

Assessment of the Land-Use/Land-Cover (LULC) and Mangrove changes along the Mandovi-Zuari Estuarine complex of Goa, India.

Ankita Misra, Mani Murali.R, Vethamony.P

National Institute of Oceanography,
Council of Scientific and Industrial Research (CSIR), Dona Paula, Goa

E-mail: mmurali@nio.org

Running Headline: Assessment of LULC and Mangrove changes along Mandovi-Zuari Estuarine Complex

Abstract

Land-use/ Land cover change dynamics along the estuarine complex of Mandovi - Zuari in the coastal state of Goa, India is studied by the application of multi-temporal remote sensing data. This tropical estuarine region has faced significant changes in the last few decades due to diverse pressures from various sectors, mainly of anthropogenic origin. Spatial and temporal changes in the LU/LC classes have been evaluated using satellite datasets from Landsat MSS, TM and IRS-LISS III for the years 1973, 1989, 2001 and 2011. Considering a spectrally heterogeneous landscape of the region, the LU/LC changes are identified by using Principal Component Analysis (PCA) as a pre-classification step, followed by the implementation of a combination of supervised and unsupervised classification called Hybrid Classification. The application of PCA has proved to be suitable to successfully identify discrete land surface classes for this study area. An overall accuracy of 95.56% ($\kappa = 0.9556$), 92.93% ($\kappa = 0.92$), 84.64% ($\kappa = 0.85$) and 86.36% ($\kappa = 0.85$) has been obtained for the year 2011, 2001, 1989 and 1973 respectively. The study reveals a gradual increase in built-up area due to urbanization corresponding to a decrease in agricultural land and a considerable loss in beach area. Changes in the mangroves are also assessed within this extent as Goa has significant pockets of mangroves which are located mainly along the estuarine complexes of Mandovi and Zuari (along with the Cumbarjua canal complex). The results highlight an increase in mangrove coverage within the study extent by 1585.8 ha from 1973 to 2011. The mangrove areal extent along Mandovi has increased from 149.45 ha to 1059.77 ha and from 142.95 ha to 676.12 ha along Zuari (including Cumbarjua canal). Increasing awareness and the steps taken by the forest department to provide suitable environment for the growth of mangroves are the main reasons for this increment.

Keywords

Mangroves, tidal influx, Principal component analysis, Hybrid classification, change detection

1. Introduction

Land use land cover (LULC) is perhaps the most relevant form of global environmental change phenomenon occurring at varying spatial and temporal scales. LULC clearly reflects the dimensions of anthropogenic activities on the environment (Lopez et al., 2001) and can be defined broadly to include the conversion of lands into croplands and pastures, the abandonment of agricultural lands, change in cultivation patterns, forest cover changes and urban sprawl (Evrendilek and Wali, 2004). Drivers of LU/LC mainly include external and internal drivers (Campbell et al., 2005) such as rapid growth rate of population and consumption, lack of valuation of ecological services, negligence of biophysical limitations etc. Ataollah Kelarestaghi & Zeinab Jafarian Jeloudar (2011) studied the land use and cover change detection in the Lajimrood Drainage Basin in northern parts of Iran which is an area characterized by rich and diversified agricultural and forests. An understanding of the change dynamics and its effects are essential for ecologically feasible developmental planning in order to monitor and mitigate unplanned and haphazard alterations in the LULC pattern. Thus it is imperative to analyze and map the land use/land cover of a region and assess the trends of change that have contributed to the present environmental condition of that area, especially from the perspective of policy making, planning and implementing of natural resource management (Alphan, 2003; Muttitanon and Tripathy, 2005; Ioannis and Meliadis, 2011; Knorr et al., 2011). Satellite images are used for effective visualization and comparison with the old images of the same area (Ruzinoor Che Mat et al, 2012).

The main objective of LULC analysis is to provide a sustainable pattern of land usage for the population. Several LULC studies covering different regions have been done in India, especially by using Remote Sensing (RS) and Geographical Information Systems (GIS) (Gautam and Narayanan, 1983; Sharma et al., 1984; Jain, 1992; Brahmabhatt et al., 2000, Romshoo and Rashid, 2012, Badreldin and Goossens, 2013). Urban land use mapping of greater Bombay was carried out using Landsat TM data by Pathan et al. (1989). Chauhan and Nayak (2005) analyzed LULC changes in Hazira area near Surat, Gujarat using IRS-LISS-III data; Anil et al. (2011) carried LULC studies and change detection for part of South West Godavari District using RS and GIS. Multi-temporal remotely sensed data and GIS have facilitated the derivation of ecological inventories and the monitoring of LULC changes on the local and regional levels (Berberoglu, 2003; Berberoglu et al., 2004). Multivariate analysis for land use management was carried out in El-Sharkiya, Egypt (W. A. Abdel Kawy & Kh. M. Darwish, 2012). Beijing's land cover types were detected and their spatiotemporal changes using time series remote

sensing and GIS techniques from 1978 to 2010 were also studied (Jinling Zhao et al., 2013). Image Classification technique (Karteris, 1990) followed by change detection provides an efficient ways to recognize LULC on digital images that change features of interest between two or more dates with sufficient accuracy. However, successful implementation of remote sensing data for LULC and change detection studies depends upon an adequate understanding of landscape features and application of information extraction methodology, relevant to the aim of analysis. This can be achieved by either pixel based approach or object based classification techniques. For the former, the general methodology is to apply pre-classification steps for.eg. band ratios, Principal Component Analysis (PCA) etc whereas object oriented includes standard algorithms such as Support Vector Machines (SVM), K Nearest Neighbor (KNN) or application of fuzzy logic (Al Fugara et al., 2009; Tehrani et al., 2013a, 2013b) etc.

The primary objective of this study is to illustrate the LULC changes along the estuarine complex of Mandovi- Zuari in the coastal state of Goa, India. The study area suffers from intense developmental pressures by virtue of population, tourism, mining and urban development which poses a threat to the coastal habitat along this region. Mani Murali et al. (2006) have done a change detection study of Goa, where they have used supervised classification for the year 1990, 2001, 2003. This study reported an increase in urbanization and subsequent reduction in beach area as well as a minimal decrease in the mangrove area. Coastal erosion was triggered in this study region due to a grounded ship (Mani Murali et al., 2013). Although this study had a small temporal coverage, it highlighted the dynamic nature of LULC of the area which is the basis of our first objective - to quantify the LULC of the region over a long temporal extent of 38years. Here, we have used Principal Component Analysis as a pre-classification technique for the differentiation of the various classes. This technique has been chosen over traditional direct image classification after visual interpretation in order to ensure maximum separability between the various classes. Subsequently, we have applied a combination of supervised and unsupervised classification called Hybrid Classification to the PCA generated dataset to obtain LULC maps of enhanced accuracy.

The second objective of this study is to quantify and assess the changes in the mangrove extent along this region. Mangroves are highly productive ecosystems with a rich diversity of flora and fauna in the intertidal zones of tropical and subtropical coastlines and river estuaries (Abeyasinghe et al., 2000; Jennerjahn and Ittekkot, 2002; Twilley and Rivera-Monroy, 2005; FAO, 2007a). They are of great ecological and economic importance as they provide a number of forest goods as well as play a vital role

in shoreline stabilization, reduction of coastal erosion, sediment and nutrient retention, storm protection, flood and flow control and water quality (Dahdouh-Guebas et al., 2005; Giri et al., 2007; Alongi, 2008; Bahuguna et al., 2008). These valuable mangrove forests have been facing intense pressure due to agricultural, industrial and urban development (Blasco et al., 2001; Dahdouh-Guebas et al. 2005; Duke et al., 2007; FAO, 2007b), and hence are rapidly declining. The changes in the mangrove forests therefore need continuous monitoring through research on spatial-temporal dynamism in the coastal land-use/cover patterns (Souza Filho et al., 2006; Chauhan and Dwivedi, 2008). Singh et al. (2004) reported that there has been a 44.90 % increase in mangrove cover in the state of Goa, which is a positive difference between this state and other states of the country. Through this study, the effort is also to understand the spatial and temporal distribution of mangrove in this region and the factors influencing it.

In the current study, we have tried to present a pixel based methodology, a combination of PCA and Hybrid techniques which is a relatively new approach. Transformations like PCA may be applied prior to visual interpretation of the data or as a pre-processing procedure for classification as they increase the efficiency of the classification by reducing the dimensionality of the original data set. Also, the application of Hybrid approach helps to improve the accuracy of the classification as it incorporates both supervised and unsupervised classification methods. Further, we have demonstrated the capability of this approach to accurately extract the land-use/land-cover classes for this region, especially the mangrove class which poses a great challenge due to its spectral heterogeneity.

2. Study Region

The Mandovi - Zuari Estuarine complex is located in the state of Goa along the central western coast of India. The Mandovi enters Goa from the north via the Sattari Taluka, flows through Cumbarjua eventually pouring into the Arabian Sea. The Zuari River is the largest river of Goa originating in Hemad-Barshem in the Western Ghats. The Cumbarjua canal (15 km) links the two river channels of Mandovi and Zuari, forming an estuarine complex which supports a significant cover of mangroves. In order to study the mangrove distribution, it is imperative to include the associated physical aspects, especially in the case of our study region as both the rivers intrude deep into the Western Ghats. Hence, an overlay analysis was done by taking into consideration all the appropriate physical factors to demarcate the boundary of the study region.

2.1 Consideration of physical aspects for deciding the Mangrove extents

Several factors such as temperature, rainfall and salinity should be considered to demarcate the mangrove extent. Goa has an average temperature of 25- 30°C and the average annual rainfall is 2,848.7 mm, and hence both these factors make it very conducive for mangrove growth. The composition and configuration of mangrove species in estuaries varies as per the salinity gradient which varies from the mouth of the river to upstream. This gradient decreases as we proceed from the mouth to the upstream of the river and also varies from day to day due to the high tide-low tide phenomena. However, mangroves are facultative halophytes which mean salt water is not a compulsory physical requirement for growth. Most of them can grow well in fresh water but mangrove communities are not usually found in strict freshwater environments. This is because strict freshwater habitats exist where tidal inundation does not occur. Tidal fluctuation plays an important indirect role in mangrove distribution. Tidal fluctuation results in the reduction of competition due to alternate wetting and drying, transportation of relatively clean water and nutrients, export of wastes, detritus, and sulfur compounds as well as in the effective dispersal of propagules. Where evaporation is very high, tidal fluctuation wash excess salt away preventing excessively high soil salinity concentrations. Due to the above factors, mangrove systems reach greatest development around the world in low-lying regions with relatively large tidal fluctuations. Thus the salinity and tidal distribution along the Mandovi and Zuari estuary are important considerations to decide the extent of mangrove cover. This is mainly because, both of these estuaries have their upstream ends at the foothills of the Sahyadris, where they pose a serious problem in mangrove vegetation identification using traditional image interpretation, as they give similar reflectance of the adjoining forest areas. As reported by Shetye et al. (2007), these part of the channel shows a drastic drop in the tidal amplitude, which is related to the increase in elevation. Mangroves in Goa generally do not occur beyond an elevation of 10 m. Thus a combination of all these factors can help us to decide the areal extent to be considered for our study.

An elevation map Fig. 1 was generated using 90m Shuttle Radar Topography Mission (SRTM) data depicting the various elevation classes of Goa. A location based point shape-file was generated based on the study of Shetye et al. (2007) where it was reported that the tidal amplitude drops sharply from Usgao to Ganjem in the Mandovi and from Sanvordem to Sanguem in the Zuari. The study also describes the salinity profiles of 5 locations of Zuari and 6 locations of Mandovi. The profiles reveal that the salinity decreases from Mormugao to Sanguem in the Zuari River at a distance of about 55 km from the mouth

and from Aguada to Ganjem at an approximate distance of 48 km from the mouth of Mandovi during pre-monsoon. During monsoon, the salinity ingress is only upto 25 km from the mouth in Zuari and in Mandovi. This is due to the freshwater influx during this period. However, mangrove growth is not very specific w.r.t seasons hence the pre-monsoon values can be considered. Based on the overlay analysis using the physical aspects of the estuarine environment, the extent of the study area was decided as can be seen in the final LU/LC maps.

3. Materials and Methods

3.1 Satellite Data Processing

Temporal satellite data from various satellites were chosen for monitoring the spatial and temporal changes in the land-use/land-cover. In order to minimize the impacts of the changing season, it was ensured to use the data of similar season. Landsat MSS (2 March, 1973), Landsat TM (19th November, 1989), IRS LISS-III (5th February, 2001) and IRS LISS-III (17th January 2011) datasets have been used to detect and understand the distribution of mangroves over a period of 38 years. The main motive here is to obtain data over a longer extent of time having decadal separation to understand the changes appropriately. Hence depending on the availability of satellite images these datasets have been chosen for the study.

The geo-coded (UTM WGS 84 Zone no-43 and re-sampled to 30m) LISS III 2011 imagery was obtained from the National Remote Sensing Centre, Hyderabad, India which was used to geo-reference the 2001 LISS III imagery by selecting 18 ground control for image to image geo-rectification. The RMS error achieved during the geo-referencing of the image was 0.357 which ensured the accuracy and geometric integrity of the geo-rectified LISS III image. The Landsat imageries of 1989 and 1973 were obtained from the Global land Cover facility site (GLCF) with the former having a resolution of 30m and the later 57m. Although the resolution of 1973 imagery is relatively poorer, the post classifications results can be compared as the projection applied is same and the areal estimates obtained are based on number of pixels. Moreover, since MSS and TM images were acquired by different generations of sensors radiometric normalization had to be carried out to minimize the radiometric differences. This has been carried out based on the relative radiometric normalization (RRN) method developed by Hall et al. (1991) as discussed by Yang and Lo, 2000. The flow- chart of methodology is shown in Fig. 2.

3.2 Data Analysis

3.2.1 Pre-classification

PCA analysis

Principal components analysis (PCA) involves the orthogonalization of a multispectral dataset based on components generated from an eigenvector-derived factor-loading matrix (Schowengerdt, 2007). Tung Fung (1992) used Principal Component Analysis (PCA) on Landsat MSS and Spot HRV data to do a change detection analysis for Hong Kong. Abedini et al. (2012) studied the Land Use Land Cover Classification of Landsat TM over Ulu Kinta Catchment using cluster analysis where they have used PCA to yield a better understanding of DN data set representation for each LULC classes. The conceptual basis of using PCA is to reduce redundancy in the n-band data into fewer new bands that have more information. PCA analysis generally increases the computational accuracy by reducing the dimensionality of the original dataset and thus the whole process of automated classification becomes more efficient. Further, from the classification perspective, transformation of the information content onto orthogonal axes increases spectral separation of certain spectrally adjacent classes. Hence, due to the given advantages PCA has been used in the current study as a Pre-classification step in order to separate the various LULC classes. Also, with respect to the second objective of the study, to quantify mangrove extents, this approach has been applied in order to ensure maximum differentiability between mangrove and non mangrove areas. Green et al. (1998) used a number of approaches to report the best way of classification that can be used for mangrove and non-mangrove discrimination. The approach suggested by Green et al. (1998) for PCA was used in this study. The data from five Landsat TM bands (3, 4, 5, 3/5 and 5/4) were used as input to the PCA module in the ERDAS software. In case of LISS III, the ratios 2/3 and 3/1 were used according to the protocol followed by Gray et al. (1990) for Spot XS, along-with band 1,2,3. This is because both Spot XS and LISS III have similar band configuration and resolution. For the Landsat MSS data of 1973, the bands 1, 2, 3 and the ratios 2/3 and 3/1 were used. The best Principal loadings were then stacked together as a false color composite for further classification.

3.2.2 Classification of Imagery

Majority of land-cover and land-use studies use traditional image classification algorithms (e.g. maximum likelihood), which assume: (i) image data are normally distributed, (ii) the images are H-resolution (This indicates that the objects of interest on the surface are larger than the pixel size (Strahler et al., 1986); and (iii) pixels are composed entirely of a single land-cover or land-use type (Franklin et al., 2003). Image classification is the process of grouping image data into classes with similar spectral values, which are assigned to meaningful information. Robust indices using Landsat data were employed in the central part of Iraq to assess the potential of several ancillary input data for the improvement of unsupervised land cover change detection (Arsalan et al., 2013). Classification methods for remotely sensed imagery are commonly categorized into supervised and unsupervised forms (Lillesand and Kiefer, 2000). Supervised Classification requires prior knowledge of the study area and involves choosing representative training pixels from a pre-defined classification scheme that then are used with a decision rule (e.g., minimum distance, maximum likelihood, and Mahalanobis distance) to assign spectral data to information classes (Erdas Field Guide, 2005) . On the other hand unsupervised classification requires no prior knowledge, the classification algorithm searches for natural groupings in the data for clustering. The accuracy of both the methods depends on the spatial and spectral characteristics of study area under consideration. However, results obtained from the single use of standard classification techniques are not always sufficient in case of studies involving complex LU/LC features (Myers et al., 1989). For this area, we have used a combination of both supervised and unsupervised classification called Hybrid classification. Generally a hybrid approach involves 1) an initial spectral clustering, 2) assignment of clusters to user-defined classes, and 3) maximum likelihood (or similar decision rule) classification of the entire image. Here, firstly we have subjected the images of 1973, 1989, 2001 and 2011 to unsupervised classification by using the ISODATA clustering algorithm. This uses minimum spectral distance to assign a cluster for each candidate pixel. The process begins with a specified number of arbitrary cluster means or the means of existing signatures and then it processes repetitively so that those means shift to the means of the clusters in the data (Erdas Field Guide, 2005). In the second step, we collected signatures of classes which overlap or get mixed with other classes and assign it to a signature file, a result of the supervised approach. Finally, all signatures either from the unsupervised or supervised approach are appended together to form a single signature file which is used to "classify" (as a supervised classification step) the complete and full extent of the originals image using Maximum likelihood algorithm. The maximum likelihood classifier estimates the

probability of a pixel belonging to each of a predefined set of cover types and the pixel is then assigned to the class for which the probability is the highest. Once the classified image was obtained for each dataset, they are re-coded into ten individual land-use/ land-cover classes.

3.2.3 Post-classification

The classified image is filtered using neighborhood operator to get smooth thematic layer for better change detection analysis over a period of 38 years. An accuracy assessment is done for all the images using the ERDAS IMAGINE tool which generates three types of reports that includes the error report, the overall accuracy report and the Kappa statistics. The accuracy estimation is essential to assess reliability of the classified map (Foody, 2002). The accuracy assessment is done based on visual interpretation and Survey of India Toposheet for the year 1973 and 1989. In case of 2001 imagery ancillary data and previously obtained field data from institutional field trips are used and for the year 2011, 256 sampling points obtained from field survey, are chosen to assess the accuracy. An accurate classification enables to have better areal estimates of the important LU/LC classes and also helps us to understand the effect of various other classes on each other. Further, change detection analysis is performed (Baker et al., 2007; Schmid et al., 2005) in order to determine the changes in the LU/LC that have occurred over the observation period from 1973 to 2011. Change detection is an important application of remote sensing technology that gives us the changes of specific features within a certain time interval

4. Results

4.1 Pre-classification

PCA analysis

There are three main steps to compute a PC transformation: the calculation of covariance or correlation matrix using input image data sets; the calculation of Eigen values and eigenvectors; and the calculation of the principal components (Richards, 1996). The Erdas software generates a number of statistics associated with the PCA components. For each dataset, the individual components were analyzed and compared with the true image visually as well as interrelated statistically to derive the best components. In case of the 1973 image (Landsat MSS), PC1, PC2 and PC3 gave the best combination. The PC1 and PC2 give almost all the variance showing almost more than 95% of variability. A combination of PC1,

PC2 and PC3 provided maximum differentiation which enabled better interpretation of the various feature types. Similarly in case of Landsat TM, PC1, PC2 and PC3 were used for making the composite for 1989. The basis was that band 3, 4 and 5 gave the best separation of vegetation and on comparison of the Eigen matrix it was observed that component 1, 2, 3 provided with the best contrast for identification of the mangrove areas. In case of the LISS III images of 2001 and 2011, PC1, PC2 and PC3 gave significant results and were combined together to make a False Color Composite (FCC). The nature of each principal component was identified through an examination of the resultant image as well as its associated eigenvector. The main reasons for choosing these components were that they reflected the majority of informational content as well as provided the best visual discrimination of the various LULC classes.

4.2 Classification of Imagery and Post Classification

Ten land-use/land-cover classes are extracted for the entire study area for the years 1973, 1989, 2001 and 2011 using the hybrid classification technique (Fig. 3). The LU/LC classes considered are water, mudflats/tidal-flats, reclaimed mudflats/tidal-flats, mangrove, shoreline features, agriculture, plantation, vegetation, built- up and barren land. Accuracy assessment has been done for all the datasets and the Kappa coefficient and the Overall-accuracy are reported in Table.1.

The first three classes of water, mudflat/ tidal flats and reclaimed tidal flats depend on several factors like tidal phase, the season to which the satellite imagery belongs and its time of satellite pass. However, they show more or less consistent values with respect to each other. The reclaimed mudflats/ tidal flats are the areas which get exposed during low tide periods and hence are classified as a separate class as they gave completely different signature. There is significant coverage of reclaimed mudflat area in 1973.

There has been a considerable increase in urbanization of about 2612.8 ha in the past 38 years as is evident from the statistics. However, urban estimates maybe under-represented as many areas in Goa have huge canopies of vegetation over scattered built-up areas. The vegetation class is the most dominant class after water for every year. The area covered by vegetation has increased by 11% from 1973 to 2011. The mangrove class specifically, shows an over-all increase of 1585.7 ha from 1973 to 2011. The Chorao Island, Divar Island and Nerul Creek mainly contribute to the mangrove coverage along the Mandovi. There is relatively a marginal increase of mangrove growth along the Zuari River.

The Cumbarjua canal which connects both Zuari and Mandovi supports a dense network of mangroves. This change in mangrove extent has been brought about by the conversion of mudflat areas.

The shoreline class shows a significant negative trend from 1973 -2011. There is a 41% decrease in shoreline area. The beach area shows a decrease of 354.4 ha. The beaches of Candolim, Sinquerim (Mani Murali et al, 2013) and Colva show coastal erosion which poses serious threat to the coastal ecosystem and also has socio- economic repercussions.

There is also a subsequent reduction in the agricultural area from 1973-2011 and an increase in the plantation area. It is evident from the temporal analysis that between the periods of 2001 to 2011, there has been an indiscriminate conversion of agricultural land for non-agricultural purposes. Another contributory reason may be the large scale mining activities in the region during this period. The barren class is mainly represented by empty spaces such as mining pits, wastelands and unused built-up area. There is an increase in barren areas from 1989-2001 due to intensifying of mining activities during this period.

Table.2 gives the areal estimates and percentage of change for all the ten LU/LC classes extracted for the study region.

5. Discussion

5.1 PCA and Hybrid Classification

PCA helps to reduce the dimensionality of a data set consisting of a large number of interrelated variables. This is accomplished by transforming to a new set of variables which are uncorrelated (Jolliffe, 2002), thus improving the interpretability of the components. Li and Yeh (1998) reported the usefulness of PCA method to monitor rapid land-use changes and urban expansion in comparison with post classification method. They carried out a principal component analysis on two images from different dates, and an interactive supervised classification of land-use change was done on the compressed PCA image for further analysis. Singh and Singh (2011) used PCA for forest vegetation analysis and Land Cover assessment for Hasdeo River.

In this study, we have used PCA as an image processing technique to get better differentiability between the spectral classes. The application of PCA for this region ensures the boundaries of various

LU/LC types become more discrete especially in the case of 1973 and 1989 datasets for which limited prior knowledge concerning the scene was available. The enhancement in the visual differentiation achieved after PCA for the datasets of 1973, 1989, 2001 and 2011 when compared with the original images. It can be clearly seen that due to limited spectral and spatial resolutions the response of PCA is comparatively poorer in case of Landsat MSS Imagery, where the plantation patches get mixed with the mangrove signatures. Nevertheless, the PCA still gives a better representation than the original false color composite. In case of Landsat TM, the mangrove and non-mangrove differentiation is appreciable and the classes are efficiently separated. In case of LISS III images, the PCA gives good response as the mangrove areas are well differentiated from the forest areas and the boundaries are clearly demarcated for the other LU/LC classes such as mudflats etc.

The PCA technique has been followed by Hybrid Classification which as mentioned earlier is a combination of both supervised and unsupervised classification. Deng et al. (2008) suggest that the choice of classification methodology is extremely important for change detection analysis and although spectral methods like PCA enhance and concentrate the information, they are limited in obtaining 'from-to' change class information. Therefore, he encourages the use of classification methods to provide detailed change information and land-use change map. Supervised Classification is usually more appropriate when there are relatively less classes to be identified or when distinct, homogeneous regions that represent each class can be identified. On the other hand, unsupervised training enables one to define many classes easily, and identify classes that are not in contiguous, easily recognized regions (Erdas Field Guide, 2005). The Estuarine Complex of Mandovi and Zuari have a varied LULC pattern including classes which are overlapping spatially and spectrally and therefore hybrid classification is used in this case. It is essential to report here that prior the use of hybrid technique, the two techniques were singularly checked for their accuracy for LU/LC classification for the given area. The accuracy assessments of the results obtained were dissatisfying and ranged between 70-80% and hence subsequently the hybrid approach was followed.

4.2.1 Analysis of LULC changes along Mandovi-Zuari Estuarine Complex

The three classes of water, mudflat/ tidal flats and reclaimed tidal flats depend predominantly on tidal phase. The reclaimed mudflats/ tidal flats are the areas which get exposed during low tide periods and hence are classified as a separate class as they gave completely different signature. It is generally

desirable to use datasets of similar tide conditions, especially in context of coastal zone change analysis and management.

As seen from the statistics, the shoreline area has decreased along the study area over the period of time mainly from 2001 to 2011 (tidal phases during this period is comparable and hence appropriate for change analysis). Parab et al. (2011) reported that beaches of Goa are facing the problem of erosion because of which the beach sand get washed off from the shore by waves and currents and the level of water increases thereby decreasing the usable shore area. A report on coastal sand dune ecosystems of Goa (Mascarenhas .A, 1998) mentions the interference of humans in the dynamics of coastal sand dune complex. There are several reasons for the beach loss in this study region mainly including heavy construction activity such as hotels, resorts etc, sand dune extraction, construction of roads, beach shacks and recreational activities etc. Beach shacks, the most frequent and unique feature along the study region causes flattening of dunes and adds litter onto the beach. Although shacks occupy only the upper part of the beaches they contribute to significant irreversible damage to the beach ecosystem. Similarly with the increasing number of tourists to Goa, the numbers of hotels and resorts have mushroomed over the period of time, the Baga - Candolim strip is a classical example of this anthropogenic pressure. Also large scale conversion of dune belts has taken place due to setting up of residential areas. These impacts can be observed along most part of the sandy coast of Goa, including the two major estuaries in between. Thus, it can be observed that the shoreline of Goa is highly fragile and requires immediate attention to ensure protection, as they play a pertinent role in the sustenance of the coastal population of Goa which depends on it for fishing and attracting tourism.

Another important change observed through this study is the decrease in agricultural area and increase in plantation. This increase can be attributed to socio-economic causes. Cash crops provide more monetary benefits and hence there is a surge in plantation agriculture. The agriculture in Goa in totality shows a declining pattern as more and more land is getting converted for the purpose of urbanization and infrastructural development. The inland areas of this region are not highly fertile and the main crop grown as observed through field studies is rice. The dominant plantations crops grown are coconut, cashew and areca nut. The fall in agricultural practice in the state poses concern as it will lead to increase in the import of food grains from nearby states. From this perspective, there is a growing need for the government to offer incentives in order to encourage the locals for farming.

The area under vegetation has increased from 1973-2011, this is associated to the decrease in barren areas. As discussed earlier the barren areas are mainly empty places formed due to mining, wastelands etc. From 1989 to 2001 there is an increase in barren land and decrease in vegetation. This is because huge expenses of land were cleared for intense mining activity during this period. On the other hand, it can be observed that during the period from 2001- 2011 there has been decrease in mining and increase in vegetation cover, this compensation can be attributed to the growing awareness against the environmental degradation by mining and the positive steps taken by the forest department.

The most important change that can be highlighted here is the gradual increase in the urban class from 1973- 2011. This growth has serious implication on the adjoining coastal belt of this study region. Increase in population impacts the sustainable use of the natural resources, for e.g. Residential complexes encroach upon the beach areas thereby decreasing the shore extents and eventually leading to a sand budget imbalance. Construction of roads along the beach is seen at many places, concentrated mainly along North Goa and some along the South Goa stretch. Also, the increase in tourist flux to the state has led to haphazard infrastructural development in the form of hotels and restaurants along the beaches and in the interiors. Apart from causing intense pressure on the land resources, an increment in population demands an increase in agriculture and fishing (especially important in case of Goa, as majority of people depend on it for their livelihood) which can in turn accelerate dependence on the nearby states for food as well as result in environment degradation due to increased fishing activities.

4.2.2 Analysis of Mangrove changes along Mandovi-Zuari Estuarine Complex

Goa houses one of the best mangrove forests on the west coast of India. Jagtap (1993) has reported that 90 % of the mangroves in Goa are distributed along the Mandovi and Zuari estuaries. The areal coverage of mangroves along Mandovi and Zuari (Including Cumbarjua Canal) was estimated using the recoded images. The estimates show a gradual increase in mangrove area over the considered period of time. Table.3 shows the areal extent of mangroves for the year 1973, 1989, 2001 and 2011, and Fig. 4 shows the trend in the mangrove coverage cumulatively along the Mandovi-Zuari (including Cumbarjua) complex. Fig. 5 shows the spatial and temporal coverage of mangrove along these two rivers from 1973 to 2011. Mangrove growth has increased by 254.4 ha from 1973 to 1989 in case of Mandovi and 31.9 ha in case of Zuari. There is a considerable increment during the period 1989-2001 and the overall growth of 793.3 ha is estimated along both Mandovi and Zuari rivers (including Cumbarjua Canal). The rate of

growth of mangrove extent decreased from 2001 to 2011 as evident from the statistics, being only 209.7 ha in case of Mandovi and 154.8 ha in case of Zuari. In the span of 38 years there is an overall increase in the mangrove coverage of 910.3 ha along Mandovi and 533.2 ha along Zuari (Cumbarjua canal included). A visual interpretation of the classified images identifies the areas along which the mangroves have increased. There are mostly fringing patches of mangroves along these rivers with small strands distributed sporadically. Chora Island has a thick mangrove cover along the Mandovi estuary. On the other hand, Zuari has scattered and degraded patches of mangroves along its length. A considerable mangrove cover can be seen along the Cumbarjua Canal which significantly contributes to the values estimated for Zuari River. The species mainly found in these estuaries are *Rhizophora mucronata*, *R. apiculata*, *Avicennia officinalis*, *A. marina*, *A. alba*, *Kandelia candel*, *Sonneratia alba*, *S. caseolaris*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Aegiceras corniculatum*, *Excoecaria agallocha*, *Acanthus illicifolius*.

The analysis of the trends in mangrove changes for these estuaries over the period of time highlights that the appreciable increment from 1989 to 2001 can be credited to the initiatives taken up by the State Government of Goa. The Chora Island was declared as Reserved Forest under the Indian Forest Act, 1927, to protect and conserve the mangrove forests. Subsequently, this area was declared as a Dr. Salem Ali Bird Sanctuary bird sanctuary in 1988 under the Wildlife (Protection) Act, 1972. This can be seen in the satellite image as the mangrove growth in this area has increased from 1989 to 2001. This was followed by afforestation to restore degraded mangrove areas in Goa in 1985-1986; by the end of 1996-1997 the program had ensured 876 ha of mangrove cover (Forest Department of Goa). This increase in mangrove cover throws light on the importance of awareness and the need for active involvement of the state forest departments. It also stresses the significance of in-situ conservation in mangrove preservation which can be followed by other mangrove dominated areas in the country.

However, the reason for immediate concern for this region is that although there is substantial increase over the entire period considered, there is slow growth from 2001 - 2011. This is the result of the increasing urbanization (as discussed before) which has led to increased encroachment to the nearby mangrove areas. The conversion of mangroves on public lands for aquaculture, agriculture, mining (e.g. near the Mapusa estuary in Goa), human habitation and industrial purposes has led to degradation. The other reasons for the decrease in mangrove vegetation are the movement of barges (for iron -ore transfer) that causes damage to the young mangrove seedlings. Mangroves have both ecological as well

as socio- economic relevance, and their conservation is very essential for these coastal regions from the perspective of biodiversity and protection against natural hazards. It is thus essential to ensure that the conservation steps taken are sustained over the period time along with the growing development, so that this pristine ecosystem is well preserved.

The over-all assessment of the LULC and analysis of mangrove change for this study area suggests a mix of positive and negative developments. Although there has been a decrease in mining activities and increase in vegetation, particularly mangroves there is immense negative pressure from the growing population in the form of beach area loss and increase in urban areas. The question to be asked here is going by the rate of development and boost in the tourism industry, for how long environmental sustainability can be ensured for this region of study. The fact that the area depends hugely on tourism for its livelihood, an alteration in the environmental condition and natural setting of this region can prove to be a setback. It is imperative for the administrators of this region, to strike a balance between development and environmental protection, in order to ensure preservation of this unique area. Since this estuarine complex of Mandovi and Zuari encompass the important cities of Goa and is the hub of majority of developmental activities and tourist destinations, environmental changes in this region can affect the state of Goa as a whole.

6. Conclusion

In this study, we have presented a methodology involving the use of PCA as image enhancement technique and hybrid classification for studying the LULC changes along the Mandovi- Zuari estuarine complex of Goa. Various image enhancement techniques have been used for the purpose of classification in previous studies. However, the accuracy of each methodology varies with the spatial and spectral resolutions of the datasets used for the study as well as the complexity of study area under consideration. It can be emphasized that in the present work, PCA analysis has provided a good approach to separate the LULC classes along this region. The Principal components could ensure maximum visual separation between the image features enabling proper extraction of the mangrove extents as well as the other LULC classes. Further, the hybrid classification scheme proves to be a desirable method for a temporal analysis, spanning a greater time period. This is because, as both supervised and unsupervised training signatures are used, the efficiency increases especially in the case of datasets of the years in which valid field data or ancillary data is unavailable.

The results obtained clearly stresses the ecological and socio-economic importance of LU/LC changes in and around Mandovi and Zuari in terms of their impacts. It can be seen that the amount of urbanization has increased over the period of time which has contributed to increased pressure on natural resources like agricultural area, mangroves etc. There is also a striking depreciation in the shore area which can prove to be a serious problem for the people along the coast who depend on it for subsistence. An estimation of mangroves class provided the quantitative estimates for this estuarine complex which is exemplary for other regions of the country. The mangrove areas have increased since last 38 years and this increment can be attributed to the increased awareness and efforts of the state forest department. .

Therefore, it is suggested that improved tools of remote sensing and GIS should be used for the continuous monitoring of these areas so that an efficient strategy can be devised for the conservation and restoration of these important land-use / land-cover classes. The LULC trends of this region need to be monitored closely and timely for preserving the sustainability of the environment. In this context, this study provides the most recent quantitative estimates to understand the environmental conditions prevailing around the Mandovi -Zuari Estuarine complex.

7. Acknowledgement

The authors thank Director, NIO for his support to this research activity. This is NIO contribution No. xxxx.

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Table.1 Showing Overall accuracy and Kappa- Coefficient for all datasets

Dataset	Overall Accuracy	Kappa Coefficient
Landsat MSS 1973	86.36	0.85
Landsat TM 1989	86.64	0.85
LISS III 2001	92.93	0.92
LISS III 2011	95.56	0.95

Table.2 Areal Estimates for LU/LC classes in ha

Class Names	1973	1989	2001	2011	Percentage change (%)			
					1973-1989	1989-2001	2001-2011	1973-2011
Water	65979	65388.2	65104.4	65005.2	-0.9	-0.4	-0.2	-1.5
Mudflats/Tidal-flats	1110.8	621.6	2410.4	2537.9	-44.0	287.8	5.3	128.5
Reclaimed mudflat/ Tidal-flats	6307.9	5708.4	3049.8	3501.3	-9.5	-46.6	14.8	-44.5
Mangroves	364.2	630.7	1437.1	1950	73.2	127.9	35.7	435.4
Shoreline	734.9	615.3	785.8	431.4	-16.3	27.7	-45.1	-41.3
Agriculture	28318.9	24956.1	24280.4	20344	-11.9	-2.7	-16.2	-28.2
Plantation	1999.7	2145.7	2247.4	4662.9	7.3	4.7	107.5	133.2
Vegetation	47876.9	50764.5	46608.5	53006.4	6.0	-8.2	13.7	10.7
Urban	1413.9	2550.1	3144.7	4026.7	80.4	23.3	28.0	184.8
Barren	13867.3	14592.9	18904.9	12507.5	5.2	29.5	-33.8	-9.8

Table. 3 Areal distribution of mangroves along Mandovi - Zuari estuarine complex

Year	Area Estimates of mangroves (in hectares)	
	Mandovi	Zuari + Cumbarjua Canal
1973	149.4	142.9
1989	403.8	174.8
2001	850.6	521.3
2011	1059.7	676.1

List of Figures

Fig.1 Location and elevation of study area

Fig.2 Flow-chart of methodology

Fig.3 LU/LC Map for the year (a) 1973 (b) 1989 (c) 2001 (d) 2011

Fig.4 Cumulative area estimates of mangroves in Mandovi -Zuari (Cumbarjua) Estuarine Complex

Fig.5 Temporal changes in mangrove distribution in (a) 1973 (b) 1989 (c) 2001 (d) 2011 along River Mandovi and River Zuari

Fig.1

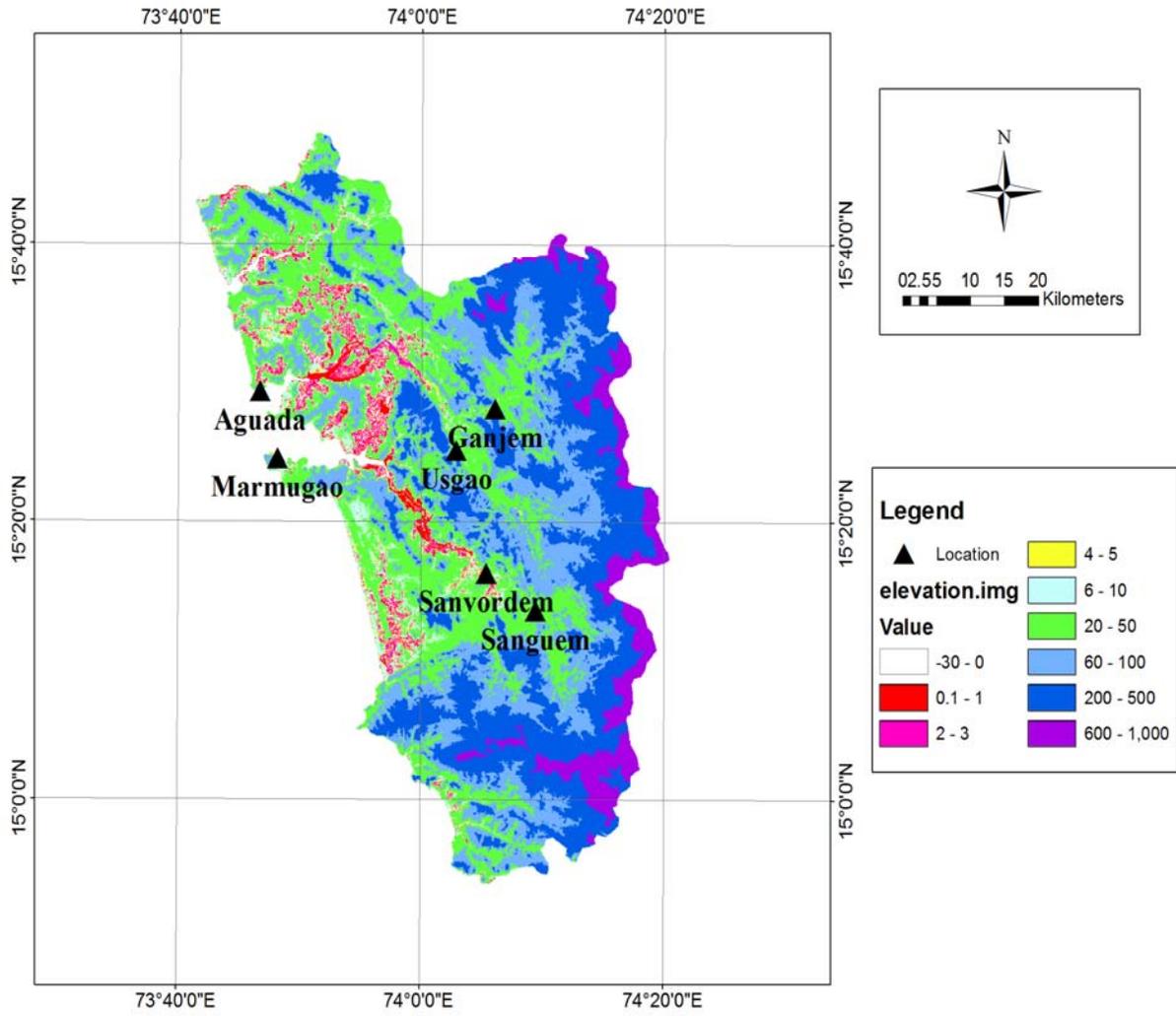


Fig. 2

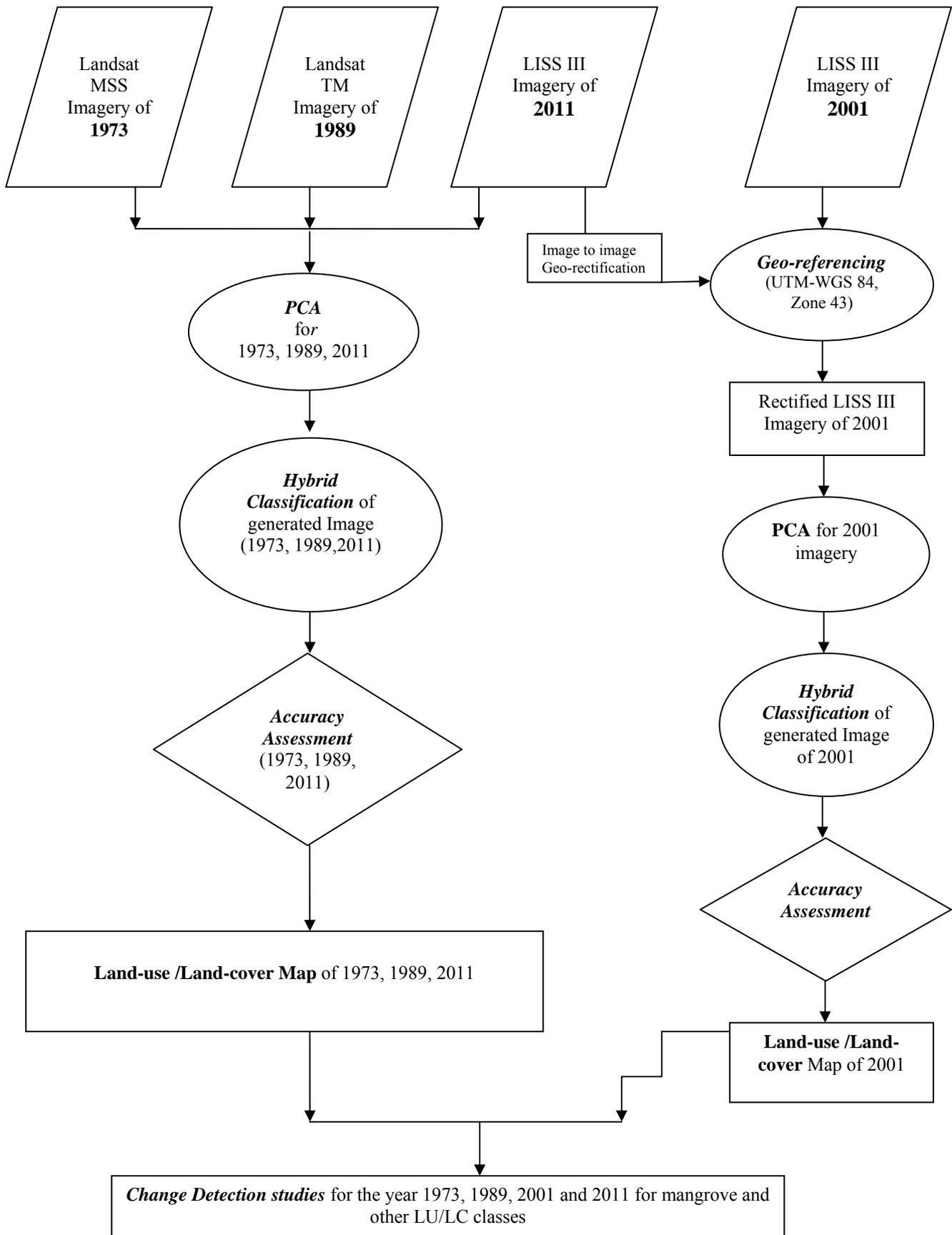
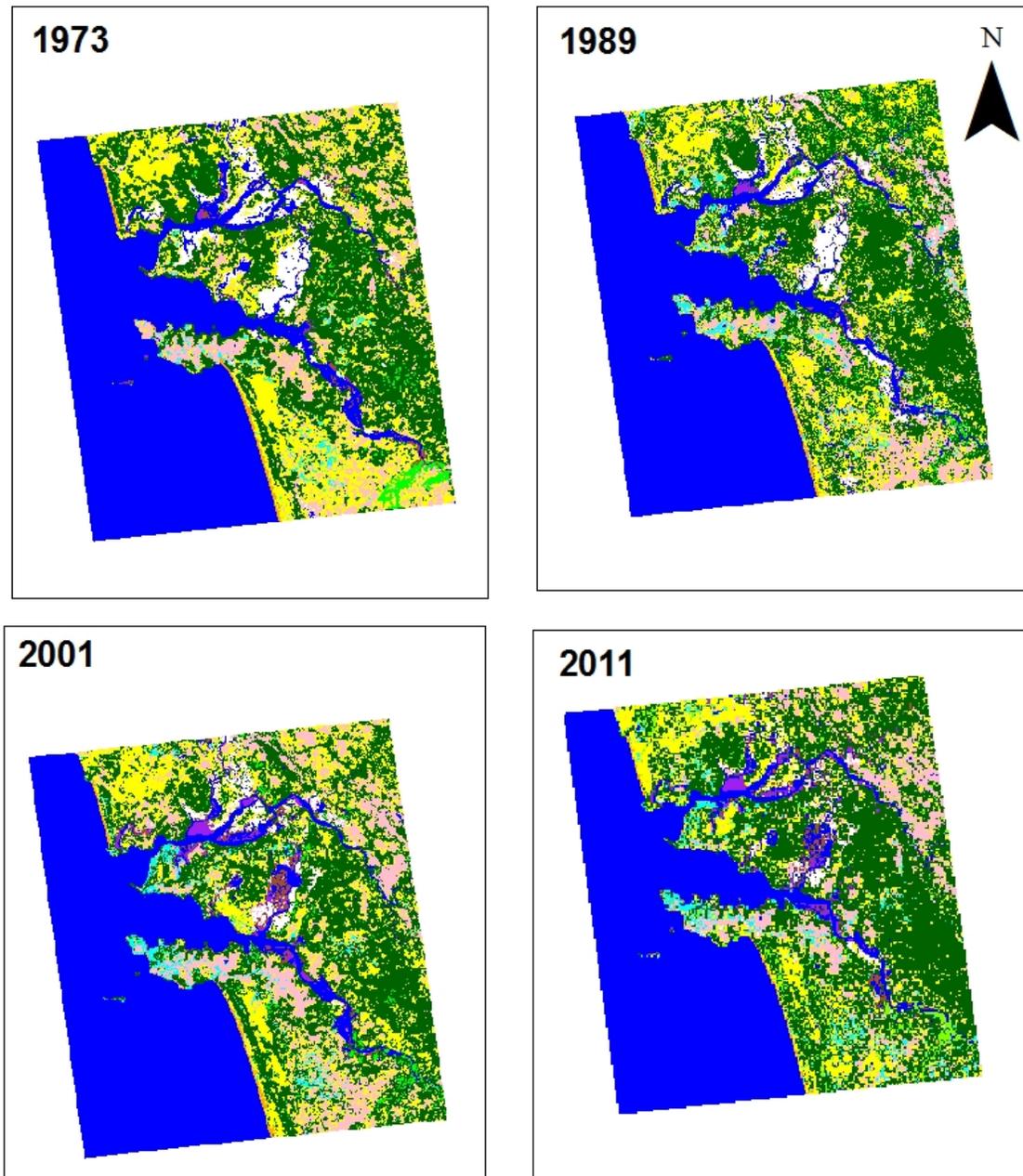


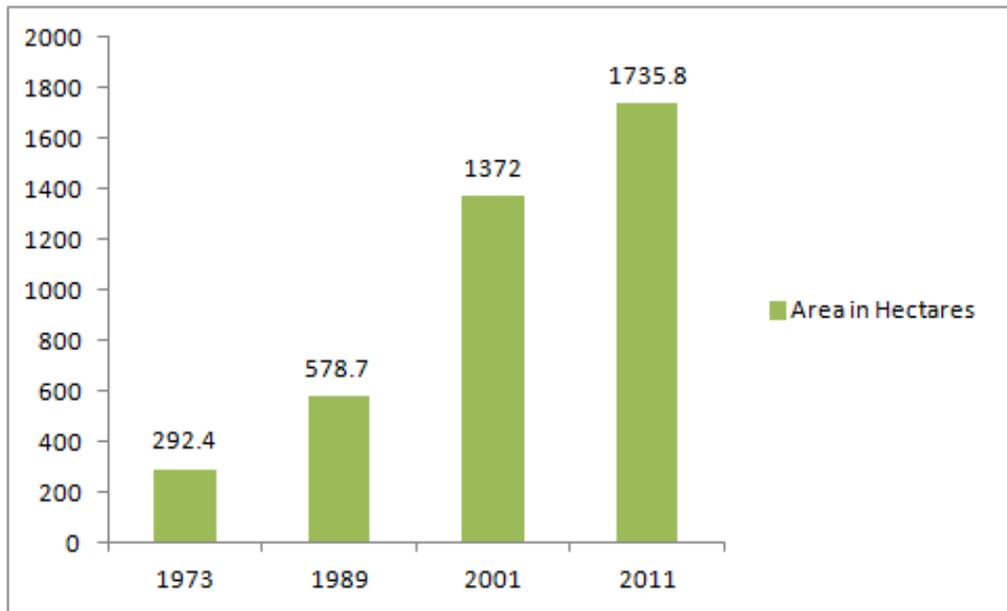
Fig.3



Legend

- | | | | |
|---|---|---|---|
|  Water |  Shoreline features |  Mudflats/Tidalflats |  Agriculture |
|  Vegetations |  Reclaimed mudflats/ tidal flats |  Mangroves | |
|  Urban |  Plantation |  Barren | |

Fig.4



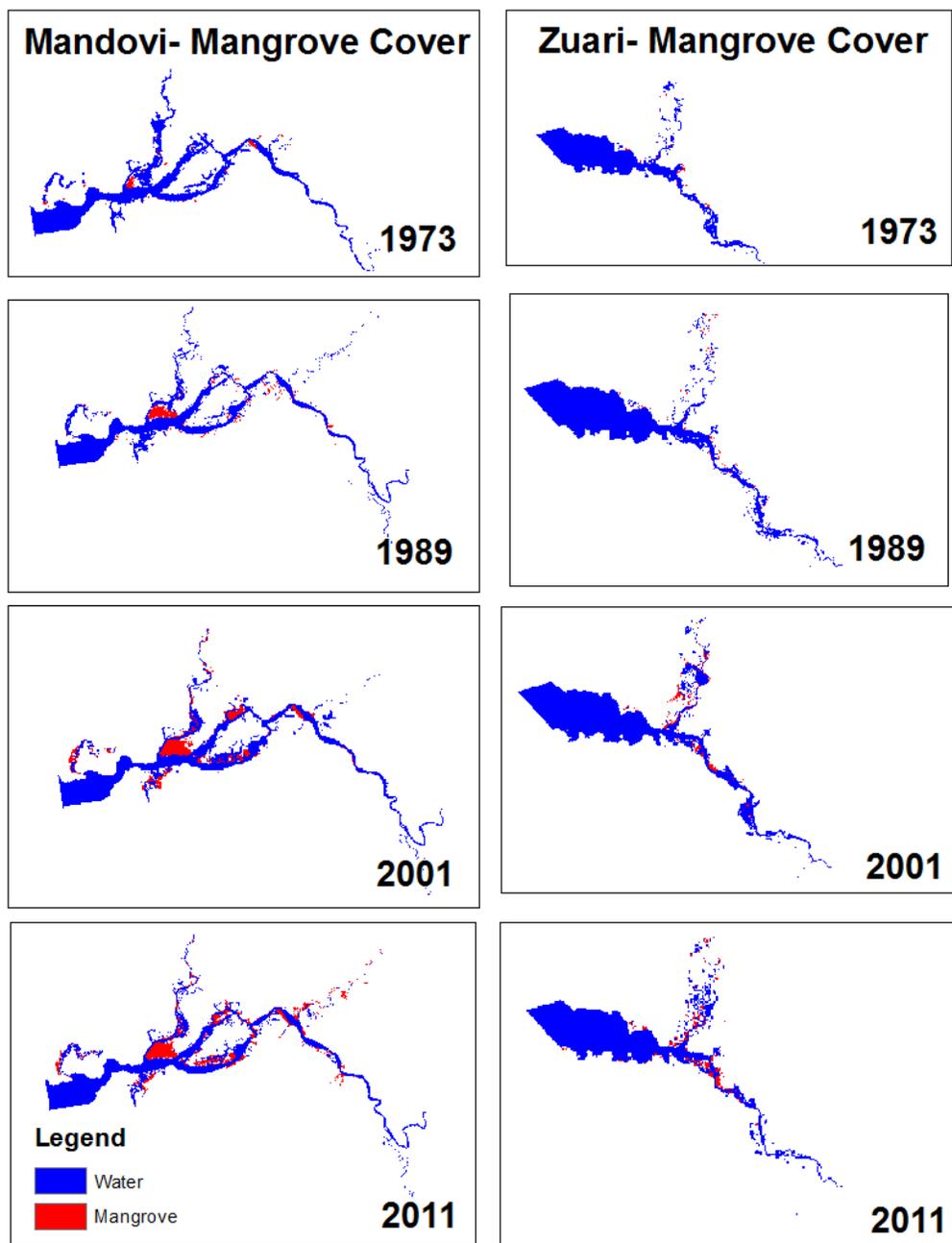


Fig.5