Satellite Based Monitoring Of the Changes in Mangroves in South Eastern Coast and South Andaman Islands of India - A Tsunami Related Study

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Satellite Based Monitoring Of the Changes in Mangroves in South Eastern Coast and South Andaman Islands of India - A Tsunami Related Study

by

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I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.
Signed …………………….

Disclaimer

Dedicated to my beloved sister…

Abstract

Indian Ocean is the home to rare flora and fauna that act as the bio-shield to many coastal communities. Indian Ocean experienced the world's most deadly natural disaster "Tsunami" on 26th December, 2004, which on one hand is unparallel in the history considering its magnitude and devastation and on the other hand, caused an unprecedented impact on the aqua and aqua terrestrial ecosystems. One of the worst effected flora is the *mangrove* species that is among the richest in the world. There are places where vast pristine tracts of mangroves have been destroyed and it may pose a long-term threat for the region, not only in terms of forest and biodiversity conservation but also in terms of the ability of the ecosystem to support the livelihoods and the coastal communities. The tragedy of Tsunami invoked the rationale for conserving and sustainably managing natural ecosystems among the researchers and scientific community.

The present research was carried out to make a post Tsunami evaluation of India's most ecologically fragile areas of Gulf of Mannar and South Andaman Island. Indian Remote Sensing Satellite (IRS 1C) and (IRS 1D) LISS (Linear Imaging Self Scanner)-III and Resourcesat –I LISS IV data have been effectively used to detect, assess and monitor the changes in the mangroves in the Pre and Post Tsunami period using multitemporal optical satellite data.

Onscreen visual interpretation was done using FCC of the data to identify the heterogeneous patches for the preliminary classification of fieldwork.A supervised classification was performed using Gaussian Maximum Likelihood (GML) classifier to obtain the pre and post Tsunami land use/land cover maps. Accuracy assessment of the classified maps were performed on pixel level using ground truth.

The changes in the Pre and Post classification maps were performed by comparison of area basis based on different land use classes and using change matrix analysis. The result highlighted the changes in the spatial extent of the mangroves and other landuse categories in the study areas as a result of Tsunami. The Damage map showed the degree (intensity) and extent of damage in mangroves on a qualitative basis.

Keywords: Tsunami, mangroves and change detection

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Barnali Chatterjee,
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1.Introduction

1.1 General Background

"One perceives a forest of jagged, gnarled trees protruding from the surface of the sea, roots anchored in deep, black, foul smelling mud, verdant crowns arching toward a blazing sun...Here is where land and sea intertwine, where the line dividing ocean and continent blurs, in this setting the marine biologist and the forest ecologist both must work at the extreme reaches of their discipline."**(Rutzler and Feller 1996)**

The above quote refers to the "mangals" or the mangrove forests. Mangrove forests are the most productive and biologically diverse wetlands of the earth. They are the salt tolerant plant species, which thrive at the interface of land and sea. According to Aubreville (1970) "the mangroves" or the "mangals" are the coastal tropical formations found along the border of the sea and the lagoons extending along the banks of the river as far as the water remains brackish growing in swampy soils and covered by the sea during high tides**.(Puri, R.K.Gupta et al. 1989)**. Mangroves embodies two concepts: it is an ecological group of evergreen plant species belonging to several families but possessing marked similarity in their physiological characteristics and structural adaptations to similar habitat performance. Second, it is a complex plant communities fringing the sheltered tropical shores. Such communities usually have trees associated with shrubs growing in the zone of tidal influence both on the sheltered coast itself and inland lining the bank of estuaries and river."**(Syed 2001)**

Mangrove plants mostly grow within the sheltered intertidal flat deltaic lands, funnel shaped bays, broad estuarine mouths, shallow or frequently tidal inundated coastlines.**(B.G.Thorn 1982)**. Mangrove forests are associated with evergreen communities and diverse groups of tropical trees, shrubs, ground fern thriving in the marine intertidal zone. Intertidal zones are mainly dynamic in nature and are characterized by harsh conditions. Mangrove can survive in this condition as they have some specialized adaptations. These adaptations include exposed breathing roots, support roots and buttresses, salt excreting leaves, and viviparous water-dispersed propagules **(N.C.Duke 1992)**

Mangroves have specially adapted aerial and salt filtering roots that enable them to survive in saline wetlands. These forests are constantly controlled by marine and terrestrial factors such as local climate, geomorphology, salinity and other edaphic characteristics. These factors combined with the distance from the sea, frequency and duration of inundation and tidal dynamics govern to a great extent the local distribution of species and its succession. Mangroves perform multiple ecological functions and have high biological productivity. They play a significant role in the coastal stabilization and promoting land accretion, fixation of mud banks, dissipation of winds, tidal and wave energy.

1.2 Distribution of the Indian Mangroves

Mangroves are mainly restricted to the tropical and subtropical zones on sheltered shorelines. India harbours mangrove forests along the east coasts and the west coasts. There is a discontinuous distribution of mangroves along the Indian coast. The mangroves in the eastern coast of India are more than the western coast because of the terrain and gradual slope of the land. The distribution of the mangrove ecosystem on Indian coastlines indicates that the Sundarban mangroves occupy the largest area, followed by Andaman and Nicobar Islands and Gulf of kachch in Gujarat. Best developments of mangroves are found at such locations with deep, well aerated soils, rich in organic matter and low in sand, usually in estuaries. The inland extend of the mangroves depends on the morphology of the soil and the forests can vary in size from a few clusters to hugely developed areas.

There are three categories of forest stratification based on the height of the vegetation in a normal mangrove ecosystem. The widest trunk with a spreading crown is found in the species like *Avicennia* and *Sonneratia*.Less spreading crown is found in the *Bruguiera* and *Rhizophora* which mainly constitute the top canopy of the forest. The next category is contributed by shrubs and small trees like *Aegeceros, Exoecaria* and *Ceriops*.The third category is mainly occupied by small shrubs and ferns. Mangrove ecosystems contain almost sixty species of true mangroves and shrubs and more than twenty associated species. They are known as the physiological halophytes as they exhibit remarkable salt tolerance. The composition mainly varies with depth, salinity, wave action, intertidal exposure etc. The diversity in the structural formation and zonation in the mangrove forests are generally noticed along the latitudinal gradients and varying rainfall gradients.

The Indian mangrove biodiversity is rather high. The increase in the biotic pressure on mangroves in India has been mainly due to land use changes and on account of multiple uses such as for fodder, fuel wood, fibre, timber, alcohol, paper, charcoal and medicine**. (Upadhyay. V.P, Ranjan Rajiv et al. 2002)**

Figure 1: Distribution of Mangroves in India

1.3 Status of Mangroves In India

The cradle of mangrove vegetation is the Indo-Malaysian region. According to the available fossil records, the mangroves vegetation was luxuriantly found in the Cretaceous to Miocene period. Mangroves have a worldwide circumtropical distribution; the highest concentration being located in the Indo-Pacific ocean region. The Indian coastline supports the most productive ecosystem in the east and

the west coast. The east coast is richer in biodiversity than the west coast. In 1960, the total area of the Indian mangroves was estimated as 6, 81, 976 ha in, which nearly 45% was in Sunderbans in West Bengal. As per data furnished by the concerned State Government, total area of tidal forest in India was about 6,740 sq. km, constituting about 7% of the world's area under mangroves. **(Singh 2000)**

A recent survey shows the total area of Indian mangroves as 4, 37,400 ha which include the Andaman and Nicobar islands. Ground scenario is different as some of the mangrove forests disappeared due to human activities. Forest Survey of India (FSI), Dehradun made independent assessments of mangrove cover five times at interval of every two years using remote sensing technology.**(Singh 2000).** Important mangroves areas are Killai and Pichavaram and Gulf of Mannar islands in Tamil Nadu, state of Kerala, Karnataka and Gulf of Kutch. The Andaman and Nicobar islands contain some best preserved and least exploited mangroves. Sundarbans formed in the vast delta complex is usually described as the largest single natural mangrove block in India. Tidal currents and fresh water supply influence the physico chemical factors in the mangrove estuarine systems to govern the distribution and zonation of the mangrove species, out of which salinity and temperature plays a vital role in the zonation of the species.

Table 1 District wise mangrove cover assessment*

State	District	Area assessment (km^2) 1997	1999	Change from 1995 assessment	Change from 1997 assessment
Andaman and Nicobar Islands	Andamans	929	929		
	Nicobar	37	37		
	Total	966	966	Nil	Nil
Andhra Pradesh	Godavari	216	241		
	Krishna	111	104		
	Nellore, Prakasam, Kurnool	56			
	Guntur	–	52		
	Total	383	397	+ 5	+ 14
Goa	Goa	5	5	+ 2	Nil
Gujarat	Bharuch	13	6		
	Bhavnagar	20	25		
	Jamnagar	118	140		
	Kachchh	836	854		
	Surat	4	4		
	Junagarh	–	1		
	Valsad	–	1		
	Total	991	1031	+ 302	+ 40
Karnataka	Dakshina Kannada	2	2		
	Uttara Kannada	1	1		
	Total	3	3	+ 1	Nil
Maharashtra	Mumbai city	2	2		
	Mumbai	46	32		
	Colaba	34	–		
	Thane	42	24		
	Raigarh	–	38		
	Ratnagiri	–	12		
	Total	124	108	– 31	– 16
Orissa	Baleshwar	3	3		
	Bhadrak	17	18		
	Jagatsinghpur	10	10		
	Kendarpara	181	184		
	Total	211	215	+ 16	+ 4
West Bengal*	Medinipur		3		
	24 Parganas North		29		
	24 Parganas South		2093		
	Total	2123	2125	+ 4	+ 2
Tamil Nadu	South Arcot	9	9		
	Thanjavur, Trichirapalli, Pudukkotai	12	12		
	Total	21	21	Nil	Nil
Grand total		4827	4871	+ 294	+ 44

*District-wise data for 1997 not reported.

*Based on the state of forest Report 1997 and 1999,Forest survey of India, Dehradun **(Singh 2000)**

Table 2 Yearwise Mangrove Cover Assessment in India*

(Area in km²)

State/UT	Assessment Year 1987	1989	1991	1993	1995	1997	1999
Andhra Pradesh	495	405	399	378	383	383	397
Goa	0	3	3	3	3	5	5
Gujarat	427	412	397	419	689	901	1031
Karnataka	0	0	0	0	2	3	3
Maharashtra	140	114	113	155	155	124	108
Orissa	199	192	195	195	195	211	215
Tamil Nadu	23	47	47	21	21	21	21
West Bengal	2,076	2,109	2,119	2,119	2,119	2,123	2,125
Andaman&Nicobar	686	973	971	966	966	966	966
Total	**4,046**	**4,255**	**4,244**	**4,256**	**4,533**	**4,737**	**4,871**

State/UT wise Mangrove Cover Assessment in India*

(Area in km²)

State/UT	Dense	Open	Total	Percent of Geog. Area
Andhra Pradesh	14	319	333	0.12
Goa	5	0	5	0.14
Gujarat	184	727	911	0.46
Karnataka	2	0	2	0.001
Maharashtra	90	28	118	0.04
Orissa	194	25	219	1.39
Tamil Nadu	10	13	23	0.02
West Bengal	1,651	430	2,081	2.34
Andaman & Nicobar	709	80	789	9.56
Pondicherry	0	1	1	0.21
Total	**2,859**	**1,623**	**4,482**	**0.14**

***Based on State of Forest Report, 2001(Singh 2000)**

1.4 Physical factors affecting the growth of Mangroves

There are few important biotic and abiotic factors influencing the growth of mangroves. These factors together form the characteristics of mangrove ecosystem. They are briefly discussed below.

1.4.1 Climatic factor

Climate plays an important and significant role for the natural growth, development and succession of the mangroves. According to Walter (1977), mangrove ecosystems are mainly found in three climatic divisions, viz., a) the equatorial zone between approximately 10°N and 5º-10º S ;(b) the tropical summer rainfall zone, north and south of the equator to approximately 25º-30º N and S, partly in the subtropical dry zone of the deserts, still further poleward; and(c) partly in warm temperate climates that donot have really cold winters and only in the eastern border of the continents in this zone.**(FAO 1994)** Air temperature of the region is mainly governed by the geographical distribution of the different species of mangroves. Temperature fluctuation ranges from 20ºC and 35ºC. Mangroves are extensively found where the water temperature of the warmest month exceeds 24ºC.Rainfall conditions are the most decisive factor for the sequence of mangrove distribution in different tidal zones. Mangroves are generally best developed in the areas of abundant rainfall, evenly distributed throughout the year. The rainwater penetrates the saline soil and reaches deep down to the soil strata more effectively. During the successive tidal flood, the land surface is inundated with salt water and the exposure of this soil substratum evaporate the water from salt mixed solution leaving behind thick salt crust on the soil surface which checks the growth of mangroves. Splashing of the rainwater frequently washes out the surface salt and leaches down the salt particles making the land suitable for the growth of the mangroves.

1.4.2 Waves and tidal range

Although mangroves are capable of withstanding wave and tidal action, the settlement of propagules and seedlings requires a low (wave) energy environment. Therefore, mangroves usually occur in sheltered areas. Together with substrate slope, tidal range determines the area where mangroves can grow in the tidal zone. The larger the tidal range, the wider the area influenced by tidal action and thus a wider area suitable for mangroves.**(Willem 2004)**

1.4.3 Salinity conditions

Mangroves are known as facultative halophytes. This unique feature enables them to grow in the coastal areas. Although all mangroves donot require salt water, but can only tolerate it. The tolerance level is not the same for all mangrove species. *Rhizophora sp*. (red mangroves) has low tolerances to high salinities and thrives best at the borders of coastal fringe forests and tidal creeks where salinity is low (10-20‰). They are however capable of forming forests in higher salinities (40-55‰). *Avicennia sp*. (black mangroves) have higher tolerances, and develop well in salinities of 60-65‰, but can survive salinities of up to 90‰(Anonymous 1991)**.** Differences in the level of salinity often determine the zonation of the mangroves. Hence on the basis of salinity mangroves are distributed into five zones. They are euhaline, polyhaline, mesohaline, oligohaline and limnatic zones. Salinity ranges from 30ppt to 40ppt.Here the wave action is predominant and gradient is gentle, thus resulting in sediment accretion to take place at the deltaic region. The sea generally washes out the sediment load. The salinity ranges from 18ppt to 30ppt in the polyhaline region. Here the wave action is low and substratum is sandy clay. The mesohaline region is characterized by 5ppt and 18ppt salinity and is characterized by low wave action and silty clay button.

1.4.4 Soil structure

Soil conditions are the main controlling agent for the distribution of the mangroves. Large variations exist in the soils of the mangrove forest along the Indian coast. Mangroves are best developed in waterlogged and anaerobic substrate such as sediments, coarse sand, silt, peat soil or coral reef.

However; mangroves grow best in silty clay soils. Soils in mangrove areas are formed by alluvium from rivers and by sediments from the sea. Mangrove soils are rich in nutrients, such as magnesium, sodium,

phosphorous and potassium. The physical and chemical characteristics of the soil depend on the source of alluvium and sediments, which in turn influence mangrove distribution.**(Hong and San 1994)**

1.5 Tsunami: Definition

Tsunamis are the large ocean waves which are triggered by underwater earthquake, volcanic activities and landslides. These waves are generated in the open oceans and are transformed into catastrophic oscillations on the sea surface near to the coastal zones. The speed of the waves diminishes as they pass into the continental coasts and that leads to the increase in the wave height. The energy flux of tsunami is dependent on both its wave speed and wave height. As the tsunami finally reaches the coast, it may appear as a series of breaking waves.

1.5.1 26 December 2004, Tsunami

India experienced devastating effects of a Tsunami caused by series of earthquakes for the first time in half a century**.** According to the National Institute of Oceanography, India, "On 26th December 2004 the Indian coastline experienced the most devastating tsunami in recorded history. The tsunami was triggered by an earthquake of magnitude 9.0 on the Richter scale at 3.4° N, 95.7° E off the coast of Sumatra in the Indonesian Archipelago at 06:29 hrs IST (00:59 hrs GMT"). The earthquakes set off giant tsunami waves of 3 to 10 metres in height, which has caused extensive damage to the south eastern coast of India**"(IUCN 2005)**

1.5.2 Potential Ecological Impacts of Tsunami

Tsunami have caused extensive damage to the eastern coastline of India which includes coastal areas of Tamil Nadu and Pondicherry.The coastal zones of India is densely populated and the anthropogenic activities in these zones have resulted in the considerable degradation in the marine and coastal ecosystem like seagrasses, mangroves and coral reefs. The primary impacts of the tsunami were generation of debris and rubble from the deposition of the sediments brought down by the waves, the erosion along the coast, and salinisation of the agricultural lands. Many of the coastal wetlands are affected by large inflow of the silt load and salt deposition. Mangroves which are the most productive of the ecosystem were also impacted by the smothering of their breathing roots by the deposition of the sand and silt. Environment was the victim of the tsunami on one hand and saver of the impact on the other hand.

1.6 Role of remote sensing and GIS in mangrove monitoring

The advent of satellites has radically changed the nature of oceanographic studies. Utilizing the advantages offered by satellite remote sensing, significant progress has been achieved in retrieval of various oceanographic parameters and processes as well as their applications including coastal zones over last decade.**(Desai 2000)**

The Earth observation using satellite remote sensing technique has made it possible to obtain uniform data covering the whole globe in a relatively short time and has also made it possible for these observations to be continued for a long time in the future. Remote sensing systems collect vast amounts of biological and physical data on multiple data, thus allowing both inventory and monitoring of the environment. Global Positioning Systems (GPS) aid in the collection of ground data and processing of remotely sensed imagery.

It is rather difficult to collect data in a conventional method because of the complexity of the data requirement for decision making and planning for the management of the mangrove ecosystem. Orbital remote sensing technique provides synoptic, multi-spectral and repetitive coverage which is very useful for studying the coastal zone.**(Nayak and Bahuguna 2001)** Recently, the importance of the remotely sensed data for inventorying, mapping and monitoring of the natural resources has been well established. Remote sensing data has provided important information on various components of coastal wetlands like density wise mapping of mangroves, brackish water areas, and suspended sediment dynamics. Orbital remote sensing has made a great contribution in mapping and monitoring of the critical habitats of the Indian coast.

The availability of high resolution data from second generation Indian remote sensing Satellites, IRS 1C and 1D which have improved spatial resolution data, extended spectral bands, stereo- viewing and faster revisit capability are assisting coastal zone studies through improved mapping and analysis capability. **(Desai 2000)**

1.6 Problem Statement

"The coastal regions of planet earth are amazing areas. The interface between land and sea, the coast is unique geologic, ecological and biological domain of vital importance to an astounding array of terrestrial and aquatic life forms including mankind**"(Beatley t, D.J et al. 2002)** The coastal ecosystem is highly fragile because of the multivariate dynamically active and pulsatory tectonic and geomorphic processes.**(S.M.Ramaswamy 2005,)**

Coastal zones of India are constantly undergoing changes due to natural forces as well as human development activities. Mangroves which are the most sensitive and fragile ecosystem are affected by coastal environmental change including sea level rise and hydrological variations in the coastal zones of India. There is an increasing evidence that mangroves may be affected by the coastal environmental change, including hydrological variations and sea level rise .The response of mangroves to such impacts

tends to be gradual and, particularly in undisturbed systems, is manifested typically as a change in their extent, structure and species composition and hence their distinct zonation. As mangroves are sensitive to even minor transitions in coastal conditions (e.g., altered drainage patterns, saltwater intrusion, accretion or erosion in response to sea level variations), changes in the zonation of these ecosystems are often indicative of broader scale changes and associated impacts in coastal regions.**(Ellison 2003)**

On 26th December, 2004 India have experienced the world's most deadly natural disaster which has no parallel in the history for its magnitude and devastation. In addition to the tremendous loss of life and property, the tsunamis have caused extensive environmental damage to the nearshore marine environment. The 2,260 kms of Indian coastal zone harbours many key marine ecosystems. According to IUCN, the effect of tsunami on these ecosystems are likely to be severe ecologically as well as economically although they varied in the region.

Tsunamis have caused unprecedented impact on the aqua and aqua terrestrial ecosystems in the coastal environment. The direct environmental impact of tsunami varied notably due to the bathymetry and geomorphology of the coastline and also some natural and manmade features. The mangroves that are the most productive of all the ecosystems might have been potentially damaged due to these huge waves. An obvious environmental impact of the tsunami is the physical damage of the mangroves that has resulted from waves and backwash. The deposit of silt may lead to the clogging of pores of the aerial roots of mangroves and cause total destruction of the plant species.

The degree and extent of damage of the mangrove is not known. Their loss can certainly prove to be disastrous in terms of coastline ecosystem functions. The present rate of degradation will certainly result in the total disruption of the sensitive ecosystem and consequent drastic depletion of marine wealth and its biodiversity. Hence, there is an imperative need for the protection and restoration of the green belt that are under tremendous threat.

1.7. Research Objectives

1.7.1 Main Objective

- To detect, assess and monitor the changes in the mangrove ecosystem in the pre and post tsunami using remote sensing and GIS in southeastern coast and South Andaman Islands of India.

1.7.2: Specific Objective

- To detect damage and destruction of the mangroves as a result of the tsunami using multitemporal optical satellite data.
- To assess the degree and extent of the damage of the mangroves caused by the tsunamis.
- To monitor the changes in mangroves extent and its condition before and after tsunami using optical satellite data.

1.8 Research Questions

- What are the damage and destruction caused to the mangroves as a result of tsunami and how can it be detected?

- What is the degree and extent of damage of the mangroves caused by the Tsunami and how can it be determined?

- How change in the condition of the mangroves be monitored before and after tsunami using optical satellite data?

1.9 Organization of the Thesis

To attain the research objectives and research questions, the thesis is outlined into six chapters. **Chapter-2**.presents the literature review of the work. It also deals with how remote sensing and geographical information techniques can be applied in mangrove vegetation studies with special emphasis on the application of optical remote sensing in the monitoring of the mangroves.

Chapter-3. Introduces the study area. It describes the geomorphologic aspects of the study area.

Chapter 4-It describes the details of the material involved and what field data are collected. It also describes the methodology followed in processing both the remote sensing data and field data. Detailed discussion of the GIS operation and image processing are also discussed in this chapter.

Chapter-5 presents the analysis and results of the data in perspective of research objectives and research questions.

Chapter-6 deals with the discussions, conclusions and the recommendations.

2.Literature Review

2.1 The Application of Remote Sensing in monitoring Mangroves

"Remote sensing is the science and art of obtaining information about object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with object, area or phenomenon under investigation**"(Kiefer 2000).** Humans and natural forces constantly modify the landscape thus making it essential to monitor and assess these alterations. Electromagnetic energy sensors are therefore to assist in inventorying mapping and monitoring earth resources. Mangroves are the littoral plant formations of tropical and subtropical sheltered coastal lines. A general awareness of mangrove ecosystem has arisen in the recent world. Numbers of studies are being carried out to study mangroves with maximum understanding of the ecosystem with minimum cost involved. Thus remote sensing is considered to be one of the vital source of spatial data which can be used to detect and monitor mangrove forest. Surveying of the mangrove forest by remote sensing or more precisely by aerial photography started since nineteen twenties. Aerial photography was used to study Irrawady tidal forest in Burma in 1924.

The ability of the remote sensors to distinguish between the terrestrial features depends on various factors among which are the spectral characteristics of the objects on the ground and their morphology as well as the discrimination capabilities of the sensor used. There are wide range of systems available and procedures developed in remote sensing which are used for identifying vegetation cover and its classification and mapping. One should effectively use the technique or the combination of techniques which permit the rapid acquisition of data; provide the required information and are cost effective. An interpreter generally produces more accurate results in aerial photography than with satellite images.
The major remote sensing systems which are recognised to have a veritable place in vegetation classification and mapping particularly with regard to mangroves-include aerial photography, multispectral scanners (MSS) and radar.

The principal advantages of each are

- Aerial photography is the simple to use and lend itself to wide scale applications.
- MSS provides a wider range of information than other systems and is suitable for automatic data processing and satellite applications.
- Radar presents all weather capability, which is particularly useful in cloudy areas such as tropical zones and is also suitable for regular monitoring.

2.2 The application of optical satellite data in monitoring mangroves

Remote sensing data can contribute to our understanding of coastal systems in a quantitatively accurate and visually compelling way, reflects the development which has taken place both in the algorithms necessary to properly process these data and also the realisation by scientists and policymakers alike that without such data a global assessment of ecosystems is next to impossible**.(Stelzer et al, Brockmann et al. 2004)** The main advantage of remote sensing data is that they provide a synoptic view over a large area, whose measurement would not be possible by using ground based techniques. There is a limit to the use of optical sensors and which sensor is suited for which parameter is one of the initial criteria.

Different objects absorb and reflect differently at different wavelengths. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient **spectral resolution** to distinguish its spectrum from those of other materials http://www.crisp.nus.edu.sg/~research/tutorial/optical.htm. The wavelengths in the optical part of the electromagnetic spectrum range from 0.3 µm to 14 µm. These are visible wavelength ranging from 0.4 to 0.7 µm and infrared wavelength 0.8 to 1.4µm. **(Kiefer, 2000).** The spectral properties of canopies of different plants are produced by the combination of optical properties of individual vegetative components, its effect on growth forms, density, height, tidal stage and soil type **(Bahuguna, 2000).** Vegetation has different optical properties in visible, near infrared and mid-infrared region. Due to pigment absorption there is low reflectance in the blue and red region of the electromagnetic spectrum. The near-infrared region has got the highest reflectance as the multiple scattering takes place between the intercellular airspaces in mesophyll. Infrared energy reflects well off of healthy vegetation so the infrared bands can be useful in detecting changes in vegetation**. (Singh, 1989).** Near –infrared bands are therefore useful in distinguishing land and water properties. Mid-infrared region is generally very sensitive to leaf water content. Vegetation has got unique spectral reflectance properties, which quickly distinguishes it from other land cover categories in an optical image. The key to interpret multispectral data is to thus to understand the reflectance properties of different surfaces.

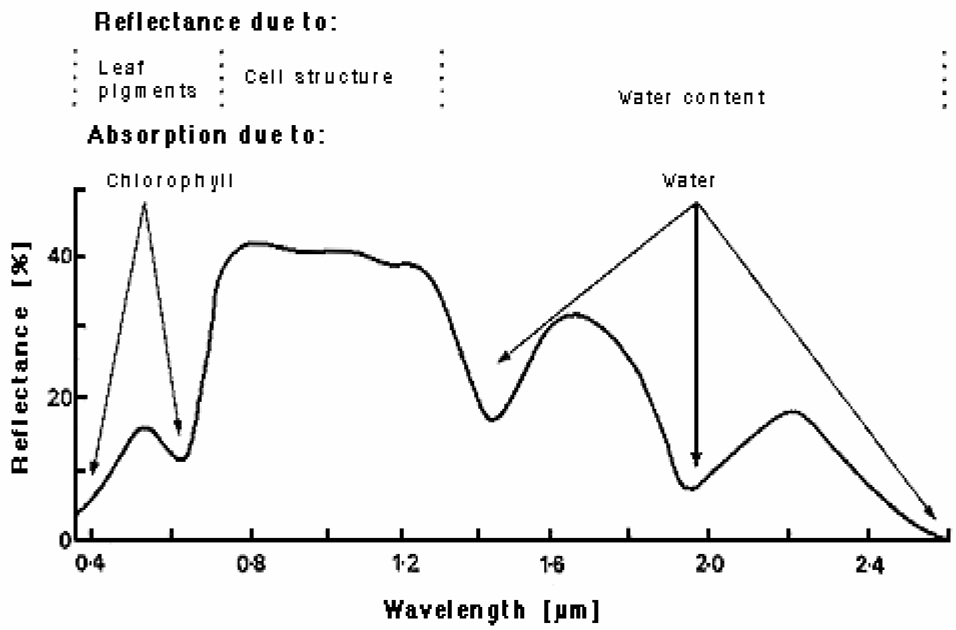


Figure **2:** Typical reflectance and absorption characteristics of green vegetation.

Source: http://ceos.cnes.fr: 8100/cdrom/ceos1/irsd/pages/di2.htm

2.3 Role of Indian Remote Sensing in monitoring mangroves

During the last twenty years there has been extensive development in the monitoring of the tropical coastal environments with the aid of remote sensing. Some of the recent studies focuses mainly on the the zoning of the dominant mangrove communities based on their ability to grow under varying tidal conditions substrate and salinity. Numerous studies have been reported that mangrove forests can be easily distinguished from other vegetation formations on satellite images. Remote sensors like Landsat TM and SPOT are successfully used in the classification of vegetation type.

In India, remote sensing data especially Indian Remote Sensing (IRS) data, having moderate (23-36m) to high spatial resolution (6m), have been used to generate the database on various components of coastal environment of the entire country. IRS data have been useful in identifying dominant plant communities in many mangrove areas. This is a unique approach for providing spatial information and can be seen as the first step towards biodiversity assessment.**(Nayak and Bahuguna 2001)** IRS LISS II have also proved extremely useful for wetland mapping as well as for delineation high and low water lines. Likewise; it is possible to distinguish mangroves from other plant communities.**(Upanoi and Tripathi 2003)**

Since both the sensors have same resolution, the 1986 TM and 1993 IRS LISS II data have helped to quantify the changes in the area cover of mangroves. Landsat and IRS were effectively utilised for mapping and monitoring of the mangrove extent in Pichavaram and Muthupet wetlands. Mangrove wetland mapping of Bhitarkanika National Park, Orissa were also done with the help of IRS LISS II data under the Project Coastal System Research.**(B.Satyanarayana, et al. 2005)**

IRS 1B LISS II Remote sensing data of 1994 was digitally analysed to find the extent of mangroves, degraded area in mangrove forest, wetland, and agricultural area and casuarinas in coastline nearby forest.**(MSSRF,2001)**
(http://www.mssrf.org/special_programmes/rs_gis/rs_gismain.htm).

M.S.Swaminathan foundation has extensively worked on the mangrove conservation and management in the wetlands of east coast of India namely Muthupet, Pichavaram, Godavari, Krishna, Bhitarkanika, Mahanadi and Devi mouth of Tamil Nadu, Andhra Pradesh and Orissa.Remote sensing data of 1986,1996 and 2000 were used to analyse the changes in the mangrove forest area and were efficiently mapped during 1986-2000.Numerous studies have been carried out using IRS LISS II data on changes in the coastal wetlands. Mapping of mangroves and change detection around Mumbai was carried out to detect the changes in the mangrove habitat using IRS-ID and IRS-IC.In India, a number of workers have carried out change detection studies using remotely sensed data. All these studies show the relevance of remote sensing in the change detection of the extent of the mangrove environment.

In 1997, Department of Biotechnology (DBT) and Department of Space (DOS) and Government of India undertook a project on the study for “Biodiversity characterisation at Landscape level using Satellite Remote sensing and Geographic Information system”. The main objective of the project was to create a database which would help in mapping different ecosystems, disturbance regimes and biologically rich areas for prioritising conservation and bio respecting. There are very few attempts made to classify different vegetation types in the Andaman and Nicobar islands. IRS-IC LISS III data and Landsat TM data were effectively used to map the vegetation types .In the south Andaman islands mangroves formed 10% of the area. The study brought out a better separability of mangrove vegetation in Landsat data. Forest density mapping and Landscape analysis were well brought out in the study.**(IIRS 2003)**

2.4 Bi Temporal Change detection

Digital change detection generally encompasses the quantification of the temporal phenomena from multidate imagery that is most commonly acquired from satellite based multispectral sensors. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. It is a digital image analysis which is commonly used to detect landcover changesfrom remotely sensed imagery. The changes in landcover generally result in the changes in radiance values than radiance changes caused by other factors. Numerous techniques have been applied to identify the landcover changes for using remote sensing. Change detection is useful in many

applications such as landuse changes, habitat fragmentation, rate of deforestation, coastal change, urban sprawl, and other cumulative changes through spatial and temporal analysis techniques such as GIS (Geographic Information System) and Remote Sensing along with digital image processing techniques. The multi date images from the same time period is difficult to obtain especially in the tropical areas where cloud free images are not available frequently. Accurate geometric correction is essential in order to avoid erroneous results.

When monitoring natural resources, we can think of two processes: In short time monitoring and long term monitoring. In short term monitoring changes that deviate from the normal vegetative succession and seasonal variation. In forestry those changes may be cuttings, manmade disturbances as well as damage. A short time span of successional observations is optimal for detection of these changes. In long term monitoring trend detection and forecasting are of special interest. For this type of monitoring, a long time span is needed and number of observations must be larger.**(T.Hame, I Heiler et al. 1998)**

Macleod and Congalton (1998) described four important aspects of change detection for monitoring natural resources: detecting if a change has occurred, identifying the nature of the change, measuring the areal extent of the change and assuming the spatial pattern of the change. The selection of the approximate change detection technique is also important for the determination of change direction. According to Colwel and Weber (1981), "All digital change detection is affected by spatial, spectral, temporal and thematic constraints. The type of method implemented can profoundly affect the qualitative and quantitative estimates of the disturbance.**(P. Coppin, I. Jonckheere et al. 2004)**

Most of the change detection studies fall into five broad categories. Change detection can be performed manually using on screen digitising to know the areas of change. Write function memory insertion combines different colours to display changes between images. Enhancement includes mathematically combining imagery from different dates which can be achieved through image ratioing and image differencing, vegetation image differencing, image regression, PCA. In order to make a comparison of independent classified images, post classification comparison is best suited.

2.4.1Manual

Manual change detection can be performed using the onscreen digitising to determine the changes between images. Satellite images are georectified and compared using standard techniques. This technique is effectively used to detect the changes over smaller areas but is not suitable for larger areas.

2.4.2 Write Function Memory Insertion

Write function memory insertion is the simple change detection technique. By displaying one band of imagery in either red, green or blue write function memory banks and displaying the same band from an image obtained on a different date in different colour changes can be observed. Areas that have not changed will appear in shades of the colors that results from the combination of the two original colors. Areas that have changed will appear in one of the two colours that were used to display the original bands. This technique provides information on a preliminary basis to determine a suitable quantitative change detection method.

2.4.3 Image Differencing

Georeferenced images of two different time periods t1 and t2 were subtracted on a band by band and pixel by pixel basis to produce an image which represents the change between the two time periods.

Dxk ij = Xk ij(t2) - Xkij(t1) + C

where, Xkij = pixel value for band k and i and j are line and pixel numbers in the image, t1 =first date and t2 = second date and C = a constant to produce positive digital numbers. This technique takes into account the difference of radiance values of pixels between two different dates. Differences in atmospheric condition, differences in sensor calibration, moisture condition, and illumination condition also affect the radiance of the pixels. Therefore this technique is better suited to cases as changes in radiance in the object scene is larger compared to changes due to other factors. Frequency analysis of the image show that the pixels with the radiance are found in the tails of the distribution while non-radiance change pixels tend to be grouped around the mean.**(Ramachandra and Kumar 2004)**

2.4.4 Image ratioing

Geocorrected images (G, R and NIR bands) of different dates are generally ratioed pixel by pixel (band by band) basis.

Rxkij = Xkij (t2) / Xkij (t1)

Where, Xkij (t2) is the pixel value of band k for pixel x at row I and column and j at time t2. If the intensity of reflected energy is nearly the same in each image then Rxkij = 1 indicating no change. The ratio value greater than 1 or less than 1 represents nature of changes that have occurred between the two dates.

2.4.5 Thresholding

In order to separate the landcover changes from other changes detected in the image enhancement, it is essential to identify a threshold value. Based on the mean and standard deviations threshold levels

can be applied to the tails of the distribution in order to find the threshold value that produces the highest classification accuracy.

2.4.6 Principal Component Analysis

PCA is a multivariate technique that is used to reduce the number of spectral components in the original image to those accounting for the most variance **(Singh,1989).** The PCA of two dates of imagery can be compared using image differencing and image regression.**(J.Daniel and**

Sader.A.Steven 1991) compared PCA to NDVI image differencing and RGB-NDVI image classification. But the interpretation of the PCA change imagery seems to be more complicated.

2.4.7 Direct Multidate Classification

This is another method of identifying areas of change in satellite imagery. This method simply uses a method either supervised or unsupervised on two combined dates of imagery. The classes representing areas of change will have different statistics that classes that remain unchanged. There are both advantages and disadvantages of the system. Classification is only required here but information on the type of changes are lacking.

2.4.8 Post Classification Comparison

Post classification comparison is the most common approach used for change detection. It is also known as 'Delta classification'. It involves independently produced spectral classification results from each end of the time interval of interest, followed by pixel-by-pixel or segment-by-segment comparison to detect changes in land cover type. By adequately coding the classification results, a complete matrix of change is obtained, and change classes can be defined by the analyst.**(P. Coppin, I. Jonckheere et al. 2004)** The main advantage of this classification is that the two dates of imagery are separately classified. Hence the radiometric calibrations between the two dates are minimized. However the accuracy of this method entirely depends upon the accuracy of the previous classification. In this research post classification comparison has been used to detect the changes in the post tsunami period

The selection of appropriate change detection algorithms should be taken into considerable significance. A plethora of image processing techniques are there to classify remotely sensed data of mangroves.

A RGB-NDVI was developed to quantify mangrove forest change using three dates of imagery in Krabi, Thailand.**(Upanoi and Tripathi 2003)** There are some techniques which can provide information on the change and non-changed areas but there are some techniques like post classification comparison which provides a complete matrix of change directions. A high quality change detection product can only be obtained when the remotely sensed data and study areas are identified.

(Somjai sremongkontip, Yousif Ali Hussain et al. 1997) carried out a study to detect, identify and delineate the area of mangrove forests in Pang-Nga Bay area, defined all changes happened to the mangrove forests during the last 20 years using the multitemporal analysis and identify the degree of degradation in the mangrove forests.**(Ramachandran and Krishnamoorthy 1999)**have also carried

out study on the mangrove mapping and change detection and identification of the species and biomass estimation. **(Vaiphasa and SOngsomwang 2004))** have tested the performance of hyperspectral data in discriminating mangroves in species level. The results revealed that spectrally mangroves were separable and therefore it was anticipated the use of hyperspectral data in species level classification. **(Vadlapudi 2003)** has carried out research on mapping of mangroves and its environs to identify the parameters that have affected the mangroves and the related ecosystem using remote sensing data. The basic principle of change detection analyze using IRS data over a period of time was applied for such monitoring.**(Hirose, Maruyama et al. 2002)** carried out extensive work on the mangrove forests of Can Gio Biosphere Reserve to detect the environmental changes using Landsat, JERS-I and ASTER data.

The study on coastal zone environment management with emphasis on mangrove ecosystems was carried out to identify an effective approach for sustainable mangrove forest management using Remote Sensing and GIS technology. Monitoring of the mangrove forest landuse zonation corresponding to species was effectively carried out with the high resolution data of LANDSAT-TM and SPOT-PLA in Klung, Chantaburi area.**(Sr. Suvit Vibulsresth, Dr. Surachai Ratanasermpong et al. 1990).**The research work on the ability of three different radar satellite imaging systems and three different optical satellite systems were carried out to detect mangrove deforestation in the delta of the Mahakam River, East Kalimantan, Indonesia.**(Hussin, Zuhair et al. 1999)**

Wetland mapping should be done for the better understanding of various conditions of the wetlands and for the delineation of areal extent and boundaries of wetland especially coastal wetlands. These maps will serve as baseline data for classifying the coastal zones into preservation, conservation and development zones.**(L Kannan, Kumar et al. 1995)**

3.Study Area

3.1 Geographical Distribution Of the Study Area

3.1.1 Mandapam Islands of Gulf Of Mannar Marine National Park

The Gulf of Mannar is located on the southeastern tip of India in the state of Tamil nadu. It is in this region India's first and foremost marine biosphere reserve is situated. Popularly known as the biologist's paradise, the region harbours more than 3,600 species of plants and animals making it one of the world's richest marine biosphere reserve. Owing to its shallowness, semi-enclosed nature less fluctuating temperature regimen, biophysical and ecological uniqueness nutrient enrichment etc, it has acquired special status in the biodiversity map of the Indo-Pacific oceanic realm. It has a chain of 21 islands stretching from Tuticorin to Rameshwaram.The geographical distribution of the area is 8º 55'N-9º15'N and 78º-79º16'E.The area of Gulf of Mannar under the Indian EEZ is about 15000 sq.km.all the 21 islands are classified into 4 major group. 1) Tuticorin 2) Vembar 3) Kilakarai 4) Mandapam.There are 7 islands in the Mandapam group. Poomarichan, Pullivasal and Krusadai are the three islands in the Mandapam group that were taken into account.

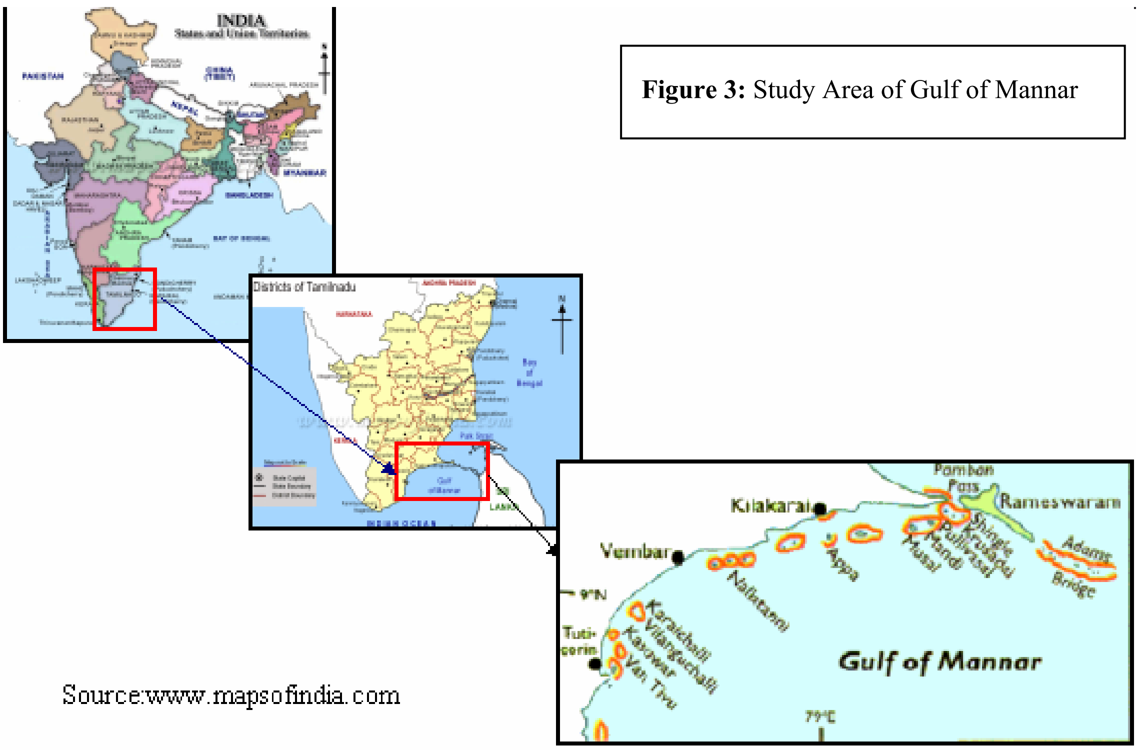


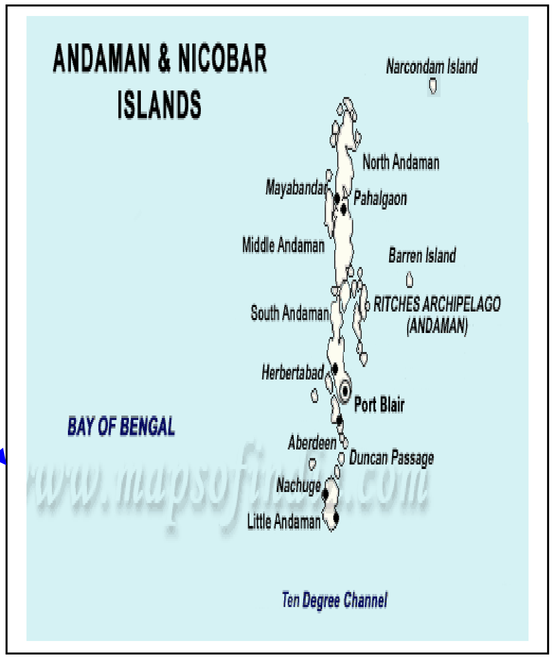
Figure 3: Study Area of Gulf of Mannar

Source:www.mapsofindia.com

3.1.2 South Andaman Islands

The Andaman and Nicobar Archipelago extends from 6-14ºN and 92-94ºE .It consists of 572 islands and islets and lies in the lap of Bay of Bengal. These islands are often described as "islands of Marigold Sun". The island have a maximum width of 575 km and is oriented in a north –south direction and simulating an arc stretching over a length of 912 km. The islands have a total land area of 8249 sq km with a coastline of 1962 km that is highly indented and several creeks penetrate into the island from inland bays. Due to its tropical humid climate and insular nature with no contiguity of land with the rest of India, Andaman and Nicobar islands is unique among al the states and union territories. According to P.S.N.Rao "Classified to be one of the 12 biogeographical zones in India, the Andaman and Nicobar islands have a biodiversity profile of over 5500 animal species, 2000 indigenous and several non indigenous angiosperm species besides many cryptogamic species in three important natural ecosystems viz., the forest ecosystem, the marine ecosystem and the interface between the two, the mangrove ecosystem"**(Hazra.P.K, Rao.P.S.N et al. 1999).**The South Andaman division is most inhabited and the disturbed regions.Latitudanal and Longitudanal zonation of the division is 11°55 and 92 °37E and the total geographical area is 1456.27 sq.km.

Figure 4: Study area of Andaman and Nicobar Islands



3.2. Biophysical Environment

3.2.1 Topography

There are no hills on any of the islands in Gulf of Mannar. Most of them are less than three metres above the level of high water springs. The islands are irregular in shape with spits and partially enclosed bays. Sandy beaches are found in many of the islands and in the island coast. The islands of Poomarichan and Pullivasal are almost in a horseshoe shape with the land connection during low tides.

The islands of Andaman are mainly composed of thick Eocene Sediments deposited mainly in the fine grey sandstones, shales and silt stones in which basic and ultra basic igneous rocks are found to be intrusive. Higher elevations are characterized by Serpentine and gabber formations while coral reef formations are important geological formations in the intertidal belt.

3.2.2 Climate

The area of Gulf of Mannar comes under the spell of both southwest and northeast monsoon. The southwest monsoon pours very little showers. Rainfall is moderate to heavy during October to Mid December with occasional gales. The mean annual rainfall varies from 762 mm to 1270 mm. The monthly average annual temperature ranges from 25ºC to 31ºC with maximum and minimum in May and January respectively.

In Andaman Islands the monsoonal regime of Southeast Asia governs the climate of the islands. The general climatic condition of the islands is mainly that of humid tropics. The temperature ranges between 22ºC and 30ºC.The islands mainly receive heavy showers from southwest and northeast monsoon. The average annual rainfall ranges from 3000 to 3500 mm. Cyclones and thunderstorms are frequent in these islands. The mean relative humidity ranges from 82%to 85% throughout the year.

3.2.3 Currents

The currents are swift .The sea remains rough between April and August. It is very stormy during June to August. During June to August, it is very stormy and calm during September, October to December months having northeast monsoon with occasional gales.

3.2.4 Soil conditions

The soil is typical coastal sand, strewn with shingles in places and there are swamps in places like Poomarichan, Krusadai and Pullivasal islands. Quick sand is seen in Krusadai islands in Mandapam group in Gulf of Mannar.The soils are immature, loose in texture, poor in drainage and low in moisture content. Sandy alluvial soil is mainly found in the Creeks and sheltered coasts. The grey, brown and red soils are found in the inland forests and torrential rains wash away the accumulated humus.

3.3 Mangrove ecosystems of Gulf of Mannar and Andaman islands

The Gulf of Mannar islands possess unique mangrove vegetation and such vegetation consists mainly of species *Rhizophora, Avicennia, Bruguiera, Ceriops and Lumnitzera.*Although the mangroves are obtained on a majority of the islands, Krusadai, Pullivasal and Poomarichan are found to be more productive in mangrove vegetation compared to other islands. The trees are not very tall perhaps the height is curtailed by the strong winds lashing perennially and with greater velocity during monsoons and cyclones. The whole island is carpeted with pneumatophores wherever the mangroves are formed.

The irregular and deeply indented coastline of these islands results in innumerable creeks, bays and estuaries which facilitate the growth of extensive mangrove forests. They are found in the Wrafter creeks .The mangrove vegetation is evergreen in nature and simple in structure and its height varies from 6 to 24 m. The mangroves form an easily discernible transitional zone between the forests on land and open sea with light green foliage and uniform size. The mangrove creeks have plentiful of organic detritus and nourishes a wide variety of marine fauna. The most common trees are *Rhizophora mucronata, R.conjugata, Bruguiera gymnorrhiza, B.parviflora* and *Ceriops tagal*. *Avicennia marina* is seen in small patches. *Nypa fruitcans* is a palm found in mangrove forests.

3.4 Habitation

The islands of Gulf of Mannar are uninhabited. The south Andaman Island is the most habited and disturbed zone. The capital of the territory Port Blair is situated here. The Andaman and Nicobar islands are characterised by two distinct cultures. One is the Negroid and the other is the Mongoloids.The main aboriginal tribes are the Jarawas. The jarawa reseves mainly are concentrated from Middle Strait to Miletilak.The tribals serves as the protectors of the forests and cultures a lot of ethnobotanical knowledge. The region around the Port Blair area is under great anthropogenic pressure. The huge pressure of the population has led to the encroachment of the forest areas near the settlements. Some of the parts of Port Blair has experienced heavy clearing and is occupied by Coconut (*Cocos nucifera*) and Arecanut (Areca catechu) plantations.or covered by long coarse grass

4.Material and Methods

4.1.Materials Used

Different remote sensing satellite images were acquired and used in this research. Besides the remote sensing data other ancillary data like toposheets from survey of India were used.

4.1.1 Satellite data used:

In this research four remote sensing satellite images were acquired and used. Two optical satellite images of IRS IC LISS III acquired on 10th December 1999 and Resourcesat I LISS IV acquired on 28th December 2004 were used as the pre and post Tsunami period for the Gulf of Mannar Study area. Another two optical images IRS IC/ID LISS III acquired on 16th February, 2001 and 11th February 2005 for the South Andaman Islands were used respectively because of their availability and they are the closest dates after the Tsunami event. Detailed description of remote sensing data is given in the table below:

Table 3 Detailed description of the optical sensors used for Gulf of Mannar

Time period	Sensors used	Date of acquisition	Spatial resolution	Spectral bands
Pre Tsunami	IRS IC Linear Imaging and Self Scanning Sensor (LISS III)	10th December, 1999	23.5 m	Green Red Near infrared Middle infrared
Post Tsunami	Resourcesat 1 Linear Imaging and Self Scanning Sensor (LISS IV)	28th December, 2004	5.8 m	Green Red Near-infrared

Table 4 Detailed description of the Optical sensors used for South Andaman Island

Time period	Sensors used	Date of acquisition	Spatial resolution	Spectral bands
Pre Tsunami	IRS IC Linear Imaging and Self Scanning (LISS III)	16th February, 2001	23.5 m	Green Red Near infrared Middle infrared
Post Tsunami	IRS IC Linear Imaging and Self Scanning (LISS III)	11th February, 2005	23.5 m	Green Red Near infrared Middle infrared

4.1.2 Ancillary data used:

Topographic maps numbered 89A/9, 89 A/10, of 1:50000 and 1:250000 scale were used to prepare the base maps for the South Andaman Islands and Gulf of Mannar .

4.1.3 Field data and Information from Interviews:

The major part of the data and information about the damage due to Tsunami were the field data and information from the interviews of the local people taken. In the fieldwork following instruments were taken for the validation

4.1.3.1.GPS

Since the launch of first satellite in US Navigation System with Time and Ranging(NAVSTER) has been used extensively in remote sensing studies.The US Navstar GPS consists of a constellation of 24 satellites orbiting the earth, broadcasting data that allows a GPS receiver to calculate its spatial position**(ERDAS Imagine,2001)**.This set of GPS data primarily includes two parts:

- Ground truth data that records the coordinates for the polygons of homogeneous area
- The coordinate that will be used for geometric correction.

4.1.3.2.Ground Truth data

The classification and validation of the images is usually done with the help of this set of ground truth data. The user identifies a homogeneous area of identifiable landcover on the ground and records its location using the GPS receiver. These locations are then plotted in the image to train a supervised classifier and also to test the validity of a classification.

4.1.3.3 Sun Compass

It is the compass that determines the location of a place with respect to true north position.

4.1.4 Software used

- **ERDAS imagine 8.7**

It comprises a complete suite of geoprocessing tools for geoscience and earth resource applications for use in image processing, GIS in remote sensing and photogrammetry. The classification process was run on this software.

- **ArcMap**

This software was mainly used for preparing the map layouts and composition.

- **Microsoft Excel**

The spreadsheet applications and generation of graphs were carried out in the Microsoft excel applications.

4.2 Methods of Research.

In order to attain the research objectives the following steps were applied in this research. The whole research is divided into three phases:

- Pre fieldwork phase (Prepatory phase)
- Fieldwork Stage (Data collection phase)
- Post fieldwork (Data analysis phase)

4.2.1 Pre fieldwork Stage:

4.2.2 Review of pertaining literatures:

To formulate the research problem the literature pertaining to the research topic were collected and studied. The research problem, objectives and research questions were developed based on the study of the problem.

4.2.3 Image Preprocessing

Prior to classification and change detection, pre-processing of satellite images is very essential. There are plenty of sequential operations in order to carry out the preprocessing of satellite images. The processes that are followed in this research are described below:

4.2.3.1 Geometric correction

Images, which are in raw form, contain geometric distortions so significantly that they cannot be used as the map base. Remotely sensed images in raw format contain no reference to the location of the data. To integrate these data with other data in GIS it is required to correct and adapt them geometrically. Remotely sensed images are transformed to the scale and projection of the map of the same area. This transformation

of scale and projection properties is called geometric correction**.(Syed 2001)** Georeferencing is the process of assigning map coordinates to image data. Geometric rectification of the imagery resamples or changes the pixel grid to fit that of a map projection or another reference image. This becomes especially important when scene-to-scene comparisons of individual pixels in applications such as change detection are being sought (ERDAS, 1999). The optical images that were acquired were georeferenced .The assignment of GCP points, second order transformation and nearest neighbour resampling of the uncorrected imagery was performed. Three processes can modify the spatial resolution of an image. Nearest neighbourhood interpolation, bi-linear interpolation and cubic convolution.

- **Nearest Neighbour Interpolation**: This method assigns the value of the nearest pixel in the input image to the pixel in the output image. This is mainly suited for use with classified data
- **Bi-linear Interpolation:** This method estimates the output pixel value by interpolating between the centre points of input pixels that overlap the output pixel. This works relatively in continuous and smooth surfaces.
- **Cubic Convolution:** This method mainly assigns the output image pixel a weighted average of the input pixels within a rectangular window centred on the output pixels.

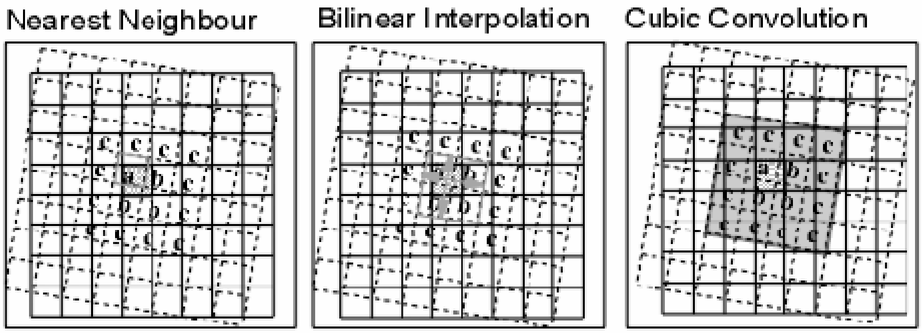


Figure 5 The Three Resampling Procedures

Nearest neighbour Analysis method was used because it is the quickest interpolation method and it retains the original reflectance of the image. The satellite images were georeferenced at UTM and Polyconic Projection for Gulf of Mannar and South Andaman Islands respectively. The RMSE error, which is the distance between the input location of the GCP and the resampled location of the same GCP, was about 0.3 pixel (less than 0.5 pixel).

4.1.1.1 Image Enhancement

The greatest strength of image processing lies in its ability to enhance the view of an area by simply manipulating the pixel values, thus making it easier for visual interpretation. Image enhancement is the process of making an image more interpretable for a particular application. The enhancement techniques are

primarily carried out to improve the interpretability of the image by increasing apparent contrast among various features in the image. The enhancement techniques mainly depends on two factors

- The digital data (with spectral bands and resolution)
- The objectives of interpretation

There is plethora of image enhancement techniques like image magnification, band ratioing, spatial filtering, Fourier transformations; principal component analysis and texture transformation .The images were enhanced by the method of simple brightness/contrast method.

4.3.Visual interpretation of images from different sensors

Following the geometric correction the images were visually interpreted. Simple principles of visual interpretation were used to detect and demarcate the areal extent of mangroves. The most important of the identification criteria considered were tone/colour, texture and association with coastal waters. **(Nayak *et al*,99*)***. In the present study colour, texture and location of visual interpretation were useful in delineating mangroves from other land categories. Association and location of the mangroves generally provide better delineation accuracy. Preliminary classification of images by onscreen visual interpretation was done for fieldwork. The images were visually interpreted to identify the number of classes and the possibility of the features and patterns observed in the field can be noticed. Different landcover types have different spectral properties. In order to show the distribution of reflectance value the spectral reflectance curves for all the bands in each land categories were produced.

4.4 Fieldwork Stage

Field visit is important for a good image classification. Adequate number of representative training samples cannot be derived without a good field visit. Prior to the classification an extensive fieldwork was carried out in the three islands of Gulf of Mannar Marine National Park and South Andaman Islands using GPS equipment. Ground-truth surveys are essential components for the determination of accuracy assessment for classified satellite imagery**(Brandon.R.Bottomley 1999).** Fieldwork was performed in the first week of August and the second fieldwork was in the month of mid September.

4.4.1 General Fieldwork observations in Gulf of Mannar

The field survey was performed to obtain the accurate locational point data for each landcover class and random sampling technique was applied as the survey method with reference to the occurrence of the distribution of the species. The fieldwork was carried on the three islands of Mandapam group in Gulf of Mannar.All the islands have good vegetation and the fringes of the islands in the intertidal zone is having mainly the mangrove species like *Rhizophora mucronata,Avicennia marina and Ceriops tagal.*There was all over heterogeneous patches of mangroves mainly confined along the shoreline. Other mangrove associates that were found in the luxuriant variety were *Salvadora persica* and *Thespesia*.The shores are protected by good growth of an endemic species *Pempis acidula*. Ground level halophytic grasses and

uniform belt of phoenix were also found along with acacia group of plants. The landcover classes were categorised as mixed mangroves, mangrove associates, other vegetation types, and herbaceous vegetation. The mangroves were in good condition. There was no damage of the mangroves detected in these uninhabited islands due to Tsunami. The effects of Tsunami waves were negligible and the mangroves had protected the other vegetation types as well as the island from destruction. The strong waves of Tsunami did not have a significant impact on the Mandapam group of islands but the shoreline was narrowed down to some extent. There has been a change in the spatial extent of the mangroves and other vegetation types.

4.4.2 General Fieldwork Observations of South Andaman Islands

The earthquake and the Tsunami wave caused major devastating effects in the Andaman and Nicobar Archipelago. The quake caused the subsidence of the portion of the South Andaman Island. The subsidence of the South Andaman Island by almost 1m has caused high tides reaching inland and flooding of lowland flatlands including agricultural lands, human habitation. This has resulted in the drying up of the mangroves along the creeks and marshes due to submergence during low tide. The upheaval and the Tsunami caused drying of the frontline mangroves along creeks in marshes. The mangrove trees which have been totally dried up are burnt due to the Tsunami waves are heavily damaged because the drying up of the roots and the leaves has certainly led to the mortality of the mangrove trees. The mangroves that have undergone partial drying up are moderately damaged. The few trees that are affected have undergone little breakage and leaning of trees are least damaged mangroves.

Table 5 Parameters for Degree of Damage in South Andaman Islands

Degree of damage	Impact on Mangroves	Recovery
Minor	Few trees are affected. Little breakage and leaning of trees	Natural regeneration over short period of time
Medium	Partially drying up and some breakage of trees	Requires some restoration measures
Major	Totally dried up, defoliation of leaves, Broken roots led to the total destruction of mangrove trees.	Requires restoration measures and can recover naturally if remain undisturbed.

In South Andaman Islands, the damage of mangroves was clearly detected in the field. GPS points were taken at the location of damage.

4.5 Post Fieldwork Stage

4.5.1 Classification in Remotely sensed data

“Classification can be considered as the process of pattern recognition or identification of the pattern associated with each pixel position in an image in terms of the characteristics of the objects or materials those are present at the corresponding point on the earth's surface.(Syed 2001)The principle of image classification is that a pixel is assigned to a class based on its feature vector by comparing it to predefined clusters in the feature space. Doing so far for all the image pixels results in a classified image. There is a plethora of image processing methods to classify remotely sensed data of mangroves for finding the appropriate one is a difficult task. The lack of accuracy information is by no means unique to remote sensing work on mangroves. It appears to feature of remote sensing in the wider coastal management context(E.P, P.J et al. 1998.)

4.5.2 Supervised Classification

Supervised classification can be defined normally as the process of samples of known identity to classify pixels of unknown identity. This has been the most frequent method by which remotely sensed data of mangrove areas has been classified.**(E.P, P.J et al. 1998.)**There are three stages involved in the classification process. Each one of them is described below:

4.5.2.1 Training Stage

The spectral response pattern for each landcover type to be classified in an image is to be assembled in a set of statistics. In order to train the classifier the user generally select the training samples in the images to represent the typical spectral information of the landcover classes that are popularly known as the training samples. Training data must be complete and representative to provide acceptable classification results. All spectral classes constituting each information class must be adequately represented in the training set statistics used to classify in an image. The more pixels that can be used in training, the better the statistical representation of each spectral class.**(Kiefer 2000).** After the selection of training sites on the image, the classification was run on the images.

4.5.2.2 Spectral signature Analysis

Prior to the classification signature separability analysis using transformed divergence (TD) was carried out on the training signatures for better classification. Separability or classification is a statistical measure of the distance between the two signatures. There are four methods for calculating separability of classes.

- Euclidean
- Divergence
- Transformed Divergence
- Jeffries Matusita

Transformed divergence is calculated by the following formula:

$$\mathbf{TD_{ij} = 2(1 - \exp(D_{ij/8}))}$$

It is the measure of signature separability that determines whether the classes are separable. TDij values ranges from 0 to 2000. TD has an upper bound of 2000 and lower bound of 0.If the calculated divergence equals to the upper bound then the classes area said to be completely separable and if the calculated divergence is near the lower bound then the classes are said to be inseparable. For this study, any class combination having TD value of more than 1900 are said to have good separability. Any classes that have the TD values of 1700-1900 are moderately separable and that below 1500 have the poor separability between the classes.

4.5.2.3 Classification stage

In this stage, classification was performed after specifying the number of training samples and a certain classification algorithm. Classification was run on both the pre Tsunami and Post Tsunami images. Maximum
likelihood classifier is used in the supervised classification. It is the most efficient and accurate classifier because it depends upon the decision rule based on a normalised (Gaussian) estimate of the probability density function of each class. It quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel.

Maximum Likelihood Classifier in parametric rule was applied for both the optical images using ERDAS software." The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes and that input bands have the normal distributions"

4.5.3 Accuracy Assessment

Accuracy assessment forms the most integral part of the classification process. No classification is complete until its accuracy has been assessed. Classification remains a pretty picture without an accuracy assessment. Accuracy simply denotes the level of agreement between labels assigned by the classifier and the class allocation on the ground collected by the user as the test data. The sample was selected without any biasness. The known reference data was another set of data different from that which is used for the classifier used in the performance of accuracy assessment. The two methods are primarily followed.

- **The Error Matrix**

Error Matrix is the most effective way of representing map accuracy in which the individual accuracies of each category are mainly described along with both error of commission and error of omission.
User's accuracy, producer's accuracy and overall accuracy can be judged with the help of error matrix method. The brief description of the accuracy indexes are given below.

- **Overall accuracy**

The proportion of the reference pixels which are classified correctly is known as the overall accuracy. It is computed by dividing the total number of correctly classified pixels by the total number reference pixels. It is a very coarse measurement and does not provide the information about the classes that are classified with good accuracy.

- **Producers accuracy**

It generally estimates the probability that a pixel which is of class I in the reference classification is correctly classified. It is estimated with the reference pixels of class I divided by the pixels where classification and reference classification in class I.

- **User's accuracy**

It is estimated by dividing the number of pixels of the classification result for class I with the number of pixels that agree with the reference data in class I. User's accuracy mainly predicts that a pixel classified as class I is actually belonging to class.

- **Kappa Statistics**

The Kappa coefficient of agreement is a discrete multivariate analysis technique used to evaluate the accuracy of change detection and classification maps created with remotely sensed imagery**.(Jensen, 1996).**It is calculated from the error matrix and measures the performance of the classification compared with the reference data. The result is the KHAT statistic which is another method of agreement or accuracy.It includes all elements of the confusion matrix. The KHAT Statistic is a measure of the difference between the actual agreement between the reference data and an automated classifier and the chance agreement between the reference data and a random classifier. It is calculated as:

Kappa = (Observed agreement - Chance agreement)/(1 - Chance agreement)

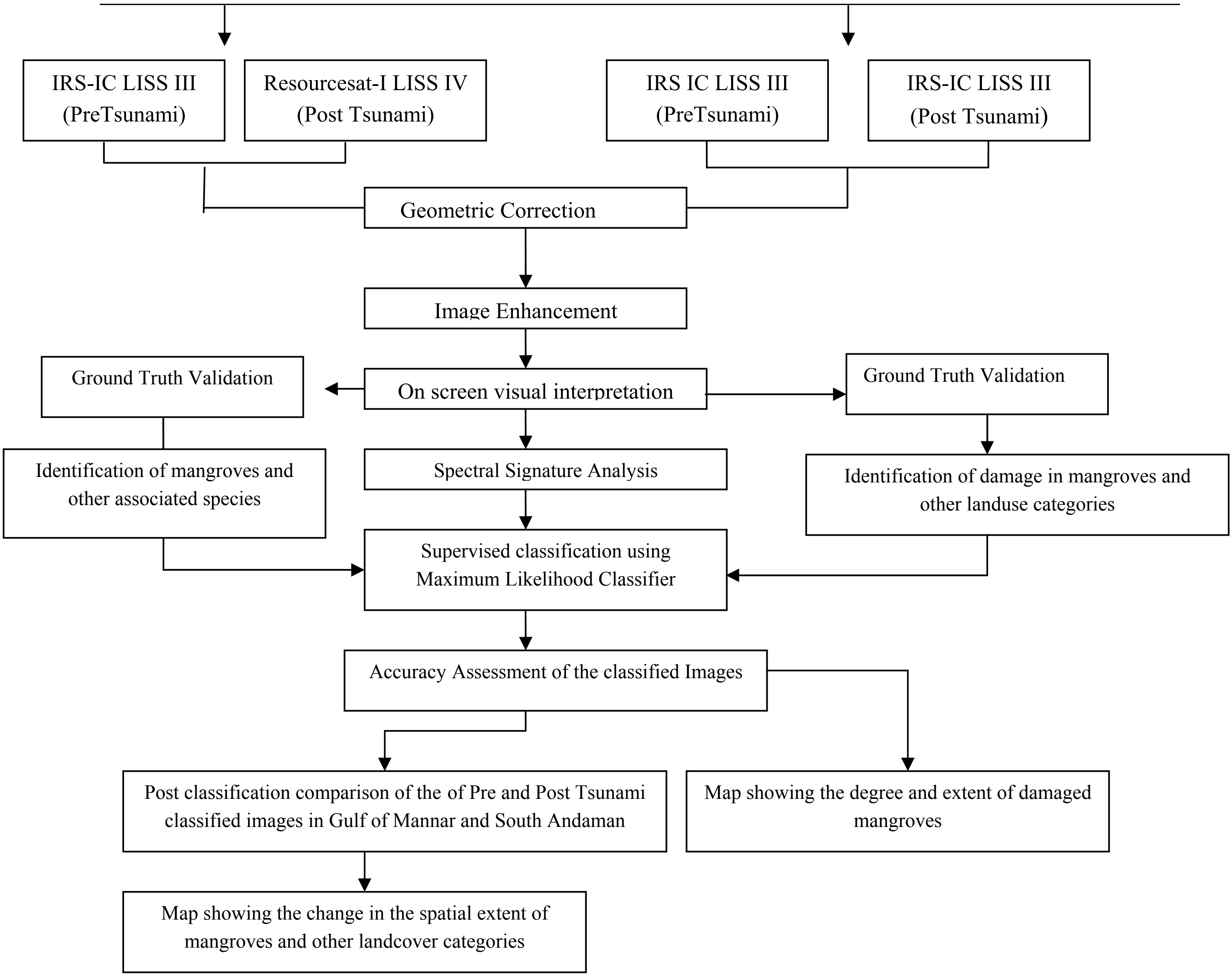
The statistic serves as an indicator of the extent to which the percentage correct values of an error matrix are due to "True" agreement versus "chance" agreement. As true agreement approaches 1 and chance agreement approaches 0, k approaches 1.The main advantage of using the KHAT is the ability to use the value as the basis for determining the statistical significance of any given matrix or the differences among matrices.

4.6 Post classification comparison

After the images of the two time periods (T1 and T2) were classified independently, the post classification change detection method was applied to determine the changes and to see the nature of changes. The change in the spatial extent of mangroves and other landcover types were detected in the pre and post Tsunami conditions. In order to monitor the change in the condition of the mangroves in South Andaman Islands comparison has been made between the pre Tsunami condition and the post Tsunami condition. The degree and extent of damage has been mapped and the percentage of damaged and intact mangroves were clearly marked out in the post Tsunami situation.

4.7 Flowchart showing the Method of Research

Gulf of Mannar **South Andaman Islands**


IRS-IC LISS III (PreTsunami)
Resourcesat-I LISS IV (Post Tsunami)
IRS IC LISS III (PreTsunami)
IRS-IC LISS III (Post Tsunami)
Geometric Correction
Image Enhancement
Ground Truth Validation
On screen visual interpretation
Ground Truth Validation
Identification of mangroves and other associated species
Spectral Signature Analysis
Identification of damage in mangroves and other landuse categories
Supervised classification using Maximum Likelihood Classifier
Accuracy Assessment of the classified Images
Post classification comparison of the of Pre and Post Tsunami classified images in Gulf of Mannar and South Andaman
Map showing the degree and extent of damaged mangroves
Map showing the change in the spatial extent of mangroves and other landcover categories

5. Results and Discussions

5.1Results of Visual interpretation of the Satellite images

5.1.1 Gulf of Mannar

Visual interpretation of remote sensing images for extracting desired information could be achieved in an efficient and effective manner by using several basic interpretation keys (or) elements.**(Cho, C *et al.* 2004).** False colour composite (FCC) generated from the bands for visual interpretation to identify the heterogeneous patches distinctly pertaining to various landcover classes. The training polygon obtained from the field GPS were overlaid on the FCC image and the patches corresponding to mangroves were demarked. Since chlorophyll content in mangroves reflect high in the NIR band of the electromagnetic spectrum so they could be distinguished from other landcover types with bright pixel in the image. Other vegetation types and herbaceous vegetation could be easily visually interpreted with the help of visual interpretation keys. However the distinction between the mangrove associated species and other vegetation types could not be marked out because of the similar tone and texture. In contrast in the post Tsunami image, the damage of the mangroves and other vegetative types was not discernable.

A brief description of the landcover classes that were categorised visually are described below:

- **Mangroves -** Mangroves were identified by bright red tone and smooth texture and their association in the intertidal areas. The dense patch of mangroves appeared bright red and pinkish red where mangroves were sparsely distributed. The mangroves had similar appearance in both the pre and post Tsunami images which indicated their healthy existence.
-
- **Other Vegetation** -Other vegetation types were identified by their light pink colour and smooth texture .The islands are luxuriantly covered with nonmangrove species.

- **Herbaceous vegetation –** The herbaceous vegetation appeared as light pinkish in colour where the moisture content was less and at some places it appeared green because these species were found in the shrub form with moisture content in it. The image acquired in the month of December shows the the presence of moisture in the vegetation it since the study area receives rainfall in this month which corresponds to the winter season in India.

- **Shoreline-** The shoreline appeared as a crescentic linear feature located in the intertidal zone of land and sea .It gave the bright whitish appearance with smooth texture making it distinguishable from other landcover features.

5.1.2 South Andaman Islands

In order to detect the damage of the mangroves and other habitation areas due to Tsunami, the pre and post Tsunami images were visually interpreted. The false colour composite of 321 in the LISS III Images gave the best results and brought out the differences between the mangroves and other landcover/landuse classes quite distinctly. From figure no **6,** it is clear that mangroves in the Pre Tsunami image appeared as bright red in colour but the same patch of mangroves in the post Tsunami image appeared as dull /pale red in colour. There is a clear indication of water underneath mangroves that can be seen as small patches in cyan colour. Stagnant water in some of the landuse classes appeared as dark green in colour. The damage in the post Tsunami image of the south Andaman Islands is clearly discernable through the image.

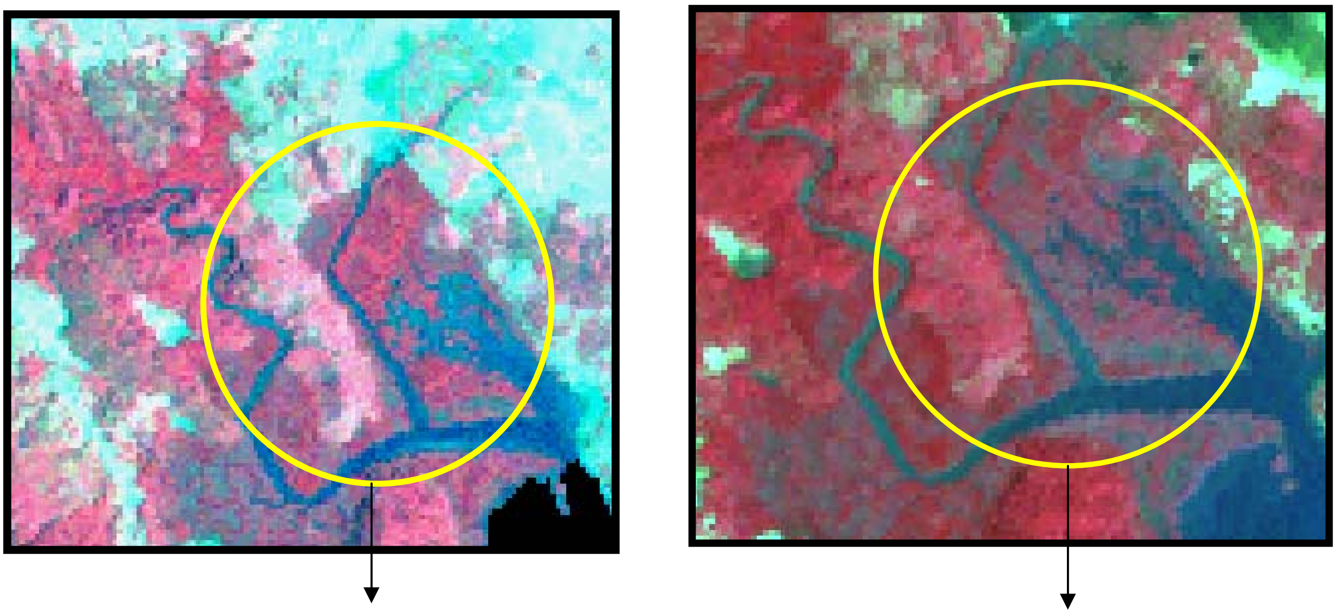


Figure 6 Healthy Mangroves Patch in Pre Tsunami and Dry Mangrove Patch in Post Tsunami Image

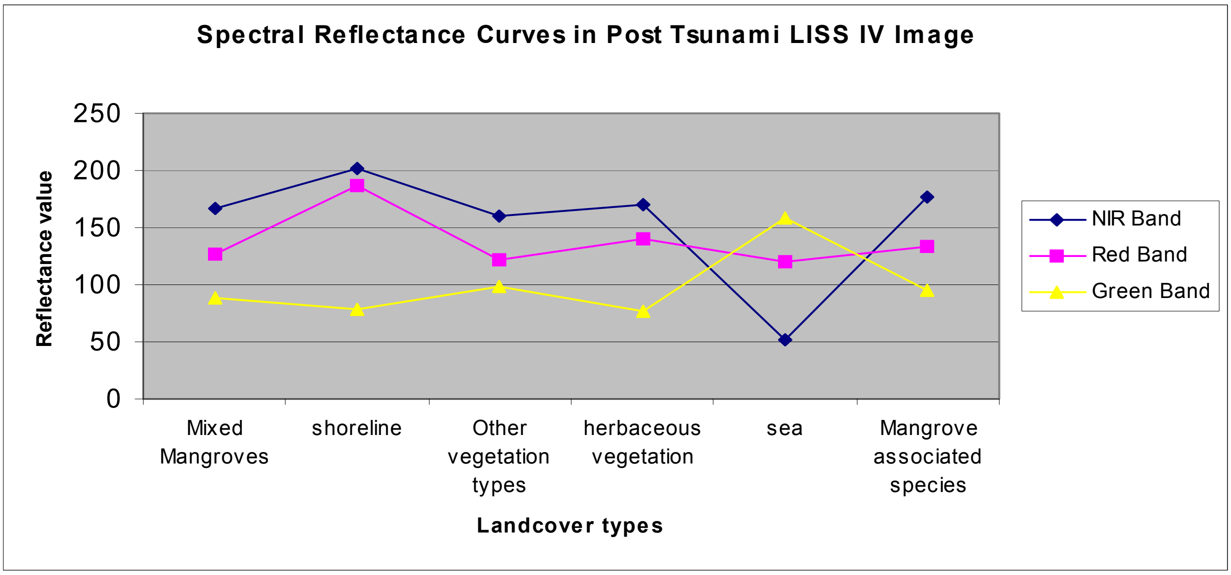
The damage is highlighted in the southern part of the post Tsunami LISS III image of South Andaman Islands. At some places the submergence of the agricultural lands and settlement areas could be well identified due to the presence of stagnant water which appeared as dark green colour.

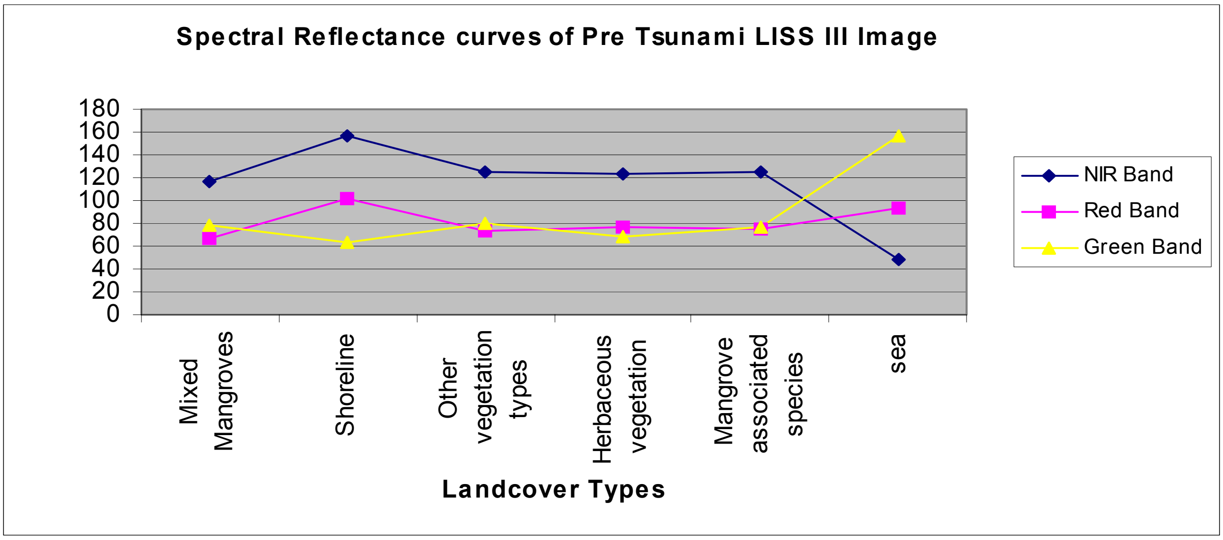
5.2 Results of Spectral Signature Analysis

5.2.1 Mandapam islands in Gulf of Mannar

The main objective of spectral signature analysis is to evaluate the spectral separability in each landcover classes. Spectral response pattern was studied for each landcover class with the help of reflectance curves for different spectral bands. In an optical image, vegetation can be readily distinguished due to its unique spectral signature. The reflectance of the mixed mangroves class and other vegetation classes clearly has a high peak in the NIR band and low in the red region of the spectrum due to the absorption of the chlorophyll.. The watermass is showing its lowest reflectance in the NIR band and higher reflectance in the visible bands.

Figure 7 Spectral reflectance curves of Pre and Post Tsunami Images in Mandapam Islands, Gulf of Mannar

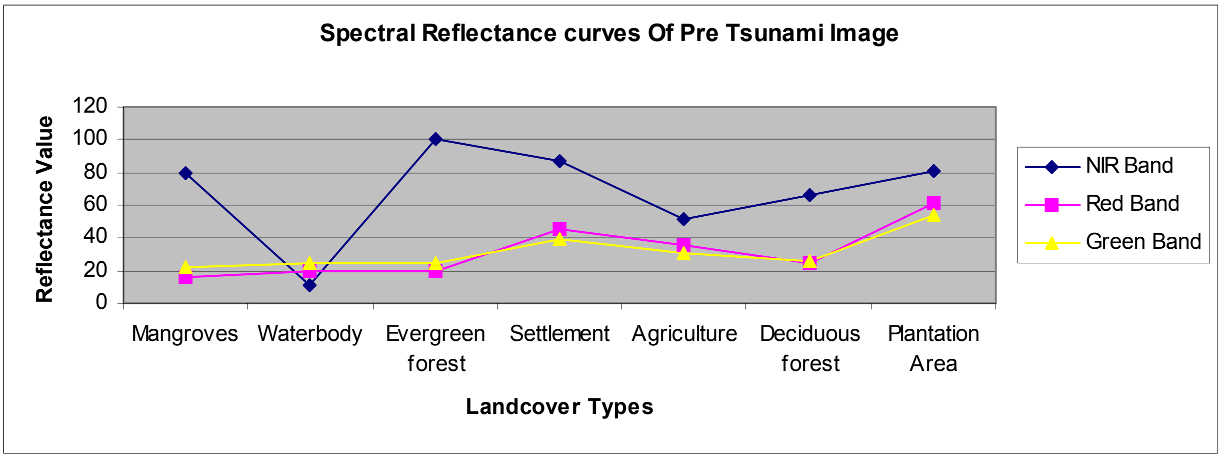


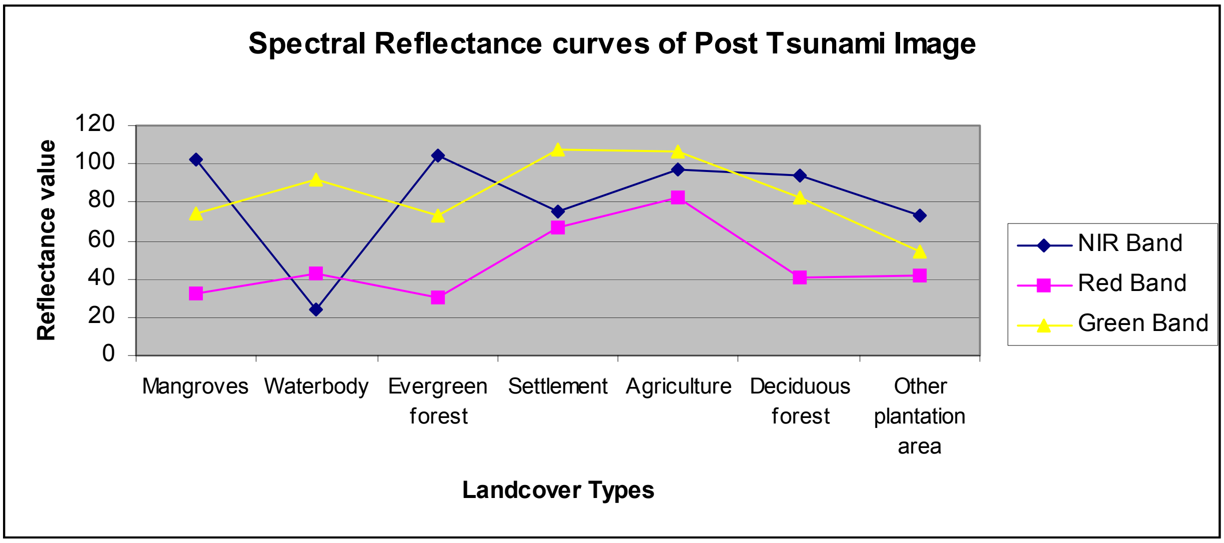


5.2.2 South Andaman Islands

Evergreen forest, deciduous forest, and mangroves have the highest reflectance value in the NIR band whereas the agriculture and settlement shows the highest reflectance in the red band as shown in figure 8. Waterbody shows greater reflectance in the visible bands than in the NIR band in the Pre Tsunami image. Agriculture and Settlement classes are showing greater reflectance in the green band due to the presence of water brought down by the Tsunami waves. The reflectance of the mangroves in he visible bands is low compared to the NIR band.

Figure 8 Spectral Reflectance curves of Pre and Post Tsunami Image of South Andaman Islands





5.2.3 Evaluation of Spectral Separability of Landcover classes

5.2.3.1 Best Separability of Landcover classes by Transformed Divergence Method (TD)

There are various measures that express the degree of separability of the spectral classes .The better separability of the training class signatures can aid in the classification result leading to more accurate thematic maps. Out of the separability measures, Transformed divergence method have been used in the study because of its efficiency and ease of their computation.

The transformed divergence value of 2000 represents the best separability between the classes. From the table below, the classes of sea and suspended sediments show the best separability with the other landcover classes. The mixed mangroves have got the best separability with the classes of suspended sediments and watermass (TD value of 2000). There are chances of the mixed mangroves class mixing with the other associated vegetation class due to its least TD value. The TD value between the mixed mangroves and mangrove associates is 435, which shows that these two classes are least separable. Herbaceous vegetation has got best separabilty with the classes of suspended sediments and watermass which shows the TD value of 2000.The other vegetation class has the best separability with the class of suspended sediments and watermass (TD value of 2000) but it shows the least separability with the mixed mangroves (TD value of 859) and herbaceous vegetation (TD value of 1007).

Table 6 Transformed Divergence Matrix of the Landcover classes in Mandapam Islands

2000 -The best separability between the classes
1900-2000 –Good separabilty between the classes.
1700-1900- Average separability between the classes.
< 1700- Poor separability between the classes.

Sl no	1	2	3	4	5	6	7
1	-	1935	1958	1965	1984	1980	1992
2	1935	-	435	1126	253	**2000**	**2000**
3	1958	435	-	1007	859	**2000**	**2000**
4	1965	1126	1007	-	**2000**	1535	**2000**
5	1984	253	859	2000	-	**2000**	**2000**
6	1980	**2000**	**2000**	1535	**2000**	-	1035
7	1992	**2000**	**2000**	**2000**	**2000**	1035	-

1-Shoreline**, 2**-Mangrove associates, **3**-Other vegetation types, **4**-Herbaceous vegetation, **5**-Mixed mangroves, **6**- Suspended sediments, **7**-Sea

5.2.2.2 Best Separability of Landcover classes by Transformed Divergence Method (TD)

The best separability of landcover classes was studied for the Pre and Post Tsunami images in South Andaman Islands. The mangrove swamps and the evergreen forest shows the best separability with agriculture and settlement class (TD value is 2000). There are chances of evergreen forest to be mixed with plantation class due to its low TD value (TD value is 1322). The deciduous forest has got the best separability with agriculture, settlement and tidal creeks/watermass (TD value of 2000 and TD value of 1996, 1978, 1997 in the post Tsunami Image). The plantation class shows the best separability with the tidal creeks/watermass and poor separability with the deciduous forest. Agriculture has got the best separabilty with all the classes and shows least separability with the settlement class. (TD value is 1608).

Table 7 Transformed Divergence Matrix of landuse/landcover classes in the South Andaman Islands

2000-The best separability between the classes
1900-2000 –Good separabilty between the classes.
1700-1900- Average separability between the classes.
< 1700- Poor separability between the classes.

Sl no	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	-	**2000**	**2000**	**2000**	1999	**2000**	**2000**
2	**2000**	-	1608	**2000**	**2000**	**2000**	1998
3	**2000**	1608	-	**2000**	**2000**	**2000**	1999
4	**2000**	**2000**	**2000**	-	1982	1587	677
5	1999	**2000**	**2000**	1982	-	1937	1958
6	**2000**	**2000**	**2000**	1587	1937	-	1322
7	**2000**	1998	1999	677	1958	1322	-

1-Tidal creeks, **2**- Settlement, **3**-Agriculture, **4**-Deciduous forest ,
5- Mangrove swamps,**6**-Evergreen forest, **7**-Plantation Area

5.2.2.3 Bandwise comparisons of Mean and Standard Deviations for LISS III and LISS IV Images of Mandapam islands, Gulf of Mannar

Table 8 Shows the Mean and Standard deviations of the Training Sample Set in each Landcover types in Pre Tsunami Image

Bands	No. Of Observations	Mean	Standard deviations
1	7	8.08	2.24
2	7	6.17	1.04
3	7	7.14	3.28

In order to show the dispersion of values from the mean in each landcover types of all the bands the standard deviations were calculated. The calculation is totally based on the training sample sets that were taken prior to the classification .The mean and standard deviation of all the landcover types were calculated for all the bands(given in the appendix).In the Pre Tsunami LISS III Image, Band 3 is showing maximum value of standard deviation than the other bands. Band 2 is showing the least value of 1.04. The highest value of standard deviation indicates well separability between the classes and has an high impact on the classification on that particular band.

Table 9 Shows the Mean and Standard deviations of the Training Sample Set in each Landcover types in Post Tsunami Image

Bands	No. Of Observations	Mean	Standard deviations
1	7	7.18	1.72
2	7	7.93	2.82
3	7	6.73	2.51

In the post Tsunami image the highest standard deviation in band 2 indicate a very good separation of the landcover classes in that band. The minimum value is seen in band 1 followed by Band 3.

A comparison of both the table reveals that band 2 is giving the highest value in LISS IV and lowest value in LISS III whereas in band 3 has shown the highest value of 3.28 in LISS III and moderate value of 2.51 in LISS IV for all the landcover types. Band 1 has shown the moderate value of 2.24 in LISS III and least value of l.72 in LISS IV respectively.

5.2.2.4 Bandwise comparisons of Mean and Standard Deviations for LISS III Images of South Andaman Islands

The standard deviation is basically the degree of dispersion of the mean value. It simply indicates how well the values are dispersed from the mean value. **.**The standard deviations for each landcover types were calculated separately (Table shown in the Appendix**).**

Table 10 Shows the Mean and Standard deviations of the Training Sample Set in each Landcover types in Pre Tsunami Image

Bands	No. of Observations	Mean	Standard deviations
1	7	11.87	4.52
2	7	4.92	3.88
3	7	3	1.80

Band 3(green) is giving the minimum reflectance in all the classes and showing a Standard deviation value of 1.80. Band 1 and Band 2(red) are showing the standard deviation value of 4.52 and 3.88. This indicates that the NIR band (Band1) is showing the highest reflectance in almost all the cover types excluding the waterbodies because vegetation cover types can be well distinguished in the NIR band.

Table 11 Shows the Mean and Standard deviations of the Training sample sets in each landcover types in Post Tsunami Image

Bands	No. Of Observations	Mean	Standard deviations
1	7	6.5	3.99
2	7	6.4	5.06
3	7	11.2	2.43

From the table 11 the standard deviation for Band 2(red) shows the highest value of 5.06 in all the landcover classes and Band 1(NIR) and band 3(green) are showing the standard deviation values of 3.99 and 2.43 respectively. Although the reflectance is from the same sensor LISS III but the values of standard deviations are different in each band for both the Pre and Post Tsunami Images

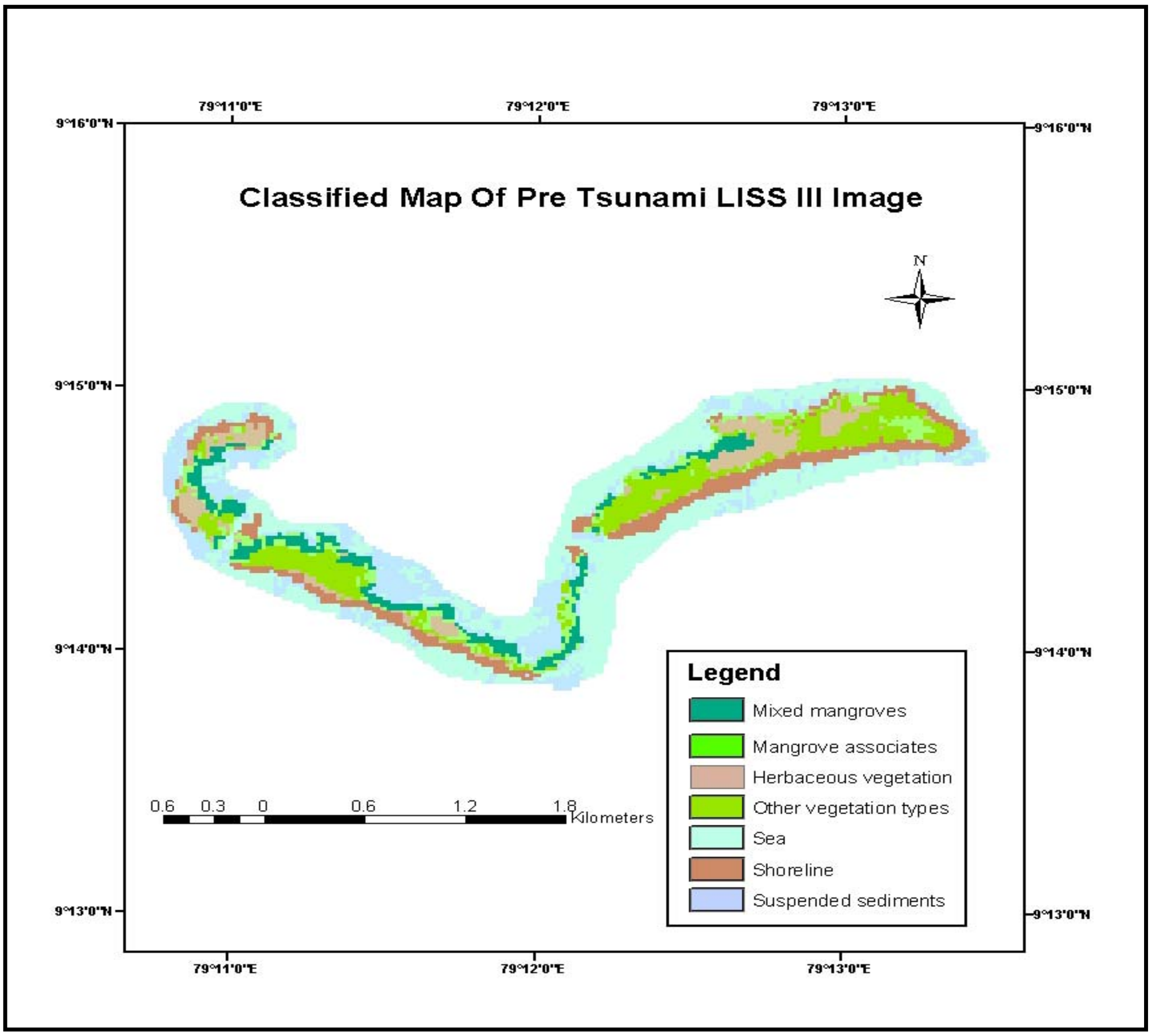
5.3 Digital Image Analysis

5.3.1 Supervised classification

Images of Pre Tsunami LISS III and Post Tsunami LISS IV were classified individually with separate training samples for each sensor. The qualitative and quantitative evaluation of the classification results is discussed as under: -

5.3.1.1 Pre and Post Tsunami Classified Images of Mandapam Islands of Gulf of Mannar

Supervised classification was performed with the help of training site obtained from the field on both the LISS III(of spatial resolution of 23.5m) and LISS IV(of spatial resolution of 5.8m) images of Mandapam islands of Gulf Of Mannar.Seven landcover classes were identified. Apart from mangroves, the classes that have been identified are Mangrove associates, herbaceous vegetation, other vegetation types, shoreline, corals and sea. There was mixing of the other vegetation class with the mangrove associates class. The classes were then identified in the field and were detected in the images. Many species of mangroves were identified in the field but they were not individually marked in the post Tsunami image because classification comparison of post Tsunami image with the preTsunami image (23.5 m) would have been difficult and would produce confusing results. Hence, the different groups of mangroves were grouped into single class of mixed Mangroves.



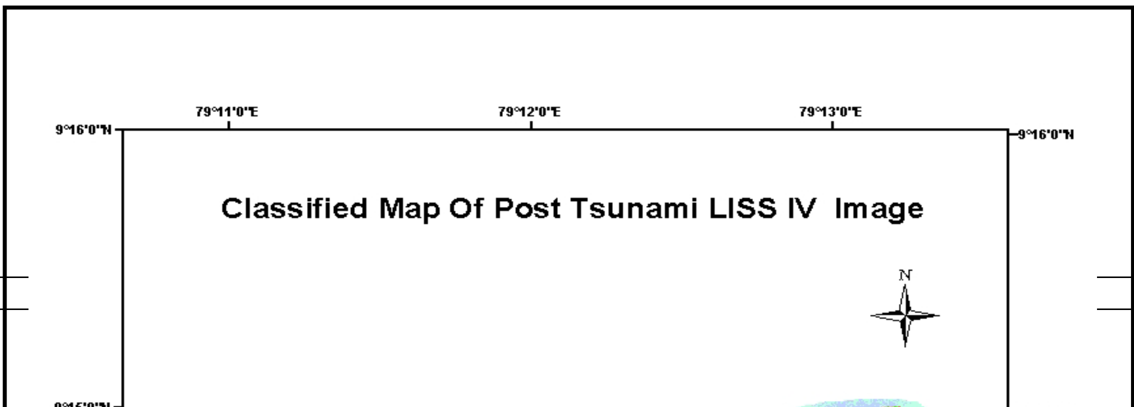


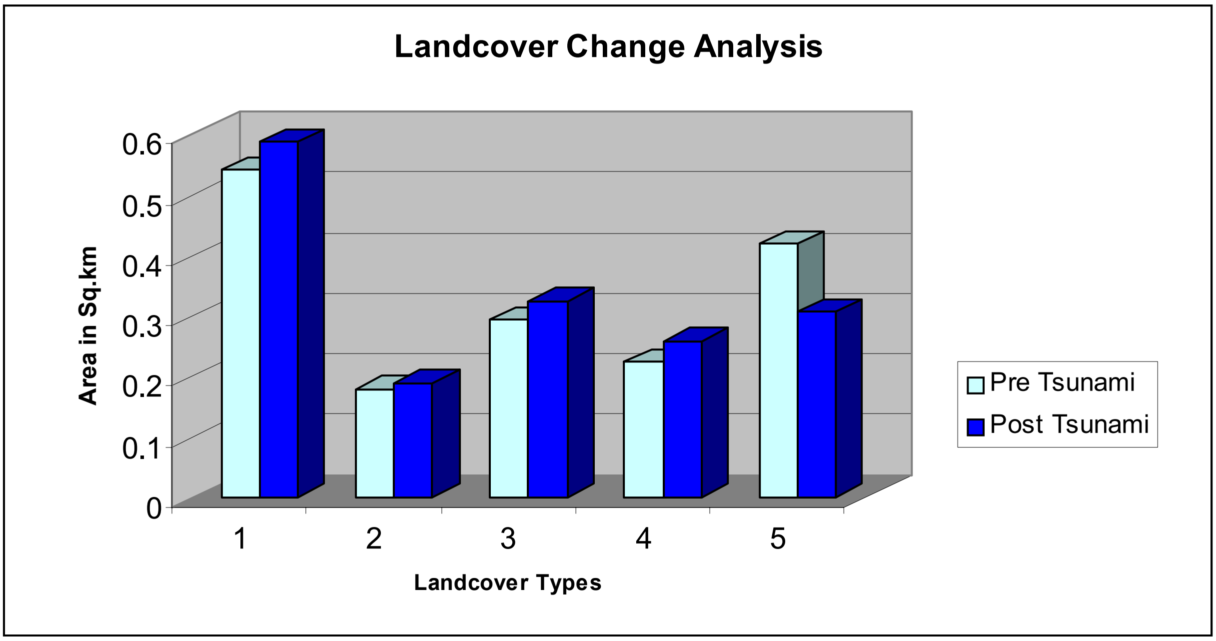
Figure 10 Post Tsunami Classified Map of Mandapam Islands, Gulf Of Mannar

5.3.1.2 Change in the spatial extent of Landcover types in Mandapam Islands

Temporal satellite data used in this study helped in estimating the changes in the spatial extent of the mangroves along with other landcover classes in the Mandapam islands in Gulf of Mannar.Over the past five years, areas of some mixed mangrove classes along with other vegetation classes have increased and the shoreline have considerably decreased as given in Table 12. From the table 12, it can be seen that the area of the shoreline have decreased and it is clearly discernable from the post Tsunami images. The change in the shoreline may be due to the island erosion and accretion caused by the action of waves and wave induced current and long shore currents along the shores of islands. The change in the vegetation classes is mainly caused due to the regeneration of many plant species. From the table, it is indicated that the change in the area of the mixed mangroves has been 0.01 sq.km from 1999 to 2004.Mangrove associates has also regenerated over the years from 0.22 sq.km to 0.25 sq.km. The most interesting change that has been noticed is the change in the shoreline. It is clearly indicated from the table that the shoreline has narrowed down from 0.41 sq.km to 0.30 sq.km.There has been a total decline 0.11 sq.km. of shoreline in the study area after the Tsunami.

Table 12 Area wise Change in the Landcover Classes of Mandapam Islands

Landcover classes	Area (1999) (T1)	Area (2004) (T2)	Change in the Area (sq.km) (T2-T1)
Mixed mangroves	0.18003	0.19013	0.010
Other vegetation	0.54175	0.58752	0.0457
Herbaceous vegetation	0.29324	0.32391	0.030
Mangrove associates	0.224213	0.25789	0.033
Shoreline	0.419157	0.306124	-0.113
Total Area	1.6584067	1.665558	0.00751



1-Other Vegetation Types, 2-Mixed Mangroves, 3-Herbaceous vegetation
4-Mangrove Associated species 5- Shoreline

Figure 11 Landcover Change Analysis of Pre and Post Tsunami conditions

5.3.1.3 Pre and Post Tsunami Images of South Andaman Islands

Due to the complexities of the spectral separation between the classes the classification has been limited to seven classes only. The classes that were identified in the field were clearly detected in the image but due to lack of extensive fieldwork further classification in the landcover classes could not be made. After running the MLC algorithm the majority of the classes were mixing with each other. The classes were well separated after recoding.

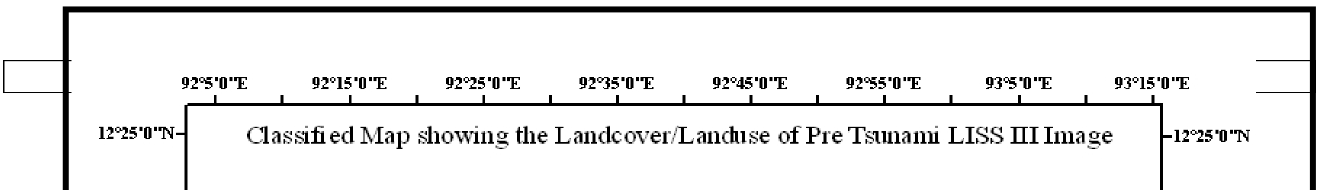


Figure12: Classified Map showing the Landuse/Landcover of PreTsunami LISS III Image of South Andaman Islands

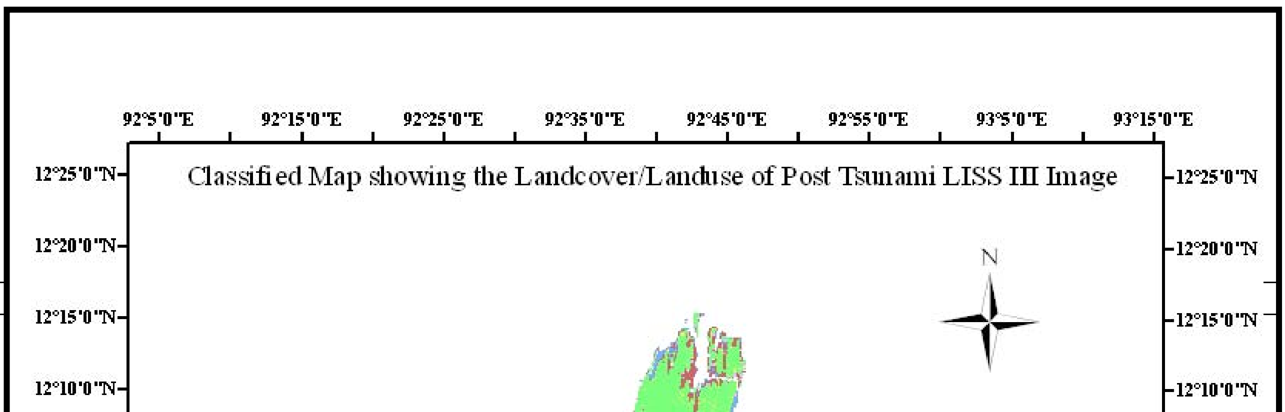


Figure 13 Classified Map showing the Landuse/Landcover Of Post Tsunami LISS III Image of South Andaman Island

5.3.1.4 Change in the spatial extent of mangroves and other land use in South Andaman Islands

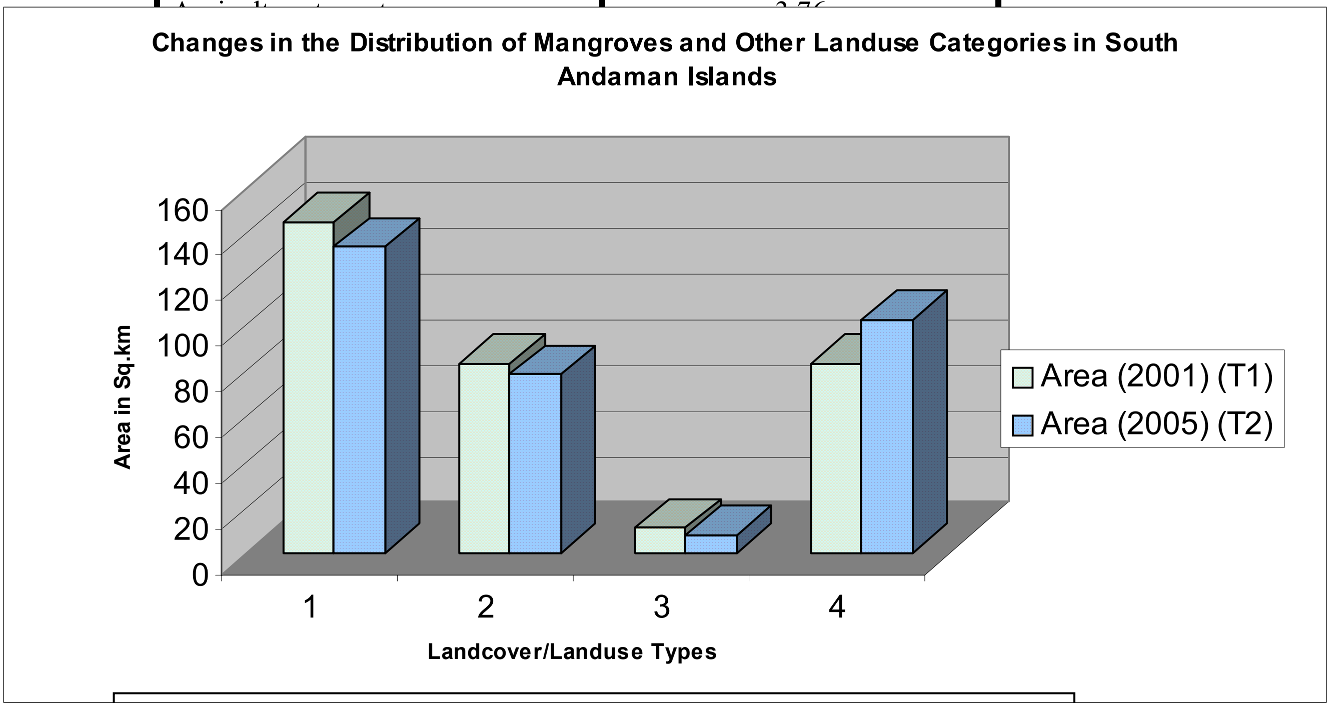
The area statistics in table 13 shows that the landcover /landuse classes of the South Andaman Islands has undergone remarkable changes over the past few years. There is a decline in the spatial extent of the mangroves of 7.5 % after the effect of Tsunami. There is an increase in the percentage of area of settlement and watermass. The percentage increase in the watermass indicates that water is still present in some of the landuse /landcover classes due to the dual impact of Tsunami and tectonic submergence. The agricultural land and settlement areas have undergone submergence and is showing decline in the area of the land due to the damage caused to these habitation areas as a result of Tsunami.

Table 13 Changes in the distribution Of Mangroves and Other Landuse categories After Tsunami

Landcover classes	Area (2001) (T1)	Area (2005) (T2)	Change in the Area (T2-T1)	% Of area changed
Mangrove Swamps	145	134	-11	7.5
Agriculture	83.01	78.04	-4.96	5.98
Settlement	11.14	7.84	-3.3	29.6
Tidal creeks/water mass	82.99	102.25	19.26	23.20

*Area in sq.km

Landuse/Landcover category	**% Change in the Area**
Mangroves to Agriculture	0.6
Mangroves to Tidal creeks	2.3
Settlement to Watermass	4.3
Agriculture to settlement	0.4
[illegible]	[illegible]



1-Mangrove Swamps 2-Agriculture 3-Settlement 4- Tidal Creeks/Watermass

Figure 14 Post Tsunami Changes in the distribution Of Mangroves and Other Landuse categories

Table 14 Change in Mangroves and other Landuse categories in South Andaman Islands

An estimate of spatial extent of various landuse/landcover types has been worked out. In case of mangroves, there is a change in the percentage of area. Mangrove bearing areas have also changed to agriculture (0.6%)

and tidal creeks (2.3%). After the devastation of Tsunami, most of the frontline mangroves have gone to the tidal creeks. The settlement that has undergone change to the watermass is simply due to the submergence of the land due to the tectonic activity. Some of the parts of agriculture have changed to settlement and some are still under water. There has been a change of 0.4% change in the agricultural lands to settlement and 3.76% change in the agriculture lands to watermass. Due to the aftermath of Tsunami and tectonic subsidence, most of the agricultural lands in the southern part of the island have been submerged into water. Thus it can be concluded that the dual impact of the Tsunami and the tectonic activity has led to the submergence of most of the habitation areas. Mangroves have suffered greatly in the South Andaman Islands especially near the creeks where the water is still stagnant and is clogging the pores of the mangroves leading it to declination

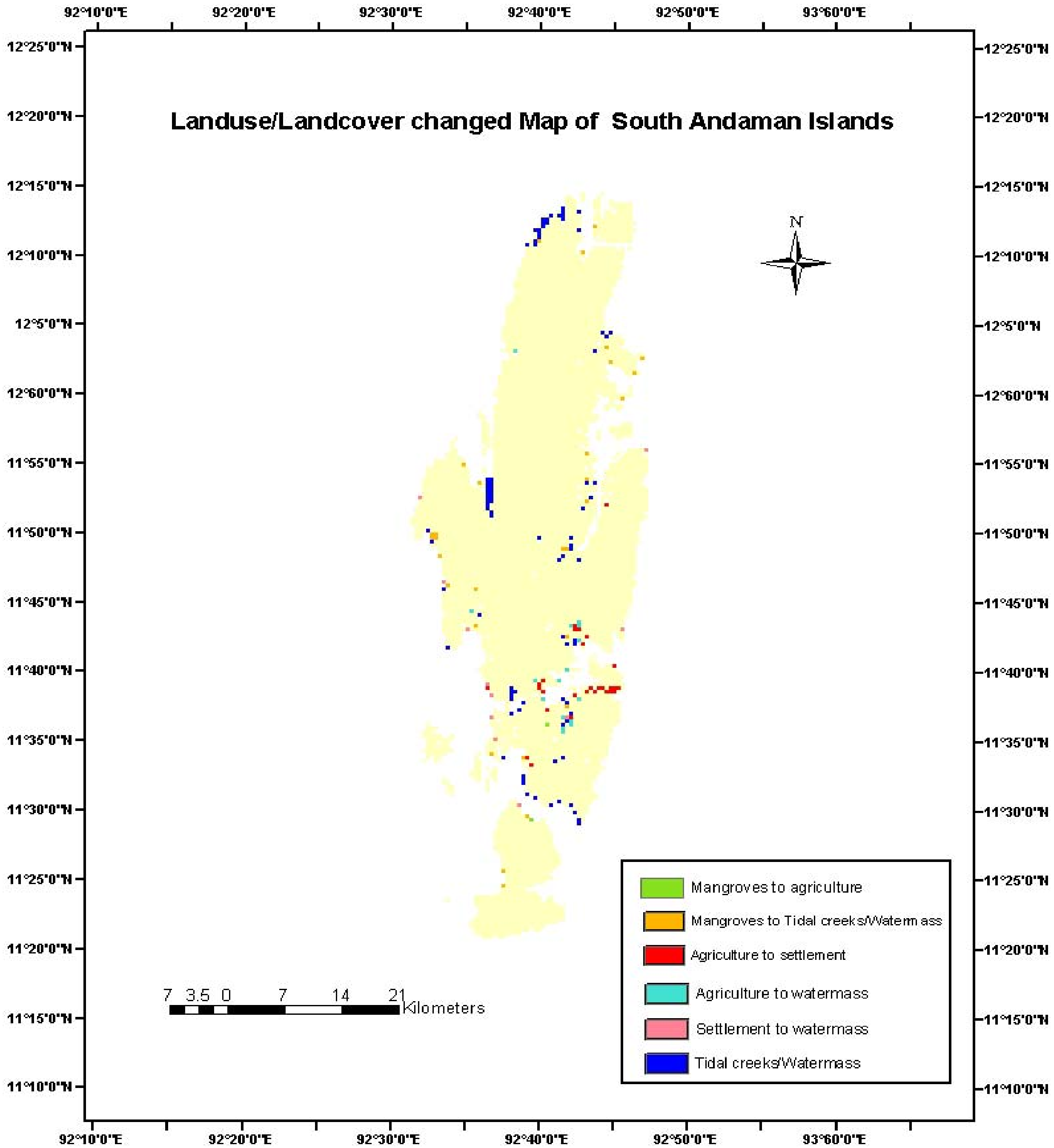


Figure 15 Classified changed Landuse /Landcover Map of Post Tsunami in South Andaman Islands

5.3.1.5 Qualitative evaluation of the Degree and extent of Damaged Mangroves

The degree of damage of the mangroves has been qualitatively assessed with the aid of IUCN guidelines and field observations. For assessing the specific types of damage caused to the mangroves and other landcover/landuse categories certain parameters have been considered (already discussed in Methodology chapter). The degree of damage describes the intensity to which the mangroves have been affected by the event of Tsunami. The intensity of damage was categorised as heavily damaged mangroves, moderately damaged mangroves and least damaged mangroves. The GPS coordinates were recorded at the location of damaged mangroves were overlaid on the Post Tsunami Image. The post Tsunami image was then classified on the basis of ground truth points and earlier reports that were available on the damage. Although extensive fieldwork could not be carried out due to the weather conditions and inaccessibility of many areas along the creeks. From the classified map it is clearly indicated that the heavily damaged mangroves are observed along the creeks .The shocking of the roots and drying of the front row mangroves is due to the existence of high water tide level. During high and low tide, the mangrove areas remain submerged under water. This has led to the drying of mangroves because the roots have to be exposed for atleast six to eight hours a day. The moderately damaged mangroves are not presently dried up but are partially affected by the Tsunami waves. The least damaged mangroves have fewer casualties in comparison to the heavy and moderately damaged mangroves. The extent of damage of the mangroves is well represented in the table given below:

Table 15 Percentage of area damaged in mangroves

Degree/Intensity of damage	Area in sq.km	% Of area damaged
Heavily damaged mangroves	28.24	21.525
Moderately damaged mangroves	19.36	14.768
Least damaged mangroves	30.41	23.184
Intact mangroves	53.17	40.522

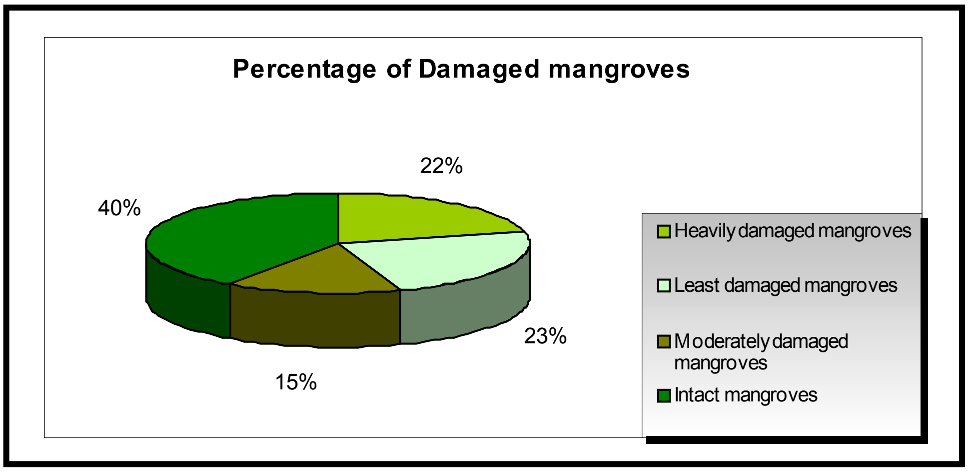


Figure 16 Percentage of area of Damaged Mangroves

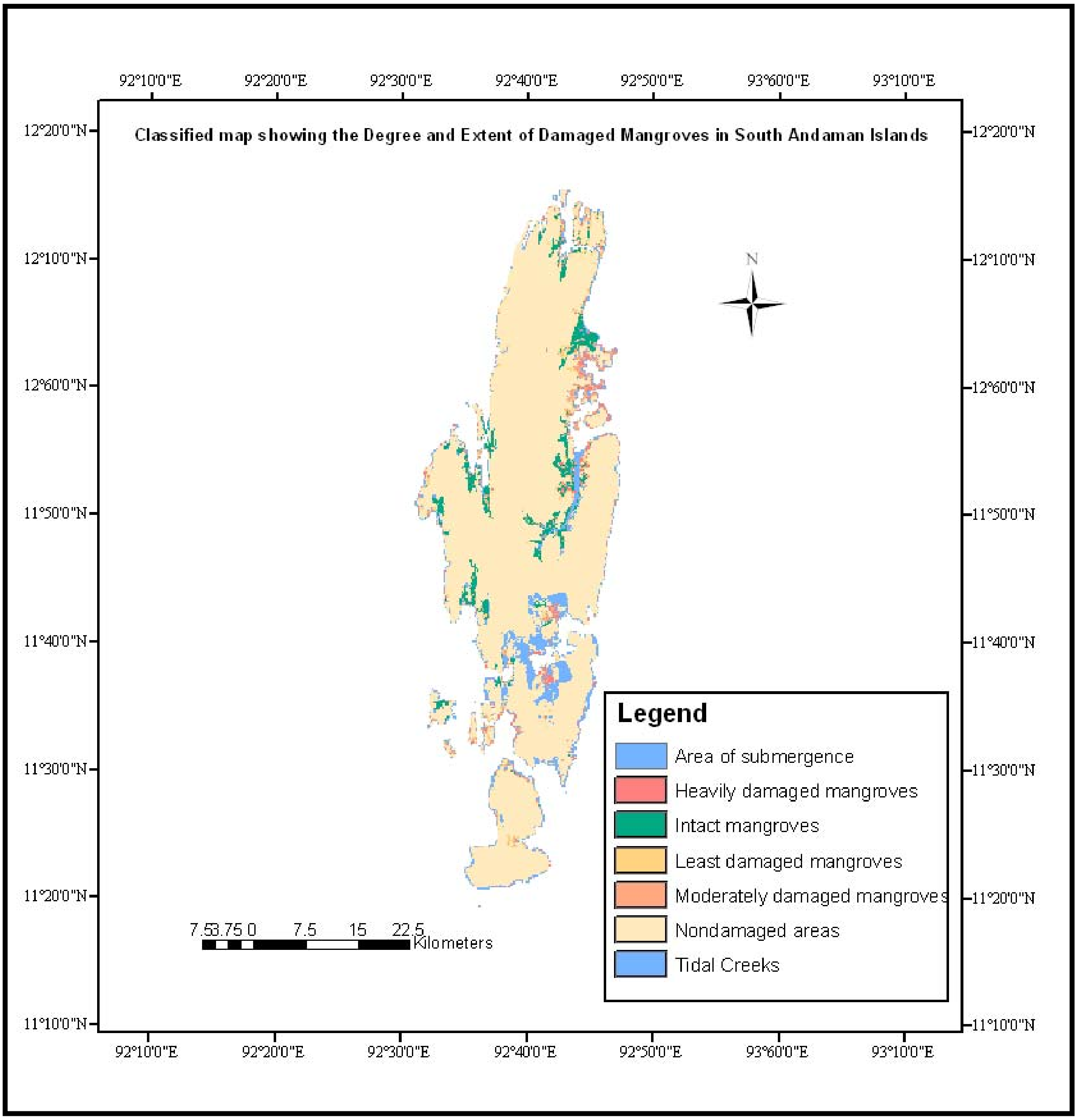


Figure 17 Classified Map showing the degree and extent of Damage Mangroves in South Andaman Island

5.4 Quantitative assessment of the remotely sensed data

5.4.1 Accuracy assessment of the classified images of Gulf of Mannar

In order to determine the classification accuracy, it is necessary to determine if the output map meets, exceeds, or does not meet certain predetermined classification accuracy criteria. The most common method by which the classification accuracy is assessed is the Error Matrix. Another method is the Kappa coefficient or the KHAT coefficient that is an index that relates to the classification accuracy after adjustment for chance agreement.

The classified images have been evaluated quantitatively through accuracy assessment of all the landcover classes in the Pre and Post Tsunami images. Producers accuracy is the measure of how accurately a class can be classified in an image. It is the percentage of pixels that should have been put in a given class but they are not. Users accuracy simply implies the confidence of the class in a classified image. Producers' accuracy is the overall accuracy of the classified image. It simply indicates the pixels that were placed in a given class when they actually belong to another class. From the accuracy table, it has been shown that the overall accuracy in the Pre Tsunami image is 85.53% and that in the Post Tsunami Image is 88 % in the error matrix .The Kappa statistics results shows a result of 0.81 and 0.85 in Pre and Post images. Mixed mangroves class has a coefficient of 0.69 whereas the other vegetative class has coefficient of 0.82 in the Pre Tsunami Image. The mangroves class has an accuracy of 100% in Post Tsunami period.

Table 16 Accuracy assessment of the Classified Images of Mandapam Islands, Gulf Of Mannar

	Pre Tsunami			Post Tsunami		
Landcover classes	Producers accuracy	User's accuracy	Kappa Statistics	Producers accuracy	Users accuracy	Kappa statistics
Mixed mangroves	100	71.43	0.6942	100	100	1.0000
Other vegetation	100	84.62	0.8201	100	100	1.0000
Herbaceous vegetation	100	87.50	0.8623	50	66.67	0.6032
Mangrove associates	100	50	0.5	75	100	1.0000
Suspended sediments	66.67	100	1.0000	100	83.33	0.7917
Sea	95	76	0.6743	100	100	1.0000
Shoreline	87.50	100	0.4583	100	50	0.4792
Overall accuracy	85.53		0.8183	88.00		0.8529

5.4.2 Accuracy assessment of the classified images of South Andaman Islands

The quality of information derived from a remote sensing data is determined by the accuracy assessment. The output results produce little value if accuracy assessment remains undone. The results that an accuracy assessment provides is an overall accuracy of the map and the accuracy for each class in the map. Through quantitative accuracy assessment identification and measurement of map errors can be done. The comparison of a location on a map against the reference information of the same location can be judged by accuracy assessment. In order to properly analyse the validity of each class as well as the classification results, the error matrix method and the kappa statistics is commonly used. Hence the efficacy of the classification has been evaluated in detail.

The overall accuracy in the Pre Tsunami image is 81.08 % and in the post Tsunami image is 84.38 %. The kappa statistics has shown a result of 0.67 and 0.74 in the pre and post Tsunami classified maps. The detailed result of the classification is given below:

Table 17 Accuracy assessment of the classified images of South Andaman Islands

	Pre Tsunami			**Post Tsunami**		
Landcover classes	Producers Accuracy	User's Accuracy	Kappa Statistics	Producer's accuracy	Users accuracy	Kappa Statistics
Mangrove swamps	100	84.62	0.6146	100.00	100.00	1.0000
Evergreen forest	95.24	80.00	0.5375	100.00	80.95	0.5937
Deciduous forest	100.00	75.00	0.7279	42.86	100.00	1.0000
Plantation area	-	-	-	100	100	1.0000
Agriculture	60.00	100.00	1.0000	50.00	50.00	0.4839
Settlement	50.00	100.00	1.0000	50.00	100.00	1.0000
Tidal creeks	100.00	100.00	1.0000	100.00	100.00	1.0000
Overall accuracy	81.08	0.6758		84.38	0.7464	

The accuracy assessment thus helps us to assess the efficiency of the sensors to detect the mangroves and other landcover classes. The entire process of accuracy assessment has been carried out with the help of Erdas Imagine software.

6.Conclusion and Recommendations

6.1 Concluding remarks

Main Objective

The main objective was to detect, assess and monitor the changes in the mangroves in Southeastern coast and South Andaman Islands of India using multitemporal optical satellite data.

Research Question concerning Research objective 1

To detect damage and destruction of the mangroves as a result of the tsunami using multitemporal optical satellite data.

Research Question #1

What are the damage and destruction caused to the mangroves as a result of Tsunami and how can it be detected?

- Using optical remotely sensed data it was possible to detect the damage caused to the mangroves as a result of Tsunami.The onscreen visual interpretation of both pre and post Tsunami images were done to detect the damage of the mangroves caused by the deadly event.

- The field investigations have confirmed that there is negligible impact of the Tsunami waves on the Mandapam Islands of Gulf of Mannar.Since the islands of Mandapam are uninhabited, it is devoid of any human interference the mangroves and other associated flora appeared to be in good condition.

- The Mandapam islands is partially sheltered by the Srilankan landmass .So these islands had minimal impact of Tsunami waves on the aqua-terrestrial ecosystem. Although long-term implications are there, further research is going on to investigate the indirect consequences to the aquatic ecosystems. The mangrove forest was in good condition and has protected the coastal land. It is thus concluded that the changes of the mangroves that are visible on the images are positive and it has simply resisted the wrath of Tsunami.

- On the contrary, the South Andaman Islands has suffered great casualties of the mangroves. It can be observed from the Pre and Post Tsunami LISS III images that the intact mangroves appeared as bright red patch whereas the damaged mangroves appeared as greyish or pale red in colour.
- Field investigations revealed that there was submergence in many parts of the island at a depth of 0.9-1m. The frontline mangroves all along the creeks are drying. There is no damage observed in the inland coastal forest. The false colour composite of the images brought out the differences between the landcover classes well for both the visual interpretation.

- Spectral signature separability of the mangroves with other classes has been quite distinctly marked out. On the basis of ground truth data and spectral signature analysis, classification with Maximum Likelihood Classifier was carried out on the images.

Research Question concerning Research objective 2

To assess the degree and extent of the damage of the mangroves caused by the tsunami

Research Question #2

What is the degree and extent of damage of the mangroves caused by the Tsunami and how can it be determined?

- The basic objective of the study was to assess the degree and extent of damage of the mangroves caused by the Tsunami. For assessing specific types of damage caused to the aqua-terrestrial ecosystems the damage has been rated on two different parameters: The degree and the spatial extent of damage. The heavy, moderate and least degree of damage of the mangroves has been observed in the field and then the information collected from the ground truth data was incorporated in the post Tsunami image.

- The classified map of degree and extent of damaged mangroves were generated. The degree of damage was classified according to the physical impact of the Tsunami waves on the mangroves.

- The extent of damaged mangroves was mapped with the aid of visual interpretation and ground truth data collected during the fieldwork. The spatial area of the affected mangroves was assessed in relation to the direction of Tsunami incursion. Overall damage caused to the mangroves was assessed on the basis of the dual criteria of ‘degree’ and ‘extent’. Proper training sites based on field observations were taken to differentiate between various degrees of damage in the study area. With the limitation of the spatial resolution of 23.5m only the areal extent of damage can be detect and assessed.

Research Question concerning Research objective 3

To monitor the changes in mangroves extent and its condition before and after tsunami using optical satellite data.

Research Question #3

How change in the condition of the mangroves be monitored before and after tsunami using optical satellite data?

- Post classification comparison was done to monitor the changes of the mangroves and other landcover/landuse categories. The classification comparison has determined the changes in the area that have taken place and the nature of changes that have taken place. A changed matrix gave a clear picture of the changes in the landuse/landcover classes.

- No change in the condition of mangroves and other vegetative species was observed in the three islands of Mandapam group in Gulf of Mannar. The other aquatic plant ecosystems may have long-term effects and may take centuries to fully recuperate. The most interesting observation has been the change in the shoreline which has narrowed down to an extent mainly due to the erosion and accretion that is taking place over the years.

- A comparative analysis was done with pre and post tsunami images of South Andaman Islands to monitor the changes in the post Tsunami conditions. There is an increase in the watermass on the agricultural lands and some settlement areas which shows a decline in the area coverage of these landuse. The frontline mangroves along the creeks are all heavily damaged and the inland forests are still in intact position. The southern part of the South Andaman Islands have suffered greater casualties .The mortality of the mangroves is mainly due to low respiration as a result of burying pneumatophores. Although mangroves remain in waterlogged conditions, the nonexposure of the breathing roots for six – eight hours a day has lead to the mortality of the mangroves.

6.2 Need for Rehabilitation of damaged Mangroves

The December 26th earthquake and the tsunami wreaked havoc on the coastal environment of South Andaman Island. The Tsunami damaged mangroves may take centuries to recover. According to FAO, rehabilitation and planting efforts should be undertaken within a larger framework of integrated coastal area management. Several reports have mentioned that extensive areas of mangroves can reduce the loss of life and damage caused by the Tsunami. Given the present rate of disappearance and degradation of mangrove forests (which was further aggravated by the Tsunami itself) there is an imperative need for the conservation and rehabilitation which in turn calls for improved planning and decision making in respect of use and management. Tsunamis occur very infrequently in the Indian Ocean .To assess and monitor the resilience of natural and modified ecosystems will help plan mitigation of the potential impacts of a range of natural risks and hazards. Short term monitoring is the key to identifying the environmental damage and prioritising environmental restorations. In order to ensure the long term sustainability and reconstruction strategy efforts can be put into the removal of the dry mangrove areas atleast where the places are accessible.

- Replanting young mangrove seedlings can help to restore the most valuable species.
- Some basic interventions like clearing of debris, unblocking water channels
- Need for site protection and restoration measures
- The areas with greater casualties can be restored through proper plantation activity or assisted natural regeneration **(ANR)**
- Degraded areas need to be restocked and fresh mudflats need to be afforested with suitable mangroves.
- Silvicultural techniques like regeneration, restoration and afforestation of mangroves can be the only alternative solution to the problem
- An integrated approach is required to prevent the further destruction of mangrove forests and is the first step for the conservation of the existing mangroves.

6.3 Limitations of the Research

There are certain limitations in this research. Due to the unavailability of the data of salinisation and sedimentation rate in the post Tsunami period, a comparative analysis of the condition of the mangroves with the above mentioned parameters could not be carried out in Pre and Post Tsunami conditions. The parameter of wave height was not taken into consideration to assess the damage of the mangroves. Absence of high resolution data for the study area of South Andaman has made it difficult to detect and assess the damage at the species level. The degree of damage was judged on a qualitative basis not on an quantitative basis. Lack of extensive fieldwork due to time constraints has resulted in the rapid assessment of the damage of the mangrove ecosystem.

6.4 Recommendations

- This type of study is advisable in the areas where the present rate of degradation and disappearance of mangroves is high and Tsunami has worsened the situation further. The same study if carried out at different sites would give more clarity to the present work.

- Further research can be carried out if different sensors with different wavelengths can be taken into consideration.

- Assessment of damage of the mangroves at the species level can be carried out with the help of high resolution remotely sensed imagery.

- Further research can be carried out with the fusion of optical and radar satellite imageries.

- Irrespective of the spectral response of the satellite images it is essential to have prior knowledge about the study area. Prior knowledge of the study area can effectively produce good classification and image processing results.

- Knowledge based classification and object oriented classification can be tried out to classify the damaged areas of mangroves.

- Various classification accuracy methods can be tried out to give better classification results.

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Appendices

Field Photographs: Mandapam Islands, Gulf of Mannar

Heterogeneous patch of mixed mangroves

Herbaceous vegetation along the shoreline

Dense growth of mixed mangroves

Stilt roots of *Rhizophora mucronata*

Other vegetation types in the Island

Narrow shoreline of the Island

7.1 Field Photographs: South Andaman Island

Drying of the roots of the mangroves leading to its mortality

Drying of the frontline mangroves

Dried Mangroves along the frontline of the creeks

Damage to Plantation areas

Damage to Settlement areas

Damage to Agricultural areas

Appendices

Pullivasal of Mandapam Group in Gulf of Mannar

LATITUDE	LONGITUDE	FOREST TYPE
9 14 23.9	79 11 11	Rhizophora, Pempis acidula
9 14 24.6	79 11 14.3	Ceriops
9 14 25	79 11 15.7	Rhizhophora
9 14 19.8	79 11 27.3	Mixed mangroves&ceriops
9 14 16.9	79 11 27.4	Avicennia
9 14 16.9	79 11 27.5	Ceriops
9 14 16.8	79 11 27.6	Narikkanna, avicennia
9 14 16.8	79 11 27.3	Pemphis Acidula
9 14 16.8	79 11 27.4	Saldora
9 14 16.4	79 11 27.2	Pemphis shrub(1m-2m)
9 14 16.1	79 11 27.2	*Pempis acidula*
9 14 15.2	79 11 27.2	saldora
9 14 14.1	79 11 26.9	Poovarashi
9 14 13.7	79 11 26.4	Pallai
9 14 13.7	79 11 26.4	Pallai dominated zone
9 14 13.1	79 11 26.0	Poovarashi
9 14 12.8	79 11 26.0	Udian
9 14 12.3	79 11 26.3	pallai trees
9 14 12.1	79 11 26.3	poovarashi
9 14 10.9	79 11 25.6	narikanna ,saldora
9 14 8.3	79 11 24.8	herbs of white grass
9 14 8.9	79 11 24.9	shrubs 1m-2m
9 14 9.3	79 11 24.9	saldora
9 14 9.4	79 11 25.2	accacia (vedatallai)
9 14 9.3	79 11 25.1	ziziphus(illandai)
9 14 9.3	79 11 25.2	virali belt(shrubs of 1 mt)
9 14 10	79 11 25.0	pallai
9 14 10.5	79 11 25.0	pallai

Kursadi Island in Mandapam Group of Gulf of Mannar

Latitude	Longitude	Forest Type
9 14 39.3	79 12 21.7	ceriops
9 14 39.4	79 12 22.4	scattered rhizophora and pempis
9 14 39.0	79 12 24.5	ceriops
9 14 39.0	79 12 25.7	avicennia and mixed mangroves
9 14 40.8	79 12 28.7	ceriops
9 14 42.6	79 12 28.7	rhizophora group
9 14 44.3	79 12 30.8	rhizophora group
9 14 48.4	79 12 31.9	no mangroves
9 14 50.3	79 12 32.3	no mangroves
9 14 53.4	79 12 35.0	kirri cherri and poovarashi 5-10 m
9 14 55.3	79 13 07.8	saldora(50 ft belt of saldora)
9 14 55.3	79 13 09.2	prosopis juliflora
9 14 54.3	79 13 09.4	saldora
9 14 54.3	79 13 09.5	pempis acidula
9 14 54.1	79 13 09.1	Aloevera
9 14 53.2	79 13 08.8	prosopis juliflora
9 14 53.0	79 13 08.8	poovarashi
9 14 51.7	79 13 09.6	saldora
9 14 48.2	79 13 11.9	virali belt
9 14 47.7	79 13 11.5	virali belt (100-150 mts)
9 14 47.3	79 13 11.3	pantanas
9 14 45.2	79 13 09.2	along the grasses(shrubs 20-30 m)
9 14 44.5	79 13 04.6	shrubs
9 14 44.9	79 12 59.7	virali belt (1.5m-2m)
9 14 45.1	79 12 59.6	virali ,phoenix,saldora
9 14 45.9	79 12 59.3	virali belt
9 14 47.0	79 12 58.4	new species
9 14 48.1	79 12 58.0	pure grasses old habitation area.
9 14 48.6	79 12 57.8	pure grasses (.
9 14 49.6	79 12 57.1	pure grasses (400m/200mt)
9 14 49.3	79 12 58.8	pure grasses

Poomarichan Island In Mandapam Group of Islands, Gulf Of Mannar

latitude	longitude	Forest type
9 14 45.8	79 10 55.9	Mixture of poovarashi, saldora and Pempis Acidula
9 14 40.0	79 10 52.4	at the edge of the sea 10 mt belt of Pempis Acidula(350 mt approx)
9 14 30.8	79 10 50.5	Uniform crop of acacias
9 14 31.0	79 10 50.7	Uniform belt of accacias
9 14 22.7	79 10 56.0	End of the uniform belt of accacias
9 14 22.8	79 10 57.4	Uniform crop of the accacia group
9 14 30.6	79 10 52.1	Uniform belt of grasses
9 14 32.1	79 10 54.5	Avicennia (50 m both side along the sea),in between rhizophora after avicennia grass patch follows
9 14 33.6	79 10 52.8	kirri I in the form of shrub,10% poovarashi,saldora
9 14 35.8	79 10 52.6	Seaside (rhizophora belt)20-25m,landside kirri dense patch
9 14 37.8	79 10 54.1	Rhizophora belt 10-15 mts
9 14 38.4	79 10 52.7	Dense patch of poovarashi saldora, pallai
9 14 39.2	79 10 54.4	Avicennia 15 mts, kirri 10 m landside, dense forest of poovarshi,saldora,vedatallai
9 14 41.4	79 10 55.6	Open kirri, rhizophora, avicennia
9 14 43.2	79 10 58.2	Mixed mangroves
9 14 46.8	79 10 58.7	Open grasses
9 14 46.1	79 11 01.8	open space mainly grasses(around 200m length,50 mts width, scattered velakanna

Table: GPS points collected for ground truth validation (South Andaman Islands)

Latitude	Longitude	Characteristics
11 42 26.4	92 42 24.5	Rhizophora mucronata (big pods (around 5 km)
11 42 33.7	92 42 19.4	Mixed mangroves (Rhizophora, avicennia, ceriops)
11 42 51	92 42 06	Dried mangroves mostly rhizophora right side coconut plantation under water
11 42 59.0	92 41 59.9	All around water the bridge is broken mangrove area rhizophora dried all over.
11 42 13.3	92 42 35.4	All around the creek side below forest the mangrove belt have dried along and a km belt
11 43 37	92 42 41	All the agricultural land is under permanently under water (at the moment it is high tide)
11 43 26.5	92 41 05.1	Water is coming in the high tide in the field everyday
11 43 21.6	92 40 24.8	High tide is reaching
11 43 21.6	92 40 19.5	Shaitankhari area (agricultural activity)
11 41 47.9	92 40 59.3	Agricultural land under water
11 40 06.1	92 40 46.1	Left side road now permanently under water
11 39 23.4	92 40 38.2	All top of coconut tree is broken and the trees are dead
11 39 21.5	92 39 57.9	Mangroves have dried left side of the road to chonedhari
11 36 19.2	92 40 40.2	Water is there but mangroves are not yet dried up.
11 36 34	92 40 55	Mangrove still lying left of this part rhizophora dried stomata drying
11 36 16.0	92 41 27.3	All dry mangroves (now road in water mark)
11 36 04.7	92 41 24.4	Right side mangrove dried and are in shrub form
11 36 09.2	92 41 49.6	Left side houses are in water right side the mangroves have dried
11 47 21.6	92 42 41.0	All around *rhizophora apiculata* very big patch. Rhizophora trees are drying
11 47 54.4	92 42 42.3	Left side rhizophora dried 500 mts around
11 52 42	92 43 44	Left side along the creek is the dry mangroves
11 53 34.1	92 43 48	All along left bank rhizophora burnt
11 48 50.3	92 42 52.8	All around the point rhizophora dried up 3-4 mts belts stand near small creek

Transformed Divergence Matrix of Landcover classes in Mandapam Islands, Gulf of Mannar

Sl no	1	2	3	4	5	6	7
1	0	**1878**	**1999**	**1970**	2000	**1998**	**1992**
2	**1878**	0	1211	**880**	**1368**	**1987**	2000
3	**1999**	1211	0	**603**	**449**	**2000**	2000
4	**1970**	**880**	**603**	0	919	2000	2000
5	2000	**1368**	**449**	919	0	2000	2000
6	**1998**	**1987**	**2000**	2000	2000	0	1173
7	**1992**	2000	2000	2000	2000	1173	0

1-Shoreline, **2**-Herbaceous vegetation, **3**-Other Vegetation types, **4**-Mangrove associates, **5**-Mixed Mangroves,**6**-Suspended sediments, **7**-Sea

Transformed Divergence Matrix of landuse/landcover classes in the South Andaman Islands

Sl no	1	2	3	4	5	6	7
1	0	**2000**	**2000**	**1996**	264	**2000**	**619**
2	**2000**	0	1920	**1978**	**2000**	**1913**	1962
3	**2000**	1920	0	**1379**	**2000**	**612**	1991
4	**1996**	**1978**	**1379**	0	1997	1136	1698
5	264	**2000**	**2000**	1997	0	2000	778
6	**2000**	**1913**	**612**	1136	2000	0	1961
7	**619**	1962	1991	1698	778	1961	0

1-Settlement, **2**- Tidal creeks, **3**-Evergreen forest, **4**-Deciduous forest , **5**-Agriculture,**6**-Mangrove swamps, **7**-Plantation Area

Table: Bandwise Mean and Standard deviation of each landcover classes of Gulf of M**a**nnar

Pre Tsunami

	1		2		3		4		5		6		7	
Bands	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
1	123.42	6.399	126.41	6.073	127.095	6.375	124.022	7.91	132.471	12.411	150.16	9.375	154.9	8.04
2	71.248	4.65	74.757	4.959	76.541	5.828	76.423	6.789	76.686	7.14	87.503	6.613	98.117	7.216
3	76.752	7.739	76.211	8.08	79.092	5.016	68.74	6.139	43.639	4.739	46.075	4.44	69.441	13.839

Post Tsunami

.

Bands	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
1	161.49	5.448	170.87	6.016	163.723	7.245	167.442	7.108	173.117	6.041	183.69	7.852	198.36	10.592
2	122.54	5.684	135.83	8.037	128.284	6.232	136.015	9.803	144.648	5.22	151.39	7.316	183.01	13.284
3	90.63	7.088	89.844	6.652	92.857	10.713	77.981	7.189	56.315	3.363	51.724	3.893	82.753	8.25

Table: Bandwise mean and standard deviation of each landcover classes of South Andaman Island

Pre Tsunami

	1		**2**		**3**		**4**		**5**		**6**		**7**	
Bands	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
1	71.847	8.04	77.37	13.47	67.398	6.585	59.62	11.26	64.932	8.722	67.584	16.275	25.286	18.79
2	18.214	1.842	19.062	1.79	22.636	2.115	38.94	9.699	40.811	9.837	28.706	7.427	19.727	1.768
3	22.735	1.466	23.644	1.513	24.92	1.414	34.199	5.078	34.115	4.965	29.07	4.745	24.557	1.843

Post Tsunami:

Bands	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
1	78.749	4.03	76.769	3.286	80.585	2.732	111.46	12.77	106.51	11.108	82.901	4.454	89.507	7.224
2	34.854	2.802	33.045	2.252	38.357	2.786	69.423	12.75	69.194	14.372	38.217	3.724	41.999	6.411
3	**95.73**	**14.19**	**110.24**	**12.963**	**95.767**	**7.249**	**75.161**	**13.23**	**97.94**	**10.319**	**104.12**	**10.98**	**27.535**	9.467

1-Mangrove Swamps, 2-Evergreen forest, 3-Deciduous Forest, 4-Agriculture, 5-Plantation Area 6-Plantation Area 7-Tidal Creeks/Watermass