectral radiance (mw/cm^2-Sr-μ), O/P is the final output of the instrument (mv), CL is the calibration constant for specified FOV and spectral band (mw/cm^2-Sr-μ)/mv) and, G is the gain indicated by range select switch.

Multiband groundtruth radiometer (model 041) manufactured by Optomech Engg Pvt Ltd, Hyderabad contains 8 channels corresponding to the first 4 spectral bands of Landsat TM and 4 bands of Indian Remote Sensing satellites (IRS 1A & 1B), and also has $15° \pm 1/2°$ standard FOV.

Table 2. Image characteristics of the coastal wetland classes interpreted on SPOT, IRS LISS II and Landsat 5 TM

	Image characteristics		
Wetland category	Tone	Texture	Remarks
Mudflat	Greyish	Medium	Slightly rough pattern
Beach sand	Whitish	Fine	Smooth pattern
Mangroves			
Dense	Dark red	Medium	Smooth pattern
Less dense	Light red	Medium	Smooth pattern
Degraded	Greyish	Coarse	Rough pattern
Forest plantations			
Interior	Dark red	Coarse	Rough pattern
Beach	Dark brown	Coarse	Rough pattern

Geographic information system

All the visually interpreted maps were digitized using a A0 digitizer into the PAMAP-GIS. For analysis, the digitized maps were given tag-id for various categories. Polygons were developed and the area for various categories calculated and the changes in wetlands analysed.

Results and discussion

Muthupet and Pichavaram

The output maps showing the wetland categories of Muthupet for the years 1989, 1990 and 1996 are shown in Figures 1 to 4. The changes observed in different categories of wetland are given in Table 3.

In Muthupet area it is observed that there is a marked degradation in mangrove forests comparing wetland maps of 1989 and 1996. Mangroves have degraded in density at some of the places and have disappeared in several other places. The degradation has occurred mostly in sparse mangrove forests due to the expansion of saltpan and human activities. The mangrove forest at Point Calimere is also found to be degraded in density. However, dense mangrove forests have increased from

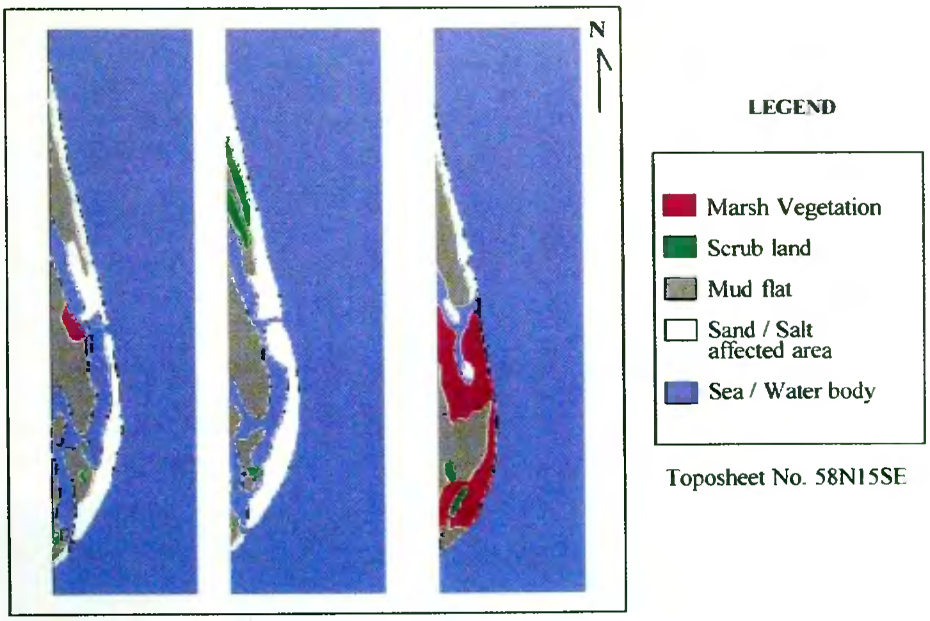

Figure 1. Changes in coastal wetland morphology of Muthupet

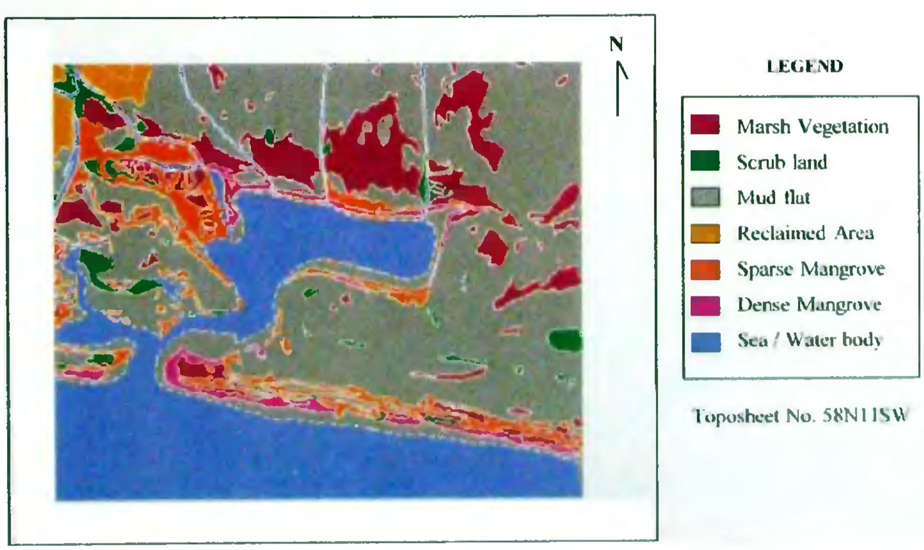

Figure 2. Coastal wetland morphology of Muthupet in 1989.

706 m^2 to 958 m^2. In total, nearly 87 m^2 of total mangrove forest have degraded in the study area. As Muthupet area is dry for most of the year, human activity like cutting the wood for fuel, grazing by cattles, etc. have caused the degradation of mangroves. Agriculture areas and habitation with vegetation areas have increased by nearly 368 m^2 and 480 m^2 respectively. The saltpan area has increased rapidly over the years by about 369 m^2, at the expense of mangrove vegetation and mudflat area (Table 3).

Change detection studies by digital analysis

In the present study the available cloud-free Landsat TM data of May 1986, IRS LISS-I data of December 1990 and IRS LISS-II data of August 1993 were chosen for the change detection of mangroves in Pichavaram. Since the spatial resolution of Landsat TM (30 m) and IRS LISS-II (36 m) are nearly equal, these two data were used for change-detection of Pichavaram mangroves. Due to the coarse resolution of IRS LISS-I (72 m), it was used to study the acreage estimation by resampling method. The digital classification of satellite data was performed with the selection of a large number of training areas from different homogenous colour patches, of both known and unknown characteristics, spread throughout the study area. Homogeneity of the selected training areas was ensured by evaluating the standard

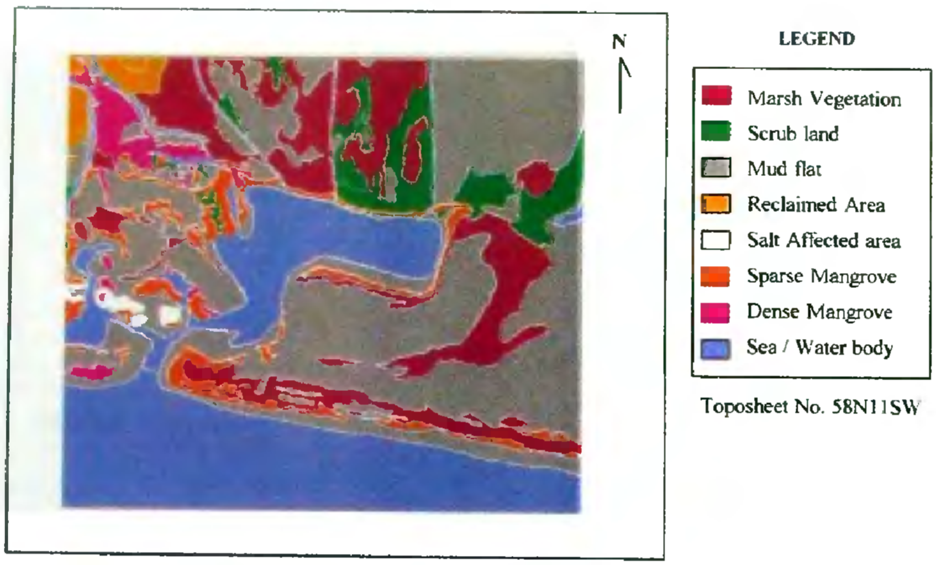

Figure 3. Coastal wetland morphology of Muthupet in 1990.

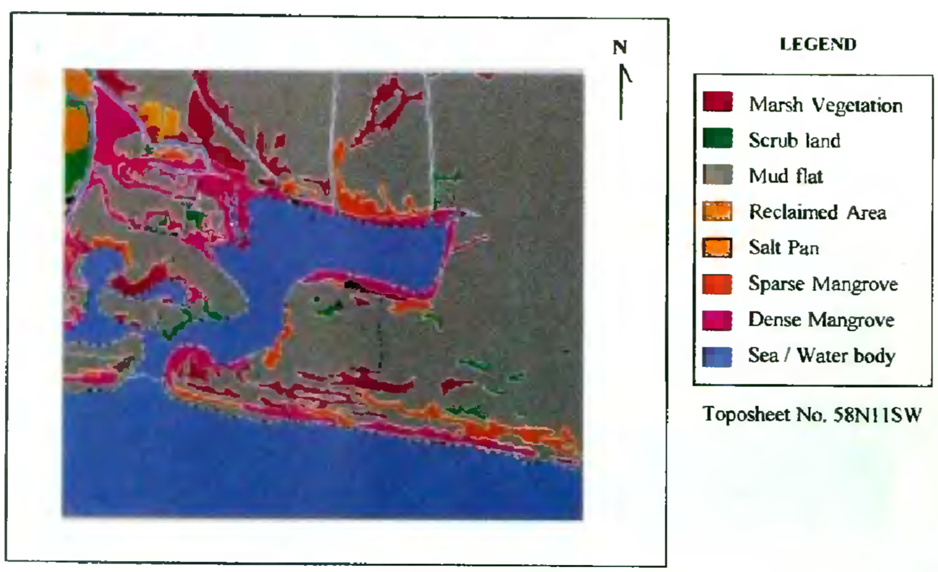

Figure 4. Coastal wetland morphology of Muthupet in 1996.

deviations for each training set. The classified outputs are shown in Figures 5 and 6. Only those training areas with standard deviation < 2.0 were used, and since the mangrove forests do not show much phenological changes, the difference in sensor data (TM and IRS LISS-II) is not expected to have any effect on mangrove change, detection based on digital classification.

The confusion matrix and classification statistics were performed and the number of pixels pertaining to each training set have been calculated to study the change detection of Pichavaram mangroves. The number of pixels pertaining to mangroves are classified as 2063 in TM (1986) and 1153 in LISS-II (1993). The mangrove areas were calculated to be 1.86 km^2 in 1986 and 1.5 km^2

Table 3. Areas of different categories in Muthupet mangrove ecosystem and percentage change in area between 1989 and 1996

	Area of wetland categories (m^2)			
Category	1989	1990	1996	% Change
Mudflat	21913.40	21,258.08	21,998.78	+ 0.39
Sandy area/beach	664.10	741.44	229.68	−65.41
Mangrove (dense)	706.38	648.48	958.99	+35.76
Mangrove (sparse)	1163.70	1068.59	524.32	−54.94
Total mangroves	1570.08	1417.02	1483.31	−5.53
Marsh vegetation	3501.14	3529.12	3550.75	+ 1.42
Scrub	3112.10	2837.09	2146.57	−31.03
Lagoon	4239.20	4365.09	4839.36	+ 14.16
Natural forest	2673.50	1970.47	2511.61	−6.06
Man-made forest	541.96	521.31	425.31	−21.52
Salt-affected land	220.75	362.89	153.18	−30.61
Saltpan	3128.87	3359.75	3497.37	+ 11.78
Reclaimed area	237.94	358.44	118.32	−50.27
Agricultural land	1101.47	2126.30	1469.50	+33.41
Habitation with vegetation	232.80	289.00	712.37	+206.00
Total	43,137.31	43,136.00	43,136.11	

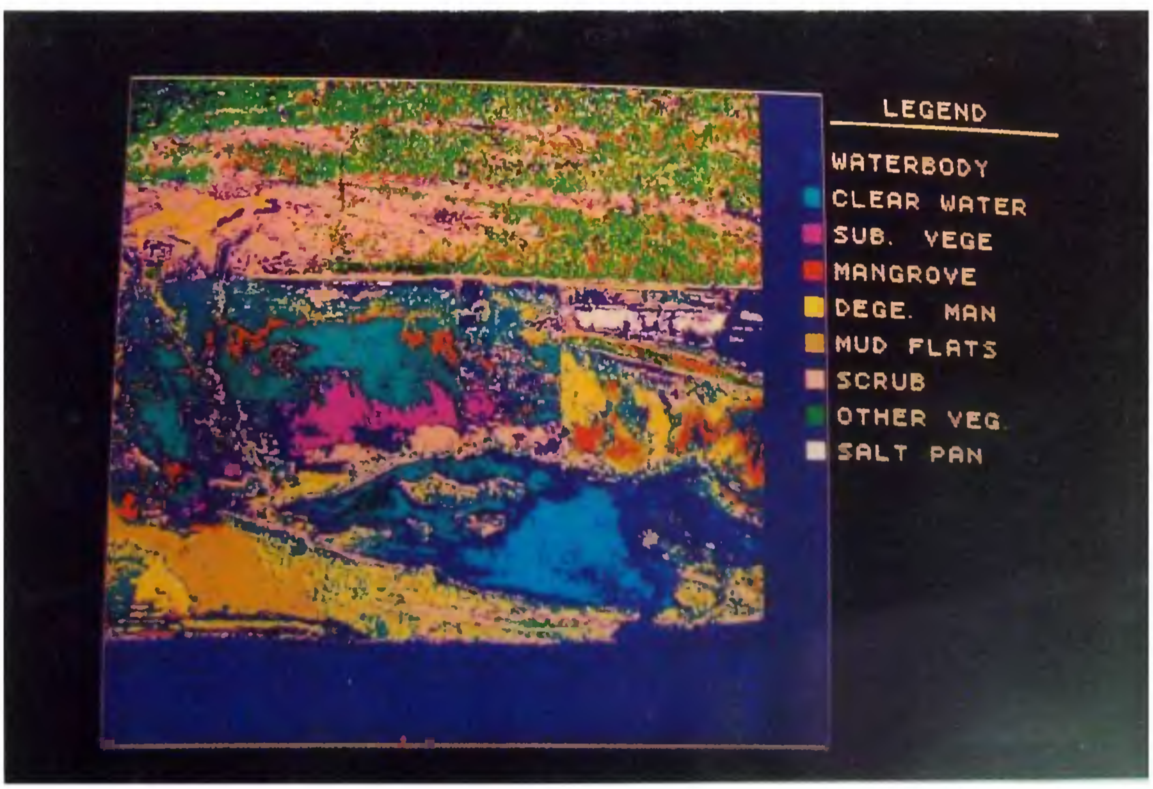

Figure 5. Classified output of Muthupet mangrove using Landsat TM.

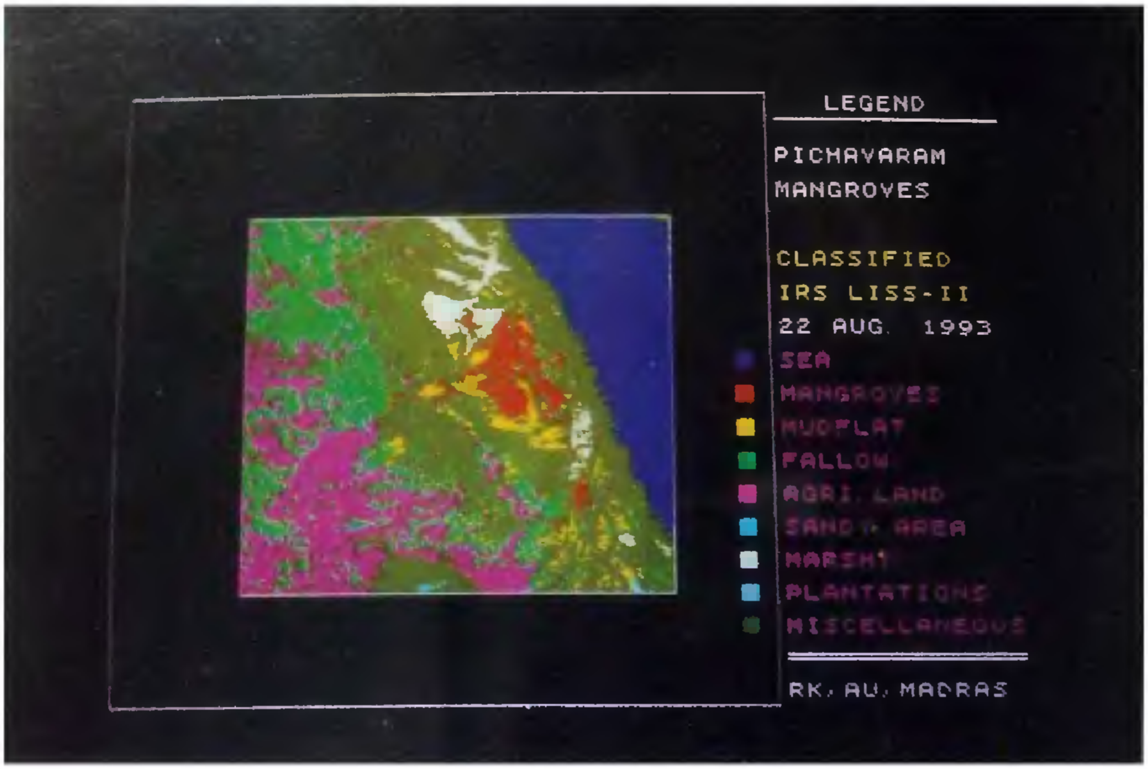

Figure 6. Classified output of Pichavaram mangrove using IRS LISS II.

Table 4. Spectral radiance of mangrove species in Pichavaram

Species	Radiance (mw/cm^2-Sr-μ) MSS band			
	Band 1	Band 2	Band 3	Band 4
Avicennia marina	2.47	2.51	8.67	8.39
Rhizophora apiculata	2.88	1.63	6.94	8.58
Rhizophora mucronata	4.12	4.19	7.94	7.8
Rhizophora lamarckii	5.34	4.19	10.41	8.39
Suaeda maritima	3.29	2.79	6.94	7.41

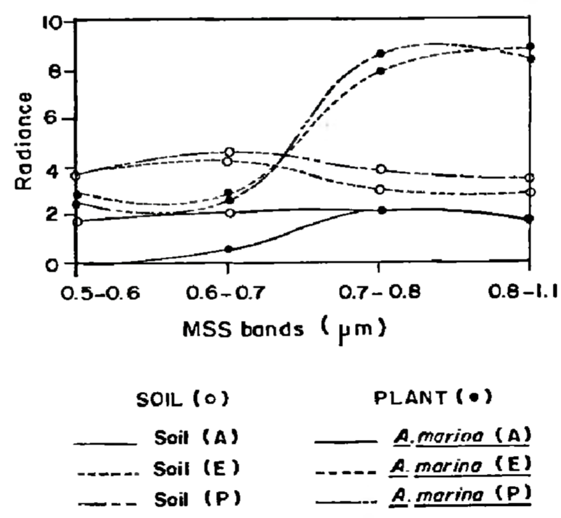

Figure 7. Spectral radiance of *A. marina* background soil.

in 1993. The loss of mangrove areas in Pichavaram between 1986 and 1993 is estimated to be 0.36 km^2. Based on the resampling of mangrove pixels from IRS LISS-I data, the total mangrove area (including waterways and mudflats) was calculated to be 4 km^2.

Spectral radiance of mangrove species in MSS bands

Since the major difference among vegetations spectral signatures is the amplitude or magnitude of reflected radiance, the Exotech radiometer of MSS bands with 15° FOV optical element was used to measure the spectral radiance of mangrove species in this study[5]. The instrument height (5 m) and the time (11.00 AM to 1.00 PM) was maintained throughout the study. Five predominant species were selected initially for spectral radiance study. Four scans were averaged together at each observation to plot spectral radiance curves and the average radiance values are given in Table 4. All the mangrove species show similar radiance patterns, but variations in intensity of radiance were observed (Figure 7).

The highest radiance was observed between 0.7 and 1.1 μm for all mangroves[5]. *R. x lamarckii* showed highest radiance values in the first three bands and *R. apiculata* in the fourth band. *A. marina* showed higher values in bands 3 and 4 than *R. mucronata.* The variations in spectral radiance of mangrove species in each band can be obtained from the standard deviation values, 1.02, 0.99, 1.33 and 0.39 respectively for MSS bands 1, 2, 3 and 4. Much deviation could be observed in bands 1 and 3 for all the species studied.

Spectral reflectance of mangrove species in TM and IRS bands

The comparison of spectral radiance of mangrove species provides some information about the variation in intensity of radiance. However, the difference in radiance may be due to changes in location. The comparison of reflectance of different mangrove species will be more useful to correlate with various related parameters of mangrove vegetation. Since the floral distribution, i.e. zonation is more in Pichavaram, 12 species in this area and four species in Muthupet were selected for spectral reflectance study during February 1995.

Normalized reflectance curves were prepared by taking average of reflectance percentage in each band of all mangrove species to understand the cumulative nature of spectral signature of all the mangrove species and also to observe the reflectance using TM and IRS band sensors. Normalized reflectance curves have crest at 0.52–0.58 μm (band 2 in IRS) and 0.52–0.60 μm (band 2 in TM) and followed by a trough at 0.63–0.69 μm (band 3 in TM) and 0.62–0.69 μm (band 3 IRS). The steady increase in reflectance status was from 0.69 to 0.9 μm wavelength region. The amplitude of spectral reflectance varies in different mangrove areas[6]. A comparison of spectral reflectance curve of *A. corniculatum* shows a higher reflectance in Muthupet than that in Pichavaram. An abnormal shift in reflectance peak could be observed in band 2, 3 and 4 of IRS. The species in Muthupet shows decrease in reflectance in band 2 and increase in reflectance in band 3. In Figure 8, the shift in reflectance peak has been marked (down arrow and up arrow).

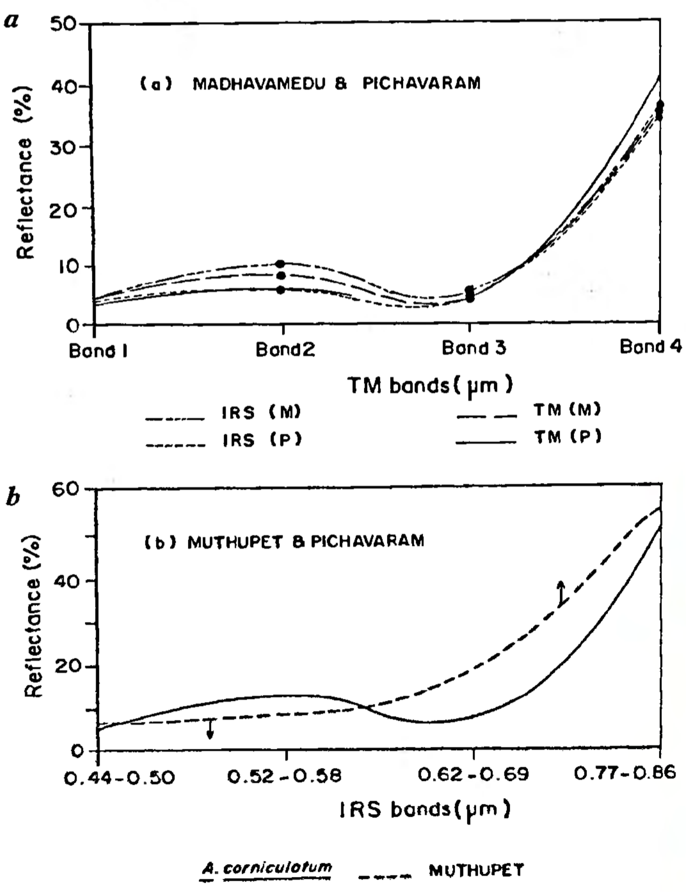

Figure 8. ***a***, Normalized spectral reflectance curve. ***b***, Spectral reflectance changes in different locations.

Table 5. Areas of different wetland categories in Andaman and Nicobar Islands

Category	Area covered (km²)
Salt-affected area	143.39
Mudflat	68.69
Sand/beach	139.72
Coral reefs	868.24
Rocky coast	43.28
Mangrove (dense)	588.32
Mangrove (sparse)	174.19
Mud with vegetation	0.96
Sand with vegetation	4.51
Forest clearing	65.97
Barren land	64.29
Forest	5998.16
Agricultural land	474.38
Submerged rocks	86.48

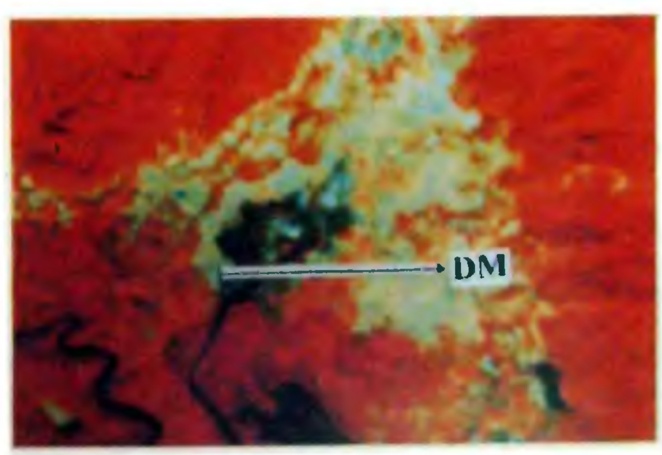

Figure 9. Satellite imagery (IRS 1B LISS II, March 1993) showing degraded mangrove areas (marked as DM) in South Andaman islands

Andaman and Nicobar islands

Mapping on 1 : 25,000 scale was carried out for the various wetland features in Andaman and Nicobar group of islands. The various wetland features mapped and the area occupied by each category is given in Table 5.

Mangroves in the Andaman and Nicobar group of islands are found in most cases bordering estuaries, neritic inlets and lagoons. Most of the mangroves in this area are found to be dense in nature. The total area covered by the mangroves is about 762 km^2. The wetlands including the mangroves have not been subjected to much disturbance and are found to be intact. Though most of the mangroves have been found to be intact, degradation to a small extent is found south of Port Blair. This degradation is attributed to the urbanization. A total area of 2.379 km^2 of mangroves have been degraded in the entire Andaman and Nicobar group of islands (see Figure 9). The coral reefs in Andaman have not been subjected to much mining activities and hence are found to be undisturbed, they cover an area of about 868.24 km^2 (Table 5). The other features are also not found to be disturbed except the forests where deforestation to some extent has taken place.

Conclusion

A careful assessment of changes in coastal environmental conditions forms a cornerstone for effective coastal zone management and leads to sustainable utilization of coastal resources. The environmental stress on the coastal zone is rapidly growing and there is a need to understand the changes in the environment and to predict the future events for making management decisions. The results of this study clearly demonstrated the use of satellite-based sensors in the mapping and monitoring of coastal ecosystems. The degradation of ecologically important wetlands in the three sites studied, indicates the increasing human interferences in the functioning of the natural ecosystems. The changes that have taken place in these wetlands from one category to other also reveal that the habitat value has been dramatically reduced because of the anthropogenic impacts. Thus remote sensing and GIS could be used effectively in mapping, monitoring and management of natural resources. Further, this study has also opened up a new avenue for the application of remote sensing techniques in assessing the biodiversity of coastal wetlands.

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