Geospatial Assessment of Spatio-Temporal Changes in Mangrove Vegetation of Pichavaram Region, Tamil Nadu, India

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Abstract

The present work is a multi-temporal satellite based spatial dynamic study of an important coastal habitat, the Pichavaram mangrove ecosystem, over a period of 15 years. The study discusses the importance and the status of mangroves on both global and regional scales. Maximum likelihood estimate method of supervised classification technique has been used to classify the land use-land cover changes in the Pichavaram Reserve Forest, Killai Reserve Forest and Pichavaram Extension. The status of the classes has been monitored using Landsat ETM+ of 2000, 2006, 2011, and OLI of 2016 satellite imageries. The total area of the Pichavaram mangrove showed a net increase of approximately 11.41% of the total study area within a span of 15 years (2000–2016).

Keywords

Mangroves · Remote sensing · Supervised classification · Spatial variability analysis · Inter-class variability analysis · Coast

5.1 Introduction

India has a long coastline of about 7516 km including its island territories, which consists of a variety of coastal habitats such as estuaries, mangroves, coral reefs, mudflats, lagoons (Venkataramana 2007; Mandal and Naskar 2008). These coastal areas are considered as critical habitats as they are unique, fragile and exhibit high biodiversity by supporting several coastal and marine ecosystems (Burbridge and Koesoebiono 1981; Salm and Clark 1984; Sivakumar 2013). However, the combined pressure of natural processes and human activities lead to deterioration and loss of these critical habitats over years (Valiela et al. 2001; Polidoro et al. 2010; Prasad et al. 2010, 2017). The United Nations Conference on Environment and Development (UNCED 1992) emphasises the need for protection of coastal and marine environment through Agenda 21. There is a need to protect these productive areas from natural and human interventions while ensuring sustainable, rational utilisation of their resources and services (Giuseppe Barbaro 2013).

5.2 The Mangroves

Mangroves, the inter-tidal halophytic vegetation are one among the most productive forest ecosystems providing wide variety of ecological goods and services (Barbier et al. 2004; Kumar et al. 2012; Singh et al. 2012; Prasad et al. 2017). Apart, they also form excellent source of livelihood for coastal population (Dahdouh-Guebas et al. 2000; Hussain and Badola 2010; Orchard et al. 2016). They are found along sheltered coastlines, shallow-water lagoons, estuaries, rivers or deltas of tropical and sub-tropical countries (FAO 2007) covering 75% of global area (Spalding et al. 1997).

The word mangrove may be derived from Portuguese and English. ‘Mangue’ means tree, and ‘grove’ means group of trees (Dawes 1998; Dholakia 2004). Mangroves are of two dominant types, the riverine-type that fringes rivers and tidal creeks and the open water type that are directly exposed to waves (Lugo and Snedaker 1974). The former type is the most common. The vegetation composition of mangroves consists of many species with varied ability to live in brackish to seawater conditions (Peter 2015).

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5.2.1 Importance

Mangroves protect the land behind as a barrier from cyclones and tsunami (Ghazali et al. 2016). They also act as a buffer against floods and prevent soil erosion by trapping fine sediments that are carried into coastal zone by floodwaters (Van Santen et al. 2007; Barbier 2011). Thus these inorganic nutrients from the terrestrial runoff are circulated within the mangrove environment (Salim et al. 2015). Leaves littered by mangroves contribute largely to the organic matter available to the ecosystem (Robertson 1988; Numbere and Camilo 2017). Due to their productive nature, they serve as nurseries for prawns, crabs, lobsters and various fishes (Chong et al. 1990; Jeyaseelan and Krishna Murthy 1980).

They also serve as a shelter for a number of endangered species such as crocodile, turtle and pelican (Wilkinson et al. 1994). They offer a variety of commercial utilities in the form of wood for timber and fuel, fodder for cattle and with substances of commercial value such as lignin, tannin, etc. (Cherian et al. 2014; Shyam et al. 2015; Razzaque 2017). As per FSI (2001) report on mangrove cover, mangroves fix more carbon per unit area than other phytoplankton in tropical oceans.

Owing to their high productivity and services they offer, they are threatened by anthropogenic interventions in addition to natural processes and disasters (Chaudhuri et al. 2015; Masood et al. 2015). As a result, high depletion in mangrove areas is noted across the world (Mesta et al. 2014). Hence there is a need to protect and restore these resourceful critical habitats (Prasad et al. 2017).

5.2.2 Status of Global Mangroves

Mangrove forests are distributed throughout the tropical and subtropical coasts of the world and are particularly well developed in estuarine areas of the tropics (Satyanarayana et al. 2011; Kannaiah et al. 2015). The most extensive mangrove areas are found in Asia, followed by Africa and America. World-wide mangroves are disappearing at an alarming rate (Giri et al. 2007). In some developing countries about 80% of mangroves were lost in the last three decades (MoEF 1989, 2008). Mangrove forests, that once covered 75% of the coastlines of tropical and sub-tropical countries, dropped to less than 50% of their spatial extent and mostly in degraded condition (Spalding et al. 1997). This leads to decline of fisheries, salinization of coastal soils, erosion, and land subsidence, as well as reduction in trapping carbon dioxide.

5.2.3 Status of Indian Mangroves

Mangroves occur in the coastal states and islands of India (Fig. 5.1). As per FSI (2015) report, mangroves in India cover an area of 4740 km^2 making up 3% of world mangrove areas. Majority of mangroves are found along east and west coast, followed by Andaman and Nicobar islands. Out of the total area, 57% of the mangroves are found on the east coast, 23% on the west coast and the remaining 20% on the Bay Islands (Andaman and Nicobar). Of the total 2764.55 km^2 of mangroves along the east coast of India, West Bengal has 2125 km^2, Orissa 215 km^2, Andhra Pradesh 397 km^2 and Tamil Nadu 27.55 $km^2$of total mangrove cover along the coast (Selvam et al. 2003).

The largest extent of mangroves occurs in West Bengal (Sundarbans) spread over 4200 km^2, followed by Andaman and Nicobar islands- 1190 km^2 (MoEF 1989, 2008). Small patches of mangroves are reported to be found in Gujarat, Maharashtra, Andhra Pradesh, Goa, Odisha, Tamil Nadu, Karnataka and Kerala. About 45 species of mangroves have been reported along the Indian coast line and the most dominant genera to which they belong are *Rhizophora, Avicennia, Bruguiera, Sonneratia, Conocarpus, Heretiera, Xylocarpus, Ceriops* and *Excoecaria* (MoEF 2008). Both natural forces and human interventions have caused the degradation of mangroves in India (Chaudhuri et al. 2015). Realising the importance of mangroves, the Government of India and many Non-Governmental Organizations have taken up measures for conservation of mangrove in the country (ICMAM 2000). In Tamil Nadu, mangroves are well developed in Pichavaram and Muthupet that extend between Vellar and Coleroon estuaries.

5.3 Remote Sensing Study of Mangroves

Mapping and monitoring of mangroves at regular intervals helps in analysing their status (decrease or increase) for better protection and implementing conservation strategies (Prasad et al. 2010). Replacing traditional methods, geospatial technology with use of remote sensing satellite data makes it easy to map, monitor and assess the status of mangrove forest ecosystems (Mesta et al. 2014). With the availability of up-to-date information on the status and conditions of this important ecosystem, remote sensing plays an important and effective role to assess, manage, and monitor the mangrove forest cover changes. Landsat MSS, Landsat Thematic Mapper (TM), and System Pour l'Observation de la Terre (SPOT) multi-spectral data are used for management practices.Several researchers used varied spatial and spectral satellite data in mapping and monitoring mangrove areas adopting different classification approaches to suggest possible mangrove restoration areas for future management and conservation (Baltzera et al. 2004; Bird et al. 2004; Fromard et al. 2004; Kovacs et al. 2004; Kovacs and Flores-Verdugo 2005; Nayak 2002; Nisansala et al. 2015; Mesta et al. 2014).

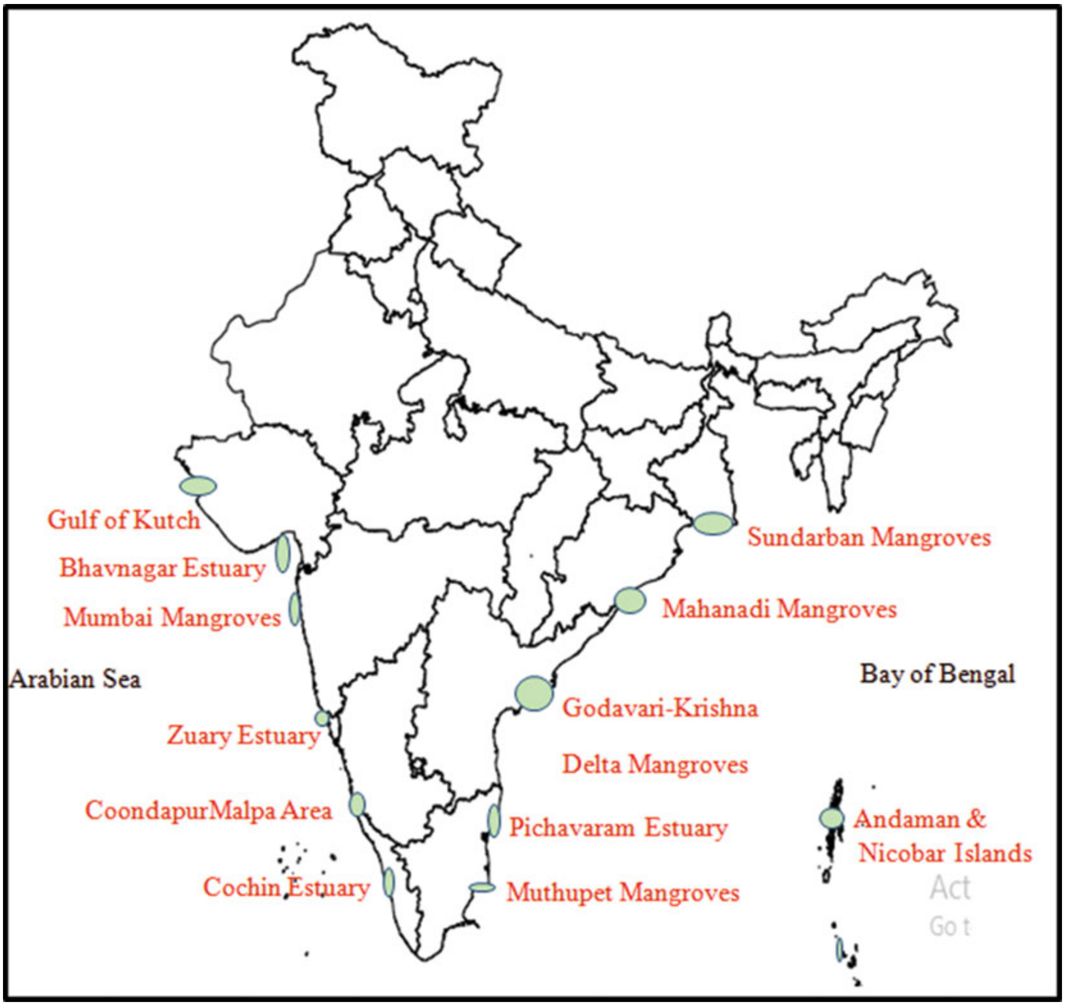


Fig. 5.1 Distribution of mangroves in India

High resolution images are preferable in change detection studies (Dixon et al. 2014).

While remote-sensing data analysis does not replace field inventory, it provides efficient and quick supplementary information. Large and inaccessible areas can be easily mapped and monitored. The use of remotely sensed data offers many advantages including across-the-board coverage, less expensive or free and historical satellite data for time-series analysis. In addition, recent advances in hardware and software used to process large volume of satellite data have enhanced the effectiveness of remotely sensed data (Prasad et al. 2010).

Remote sensing images of mangroves are for the most part reliable, accurate and collected consistently in space and time furthermore, the information can be obtained very quickly in near real time (Mesta et al. 2014). Other benefits of remote sensing in mangrove mapping are that data can be collected in a non-destructive manner since it is not necessary to move around in the mangrove areas to obtain data. Large, remote and inaccessible areas can therefore be easily mapped and monitored. Without doubt, the remote sensing technique is a serious alternative to the traditional field monitoring for large-scale tropical mangrove management (Srinivasa et al. 2011).

5.4 Study Area

Pichavaram mangroves form the major part of the mangrove forest in Cuddalore district of Tamil Nadu, located between 11°20′ to 11°30′ north and longitudes 79°45′ to 79°55′ east; and is one of the unique eco-tourism spots in south India (Fig. 5.2). It supports the existence of many rare varieties of economically important shell and finfishes, and serves as a home to local and migratory birds (MoEF 2008). The area was declared as a reserve forest in 1987 and covers an area of about 11 km^2 of which 50% constitute forest, 40% water and the rest covered by sand-flats and mud-flats (Krishnamurthy and Prince 1983). The area is surrounded by fishing villages, croplands, and aquaculture ponds.

As per the report from MoEF 2008, the Pichavaram mangrove wetland has 51 islets and the total area of the Vellar-

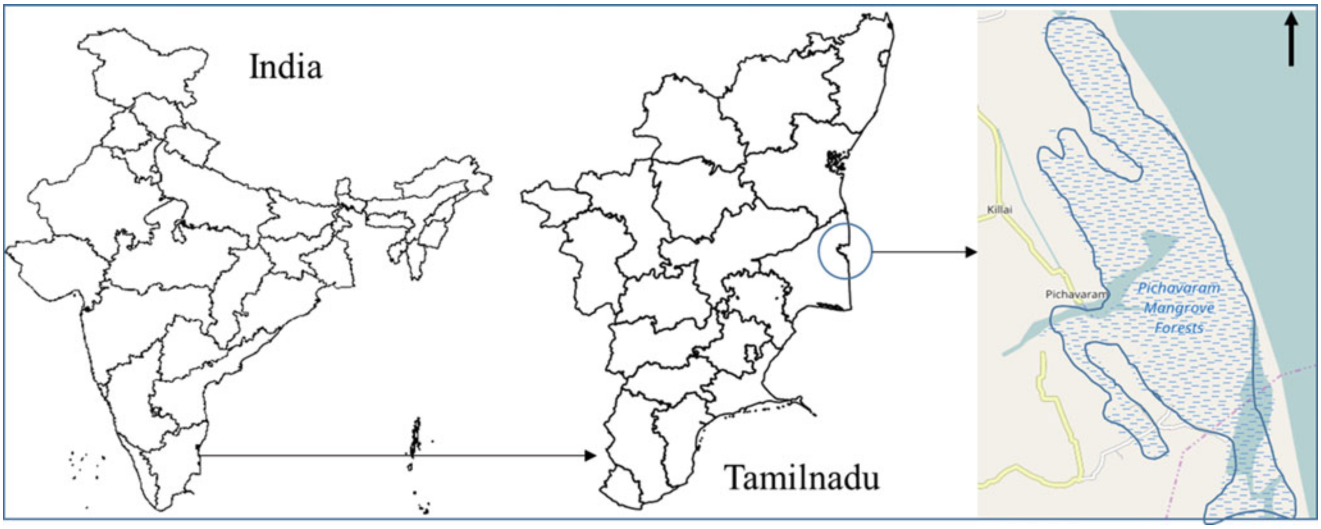


Fig. 5.2 Geographical location and extent of Pichavaram mangroves

Pichavaram-Coleroon estuarine complex is 23.355 km^2 of which only 2.41 km^2 is occupied by dense mangrove vegetation. Nearly 5.93 km^2 of this wetland are occupied by halophytic vegetation like *Suaeda*, 2.625 km^2 by barren mud flats and 12.385 km^2 by barren high saline soil. The report also says that the mangrove wetland of this total area occupies only 11 km^2, comprising the entire mangrove vegetation located in the middle portion of the Vellar-Pichavaram-Coleroon wetland.

A study conducted by Kathiresan et al. in 2005 reports that the aquaculture practise emerged in Pichavaram around 1980s and occupied about 3.99 km^2 in 1984; further increasing to 6.99 km^2 in 1996. It serves as a good example for degradation of mangroves due to aquaculture practices (Ranjan et al. 2008a). Furthermore, the anthropogenic (domestic and industrial) discharges from the nearby populated areas contribute to the ecological vulnerability of the ecosystem (Prasad 2005; Ranjan et al. 2008a, b).

While reports from MoEF (2008) shows accelerated degradation in the mangroves extent from 1970 through 1998, the study of Selvam et al. (2003) shows that there was an increase in the mangrove forests by 90% between 1986 and 2002 owing to restoration measures. A study conducted by Kathiresan and Rajendran (2005) aftermath the tsunami on 26 December 2004 indicates that the coastal mangrove forests can act as effective shield against tsunami. It is therefore an urgent call to initiate conservation and restoration measures detecting the hot spot areas in the mangrove forest.

5.4.1 Objective

In view of above context, in the current study we address spatio temporal changes in the mangrove vegetation of Pichavaram region of Tamil Nadu, India using different temporal satellite data sets.

Table 5.1 Description of satellite data used in the study

Satellite	Sensor	Spatial resolution	Date of acquisition
Landsat 7	ETM+	30 m	28th October 2000
Landsat 7	ETM+	30 m	30th January 2006
Landsat 7	ETM+	30 m	25th September 2011
Landsat 8	OLI	30 m	18th January 2016

5.4.2 Gaps Addressed in the Present Study

While some of the above works proved the effectiveness of remote sensing for studying the mangroves, there has been no significant study so far that addresses the change pattern in mangroves with a short period time interval of 5 years. The present study is an attempt in this direction; where in remote sensing techniques have been used to study the spatial dynamic of Pichavaram mangrove ecosystem over a period of 15 years. This methodology can be used for routine monitoring of the mangrove cover and plan restoration measures, wherever required.

5.4.3 Materials and Methods

Multi-temporal cloud-free satellite data of four periods viz., Landsat ETM+ of 2000, 2006, 2011 and Landsat OLI data of 2016 were downloaded from earthexplorer.usgs.gov (Table 5.1 and Fig. 5.3).

False Colour Composite (FCC) image of Pichavaram mangrove was generated with the band combinations of 2, 3, 4 and 3, 4, 5 for ETM+ and OLI data respectively

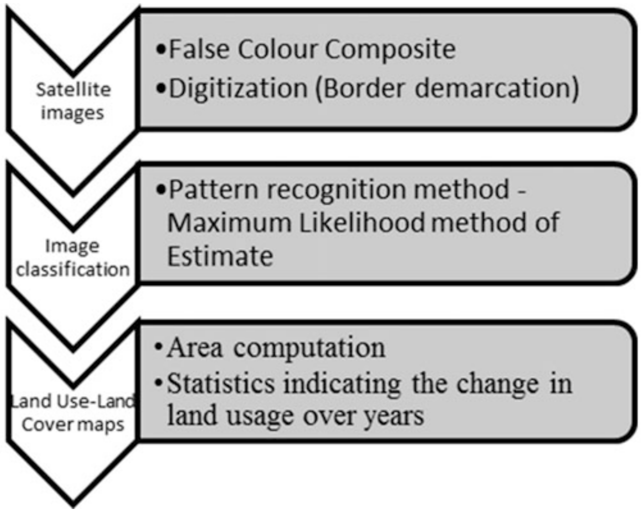
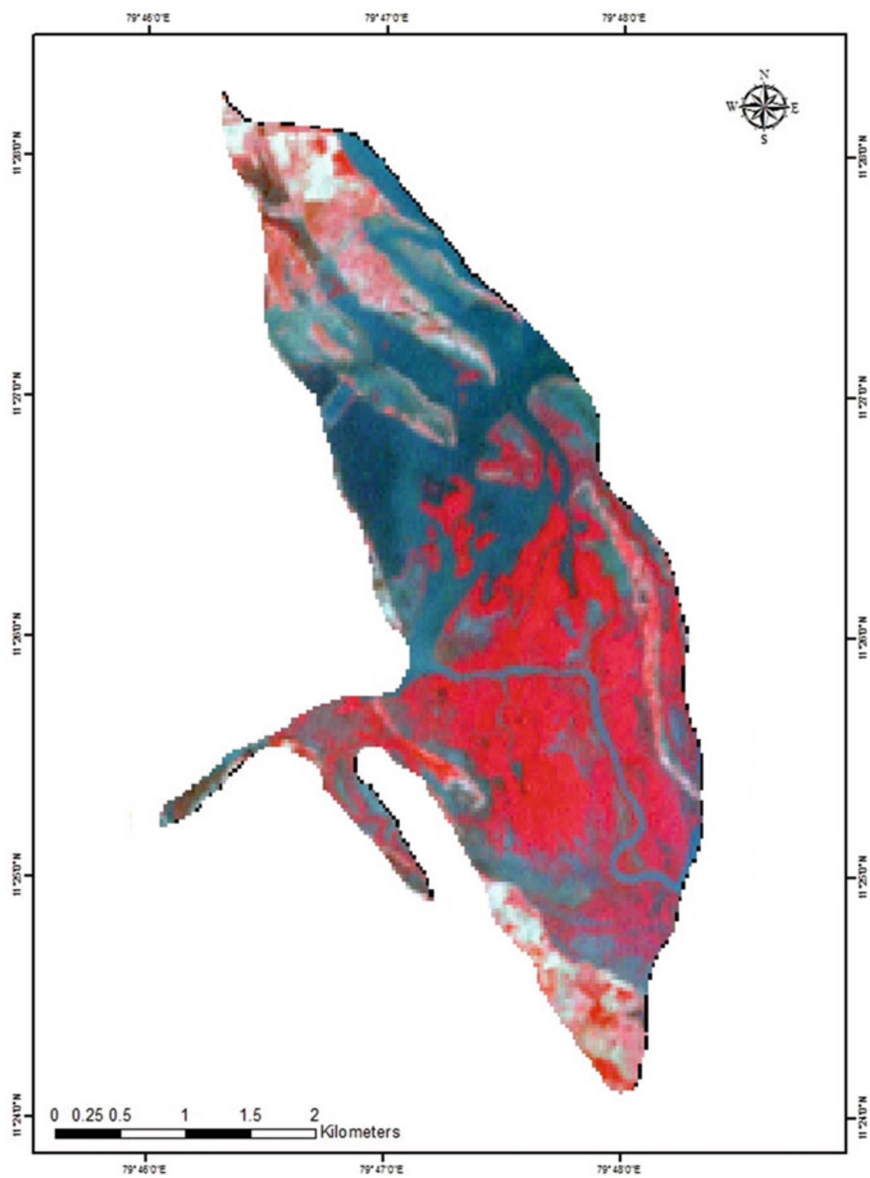


Fig. 5.3 Methodology for study on the spatio-temporal dynamic of the mangroves

(Fig. 5.4). Based on available literature data and maps, boundary of the study area was demarcated using QGIS. This vector data is used to clip the area of interest from the available satellite data of four periods. All the data sets were processed and subjected to image enhancement techniques to make the data more distinct spectrally for classification. Enhanced FCC aided in clearly distinguishing mangrove vegetation from other classes (water, mudflat, other vegetation, and sand). For classification of satellite data to create land use and land cover (LULC) maps, the clipped satellite images were imported into ILWIS software. Training sets were created for various LULC classes identified in satellite image, and was classified using maximum likelihood classifier. Finally area statistics were computed for four temporal LULC maps (Figs. 5.5, 5.6 and 5.7).

Fig. 5.4 False colour composite of remotely captured data in 2000



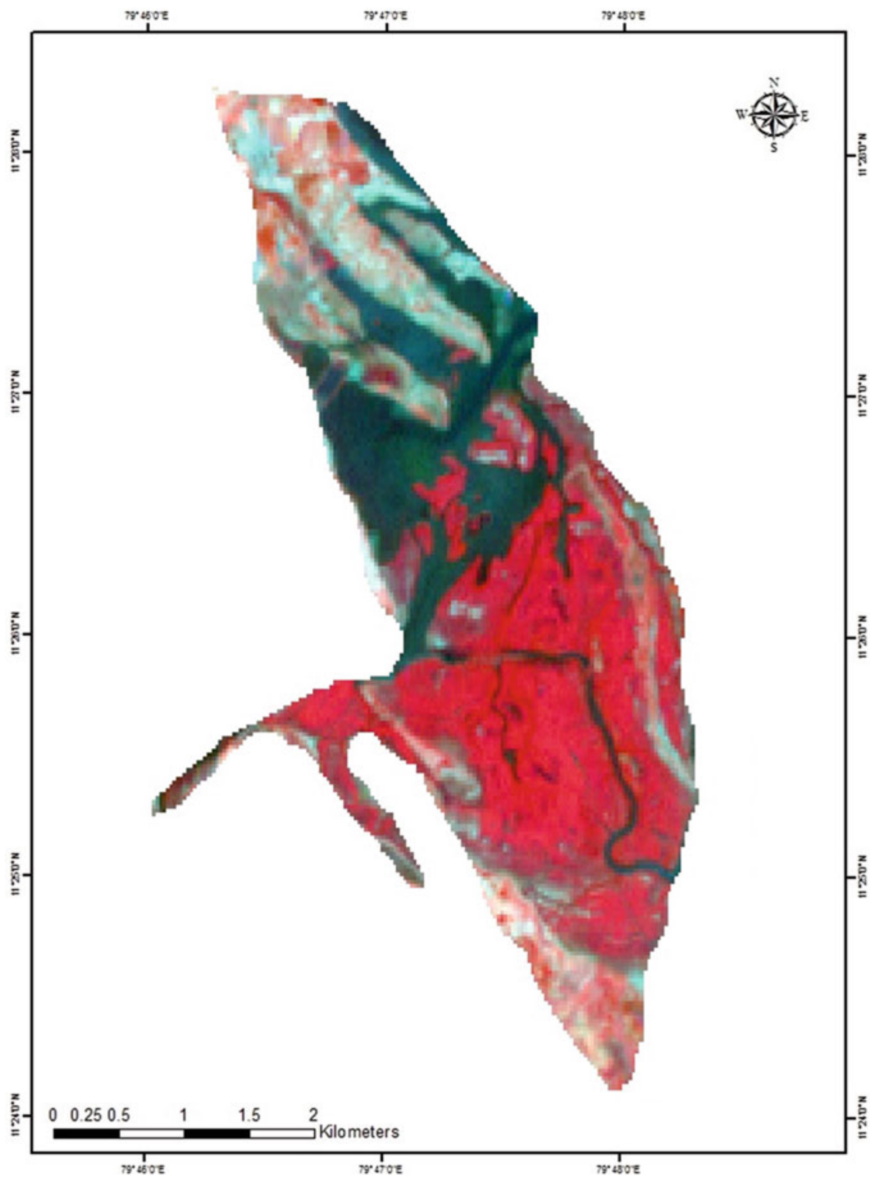


Fig. 5.5 False colour composite of remotely captured data in 2006

5.4.4 Results and Discussion

The spatio-temporal distribution of mangroves is shown in Figs. 5.8, 5.9, 5.10 and 5.11 respectively.

The statistics on spatial and temporal variation of the different classes for the study period is given in Figs. 5.12 and 5.13. The change analysis indicates that there is an increase in the mangrove cover from 2000 to 2016.

The total spatial extent of the mangroves is found to be increasing from 20.45% (332.43 km^2) in 2000, 22.37% (363.64 km^2) in 2006, and 27.19% (442 km^2) in 2011 to 31.86% (517.91 km^2) in 2016 of the total study area. However, the maximum rate of increase in mangrove cover is observed during 2006–2011 with 11.41% percentage increase in area. It is also noted that the class mudflat has also increased by about 14.74% indicating the spatial increase of the platform for mangrove regeneration.

Earlier studies indicated that mangroves have decreased from 6.4 to 3.72 km^2 between 1970 and 1987 (Selvam et al. 2002). This was mainly due to changes in the topography due to coupe felling system of management followed by various government agencies since 1911 (ICMAM 2000). In this system, healthy mangrove forests were clear felled for revenue generation in 15 and 20 years rotation. This caused various topographical changes in the biophysical condition of the mangrove wetlands leading to development of hyper saline condition that prevented natural regeneration of

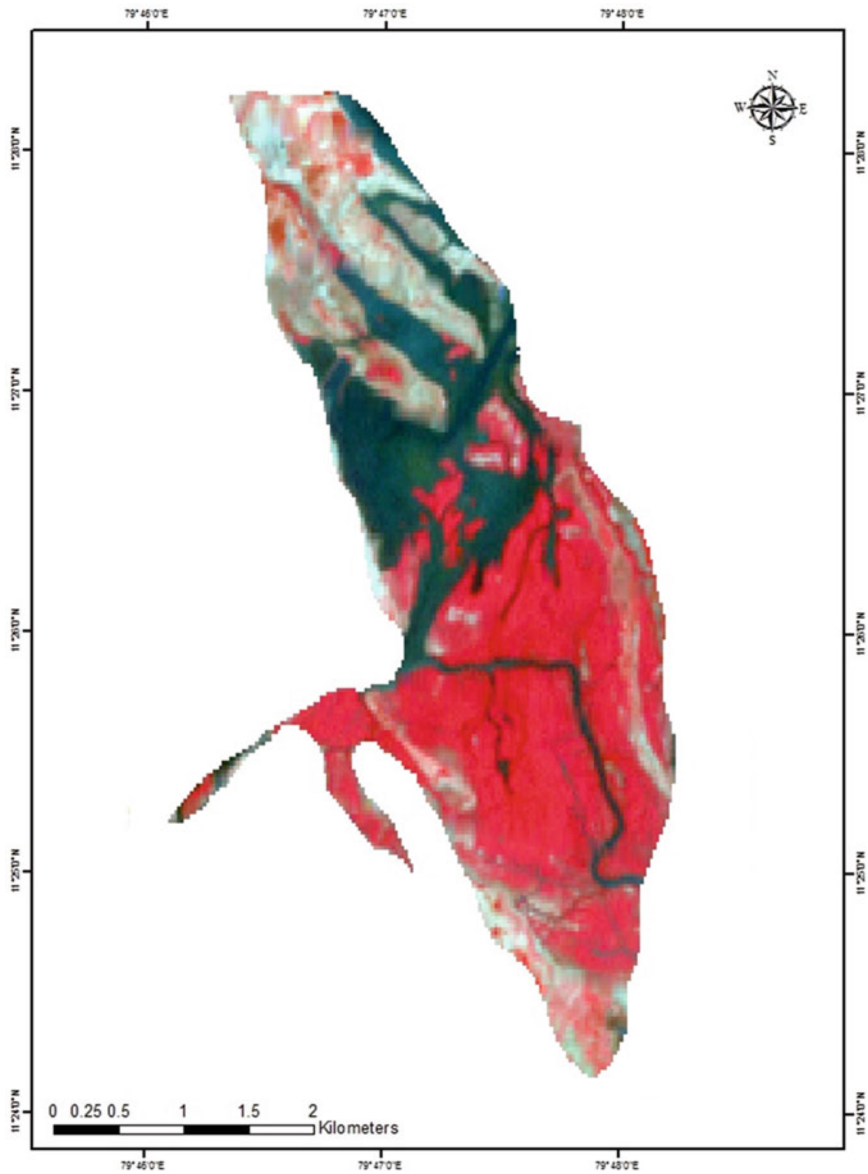


Fig. 5.6 False colour composite of remotely captured data in 2011

mangroves (Selvam et al. 2002; Prasad et al. 2017). In areas covered by coupe felling, the topography becomes trough shaped; tidal water enters and becomes stagnant leading to the development of hypersaline condition. This hyper saline condition was the major reason for the degradation of mangroves. As per the reports of MoEF (2008), cattle grazing may be a possible factor for mangrove degradation. It is also quoted that grazing continued on the peripheral areas of mangroves.

Kathiresan (2000) reported that within the last century, there has been a decline in 75% of the mangrove cover in Pichavaram and of the existing 25%, only 10% has dense vegetation, while the remaining 90% of the area has been degrading. The current study, however, indicates an increasing trend in the spatial extent of the mangrove cover of the region. During the entire period of study, it is observed that the total area of Pichavaram mangrove has gradually increased and a significant reduction in the degraded mangroves extent from 19.80% in 2000 to 7.93% of the total study area in 2016. This increase in the spatial extent of the healthy mangroves from 2000 to 2016 is attributed to the efforts of the State Forest Department along with M. S. Swaminathan Research Foundation (MSSRF), a Non-Governmental Organization who flushed the tidal waters into the areas where it was not reachable earlier (ICMAM 2000; MoEF 2008). This resulted in recruiting of young mangrove saplings into the area.

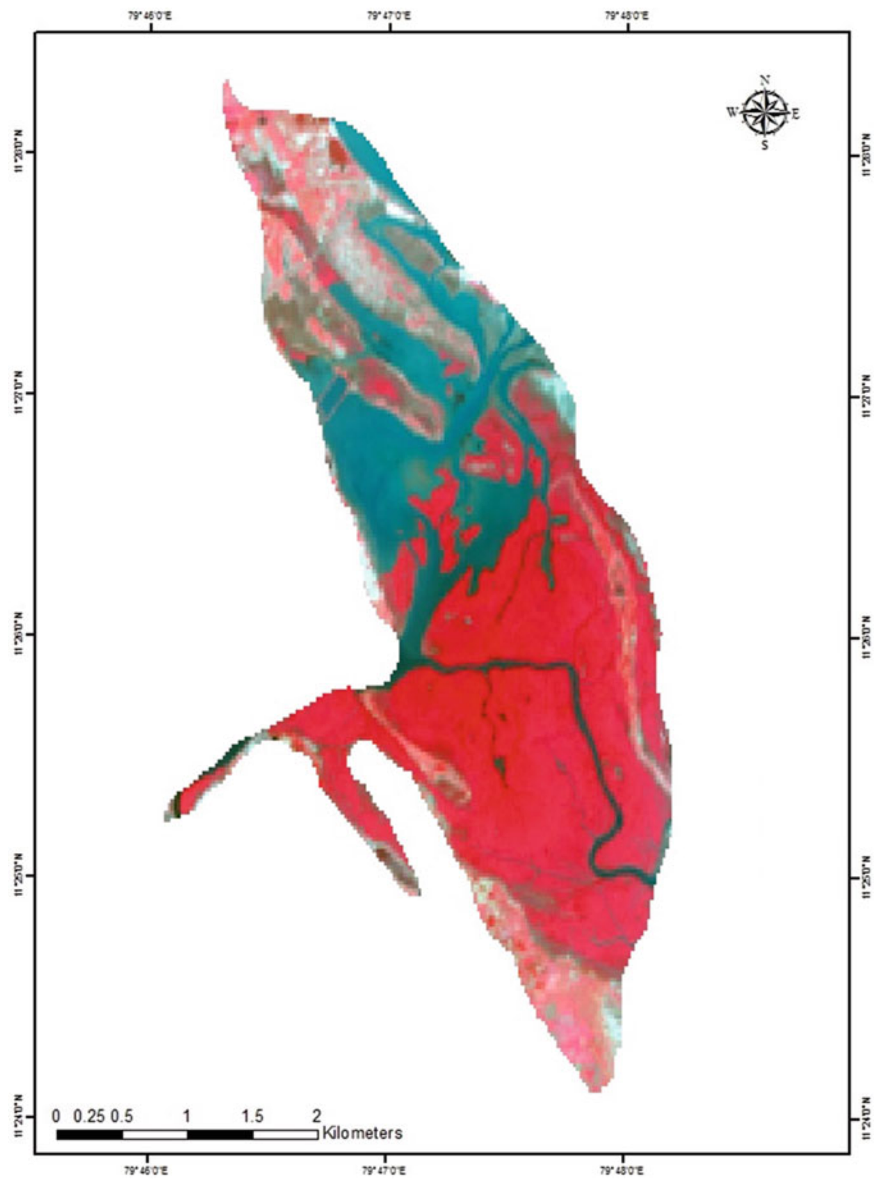


Fig. 5.7 False colour composite of remotely captured data in 2016

The MoEF (2008) report states that unsustainable exploitation of mangroves led to its degradation before the Indian Ocean tsunami in December 2004. It was that disastrous event that made the locals understand the real protecting capacity of the mangroves and the need to conserve them. Efforts to establish a nursery of endangered mangrove species has been taken up by the Tamil Nadu Forest Department. The report also states that mangroves were planted on the shore along the mangrove forest area; in over 0.5 km^2 of marshy areas and 0.02 km^2 of saltpan with dug out canals to ensure good tidal flushing.

5.5 Conclusions

Remote Sensing and GIS have been found to be extremely useful for understanding the coastal habitats, especially mangroves. The study demonstrated that by analysing the LU-LC of a location using remote sensing data and by studying their temporal variations, it is possible to get a reasonably accurate picture of the current status and change trend of the location over years. Arriving at community-level maps would require specific and more complicated techniques in conjunction with extensive ground-truthing which is time consuming. Contrary to some of the earlier

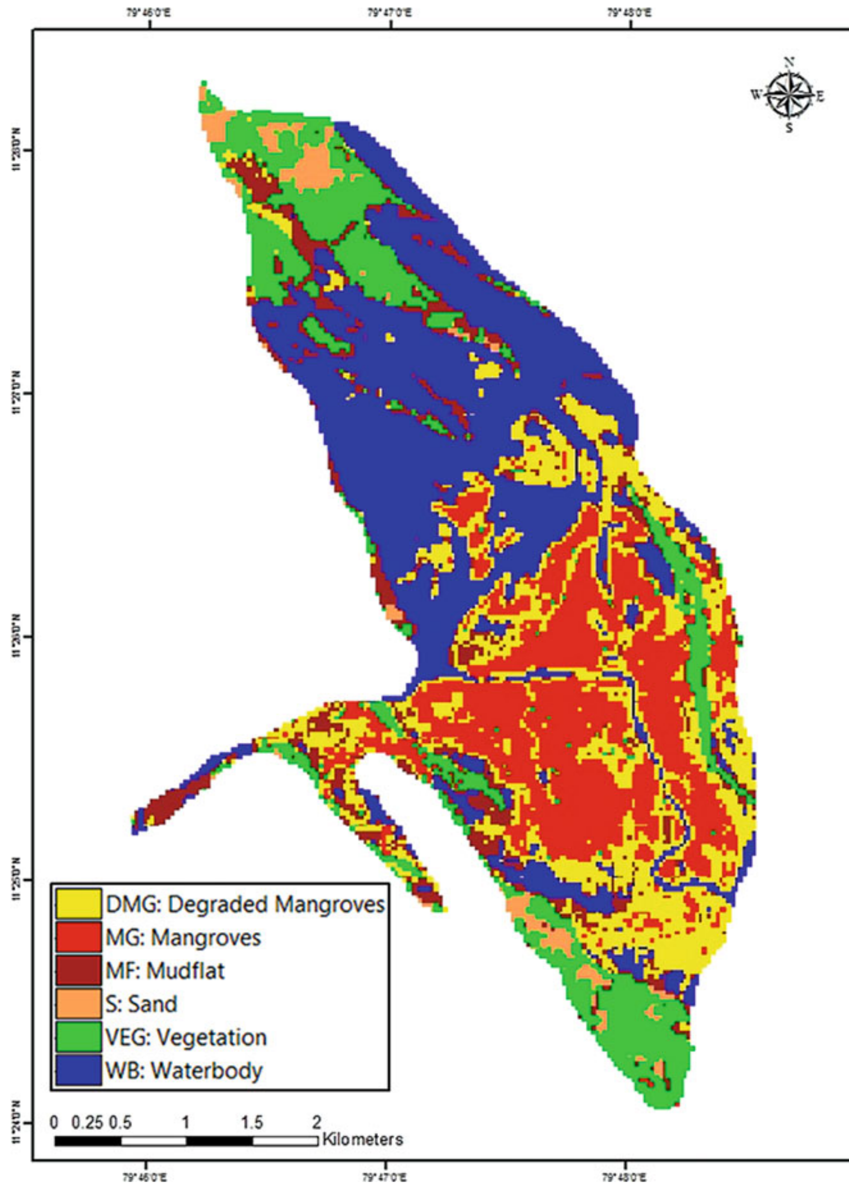


Fig. 5.8 Spatial distribution of mangroves in 2000

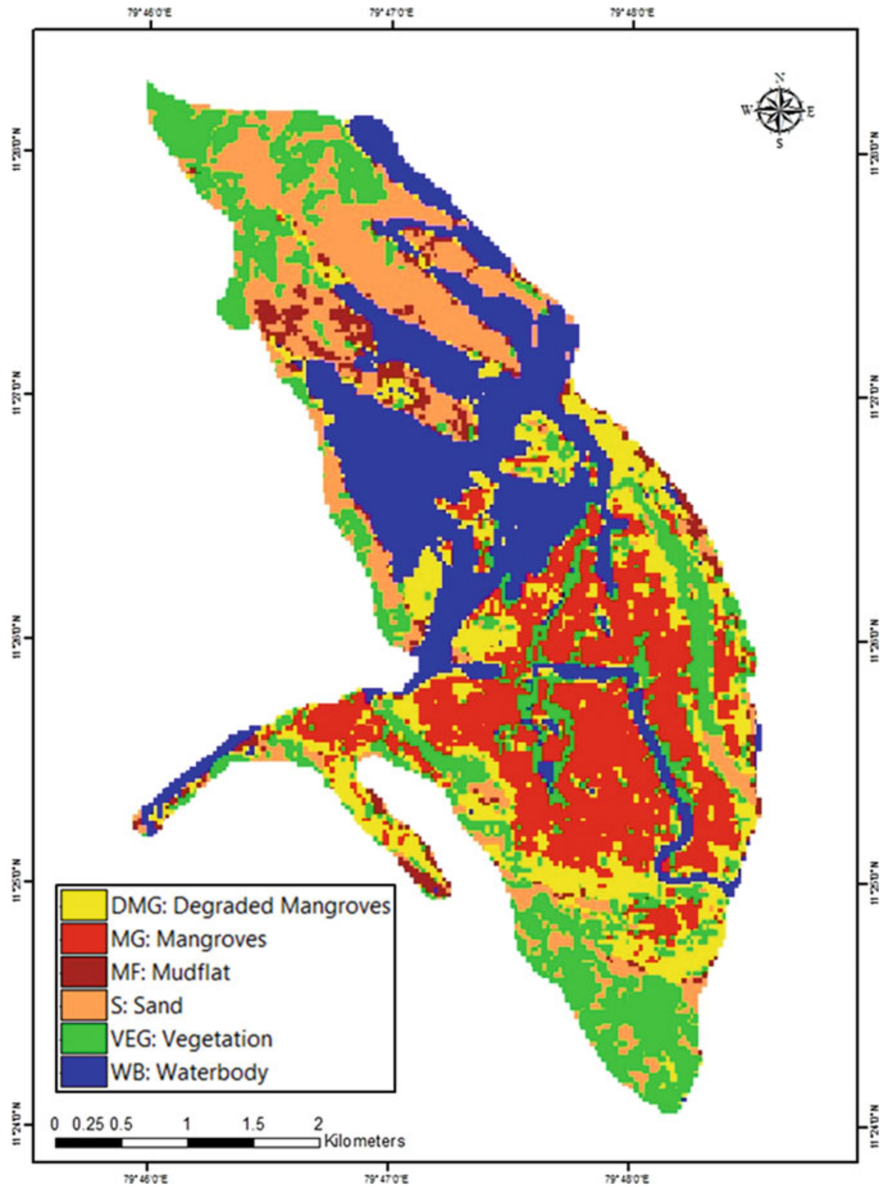


Fig. 5.9 Spatial distribution of mangroves in 2006

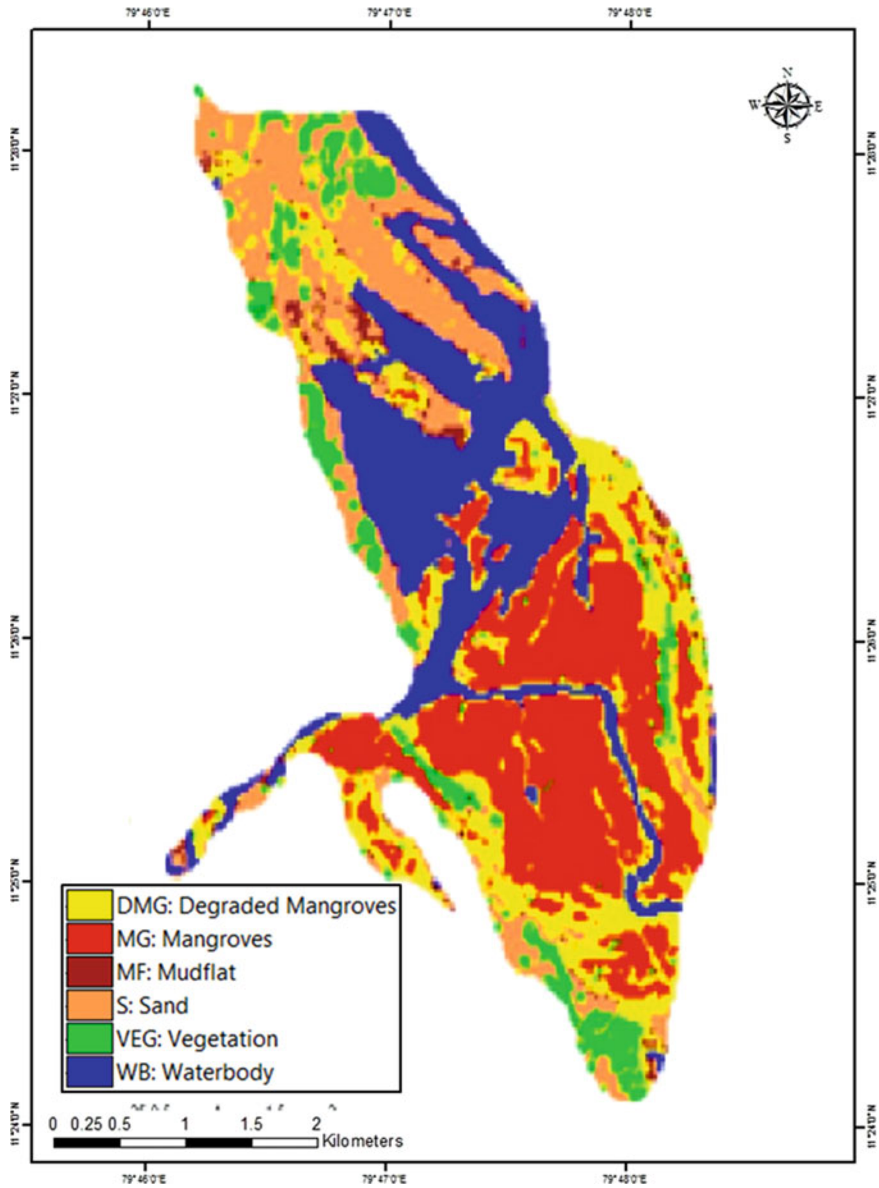


Fig. 5.10 Spatial distribution of mangroves in 2011

Fig. 5.11 Spatial distribution of mangroves in 2016

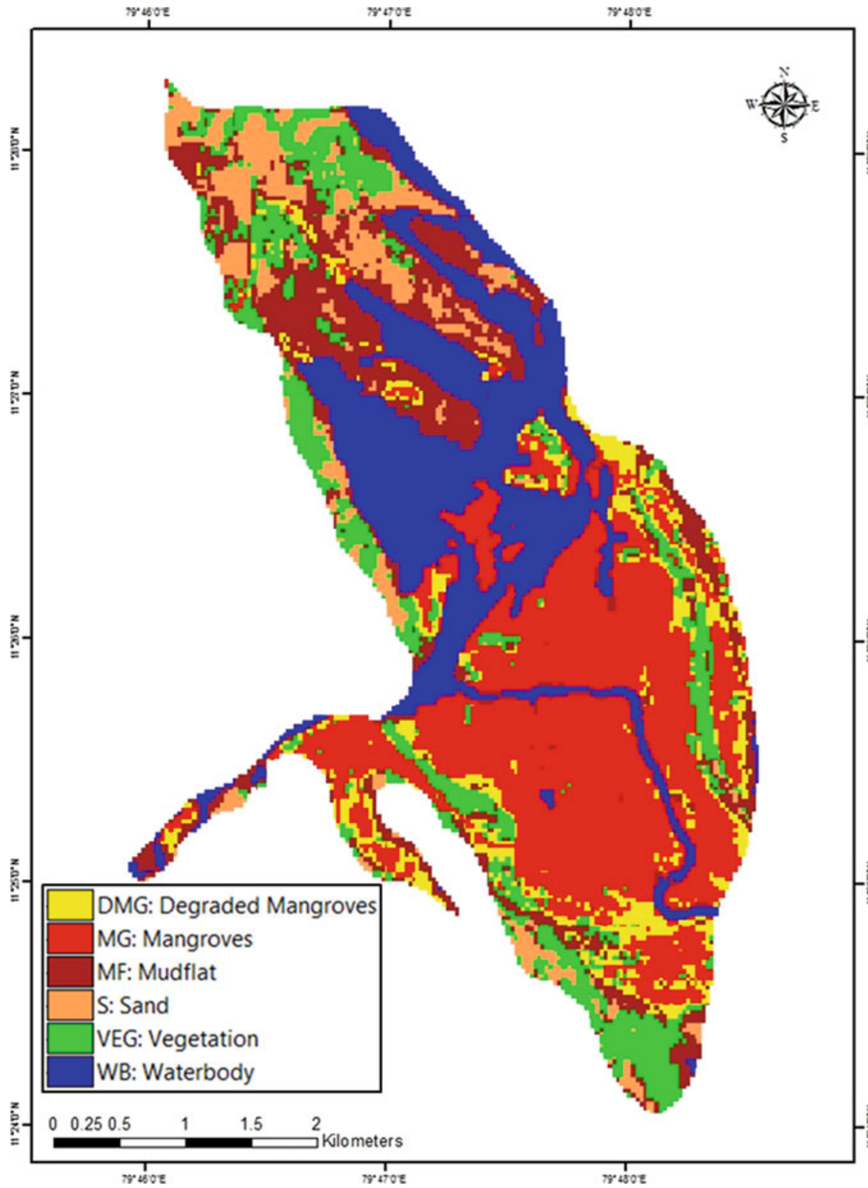
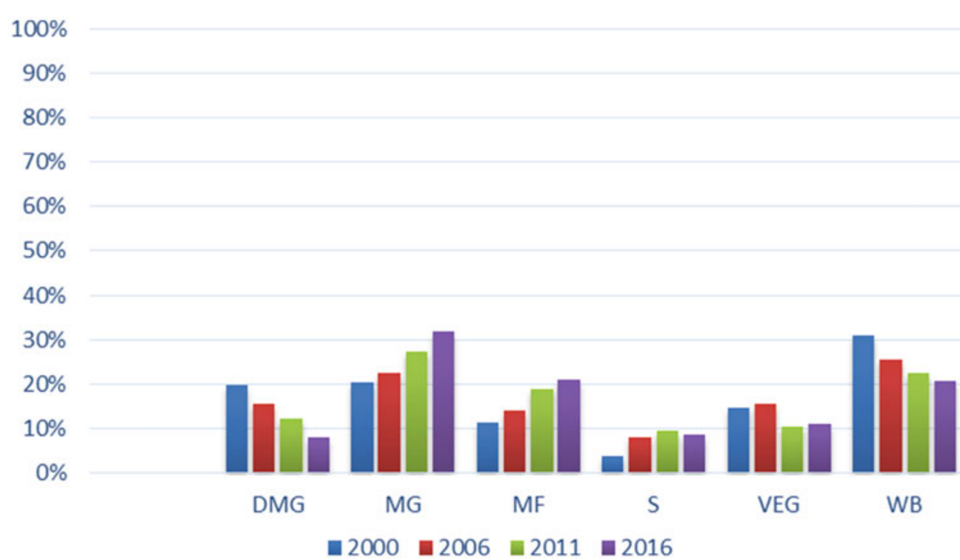


Fig. 5.12 Bar chart showing the percentage of spatial variation of different LU-LC classes from 2000 to 2016



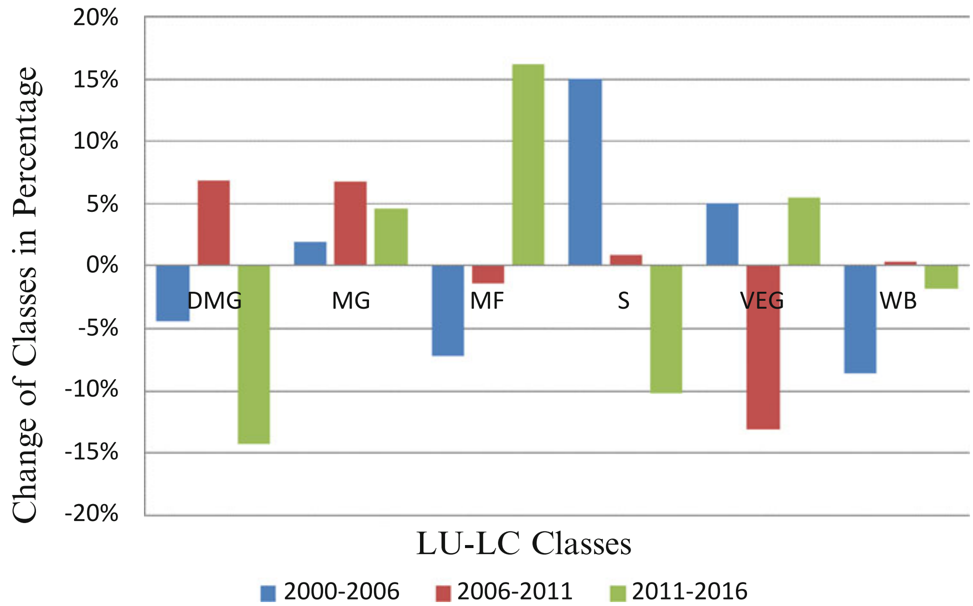


Fig. 5.13 Bar chart showing the percentage of spatio-temporal variation of different LU-LC classes from 2000 to 2016

studies, it is evident from the study that the total area of the Pichavaram mangrove showed a net increase of 11.41% within a span of 15 years (2000–2016). This is due to the identification of causative factors of mangrove degradation and subsequent conservational measures taken up by the State Forest Department.

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