

CHANGE DETECTION OF MANGROVES BY USING REMOTE SENSING AND GIS

3.1. Introduction:

Remote sensing plays an important role in classifying various types of vegetation. Mapping of vegetation can provide valuable land cover information about habitat and ecological diversity. It is a significant tool in inventorying, mapping, classifying, monitoring, management and development of effective strategies for the sustainable utilization of natural resources (Anon, 2003).

Preparing and upgrading vegetation inventories for certain regions, in different times, used for detecting the vegetation changes in those regions. This is more easily obtainable using satellite imageries and thematic mapper techniques. However, ground truth data collection, literature reviews, visual map interpretation, and collateral and ancillary data are most significant in confirmation and substantiate the satellite data interpretation and production of final maps.

Different land cover categories give various types of reflections and produce peculiar spectral signatures of individual form. The desired information could be achieved from satellite imageries in an efficient and effective manner by using several basic interpretation keys. Mangrove

vegetation gives bright red (if dense) or pale red (if sparse) or orange color tone; they are irregular in shape with a smooth texture on satellite data, and hence can be easily interpreted. Their location are in the intertidal areas associated with estuaries, creeks and low lying flats, which are subjected to weak waves and currents (Anon, 1992). Table 3.1 provides various elements for identifying different categories from the satellite imageries. The entire spectral response of mangroves is induced by the chlorophyll content in their leaves, density and structure of the forest and humidity gradient of mudflats related to tidal levels (Blasco and Aizpuru, 2002).

The objective of this chapter was to study the changes in mangrove ecosystems during the last decade as well as studying the recent situation and distribution of mangroves of Goa using remote sensing and GIS. This would significantly help in monitoring and management of the mangrove resources of Goa.

3.2. Results:

3.2.1. Spectral Reflectance Analysis:

The land use classes in the satellite imageries of the three years 1997, 2001 and 2006, showed various spectral reflectances to the different bands (Figure 3.1). Mangroves, terrestrial vegetation and the agricultural fields showed the maximum spectral reflectance to the NIR (Near Infra-Red) band. The lowest spectral reflectance was to the red band. The water

Table 3.1. Image interpretation keys for coastal mapping using remote sensing data (Source: Anon, 1992).

Category	Tone	Shape	Texture	Location	Association	Remarks
Vegetation:						
Forest Plantations	Dark red	Irregular	Coarse	-	-	Rough pattern.
Mangroves Dense Sparse Degraded	Bright red Pale red Greyish	Irregular	Smooth	In the intertidal area/ along the creeks and low lying flats.	Low energy coasts or quiet depositional area. Warm waters.	Grows on substrate mud / mud-sand composition, where the mud percentage is more. Evergreen.
Algae	Pink	Irregular	Smooth	Intertidal / subtidal area.	On reefs, rocks and mudflats.	Distinct on reef edge, reef flats and rocky coast.
Seagrass	Orange/ Orangish pink	Irregular	Smooth	Intertidal area (more on seaward side).	Soft substrate (mud/fine sand) depositions on the reef/intertidal mudflat.	Intermingle with both coral reef and mangrove community.
Marsh	Brown	Irregular	Smooth	Intertidal/supratidal area.	Saline mudflats.	Usually occur in temperate countries. Evergreen. Tidal influence is not daily.
Sand dune vegetation	Pink/Red	Irregular	Smooth	On sandy beach/sand dune	Sand	Comprises low grass to shrubs. Also plantations like Casurina, Cashew.

Non-vegetated Categories:						
Mud flats	Bluish green	Irregular	Smooth	In the tidal areas	Low energy coasts and quiet depositional areas, where tidal energy is not strong.	Made up of fine grained soft mud in the tidal zone. Act as a suitable habitat for the growth of mangroves marsh vegetation and variety of flora and fauna.
Reclaimed mud flat	Bluish white	Irregular	Rough	Above high water line.	Presence of earthen bund.	Crops are grown on it.
Sandy beach	White	Linear Crescent	Smooth	Adjacent to coast, on the land-water boundary.	Open coast	Made up of fine sand particles, broken molluscan shells etc.
Coastal dune	Red / White	Linear	Smooth	Behind the beach on land ward side	Develops in any environment in which loose particles of sand are exposed to wind action.	Detected only which vegetation present on it, otherwise the signature of dune gets mixed up with beach. <i>Casurina spp.</i> may be present
Water body	Blue/ Dark blue	Various shapes	Smooth	Off shore, inland	-	Sea, estuaries, bays, rivers, lakes, lagoons, creeks, reservoirs .etc.

High and low water line	White (HML) Blue (LWL)	Linear	Smooth	HWL located up to highest sea water influx in land during high tide and LWL to lowest level to which water recedes during low tide.	HWL in the supratidal area. LWL in subtidal area.	Maximum and the minimum level of water reached during tidal cycle.
Salt pan	Dark blue, light blue, White	Rectangular, Square	Smooth	Near the high tide limit.	On the land. Tidal influx not daily.	Dry salt pan appears white. Shallow/depressions in which water accumulates and evaporates leaving a salt deposit.

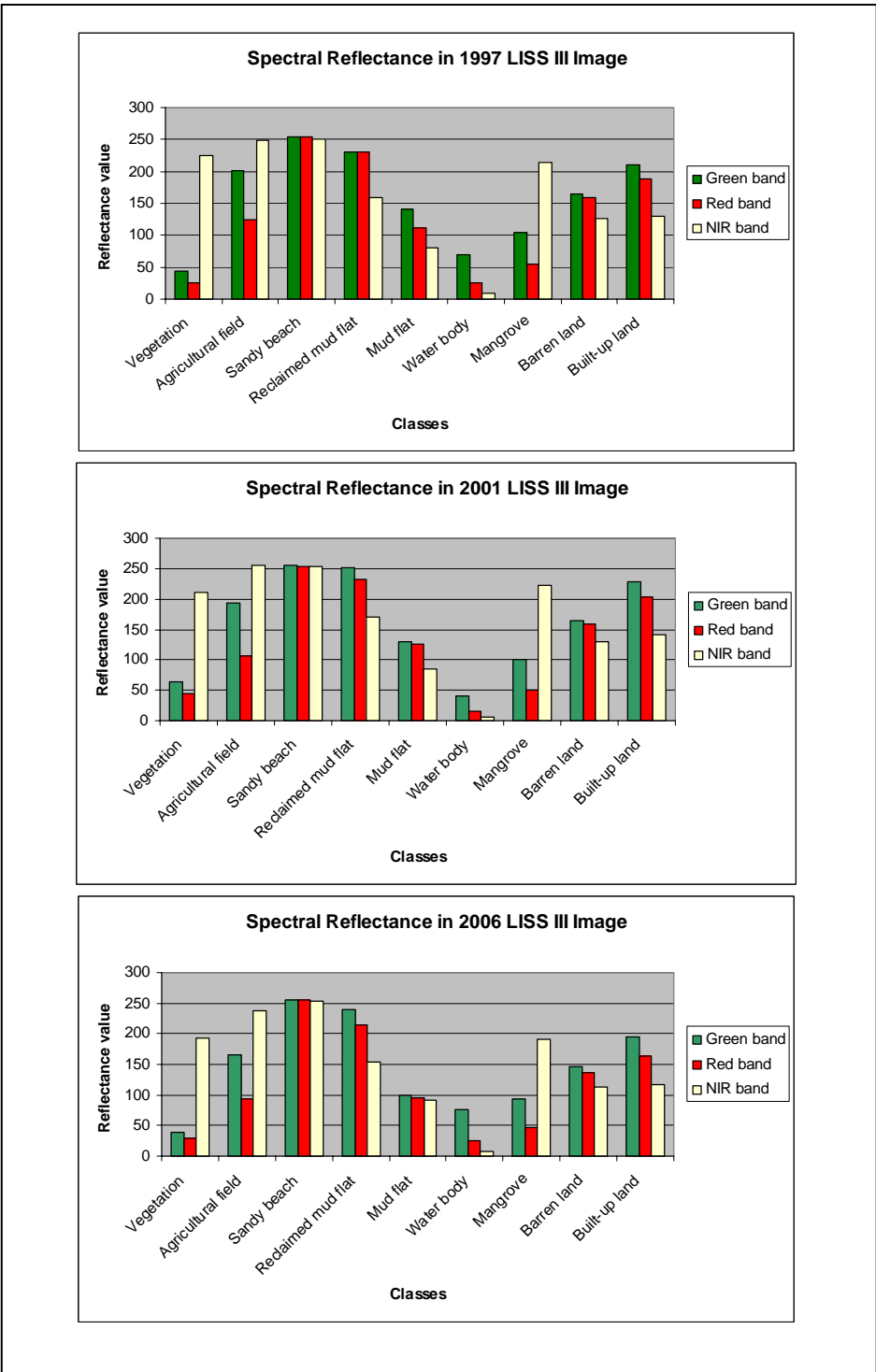


Figure 3.1. Spectral reflectance of different classes in the three imageries.

bodies, barren lands, built-up lands, mudflats and reclaimed mudflats showed the highest spectral reflectance to the green band and the lowest to the NIR band. The sandy beaches showed similar reflectance in all the three bands.

3.2.2. Separability of the Landcover Classes:

The Transformed Divergence (TD) has a scale of values (Table 3.2), which indicate the quality of separability between the different classes.

The TD separability values between the different classes of the time lapsed satellite images (Tables 3.3, 3.4 and 3.5) revealed that agricultural fields, sandy beaches, and water bodies have been separated the best with the other classes in all the three images (Figure 3.2). Mangroves exhibited good separability from the terrestrial vegetation with a TD value of 1958 and 1972 on the imageries of 1997 and 2006, respectively, whereas it showed a poor separability with a TD value of 1582 in the image of 2001. On the other hand, mangrove and terrestrial vegetation showed the best separability TD value (2000) with all other classes. Built-up land also showed good separability in comparison with barren land in the imagery of the year 2001, with a TD value of 1920 with an average separability values (TD of 1888 and 1883 of the 1997 and 2006 images, respectively). Built-up land too had a good separability from the mudflats with TD values of 1973, 1998 and 1981 in the 1997, 2001 and 2006 satellite images, respectively. Reclaimed

Table 3.2. Scale of TD separability values.

TD Value	Separability
2000	The best separability between classes
1900 - 2000	Good separability between classes
1700 - 1900	Average separability between classes
< 1700	Poor separability between classes

Table 3.3. Transformed divergence matrix of the land cover classes in 1997 image.

	1	2	3	4	5	6	7	8	9
1	**	2000	2000	2000	2000	2000	1958	2000	2000
2	2000	**	2000	2000	2000	2000	2000	2000	2000
3	2000	2000	**	2000	2000	2000	2000	2000	2000
4	2000	2000	2000	**	2000	2000	2000	2000	1964
5	2000	2000	2000	2000	**	2000	2000	1950	1973
6	2000	2000	2000	2000	2000	**	2000	2000	2000
7	1958	2000	2000	2000	2000	2000	**	2000	2000
8	2000	2000	2000	2000	1950	2000	2000	**	1888
9	2000	2000	2000	1964	1973	2000	2000	1888	**

Table 3.4. Transformed divergence matrix of the land cover classes in 2001 image.

	1	2	3	4	5	6	7	8	9
1	**	2000	2000	2000	2000	2000	1582	2000	2000
2	2000	**	2000	2000	2000	2000	2000	2000	2000
3	2000	2000	**	2000	2000	2000	2000	2000	2000
4	2000	2000	2000	**	2000	2000	2000	2000	1802
5	2000	2000	2000	2000	**	2000	2000	1758	1998
6	2000	2000	2000	2000	2000	**	2000	2000	2000
7	1582	2000	2000	2000	2000	2000	**	2000	2000
8	2000	2000	2000	2000	1758	2000	2000	**	1920
9	2000	2000	2000	1802	1998	2000	2000	1920	**

Table 3.5. Transformed divergence matrix of the land cover classes in 2006 image.

	1	2	3	4	5	6	7	8	9
1	**	1999	2000	2000	2000	2000	1972	2000	2000
2	1999	**	2000	2000	2000	2000	2000	2000	2000
3	2000	2000	**	2000	2000	2000	2000	2000	2000
4	2000	2000	2000	**	2000	2000	2000	2000	1691
5	2000	2000	2000	2000	**	2000	2000	1817	1981
6	2000	2000	2000	2000	2000	**	2000	2000	2000
7	1972	2000	2000	2000	2000	2000	**	2000	2000
8	2000	2000	2000	2000	1817	2000	2000	**	1883
9	2000	2000	2000	1691	1981	2000	2000	1883	**

1- Terrestrial Vegetation, 2- Agricultural Field, 3- Sandy Beach,
 4- Reclaimed mudflat, 5- Mudflat, 6- Water bodies, 7- Mangrove,
 8- Barren land, 9- Built-up land.

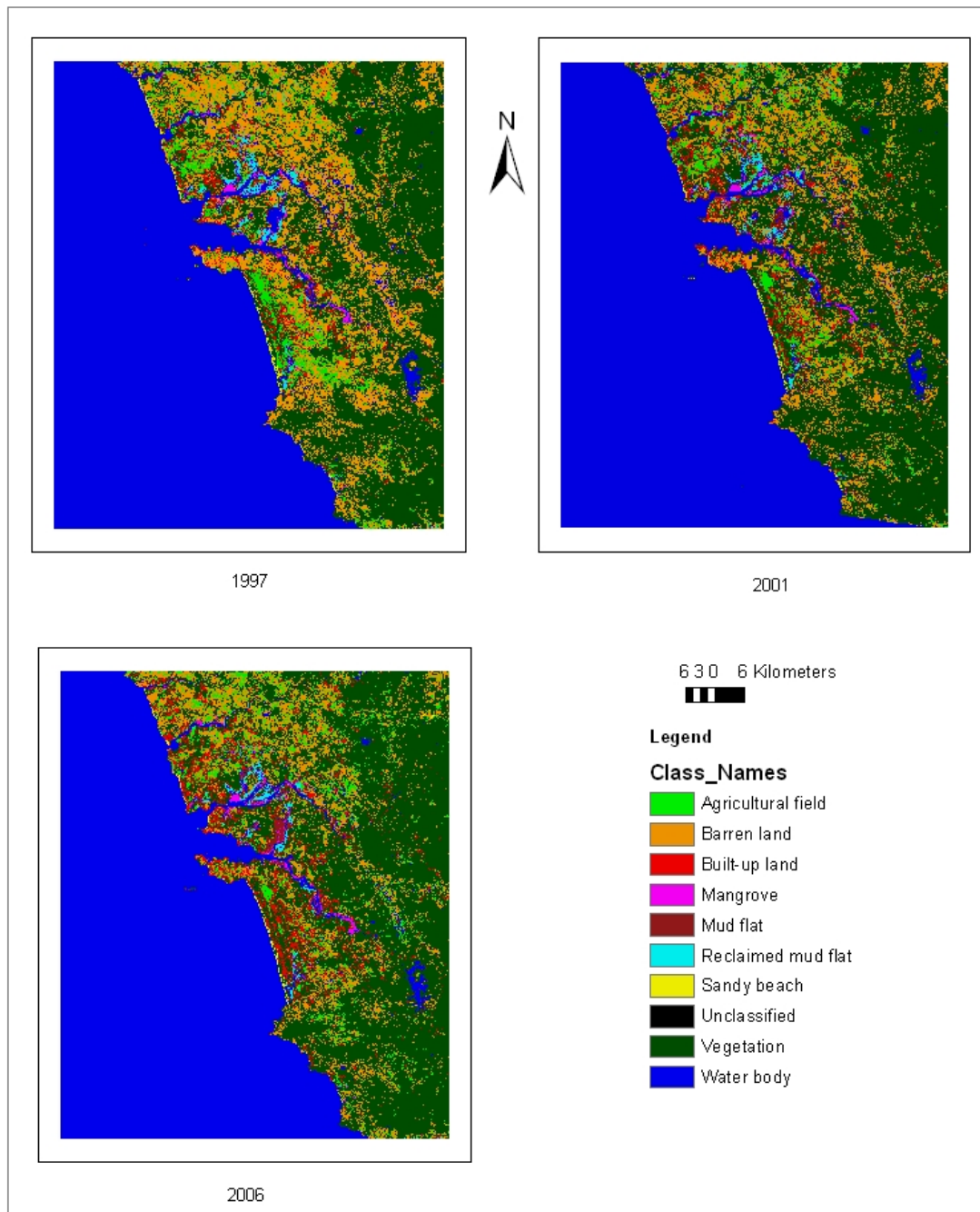


Figure 3.2. Time lapsed classified raster images.

mudflats showed an average separability with the built-up land with a TD value of 1964 in the year 1997, with an average TD value of 1802 in the 2001, and a poor separability with TD value of 1691 in the 2006 image. However, reclaimed mudflats overall found to have the best separability in comparison with all the other classes. Mudflats also showed a good separability with the barren land with a TD value of 1950 in the 1997 image, and an average separability with TD values of 1758 and 1817 in the 2001 and 2006 images, respectively, and the best separability with the remaining classes.

3.2.3. Supervised Classification:

Supervised classification was performed on the IRS-1C LISS III of the year 1997, IRS-1D LISS III of the year 2001 and IRS-P6 LISS III of the year 2006. Nine landcover classes were identified from the satellite images. These classes consisted of Terrestrial vegetation, Mangroves, Agricultural fields, Sandy beaches, Barren land, Built-up land, Mudflats, Reclaimed Mudflats, and Water Bodies. Three different classified images were generated (Figure 3.2). The classified images were subjected to statistical analysis as described below:

3.2.3.1. Accuracy Assessment of the Classified Images:

The classified images were evaluated quantitatively through the accuracy assessment of all the landcover classes. Table 3.6 shows the details of accuracy assessment of the 1997 classified image. The overall accuracy in

Table 3.6. Accuracy assessment of the 1997 classified image.

Classes	Producers Accuracy (%)	User's Accuracy (%)	Kappa Statistics (%)
Terrestrial Vegetation	77.78	97.67	0.9704
Agricultural Field	85.71	60.00	0.5766
Sandy Beach	100.00	88.89	0.8814
Barren land	62.50	68.97	0.6447
Mudflat	100.00	86.67	0.8594
Reclaimed Mudflat	100.00	55.56	0.5373
Mangrove	94.44	94.44	0.9402
Water Body	96.00	100	1.0000
Built-up land	57.14	66.67	0.6365
Overall Classification Accuracy = 84.58 %			
Overall Kappa Statistics = 0.8163			

the year 1997 classified image was 84.58% and the overall Kappa coefficient calculated to 0.82. The overall accuracy of the year 2001 classified image was estimated to be 87.75% while the overall Kappa coefficient was estimated to be 0.85 (Table 3.7). The detailed accuracy assessment of the 2006 classified image showed overall accuracy of 91.30% and overall Kappa coefficient of 0.90 (Table 3.8).

3.2.4. Changes in Percentage of the Landcover Classes:

The maximum likelihood data (the numerical and proportionate values) concerning land cover have been provided in Table 3.9. The area percentage of some classified categories in the study area are shown in Figure 3.3.

Sandy beaches and dune vegetation decreased in area from 0.23% in the year 1997 to 0.20% in the year 2001, with a negative change of 13.9%, and further decreased to 0.18% in the year 2006 with a negative change of 8.77%. The overall decrease in dune vegetation from the year 1997 to 2006 was estimated to be 21.45%. In case of mangroves, an increase by 0.05% in the year 2001 to that (0.35%) in the year 1997. It showed a positive change of 13.31% from 1997 to 2001, followed by an increase to 0.43% in its area in the year 2006, with an increase of 7.75% from 2001 to 2006. An overall increase of 22.09% in mangrove cover was observed from 1997 to 2006.

Table 3.7. Accuracy assessment of the 2001 classified image.

Classes	Producers Accuracy (%)	User's Accuracy (%)	Kappa Statistics (%)
Terrestrial Vegetation	100.00	92.73	0.9089
Agricultural Field	80.00	60.00	0.5748
Sandy Beach	94.44	100.00	1.0000
Barren land	54.29	82.61	0.7982
Mudflat	88.24	88.24	0.8739
Reclaimed Mudflat	90.00	52.94	0.5100
Mangrove	93.75	88.24	0.8744
Water Body	100.00	98.57	0.9804
Built-up land	68.18	88.24	0.8711
Overall Classification Accuracy = 87.75 %			
Overall Kappa Statistics = 0.8544			

Table 3.8. Accuracy assessment of the 2006 classified image.

Classes	Producers Accuracy (%)	User's Accuracy (%)	Kappa Statistics (%)
Terrestrial Vegetation	88.68	92.16	0.9008
Agricultural Field	72.73	94.12	0.9356
Sandy Beach	100.00	87.50	0.8677
Barren land	88.46	79.31	0.7694
Mudflat	100.00	88.24	0.8749
Reclaimed Mudflat	100.00	94.74	0.9433
Mangrove	88.89	88.89	0.8804
Water Body	98.48	100.00	1.0000
Built-up land	80.95	85.00	0.8364
Overall Classification Accuracy = 91.30 %			
Overall Kappa Statistics = 0.8975			

Table 3.9. Change detection of various classes from the year 1997 to 2006.

Classes	Change 97 - 01		Change 01 - 06		Change 97 - 06	
	Pixels	%	Pixels	%	Pixels	%
Agricultural field	-100748	-27.55	35467	27.54	-65281	-7.60
Sand & dune vegetation	-3101	-13.90	-3978	-8.77	-7079	-21.45
Reclaimed mud flat	6904	9.65	-27633	-30.91	-20729	-24.24
Barren land	-447364	-29.95	-297668	-18.11	-745032	-42.63
Mud flat	36969	95.43	35244	66.09	72213	224.58
Terrestrial Vegetation	535501	17.44	-358380	1.09	177121	18.73
Mangrove	5149	13.31	-1881	7.75	3268	22.09
Water body	43980	-0.11	-614079	-0.89	-570099	-1.00
Built-up land	24134	9.35	58008	38.64	82142	51.60

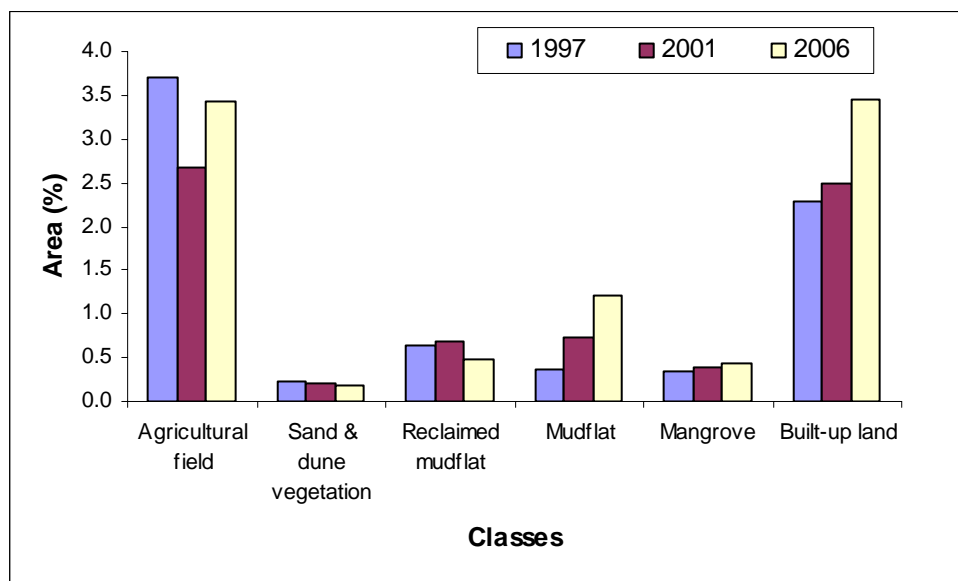


Figure 3.3. Area in percentage of various classes from 1997 to 2006.

Mudflats area increased from the year 1997 to 2006 by 224.58%, while built-up land increased by 51.60%. An increase in terrestrial vegetation by 18.73% was also observed. Agricultural fields, reclaimed mudflats and barren land showed a negative trend wherein; there was a decrease in area by 7.60%, 24.24% and 42.63% in the years 1997, 2001 and 2006, respectively (Table 3.9).

3.2.5. Change Detection of Mangroves Area in Goa:

Mangrove habitats are mainly confined to the intertidal region along banks of the nine major rivers and minor creeks of Goa (Figure 3.4). The distribution and area changes in major formations have been described in the following text.

3.2.5.1. Terekhol River:

The Terekhol River represents the border between Goa and the State of Maharashtra in the north. It has about 26 km in length, and covers approximately 349 ha of water area (Jagtap, 1985). Tidal effect could be observed up to 20 km (Untawale *et al.*, 1982). During 1997, mangrove cover was estimated to be 27.2 ha. It increased by 12.82% (30.7 ha) along the river banks and islands from the year 1997 to 2001. However, it slightly decreased (1.96%) to 30.1 ha during 2006. The overall increase of 2.89 ha in the mangrove cover was observed from 1997 to 2006 with an increase of

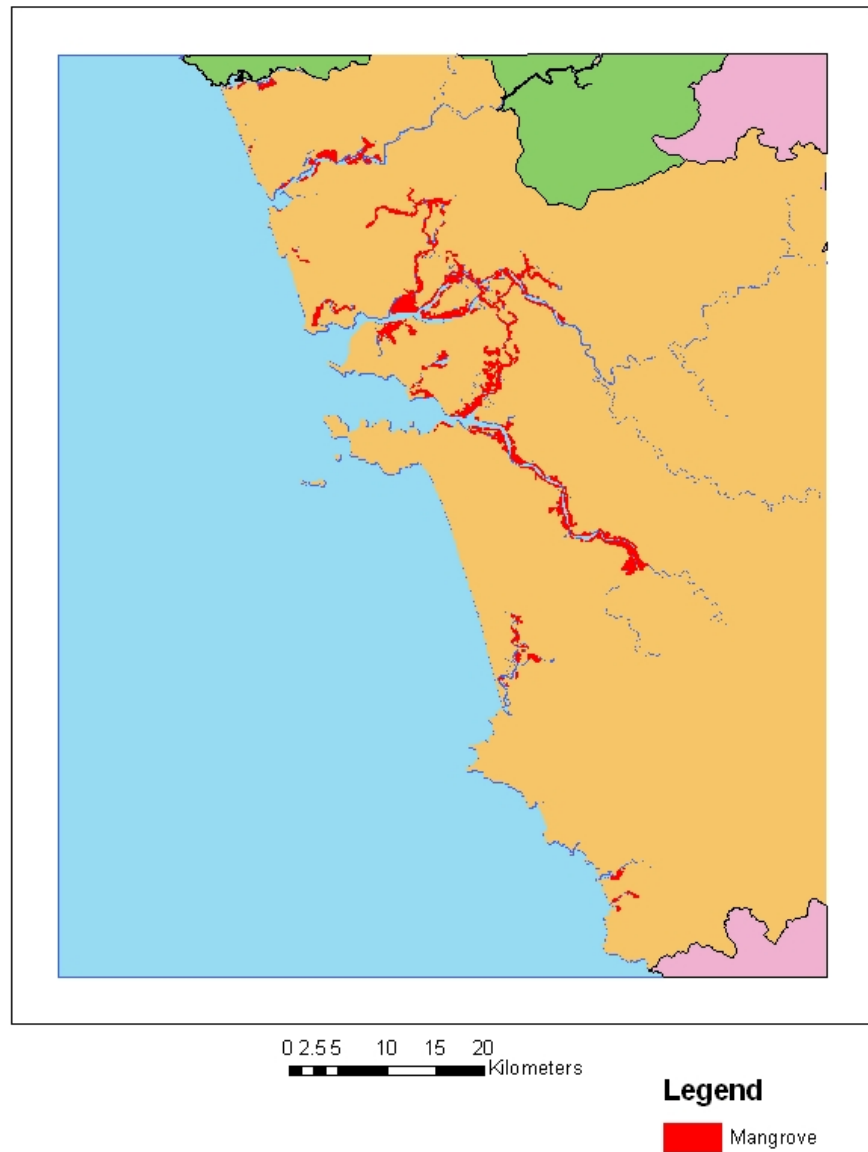


Figure 3.4. Distribution of mangroves in the state of Goa.

Table 3.10. Details of mangrove area change in Goa's rivers.

Year	1997	2001	2006
River	Area (ha)	Area (ha)	Area (ha)
Terekhol	27.22	30.70	30.10
Chapora	220.08	219.28	218.46
Mandrem	1.18	2.20	1.20
Baga	6.63	5.00	4.48
Mandovi	811.12	1055.69	1107.17
Cumbarjoa	224.27	244.18	342.42
Zuari	693.94	676.29	735.22
Sal	57.63	54.89	66.30
Talpona	14.58	11.69	14.60
Galgibag	26.71	22.90	18.85
Total	2083.35	2322.73	2538.79

Table 3.11. Mangrove cover of the rivers of Goa.

River	Water Area (ha)	Mangrove Area (ha)	Mangrove (%)
Terekhol	349	30.1	8.6
Chapora	711	218.5	30.7
Mandovi	5564	1107.2	19.9
Cumbarjoa	375	342.4	91.3
Zuari	5790	735.2	12.7
Sal	302	66.3	22.0
Talpona	40	14.6	36.5
Galgibag	26	18.8	72.3



Figure 3.5. Distribution and area change of mangroves in Terekhol River.

10.60% (Table 3.10). Presently, mangrove covers approximately 30.1 ha i.e. ~ 8.6% of the total river area (Table 3.11). The major formations exist toward the mouth and in the bay regions (Figure 3.5).

3.2.5.2. Chapora River:

Chapora River runs about 30 km in length, covering ~ 711 ha of water area. Tidal influence felt up to about 18-20 km from the river mouth (Untawale *et al.*, 1982). The present investigation revealed reduction in mangrove area from 220.1 ha in the year 1997 to 219.3 ha in 2001, with a slight loss of 0.36% of its area. It was further decreased to an area of 218.5 ha in the year 2006 to add 0.38% of its loss. Thus, the total loss in mangrove area between 1997 and 2006 was estimated to be 0.74% (Table 3.10). The mangrove covers about 218.5 ha (~ 30.7%) of the total river area (Table 3.11). Figure 3.6 illustrates the distribution and changes in mangrove habitats in Chapora River.

3.2.5.3. Mandrem and Baga Creeks:

Mandrem and Baga represent relatively very small creeks 3.3 km and 5.4 km in length, respectively. Mangroves occur in narrow fringes. Mangroves of Mandrem creek showed a slight increase (0.01 ha) in area cover from in 1997 (1.18 ha) to 2001 (1.19 ha) and further increased up to 1.20 ha in 2006. The overall increase during last nine years was 0.02 ha (Table 3.10).



Figure 3.6. Distribution and area change of mangroves in Chapora River.

Mangroves of Baga Creek occur in small patches along its banks (Figure 3.7). The satellite imageries showed steep decrease from 6.6 ha in the year 1997 to 5.0 ha in 2001 with a loss of 1.63 ha (24.58%) of its area. However, it was further reduced to 4.48 ha in 2006 with an overall loss of 32.36% during 1997 to 2006 (Table 3.10).

3.2.5.4. Mandovi River:

Mandovi River forms one of the major rivers in Goa. It covers about 5564 ha of water area along its 58 km length. Its tributaries account for an additional 109 km length (Unawale *et al.*, 1982). The estuary is about 3 km wide at the mouth (Aguada Bay) and 0.5 km width towards the upstream (Jagtap, 1985).

Satellite data showed mangrove cover of about 811.1 ha in 1997, which increased by 244.57 ha (30.15%) to cover an area of approximately 1055.7 ha during 2001, and continued to increase further between 2001 and 2006 by 51.47 ha (4.88%). The 2006 mangrove was estimated to an area of about 1107.2 ha. Overall increase in mangrove cover from 1997 to 2006 was found to be approximately 296.1 ha (36.50 %) from 1997 to 2006 (Table 3.10). Major formations were noticed along the river banks, islands (e.g. Chorao and Divar and Vaxim Islands) and subcreeks like Nerul, Mapusa and Rua de Ourem creeks (Figure 3.8).

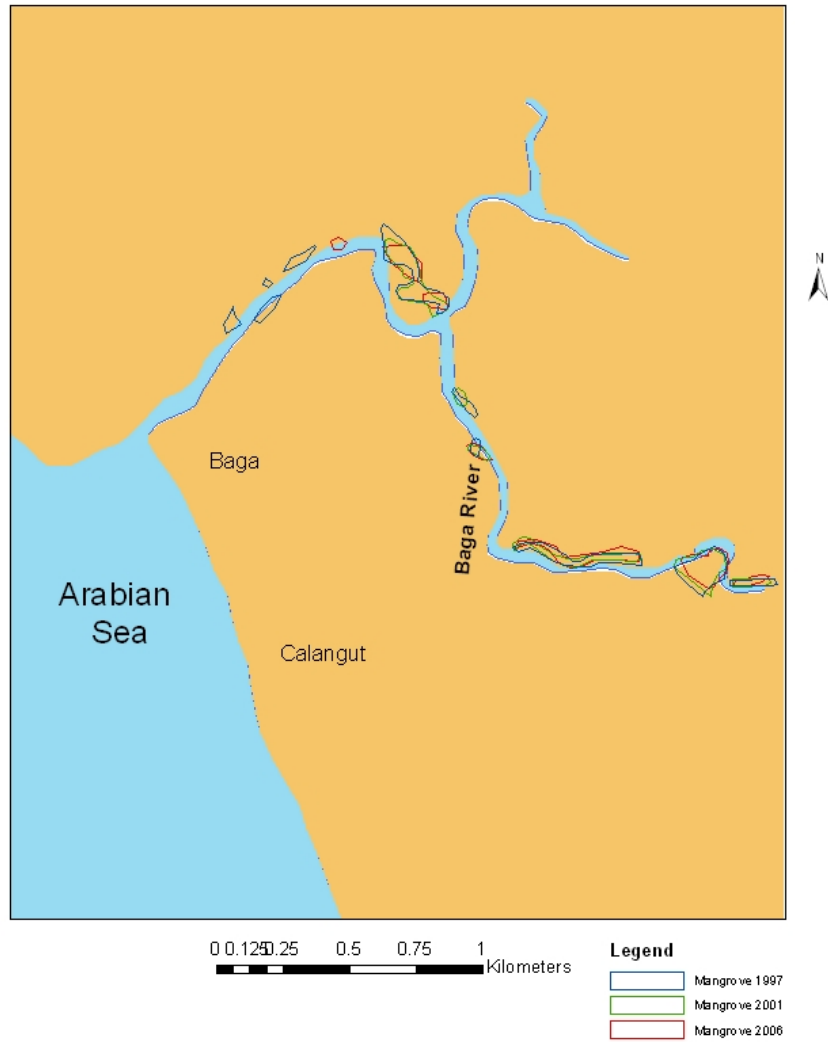


Figure 3.7. Distribution and area change of mangroves in Baga River.

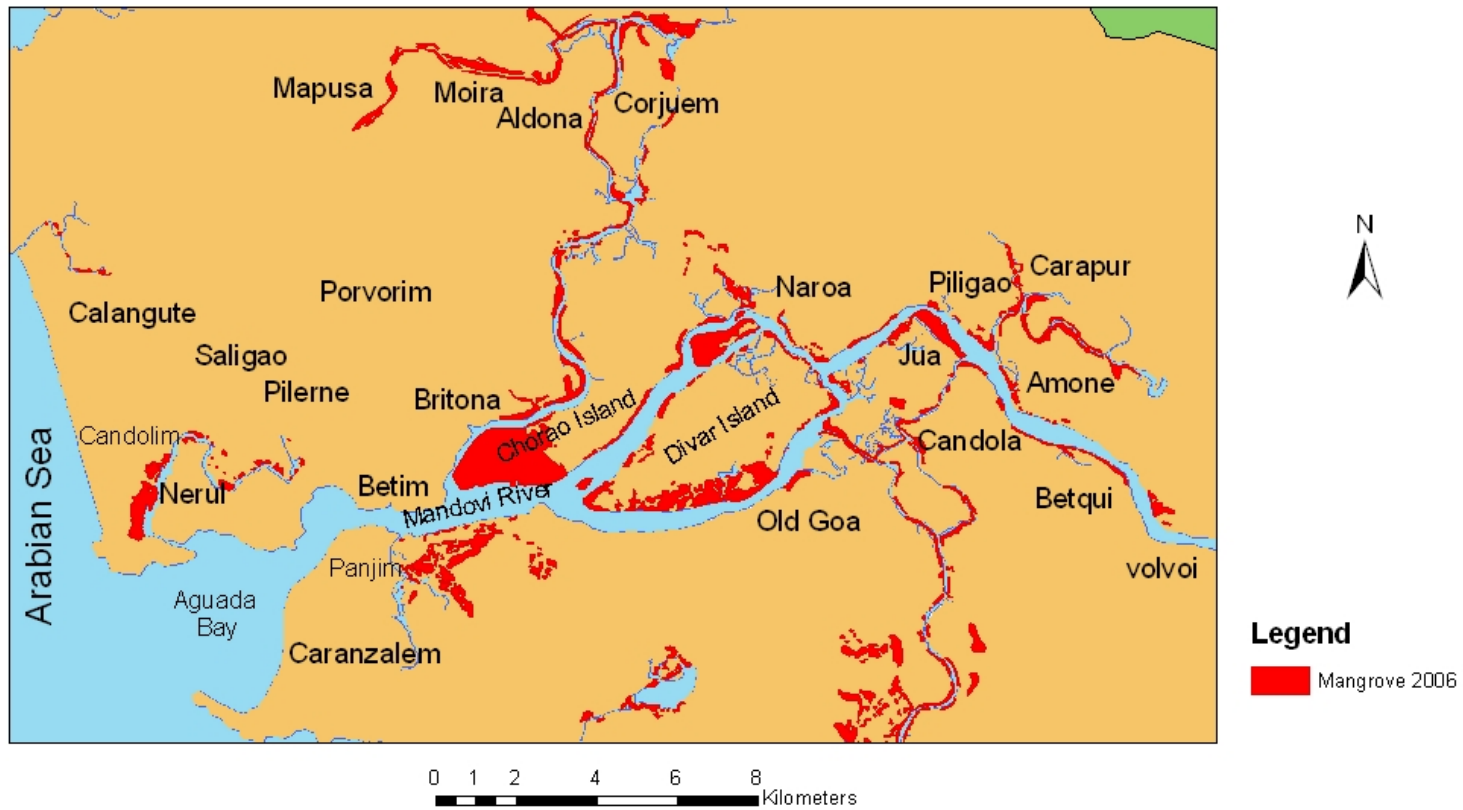


Figure 3.8. Distribution of mangroves in Mandovi River.

3.2.5.5. Zuari River:

Zuari River occupies approximately 5790 ha of water body, along about 145 km stretch of which 64 km is navigable. The estuarine mouth (Marmugao Bay) is about 6 - 7 km wide, while the upstream region narrows down to 0.5 km (Untawale *et al.*, 1982).

Mangrove vegetation cover decreased by 2.54% from about 693.9 ha in the year 1997 to around 676.3 ha in 2001. However, it showed increase of 8.71% accounting to 735.2 ha in the year 2006 (Table 3.10), with overall addition of about 41.3 ha (5.95%) from 1997. Figure 3.9 shows the distribution of mangrove habitats along Zuari River.

3.2.5.6. Cumbarjua Canal:

Cumbarjua Canal is an interconnection between Mandovi and Zuari Rivers, which form what so called “Mandovi-Zuari-Cumbarjua estuarine complex”. Cumbarjua Canal is about 15 km in length and 30 - 40 m in width. It covers about 375 ha of water area (Jagtap, 1985). However, mangrove vegetation found to be of fringing type along both banks of the canal (Figure 3.10). The area of mangrove shows increase by 8.88% from the year 1997 (~ 224.3 ha) to the year 2001 (244.2 ha). The area continued to increase extensively by 40.23% to reach an area cover of 342.4 ha in the year 2006, with overall increase of 52.68% (118.15 ha) (Table 3.10).

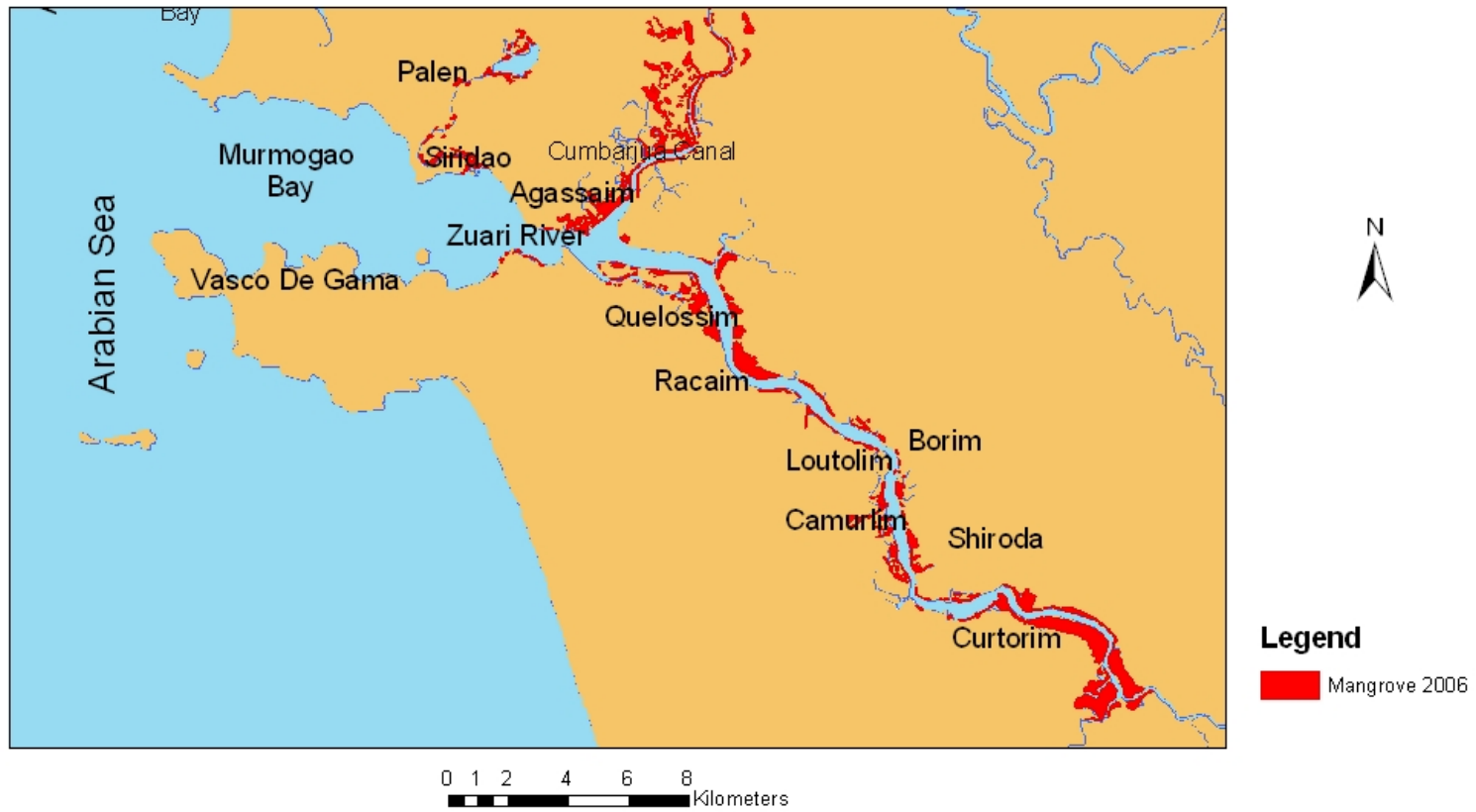


Figure 3.9. Distribution of mangroves in Zuari River.

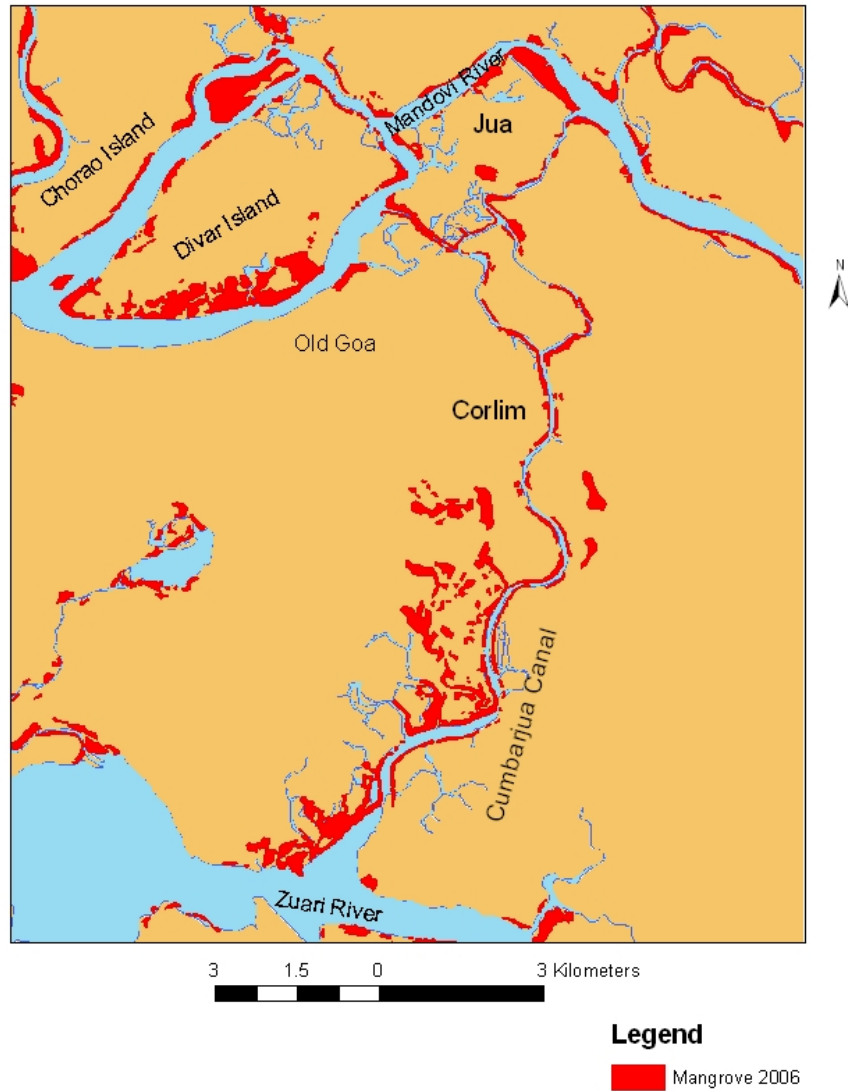


Figure 3.10. Distribution of mangroves in Cumbarjua Canal.

3.2.5.7. Sal River:

Sal River, in southern Goa, has an area of about 302 ha of water body, and it is about 16.13 km in length. The mangrove area decreased from 57.6 ha in the year 1997 to 54.9 ha in the year 2001. The area then increased by 20.78% to 66.3 ha. The results show overall increase by 15.04% (8.67 ha) between the years 1997 and 2006 (Table 3.10). Mangrove vegetation grows in a fringing pattern along the river banks. Figure 3.11 shows the distribution of mangrove in the river Sal.

3.2.5.8. Talpona River:

Talpona River covers about 40 ha of water body. It has a length of 9 km. Mangrove cover did not show much difference in the time lapsed imageries. The area in 1997 were 14.6 ha; it changed slightly to about 14.7 ha in the year 2001 and then decreased to about 14.6 ha in 2006 (Table 3.10). Figure 3.12 shows the distribution of mangrove vegetation in Talpona River.

3.2.5.9. Galgibag River:

Galgibag River covers about 26 ha of water area, with a length of 3.77 km. the mangrove vegetation showed a decrease between the year 1997 and 2006 (Table 3.10). The satellite imageries show an area of about 26.7 ha in the year 1997 which decreased to 22.9 ha in the year 2001. The

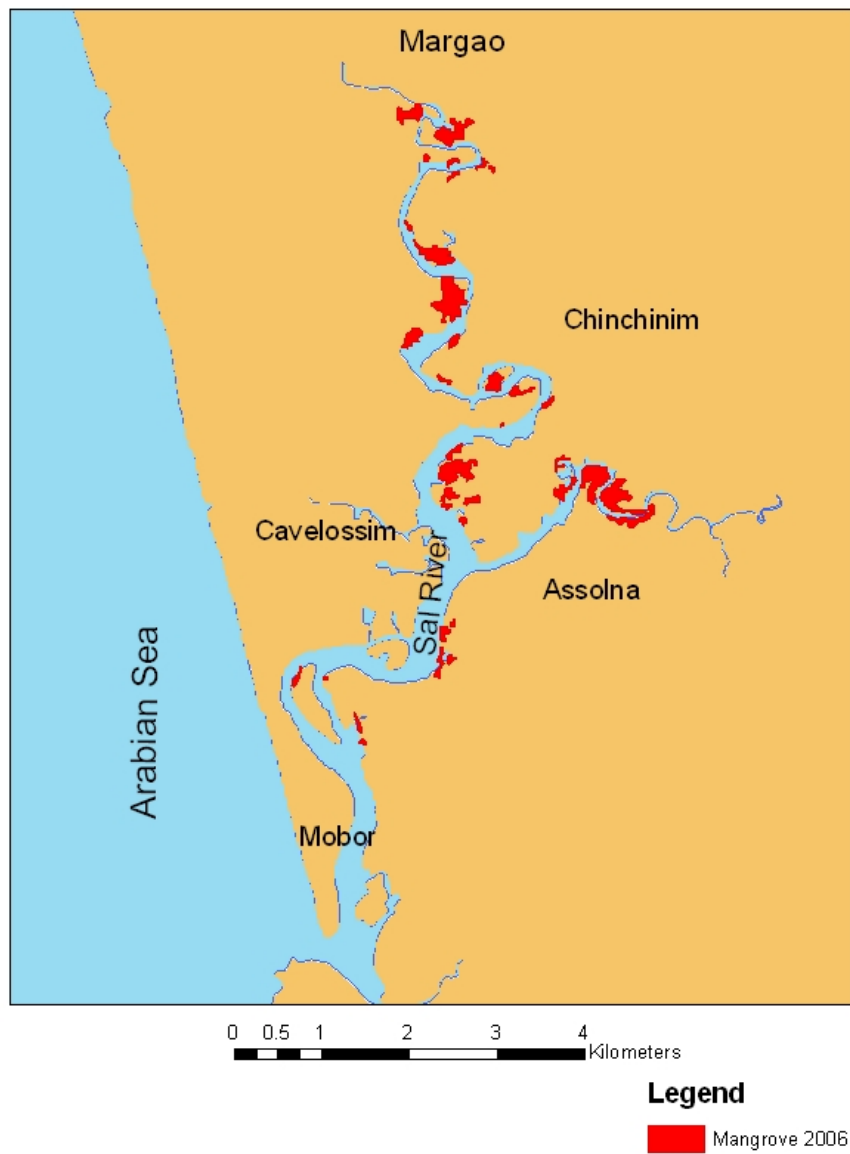


Figure 3.11. Distribution of mangroves in Sal River.

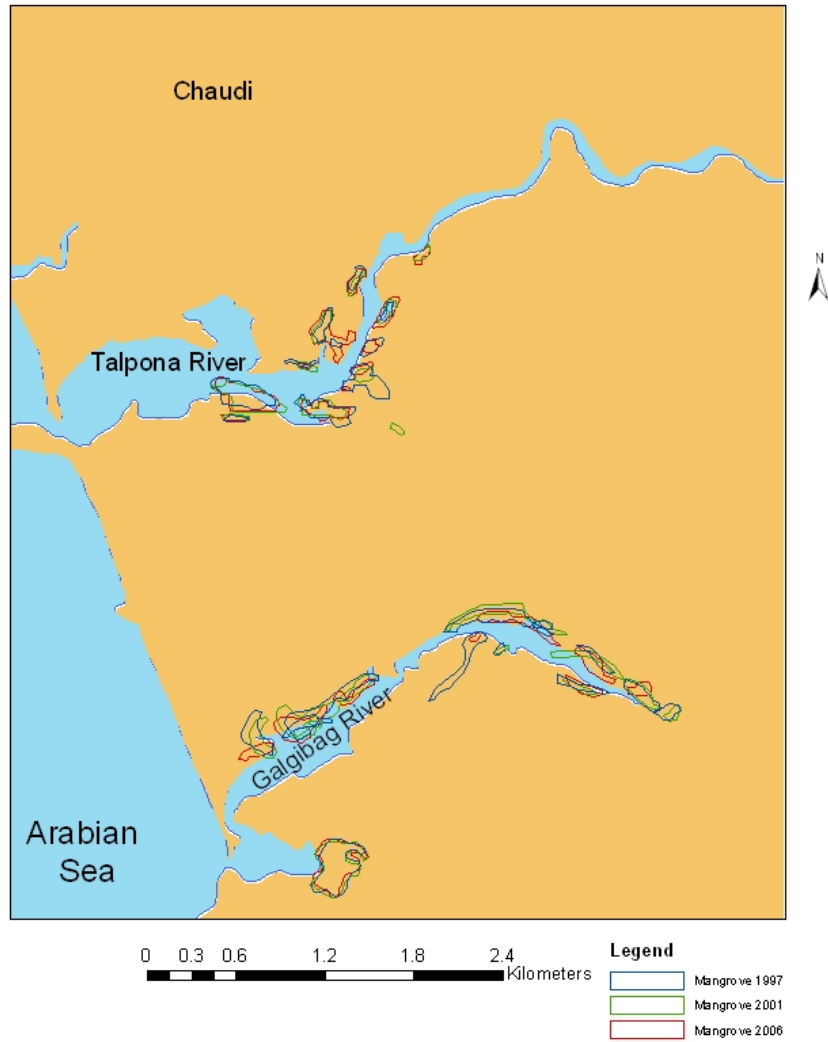


Figure 3.12. Distribution and area change of mangroves in Talpona and Galgibag Rivers.

area decreased further to 18.8 ha in the year 2006. The overall loss in mangrove vegetation between the years 1997 and 2006 was 29.44% (7.86 ha). Figure 3.12 shows the distribution of mangrove vegetation in Galgibag River.

3.3. Discussion:

Mangrove forest is usually characterized by uniform type of evergreen trees and shrubs with habitat being associated with network of meandering creeks, channels, distributaries, coastal lagoons and river inlets. The adequate and constant supply of water makes this unique ecosystem easily identifiable and interpretable by visual observations of satellite imageries. Mangroves ecosystem has been proven to be a good marker for detecting and quantifying short-term changes in the coastal zones (Filho *et al.*, 2006).

Mangroves being evergreen plants; chlorophyll pigments in these plants usually exhibit bimodal peaks. The highest peak could be observed in the months of June - July and the second peak is in the months of November – December (Oswin and Kathiresan, 1994). Therefore, imageries of January / February months were selected for the present studies. The main reason for selecting data of this period is that, the mangroves are in their best conditions of growth and the guarantee of cloud free data with relatively greater clarity in signals. Moreover, the conditions during this particular period are relatively favourable for collecting adequate ground truth data. During monsoon, due to wet condition, a large area of grasses and algal

mats covers mudflats adjacent to the mangrove area. This results in giving signals interfering with the signature from mangrove, making it rather difficult to identify the border (limits) of the mangrove habitats because of the similar tone and texture.

Remote sensing and satellite imageries have limitations such as the difficulty in distinguishing fine ecological divisions between certain vegetation classes (e.g. the border between mangroves and its adjacent ground terrestrial vegetation). However, these limitations could be overcome by conducting adequate ground truth information pertaining to the particular habitat by means of GPS instruments.

False color composite (FCC) generated from the bands (2, 3 and 4) for visual interpretation in identifying the heterogeneous patches distinctly relevant to the various land cover classes. Chlorophyll contents in mangroves reflect high in the Near Infra-Red (NIR) band of the electromagnetic spectrum (Anon, 2003), hence could be distinguished from other land cover types in images with bright red color pixels and smooth texture if they are densely distributed. The sparsely distributed mangrove appears in pinkish red color. Mangrove vegetation is located in the intertidal zone of the back waters and the river banks where the water is brackish. Other vegetation types and herbaceous vegetation could easily be interpreted visually using various interpretation keys (Table 3.1). The alterations in mangrove and other habitats could also be interpreted visually on FCC. However, the FCCs produced of the LISS III Imageries found to

yield the best results bringing out the differences between the mangroves and other land cover classes quite distinctly (Nayak and Bahuguna, 2001).

Analysis of the spectral signatures of reflectance enables to evaluate the spectral separability of different land cover categories. Response patterns of various spectral signatures were studied for each land cover class with the help of reflectance histograms in different bands in the three images. In an optical image, vegetation can be distinguished due to its unique spectral signature. Various kinds of vegetation, including mangroves, produce a high peak in the NIR band and low in the red and green region of spectrum, with reference to the absorption of the chlorophyll. In contrast, water bodies show the lowest reflectance in NIR band and higher reflectance in the visible bands. Other features like built-up land, barren land, mudflats, reclaimed mudflats and sandy beaches give lower reflectance in the NIR band and a greater reflectance in the green band. From the spectral reflectance histogram (Figure 3.1), and the Transformed Divergence Matrix (Tables 3.3, 3.4 and 3.5), it is clearly shown that, in the optical images, vegetation types including mangrove trees can be distinguished due to its unique spectral reflectance from other land cover classes.

During recent past, the mangrove cover from Goa was estimated to be approximately 2,000 ha (Untawale *et al.*, 1982; Jagtap, 1985 and Jagtap *et al.*, 2003). The major mangrove formations (~ 80%) exist along the Mandovi-Zuari-Cumbarjua estuarine complex (Jagtap, 1986). Present observations revealed a total increase of approximately 455.4 ha in

mangrove areas of Goa from 2083.35 ha in the year 1997 to 2538.79 ha in 2006 (~ 22 %). Mangrove habitats showed increase in some of the rivers, whereas it showed decrease in others. Mangrove cover has been predominantly increased along Chapora, Mandovi, Cumbarjua and Sal Rivers (Table 3.12), adding over 538 ha since last three decades; comparing with data of 1973 (Jagtap, 1985).

National Mangrove Committee (NATCOM) was established during 1989 by Ministry of Environment and Forest (MoEF). The major role of NATCOM was to promote protection, conservation, rehabilitation and sustainable management of mangroves. Individual coastal states in the country followed action plans in safeguarding these ecologically sensitive habitats since then. The increase in mangrove areas from the study region may be attributed to conservation and reforestation efforts by the state government. Chorao Island in the Mandovi Estuary was declared as a bird sanctuary in 1987 encompassing more than 187 ha. The State Social Forestry Division has proposed to develop approximately 50 ha of mangrove plantation per year, as follow-up of the National Mangrove Plan for the sustainable management of mangrove resources (Jagtap *et al.*, 2003). The mangrove flora is represented by 15 species (Jagtap, 1993), dominated by *Rhizophora mucronata* Lamk., *Avicennia alba* (Blume) Bathkh, *A. officinalis* L. , *Sonneretia alba* J. Sm. and *S. caseolaris* (L.) Engler. This sanctuary has been witnessing a steady increase in mangrove cover during the past

Table 3.12. Area change in mangrove cover from 1973 to 2006.

Rivers	Area in 1973* (ha)	Area in 2006 (ha)	Area change (%)
Terekhol	30	30.1	+ 0.33
Chapora	100	218.4	+ 118.4
Mandovi	700	1107.2	+ 58.17
Zuari	900	735.4	- 18.29
Cumbarjua	200	342.4	+ 71.2
Sal	30	66.3	+ 121.0
Talpona	20	14.6	- 27.0
Galgibag	20	18.9	- 5.5
Total	2000	2538.8	+ 26.9

(*) Source: Jagtap (1985)

decade, until it reached approximately 242 ha during the year 2006, and contributed about 22.9% of the total area cover of mangrove in the Mandovi estuary (Plate 3.1a and 3.1b).

The zonation of mangroves is mainly influenced by salinity. Mangroves have been found to be distributed in the polyhaline (18 – 30 psu) and mesohaline (5 – 18 psu) zones of estuaries (Jagtap *et al.*, 1993). Limited flora like *K. candel*, *S. caeolaris* and *Heretiera spp.* Occur in the upstream and low salinity zones (0.05 – 5 psu). Mangroves are not much distributed in mouths of the rivers due to strong waves and rocky substrates. Mangrove starts to grow only after the estuarine mouths along the river banks in a fringing pattern despite showing thick and dense population in some areas.

The intertidal expanse of muddy substratum in the some undisturbed areas such as Cumbarjua Canal and river islands, along with feeble wave action and currents, forms suitable features for establishment of mangrove seedlings to grow undisturbed and the habitat to develop further (Plate 3.1c and 3.1d). The present study showed an increase of approximately 52.7% in the mangrove habitat. The increase in mangrove cover in the Mandovi estuary could also be attributed to the reduction in agricultural area adjacent to mangroves due to abandonment of farming activities. Old bonds have been broken and agriculture areas have been infested by mangroves.

Although ground truth data indicated new formations and rehabilitation by

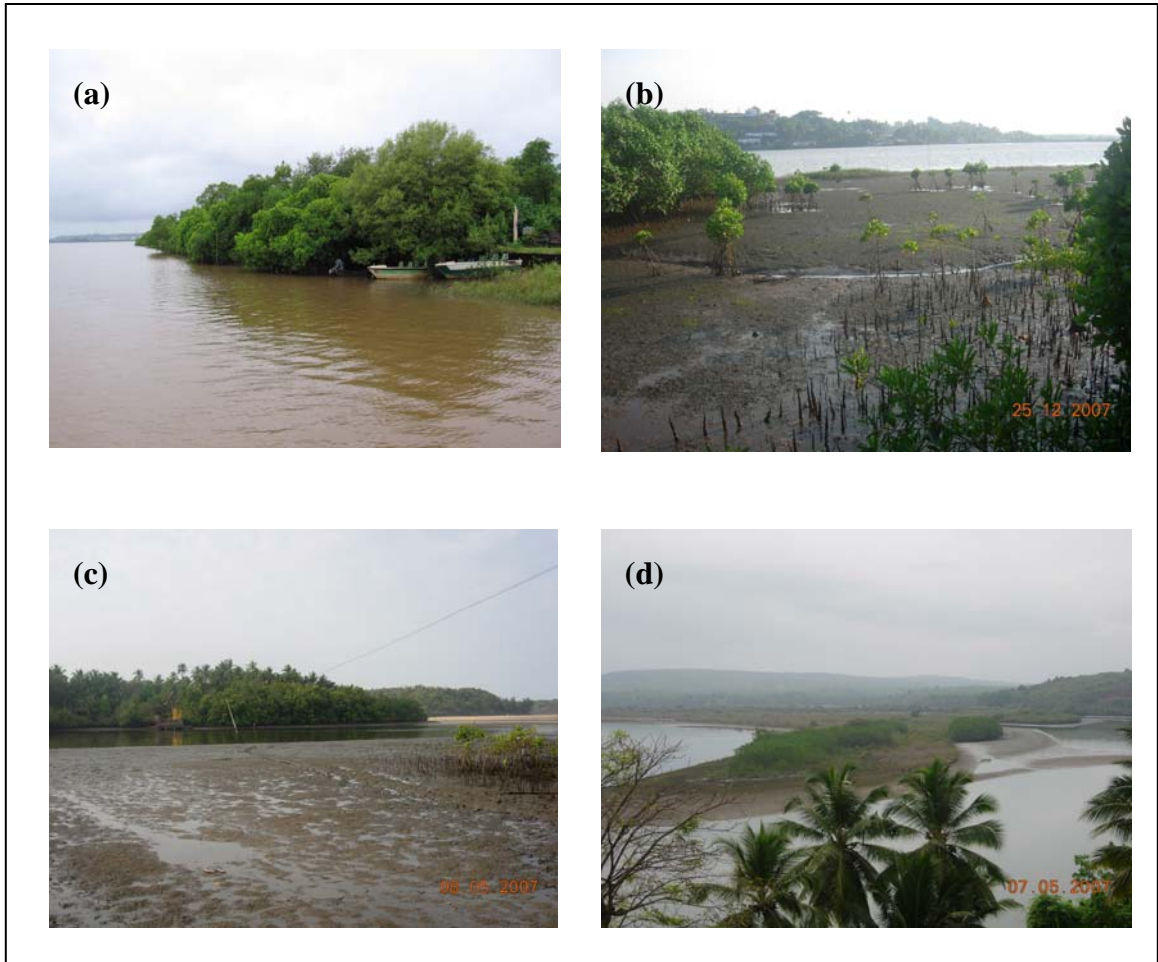


Plate 3.1. (a) & (b) Protected areas, (c) undisturbed mudflats, and (d) isolated river islands, have been contributing in developing mangrove habitats in Goa.

mangrove plantations, loss of mangrove habitats have been also observed in certain localities. Recently, mangrove habitats have been subjected to tremendous pressures from increased anthropogenic activities, particularly land conversion, grazing and habitat fragmentation. The state of Goa, being a tourist destination, is heavily pressurized from economical activities, leading to deterioration of these habitats. The most degraded habitats exist along the Baga creek in North Goa, which is major tourist hub. Baga and Mandrem creeks have been subjected to massive destruction of sensitive habitat due to construction activities relevant to tourism industries, that have been taken place in the area (Nairy *et al.*, 2003), These anthropogenic activities restrict mangroves from developing and expanding their areas. Moreover, tourism-based urbanization (Plate 3.2a and 3.2b), reclamation of mangrove areas for agriculture, mushrooming of saltpans and aquaculture farms in the mangrove areas (Plate 3.2c and 3.2d), illegal felling for firewood, construction of roads and railway tracks (Plate 3.3a and 3.3b), mining activities, construction of buildings and utilization as dumping sites for garbage and construction waste (Plate 3.3c and 3.3d), have caused considerable damage to mangrove habitats in particular locations.

Intensive mining practices during last four decades have resulted in deteriorating terrestrial and marine ecosystems. The increase in open mudflats (Figure 3.3) from the low lying regions influenced by estuaries and backwaters could also be attributed to the intensive contribution of



Plate 3.2. Tourism activities along (a) Mandrem and (b) Baga creeks, and Mushrooming of (c) salt pans and (d) aquaculture ponds adjacent to the mangrove areas are restricting mangrove from growing in of Goa.

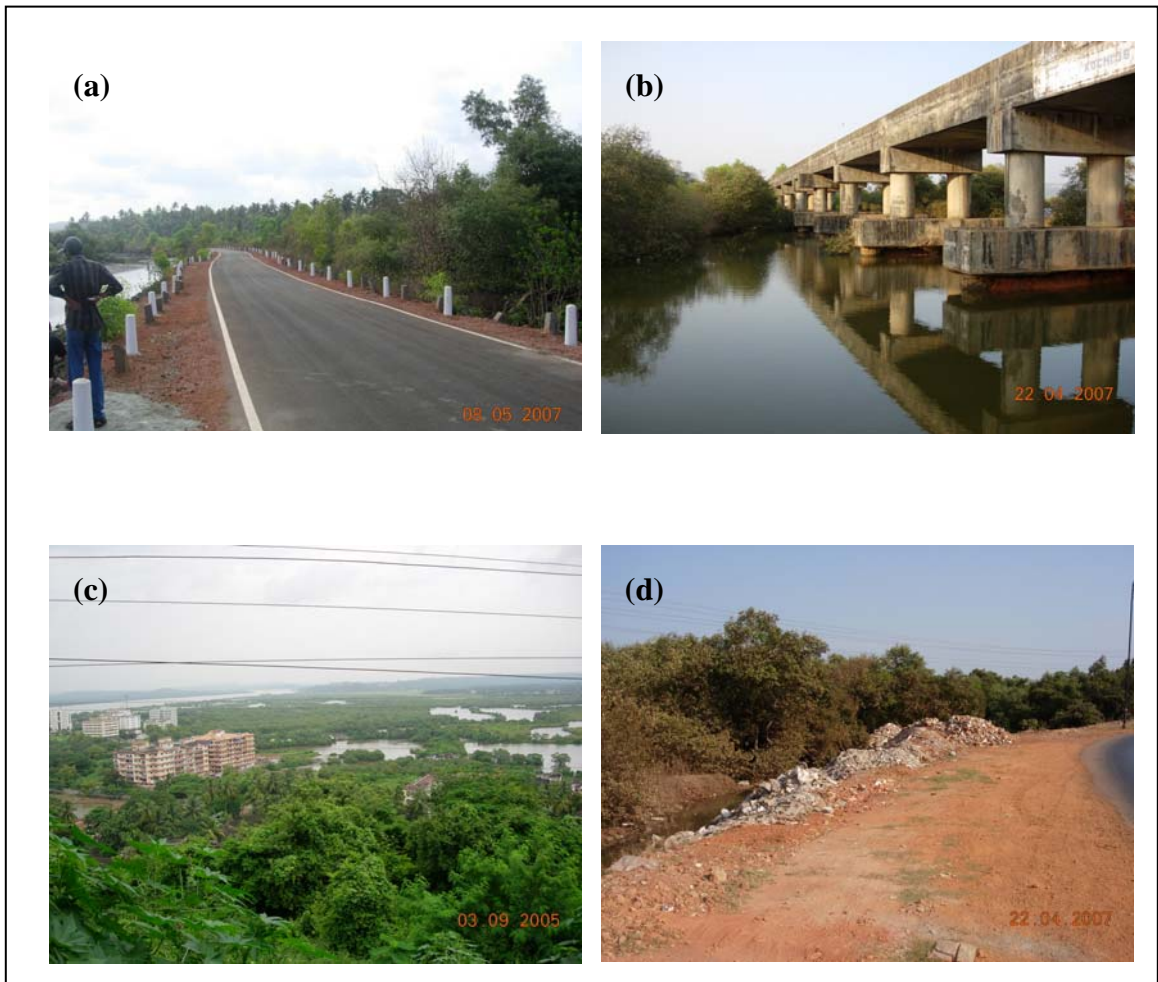


Plate 3.3. Construction of (a) roads, (b) railway tracks, (c) buildings and (d) dumping of construction waste in the mangrove areas of Goa have adversely affected these habitats.

sediments derived from mining and deforestation. In addition to this, heavy rainfall (~ 3000 mm/yr) and steep topography has also lead to severe erosion of topsoil and mining rejects, resulting in shallowing of low-lying wetlands. However, over the period the stabilized mudflat with pioneer vegetation of various algae, *Halophila beccarii* (Aschers) and *Porteresia coarata* (Roxb) Tateoka favours the new formations of mangroves, which helps land building at climax stage during succession (Jagtap, 1985; Untawale and Jagtap, 1999). Ground truth observations revealed that new mangrove formations have been established on recent mudflats between the existing mangroves and open mudflats along the waterways.

Mangroves have shown steady increase in their areas during past three decades (Figure 3.13), indicating improvement and healthy situation compare to other ecosystems such as sand dunes from the state (Table 3.9). Increase in local and migratory human population and their demands, for urbanization and infrastructure, is constantly pressurizing low laying areas, particularly marine wetlands. Considering ecological and socio-economic significance of mangrove, the limited distribution and issue of global warming and sea level rise, a top priority of the state should be conserving ecological sensitive marine habitats (ESMH). Strict implementation of Coastal Regulatory Zone (CRZ) Act and judicious development within the carrying capacity of the state would greatly help in

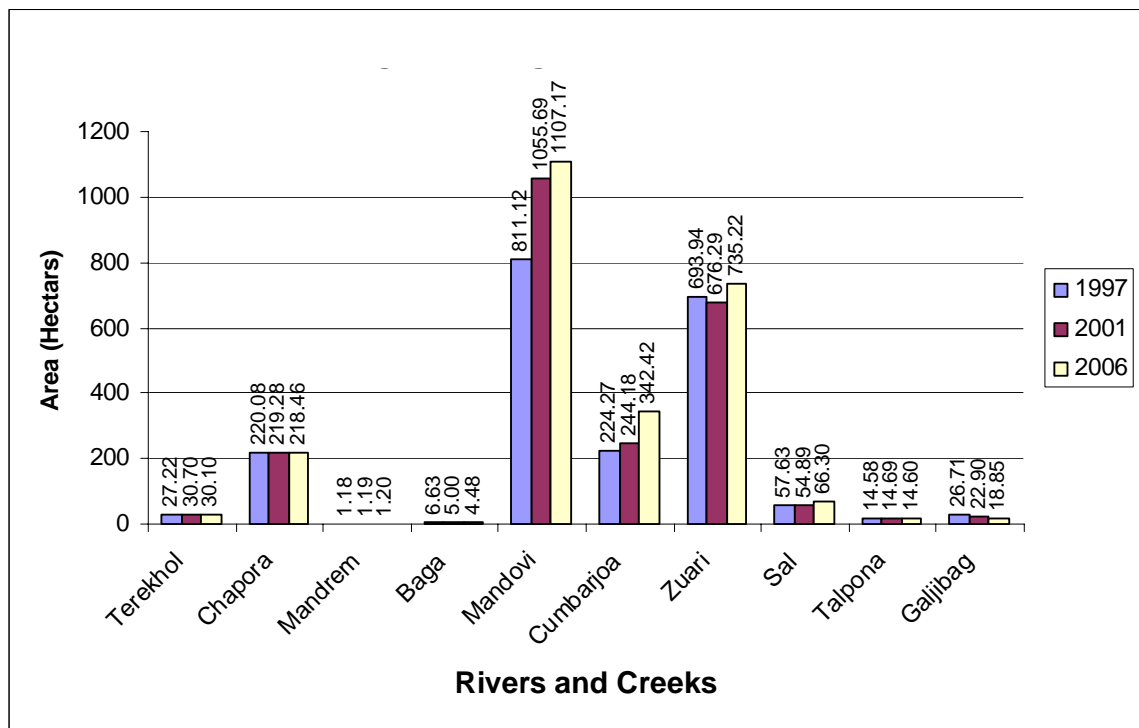


Figure 3.13. Changes in mangroves areas in the rivers of Goa.

saving loss of natural habitats.

The present study would be of help to contribute towards effective and sustainable management of ESMH, particularly mangroves. Data generated on the distribution of these mangroves will help in decision-making and ecosystem restoration, which is of prime importance for ecosystem functioning and sustainability.