Chapter 5 Result and Discussion

This chapter describes and discusses the findings of land use land cover mapping and its change detection, the diversity of coastal vegetation, the phytosociological aspects of mangroves, the geomorphological characteristics and the analysis of coastal sediments.

5.1 MAPPING OF LAND USE AND LAND COVER CATEGORIES AND CHANGE DETECTION

Land use land cover pattern of any region is an outcome of the natural and socio-economic factors and their utilization by man in time and space (Bhagawat, 2005). The land use land cover maps are crucial for managing the natural resources and monitoring environemntal changes (Muttitanon and Tripathi, 2005). The land use land cover categories observed in Jambusar, Vagra, Hansot and aliabet and their areal extent has been described separetely in the successive text.

5.1.1 LAND USE LAND COVER MAPS OF JAMBUSAR TALUKA

The maps of Jambusar taluka were prepared from the topographic sheets and from the satellite images for the year 1978, 2000 and 2012. The base map was prepared from topographic sheets published during 1973-77. Jambusar taluka comes under the topographic sheet numbers 46B/8, 46B/12, 46B/16, 46C/9 and 46C/13.This map was used as base map to understand the various land use and land cover categories of Jambusar. Plate 5.1 depicts land use land cover map of Jambusar taluka prepared from them. The map shows various categories such as mudflat, shoal, mangrove, various types of water bodies, habitation, agricultural land and industrial area. Agriculture was the major land use of the taluka which covered 59.37% of total area. This was followed by the mudflat category (21.12%) which included mudflats (barren) as well as shoal categories. The built-up area categories such as habitation and industrial area covered an area of 0.87% and 0.01% respectively. In the topographic sheets brick kilns shown near Jambusar village were considered as industrial area. The areal extent of each of these categories in terms of hectare is given in Table 5.1.

The land use land cover maps for the year 1978, 2000 and 2012 are represented in the Plate 5.2, 5.3 and 5.4 respectively. The contribution of the major categories (Level 1 classification) in terms of percentage is given in the Table 5.2. Throughout the time series, agriculture was the major land use category. This was followed by the coastal wetland category, water body, scrub, built-up land and barren land category. It is important to note here that the industries developed in the mudflat area were included under the built-up category.

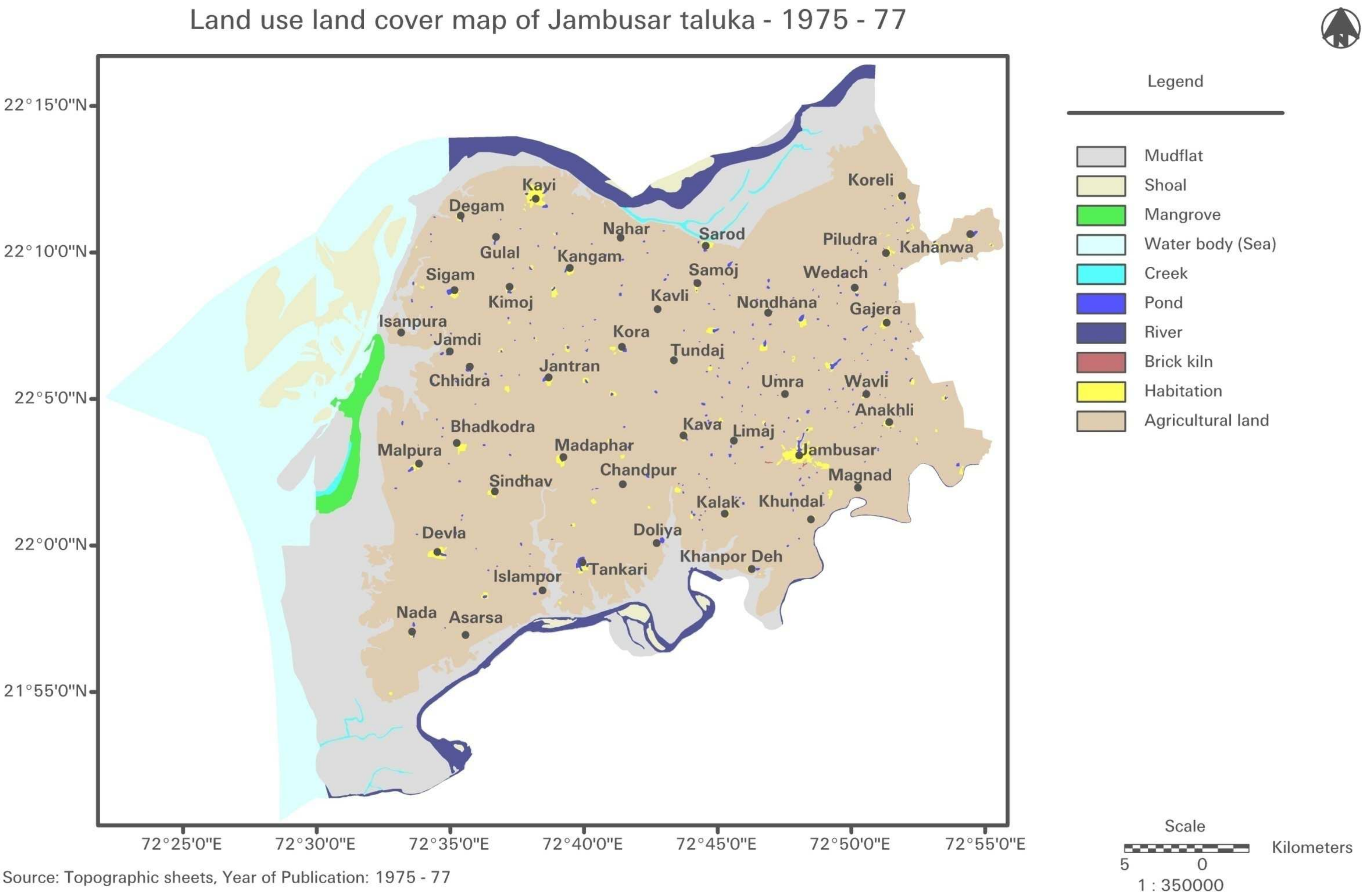
Class name	Area (in ha)
Mudflat	25171.09
Shoal	5139.43
Mangrove	1192.87
Water body (Sea)	19881.59
Creek	512.36
Pond	550.08
River	4602.50
Brick kiln	8.13
Habitation	1255.37
Agriculture land	85198.82
Total area	143512.24

Table 5.1 Area covered by various land use land cover categories demarcated from topographic sheets of Jambusar

	Year		
Categories	**1978**	**2000**	**2012**
	(Area in %)		
Coastal wetland	25.11	19.20	21.37
Water body	20.70	21.43	18.21
Barren land	1.17	1.03	1.02
Scrub	1.84	4.78	4.50
Built-up land	0.37	2.23	4.48
Agriculture land	50.81	51.34	50.43

Table 5.2 Distribution of major land use land cover categories of Jambusar taluka across different years

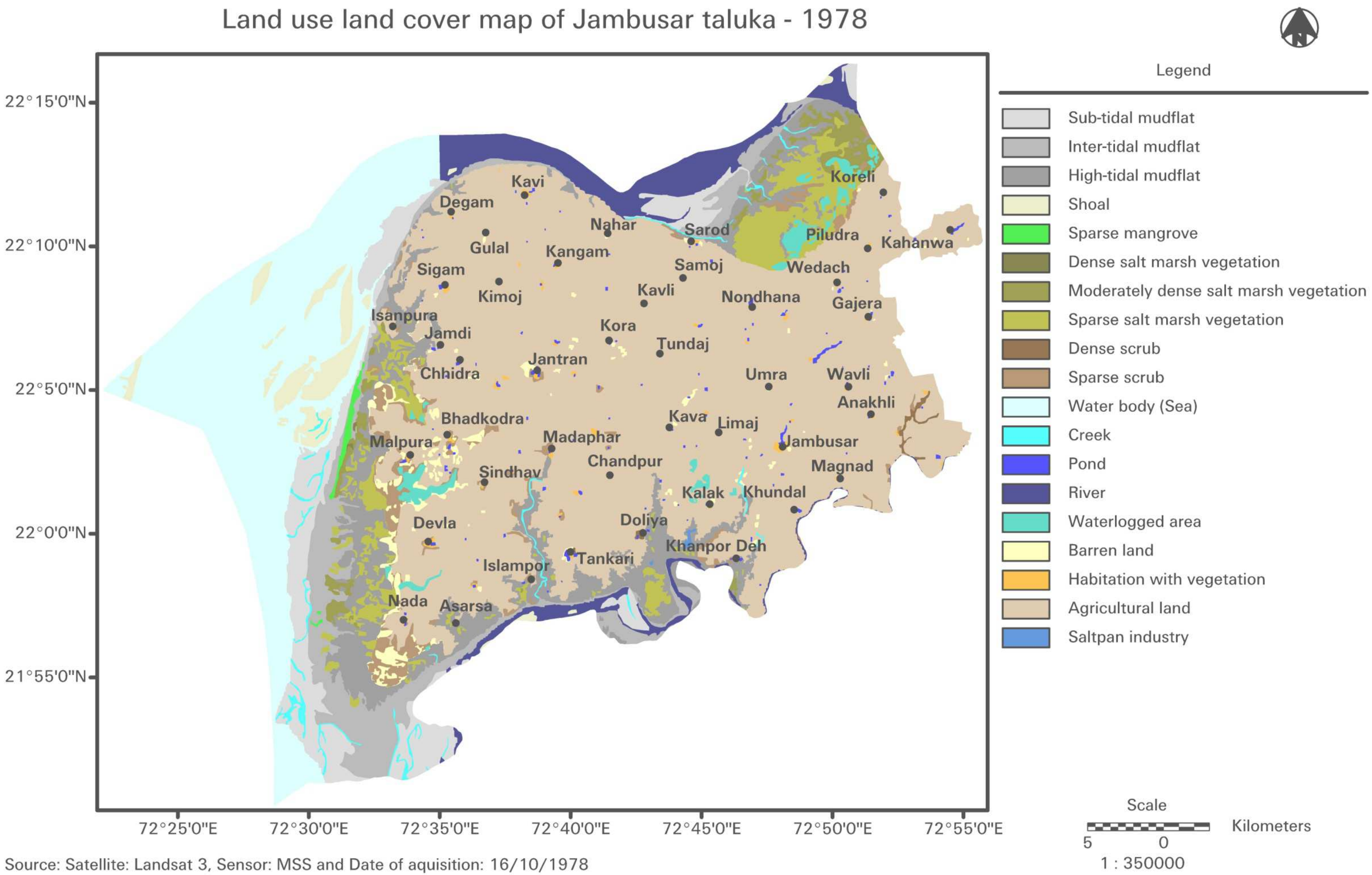
Land use land cover map of Jambusar taluka - 1975 - 77



Source: Topographic sheets, Year of Publication: 1975 - 77

Plate : 5.1

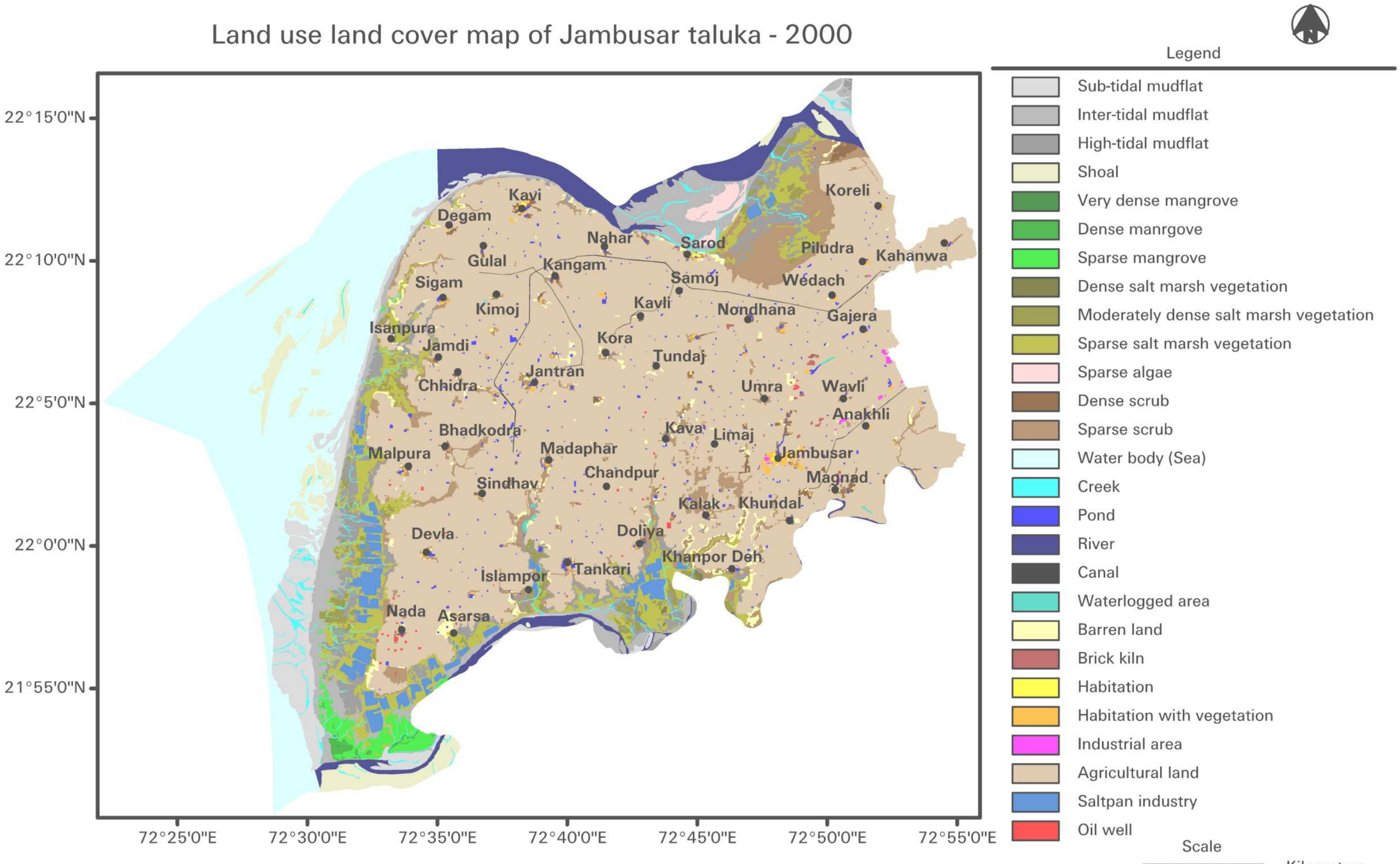
Land use land cover map of Jambusar taluka - 1978



Source: Satellite: Landsat 3, Sensor: MSS and Date of aquisition: 16/10/1978

Plate : 5.2

Land use land cover map of Jambusar taluka - 2000

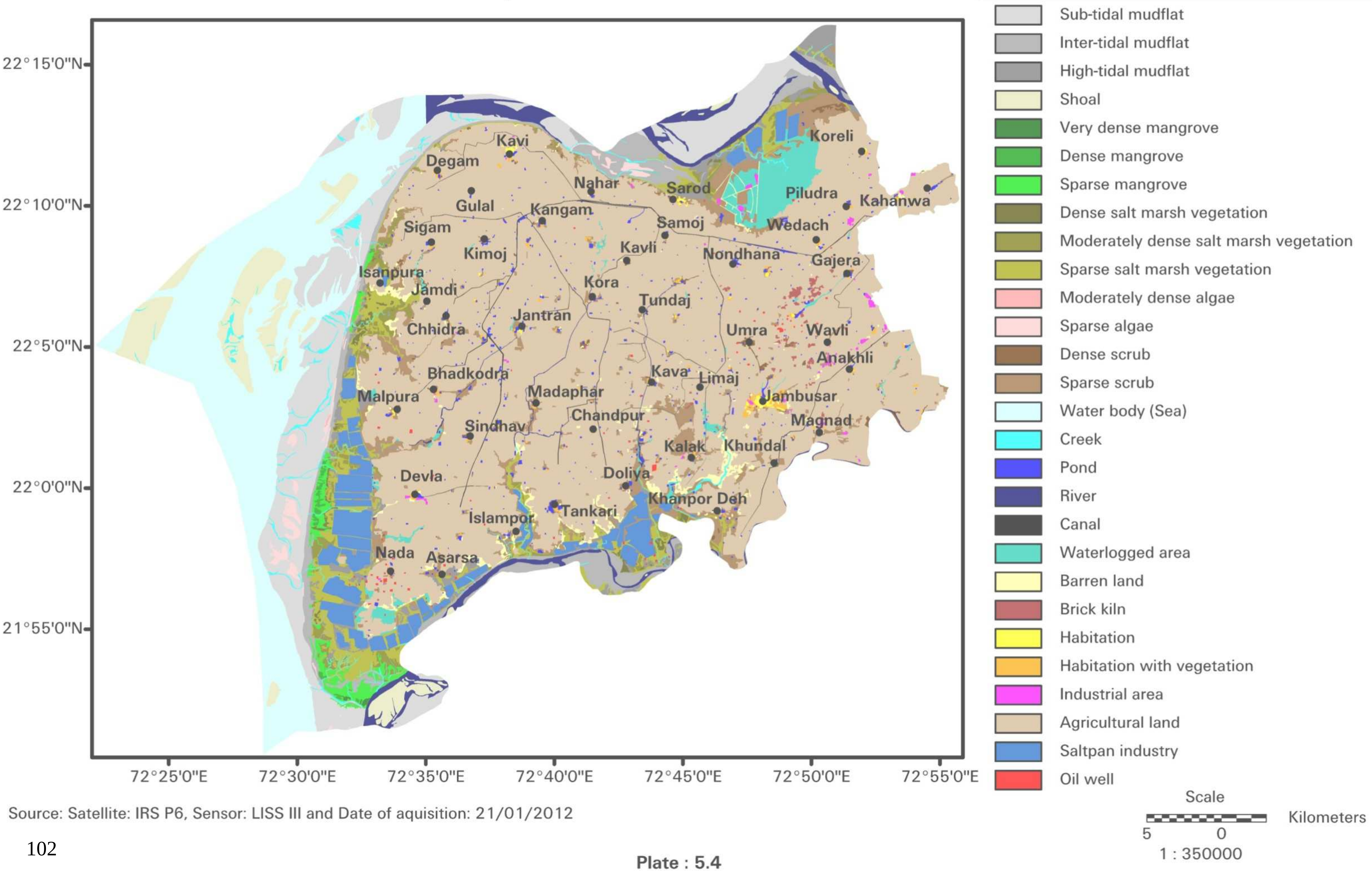


Scale
Kilometers
5 0
1 : 350000

Source: Satellite: Landsat 5, Sensor: TM and Date of aquisition: 20/03/2000

Plate : 5.3

Land use land cover map of Jambusar taluka - 2012



Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 21/01/2012

Plate : 5.4

5.1.1.1 Trend in Areal Extent of Different Land Use Land Cover Categories From 1978-2012

A. Coastal wetland: Mudflats (sub-tidal, inter-tidal and high-tidal), shoal, mangrove, salt marsh vegetation, algae were the coastal wetland categories observed in present study. Variation in these categories has been discussed below.

A.1 ***Mudflat:*** Based on the presence or absence of vegetation or any man-made features it was divided in to barren mudflats, vegetated mudflats and mudflats taken up by the various industries. The areal extent of these categories is represented graphically in Figure 5.1. The graph shows a continuous increase in the industrial activity in the mudflat area. Details of industrial activities thriving in the mudflat area have been discussed under the built-up area category. Different tidal condition of the satellite images was one of the reasons for the variation in the areal extent of barren mudflats.

A.1.1 *Barren mudflat:* Mudflats not covered by any vegetation and devoid of industrial activities were included under this category. It included the sub-tidal mudflat, inter-tidal mudflat, high-tidal mudflat and shoal categories. Among these the inter-tidal and high-tidal mudflats showed reduction whereas sub-tidal mudflat and shoal showed increase in the areal extent (Figure 5.2). The growth of mangroves in the inter-tidal mudflat and growth of industries in the high tidal mudflats were the major reasons for this change. A much lower low tide image and the resultant greater extent of sub-tidal mudflat and shoal was the major reason for the increase in the barren mudflat in 2012.

A.1.2 *Vegetated mudflat:* Mangrove, salt marsh and algae were the vegetation types observed on the mudflat. Algal vegetation was mostly restricted to the sub-tidal mudflat and partly to the inter-tidal mudflats. Algal growth is seasonal and flourishes during November-March. After this period, with increase in the temperature, its extent reduces. As satellite images of 2000 and 2012 belonged to the month of March and January respectively, this could be the possible reason for the increase in algal cover. Mangrove flourishes well in the inter-tidal mudflat and partly on the high-tidal mudflat whereas salt marsh vegetation is generally found in the high-tidal area. The mangrove vegetation was represented by a single species namely, *Avicennia marina*.

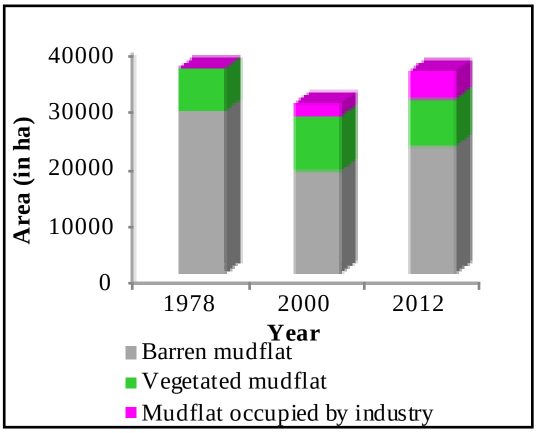


Figure 5.1 Area covered by barren mudflats in Jambusar

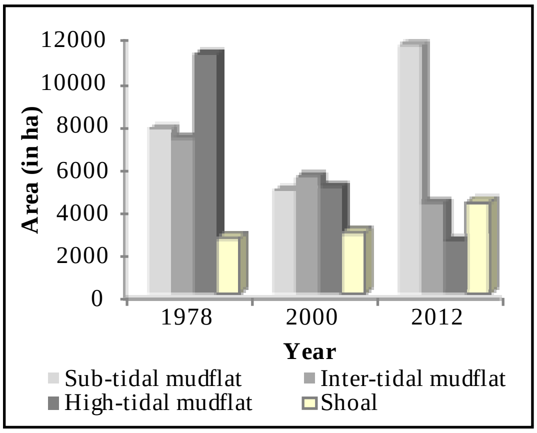


Figure 5.2 Area covered by different barren mudflat categories in Jambusar

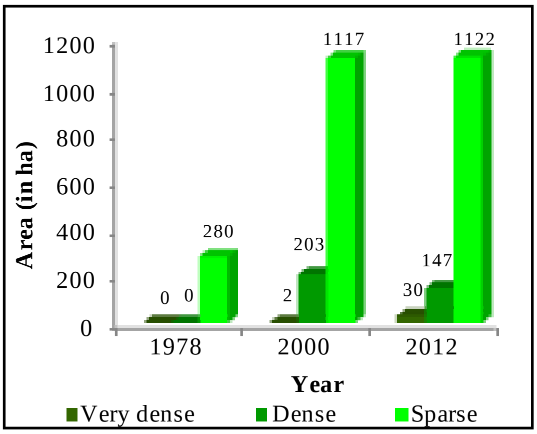


Figure 5.3 Areal extent of mangrove in Jambusar

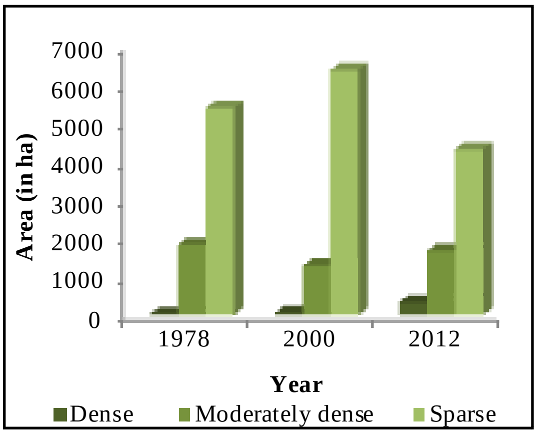


Figure 5.4 Areal extent of salt marsh vegeation in Jambusar

Mangrove patches were found to the west of Jamdi as well as Devla and to the south west of Nada village whereas salt marsh vegetation was observed along the entire coastline of Jambusar. Figure 5.3 shows increase in the mangrove and whereas Figure 5.4 shows the variation in extent of salt marsh vegetation from 1978-2012. The algal vegetation shows the increase in the area (Figure 5.5).

B. Scrub: This category was widely distributed and was present near wetlands, water bodies and agricultural ares. It mostly included area covered with *Prospois juliflora* vegetation. Major scrub patches were found to the east of Sarod village (near waterlogged area), along the coastaline of Nada village and around Kalak village. This category showed increase in the area from 1978-2000 and little drop in the year 2012 (Figure 5.6).

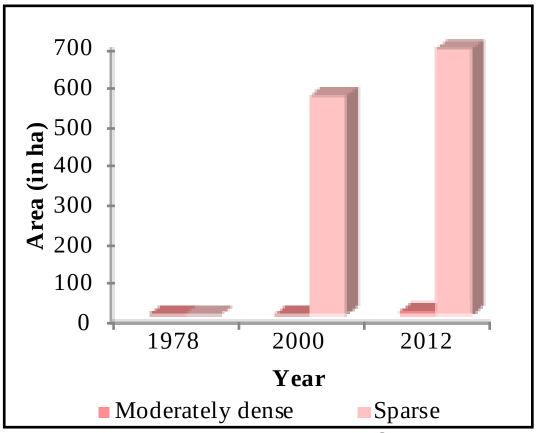


Figure 5.5 Areal extent of algae in Jambusar

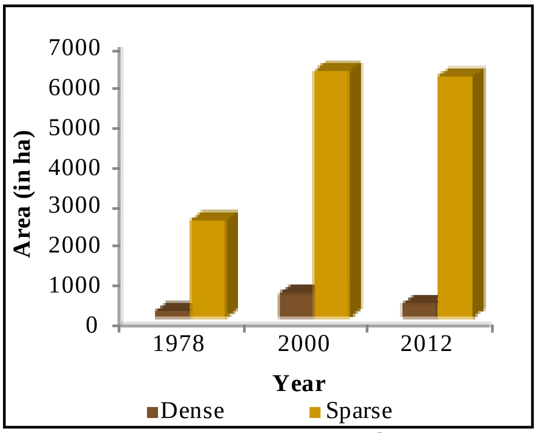


Figure 5.6 Areal extent of scrub in Jambusar

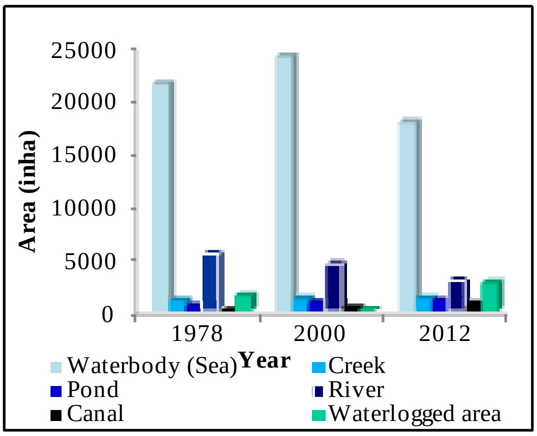


Figure 5.7 Area covered by different types of water bodies in Jambusar

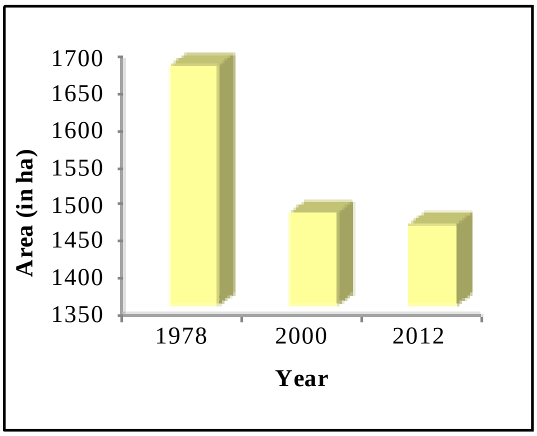


Figure 5.8 Area of barren land in Jambusar

C. Water bodies: It includes natural water bodies like sea, creek, pond and waterlogged area and man-made water bodies like canals and pond. The area occupied by each of this is shown in Figure 5.7. The graph shows an increasing trend in the areal extent of pond as well as canal network of the taluka.

D. Barren land: The areal extent of this category shows a decreasing trend and is graphically depicted in Figure 5.8.

E. Built-up land: In Jambusar habitation and industrial area were the categories observed.

E.1 ***Habitation:*** This taluka showed overall increase in the habitation (Figure 5.9). The map for the year 1978 has been prepared from an MSS image. This sensor has a resoulution of 79m and hence it was difficult to separate pure habitation patches from habitation with vegetation. Thus the map of 1978 only showed the habitation with vegetation category.

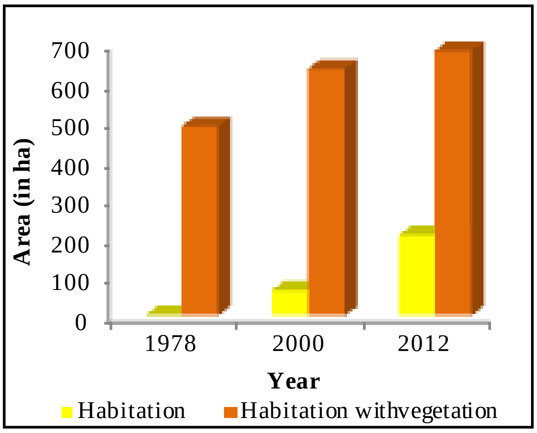


Figure 5.9 Area of habitation in Jambusar

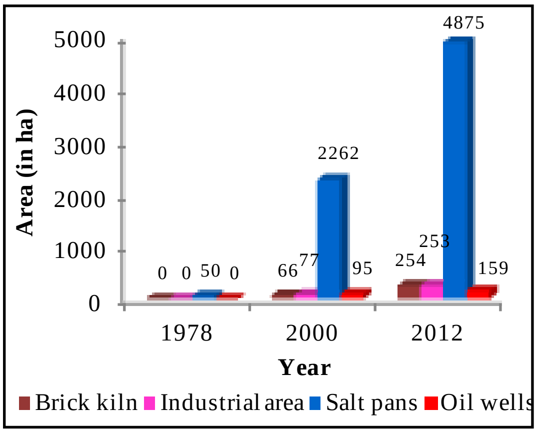


Figure 5.10 Area occupied by various industries in Jambusar

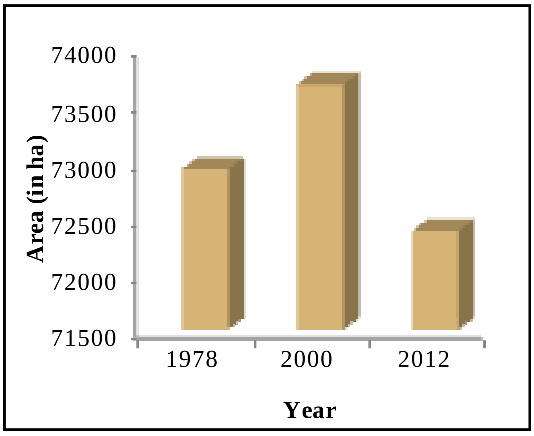


Figure 5.11 Area of agricultural land in Jambusar

E.2 ***<u>Industrial area:</u>*** The industrial area in Jambusar were classified in to saltpan, oilwell (including exploratory site of the oil or natural gas), brick kiln and land based industries. The industries were grouped in to two categories viz., sea-based and land-based industries. Salt pan was the only sea-based industry in Jambusar. The sea dependent industries had occupied the mudflat area (along the entire coastal stretch) where as land based industries had taken up the land area. Oil wells were found in the mudflat as well as in land area. The land based industries were more concentrated in the north of Jambusar (especially along Padra- Jambusar main road/ highway) and in the east of Sarod (Sterling SEZ zone). The brick kilns were restricted between Gajera and Jambusar villages. Oil wells had spread throughout the taluka but their numbers were noticeable in the south of Nada village and in the mudflat area in the south of Asarsa and Doliya villages. Figure 5.10 shows the area covered by various industries present in Jambusar.

F. Agriculture land: Figure 5.11 shows the areal extent of agricultural land in Jambusar taluka. It covered the maximum areal extent among all categories and showed variation over the study period.

5.1.1.2 Accuracy Assessment

Overall accuracy and Kappa statistics were calcultaed for the maps generated from the satellite image. Accuracy assessment was carried out using the method described earlier. The values of overall accuracy and Kappa statictics are given in the Table 5.3.

Year	Overall accuracy	Kappa Statistics
1978	96.00	0.9055
2000	93.00	0.9046
2012	92.00	0.8760

Table 5.3 Accuracy statistics for Jambusar taluka

5.1.1.3 Change Detection of Jambusar Taluka

Change detection was carried out using two sets of data, from 1978 to 2000 and from 2000 to 2012. The change detection process results in large number of change classes. The numbers of change classes formed for Jambusar were 374. Such a large number of categories and their transformation from one to another resulted in a complex map. The complexity of these “from- to” categories observed in the present study has been graphically represented in the Figure 5.12. To minimize the complexity and to highlight the changes in the mangroves and industrial area only, the change detection analysis was restricted to these categories.

***Mangrove Change Analysis*:** To understand changes in mangroves area they were grouped in to three major categories viz., mangrove improvement, mangrove degradation and no change in mangrove vegetation. The improvement in mangrove could be due to conversion of mudflat to mangrove, density wise improvement (sparse mangrove to dense mangrove; dense mangrove to very dense mangrove), salt marsh vegetation to mangrove or water body to mangrove category. Whereas degradation of mangrove could be due to conversion of mangrove to mudflat, density wise degradation, mangrove to salt marsh vegetation, mangrove to water body or mangrove to industrial area. No change category corresponds with the area in which the mangrove remains unchanged even in terms of density. Plate 5.5 and 5.6 shows the change in mangrove vegetation from 1978-2000 and from 2000-2012 respectively. The details of change or no change in the areal extent of mangroves is given in Table 5.4.

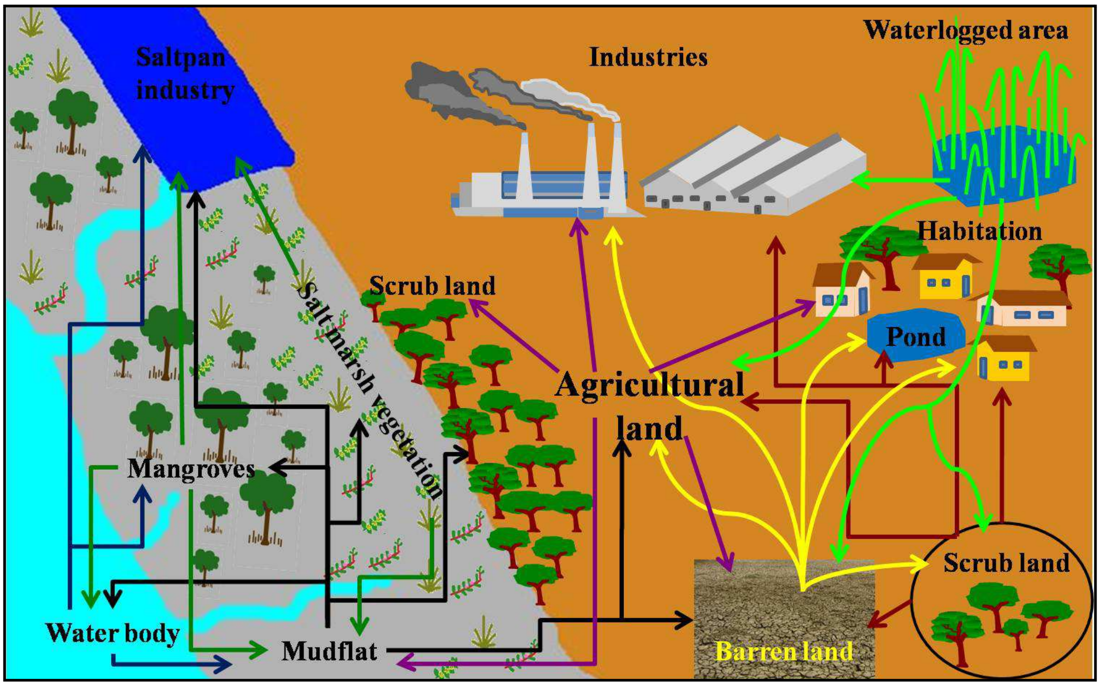


Figure 5.12 Conversion of categories "From-To" observed in the present study (the arrows indicated the direction of change)

The mangrove cover in Jambusar showed an improvement during 1978-2000 while a small drop was observed in the period of 2000-2012. In the year 1978, only a small patch of mangrove was present which increased considerably in its areal extent over a period of time. The conversions of vast area of barren mudflats and considerable amount of water body to mangrove area were major reasons for the improvement of mangrove area. The degradation of mangrove was due to conversion of mangrove to either mudflat area or to the salt marsh vegetation. In addition to this, in 2000-2012 considerable amount of mangrove patch was converted to water body, indicating the high rate of erosion prevailing in the taluka. The conversion of the water body to mangrove area and conversion of mangrove to water body was largely due to the change in the flow of the river Dhadhar in the last 34years. It is important to note here that although there was considerable developmental activity in the mudflat area, but they had not disturbed the mangrove vegetation till the year 2012. Thus, in Jambusar taluka the degradation of the mangrove area observed during the period 1978-2012 was mostly because of the natural factors.

Change in the industrial area: The industries that developed in Jambusar were salt pan industry, land based industry, brick kilns and oil wells. Plate 5.7 and 5.8 shows the categories converted to industrial area either from mudflat area or from land area. The extent of changes in cover to industry is given in Table 5.5.

Among these industries, salt pan industry had the highest cover. This industry flourished well during 1978-2000 and even during 2000-2012. The categories and their areas which were converted to saltpan industry during 1978-2000 and 2000-2012 are given in Figure 5.13 and 5.14 respectively. During the period of 1978-2000, mostly barren mudflat area and salt marsh vegetation to a small extent were converted to saltpans. The changes from 2000-2012 were however different. Once, the mudflats (barren as well as vegetated) were taken up by the saltpan industry, the further expansion of the industry was at the cost of scrub vegetation present in the mudflat area and by reclaiming the creeks. Even the barren land, waterlogged area present near by the saltpan industry and in some cases a part of agricultural land were taken up by the saltpan industry.

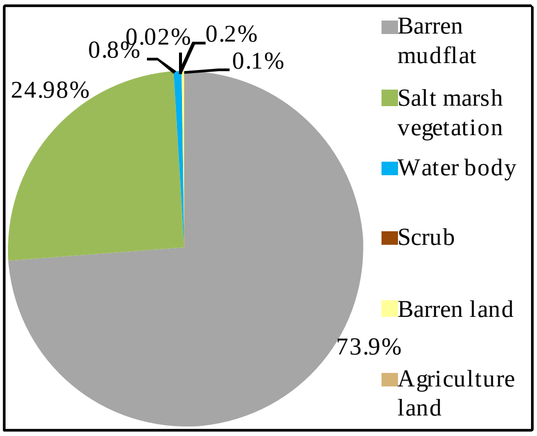


Figure 5.13 Categories converted to saltpan industry during 1978-2000

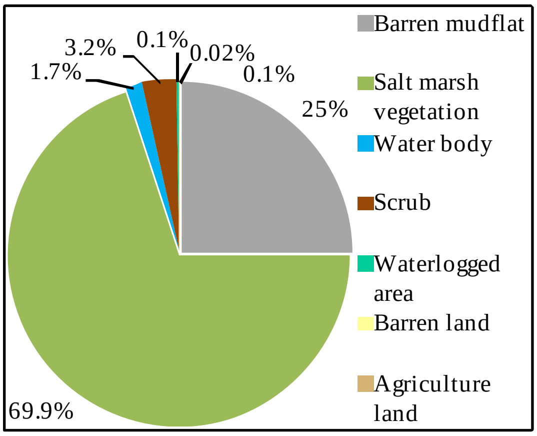


Figure 5.14 Categories convereted to saltpan industry during 2000-20012

Brick making (brick kiln) was an industry whose expansion was restricted to land area. The development of this industry was at the cost of scrub, barren and agricultural land. Three times more area was converted to this category during 2000-2012, as compared to 1978-2000. This was one of the fast growing industries in the area and occupied an area almost equal to other land based industries.

Land based other industries: This category resulted from the conversion of agricultural, scrub, barren and waterlogged area. Mudflat areas near Sarod village were reclaimed and converted to this category. The area occupied by this category more than double during 2000-2012 as compared to 1978-2000.

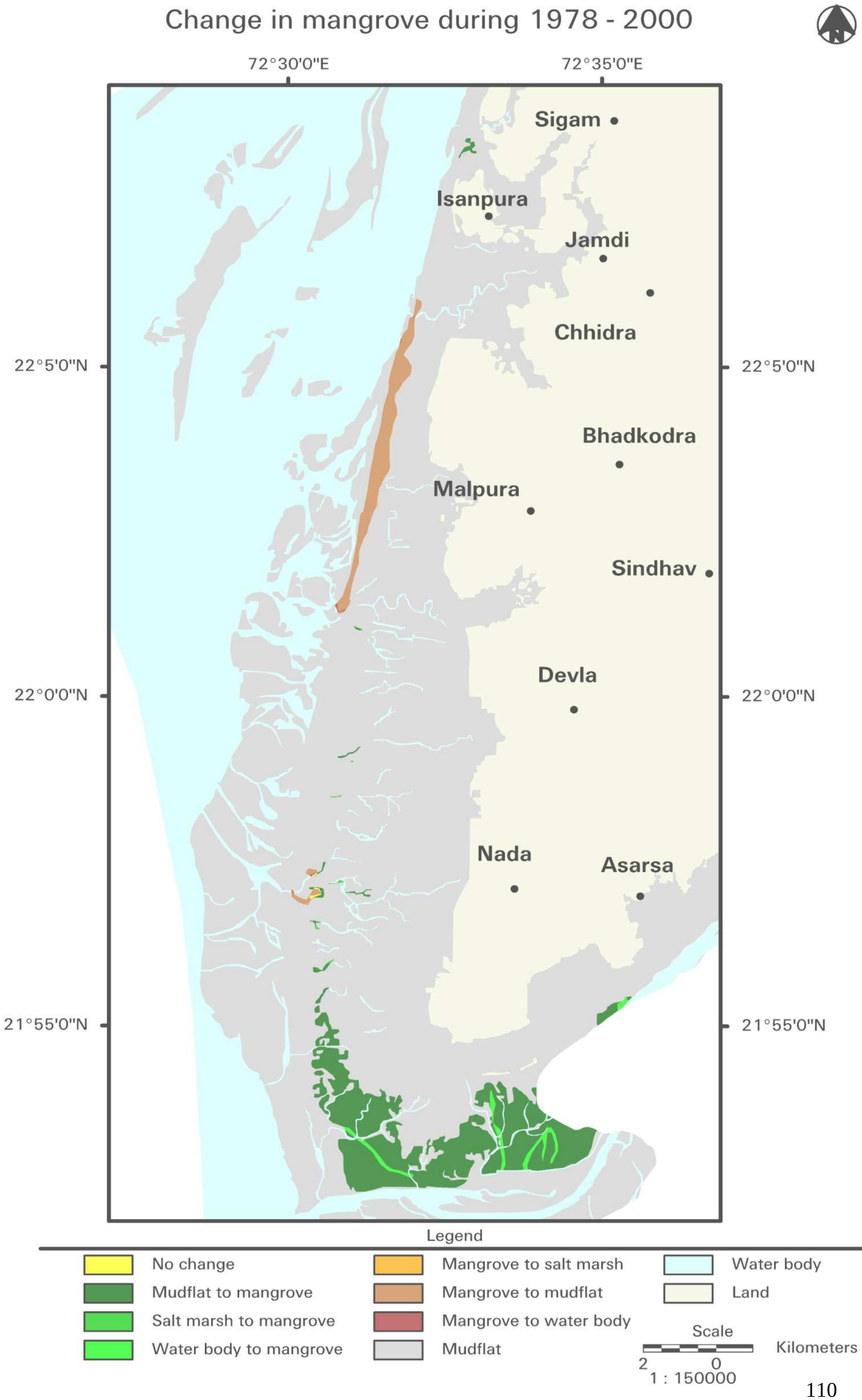

Change in mangrove during 1978 - 2000
72°30'0"E
72°35'0"E
22°5'0"N
22°0'0"N
21°55'0"N
Sigam
Isanpura
Jamdi
Chhidra
Bhadkodra
Malpura
Sindhav
Devla
Nada
Asarsa
Legend
No change
Mudflat to mangrove
Salt marsh to mangrove
Water body to mangrove
Mangrove to salt marsh
Mangrove to mudflat
Mangrove to water body
Mudflat
Water body
Land
Scale
2 0
Kilometers
1 : 150000

Plate : 5.5

Change in mangrove during 2000 - 2012

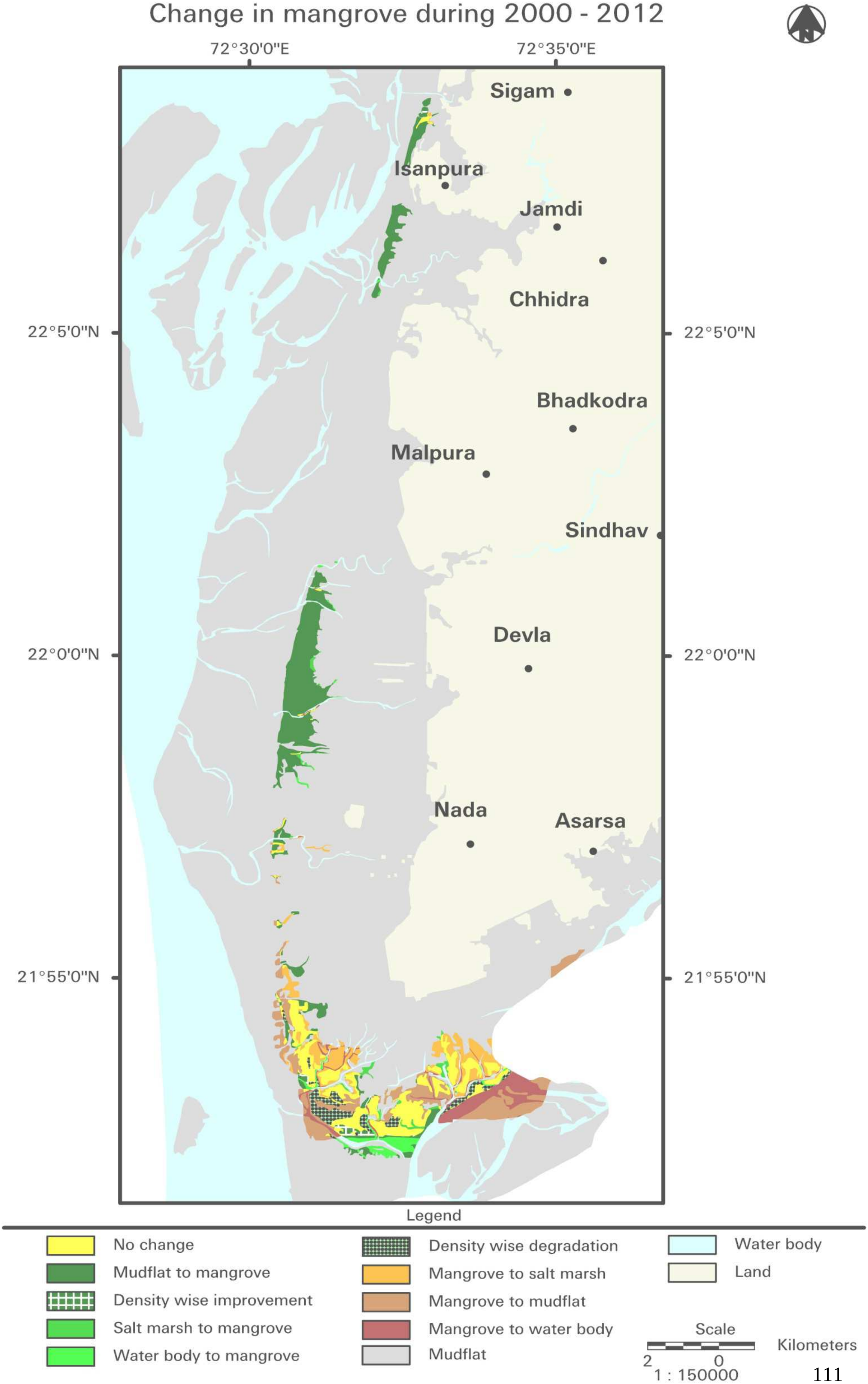


Plate : 5.6

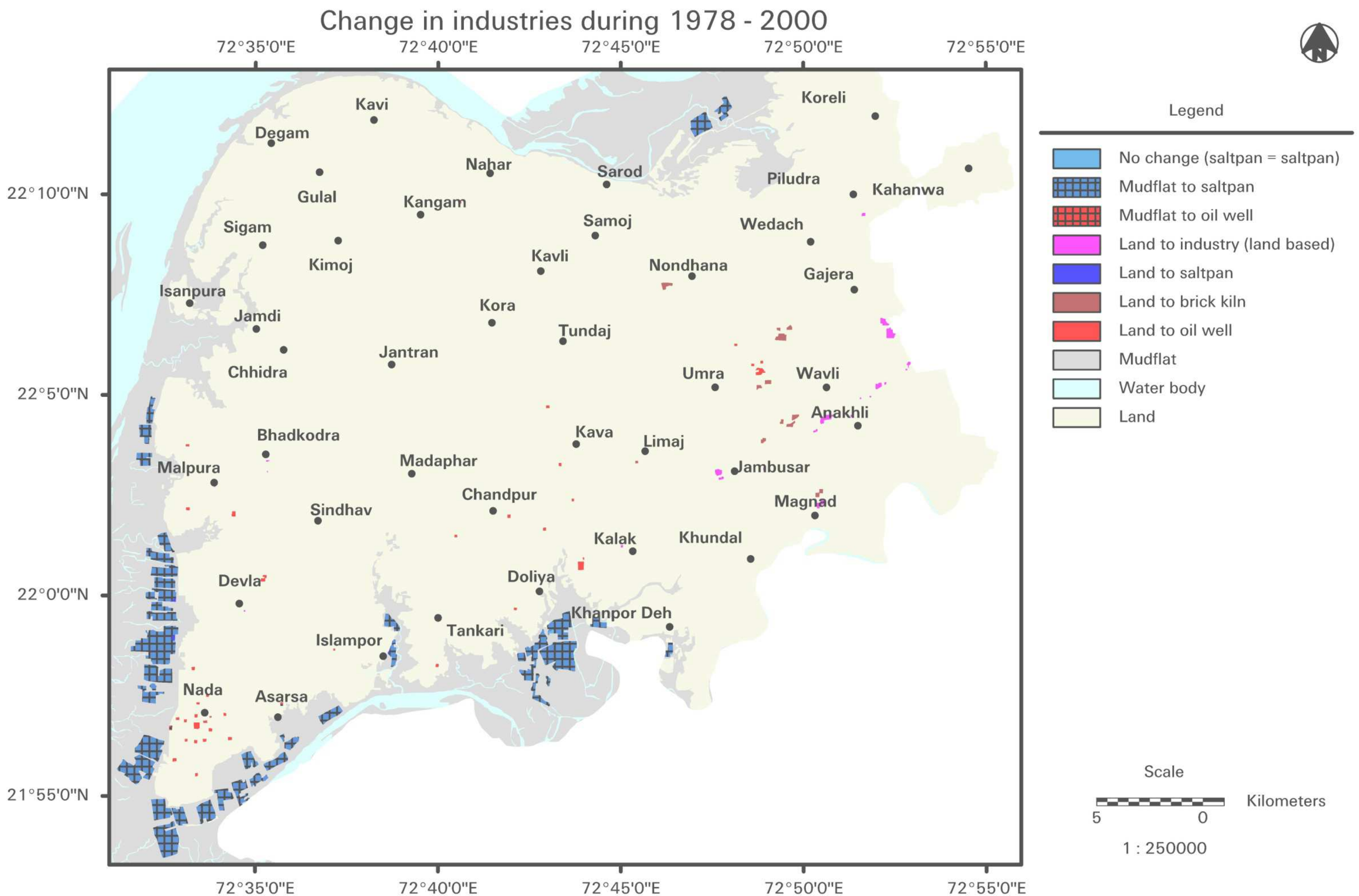

Change in industries during 1978 - 2000
72°35'0"E
72°40'0"E
72°45'0"E
72°50'0"E
72°55'0"E
22°10'0"N
22°5'0"N
22°0'0"N
21°55'0"N
Koreli
Kavi
Degam
Nahar
Sarod
Piludra
Kahanwa
Gulal
Kangam
Samoj
Wedach
Sigam
Kavli
Nondhana
Gajera
Kimoj
Isanpura
Kora
Jamdi
Tundaj
Jantran
Chhidra
Umra
Wavli
Anakhli
Bhadkodra
Kava
Limaj
Malpura
Madaphar
Jambusar
Chandpur
Magnad
Sindhav
Kalak
Khundal
Devla
Doliya
Khanpor Deh
Tankari
Islampor
Nada
Asarsa
Legend
No change (saltpan = saltpan)
Mudflat to saltpan
Mudflat to oil well
Land to industry (land based)
Land to saltpan
Land to brick kiln
Land to oil well
Mudflat
Water body
Land
Scale
5
0
Kilometers
1 : 250000

Plate : 5.7

Change in industries during 2000 - 2012

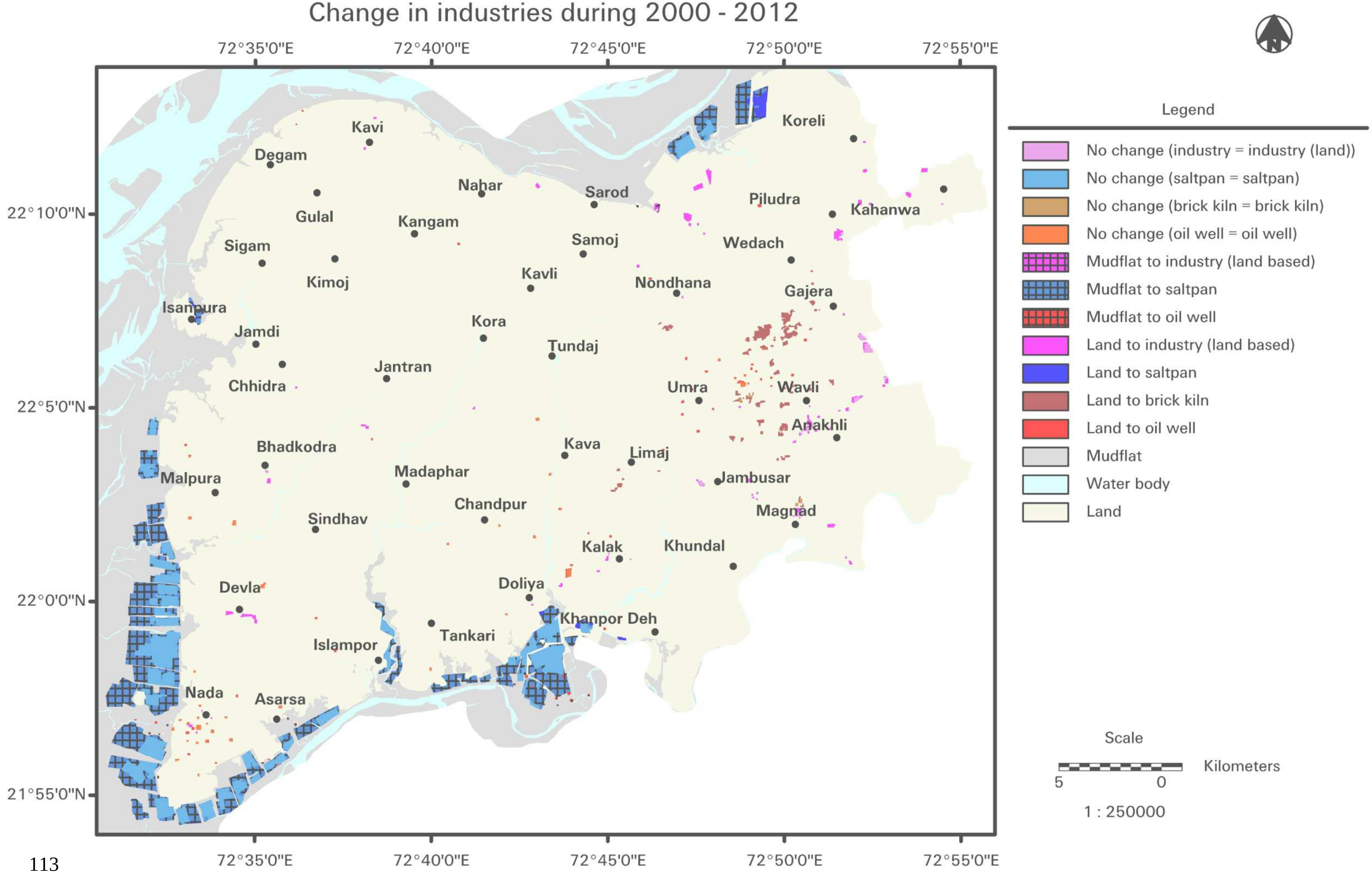


Plate : 5.8

Categories	Changed categories	1978-2000	2000-2012
		Area (in ha)	
No Change	Dense mangrove	0	3.15
	Sparse mangrove	3.07	422.48
	Total	3.07	425.63
Improvement	Mudflat to Mangrove	1243.67	627.06
	Density wise improvement in mangrove	0.00	23.34
	Salt marsh to Mangrove	4.71	37.82
	Water body to Mangrove	70.26	77.30
	Total	1318.64	765.52
Degradation	Mangrove to Mudflat	272.57	359.55
	Density wise degradation of mangrove	0.00	107.11
	Mangrove to Salt marsh	1.10	226.58
	Mangrove to Water body	3.13	179.49
	Mangrove to Industry	0.00	0.00
	Total	276.80	872.74

Table 5.4 Change in mangrove of Jambusar

Duration	1978-2000				2000-2012			
Type of industry	Area (in ha)							
	No Change	Mudflat	Land	Total area	No Change	Mudflat	Land	Total area
Brick kiln	0	0	66.18	66.18	12.32	0.00	241.60	253.91
Industry (Land based)	0.00	0.00	77.15	77.15	57.01	5.62	190.80	253.43
Saltpan industry	3.46	2250.96	7.44	2261.86	1901.03	2873.02	100.79	4874.85
Oil based industry	0.00	5.16	90.11	95.27	66.41	28.14	64.68	159.24
Total area (in ha)	3.46	2256.12	240.88	2500.45	2036.77	2906.78	597.88	5541.43

Table 5.5 Change in industrial area of Jambusar

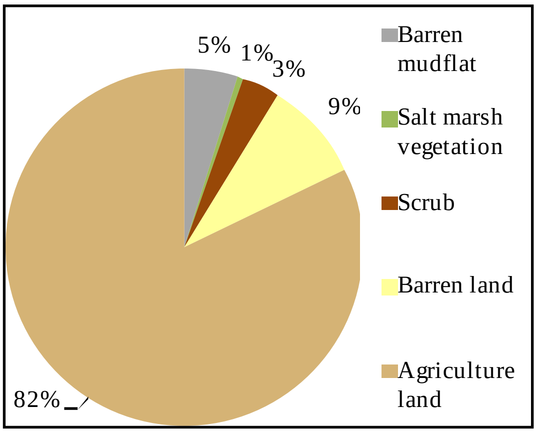


Figure 5.15 Categories converted to oil well during 1978-2000

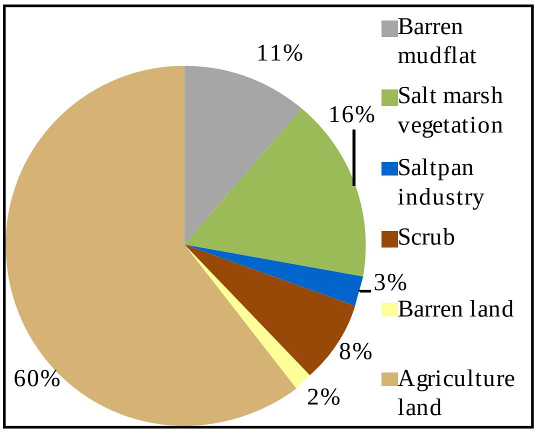


Figure 5.16 Categories converted to oil well during 2000-2012

Oil wells had come up in land as well as mudflat areas. The categories converted to oil wells and their contribution in form of percentage is given in Figure 5.15 and 5.16. Agriculture land was the major contributor to the oil well industry during the entire study duration. The area of mudflat converted to oil well was (28.14 ha) much higher in 2000-2012 as compared to (5.16 ha) 1978-2000 indicating faster development of this industry during the period.

Thus, the overall development of the industries in the mudflat area had increased during 1978-2000 and this continued during 2000-2012 as well. The development of a multiproduct SEZ in the north of Jambusar was one of the reasons for the expansion of industrial category.

5.1.2 LAND USE LAND COVER MAPS OF VAGRA TALUKA

For Vagra taluka, the maps were prepared from the topographic sheets and from the satellite images of year 1978, 1987, 1997, 2001, 2004 and 2012. The base maps were prepared from topographic sheets published in year 1973-74. Vagra taluka falls under the topographic sheet numbers 46C/9, 46C/10, 46C/13 and 46C/14. Plate 5.9 shows land use land cover map of Vagra taluka prepared from the topographic maps. It showed various categories such as mudflats, shoal, mangrove, various types of waterbodies, agriculture land, habitation, industrial area and forest. Agriculture was the major land use class which covered about 68.31% of the total area. This was followed by mudflat category (mudflat+shoal) 22.97%. The vegetated mudflat was represented by mangrove that contributed 0.15% of the total area. Habitation and industrial area occupied 0.49% and 0.02% of the area respectively. In 1975, only two types of industries were recorded on the map viz., one land based industry (Mill) near Vagra village and the other, a port near Dahej village. It aslo showed a patch of reserved forest extending from the west of Dahej up to Luhara village which accounted for 0.60% of the total area. The total areal extent of different land use land cover classes observed in the topographic sheets are given in the Table 5.6.

Class Name	Area (in ha)
Mudflat	18244.39
Shoal	1927.69
Mangrove	134.35
Water body (Sea)	1604.99
Creek	252.53
Pond	226.86
River	4460.07
Habitation	433.60
Agriculture land	59993.42
Forest	526.85
Industrial area	7.91
Jetty	6.68
Total	87819.33

Table 5.6 Area covered by various land use land cover categories demarcated from topographic sheets of Vaga

The land use land cover maps for the year 1978, 1987, 1997, 2001, 2004 and 2012 are given in Plate 5.10, 5.11, 5.12, 5.13, 5.14 and 5.15 respectively. The contribution of the major categories in terms of percentage is depicted in Table 5.7. Throughout the time series, agriculture was the major land use category. This was followed by the coastal wetland category, water body, built-up land, scrub, barren land and forest category. As, Vagra (especially Dahej and its surrounding area) had witnessed maximum developmental activities among the three coastal talukas under study, a high resolution Catrosat-1 satellite image of the western part of the taluka was used to analyse the extent of the built up area. Plate 5.16 shows the LULC map prepared from Cartosat-1 for the year 2012 while the areal extent of major categories is shown in Table 5.8. Use of cartosat data showed its superioirity in demarcating man made features such as various types of industries (saltpan, jetty, aquaculture pond, oil well and other land based industries), canals, habitation areas, vacant plots and even agricultural land. With help of this imagery precise areal extent of various categories could be retrieved. The descrimination of natural vegetation such as mangrove, salt marsh vegetation in mudflat area and scrub in land area was however, comparatively difficult using this panchromatic dataset. There was also difficulty in demarcating creek in mudflats especially at places where the creek was either very narrow or not filled with water. This suggested efficiency of cartosat -1 in demarcation of various builtup categories and its limitation in demarcating few of the coastal wetland (mangrove, salt marsh vegetation and creek) categories.

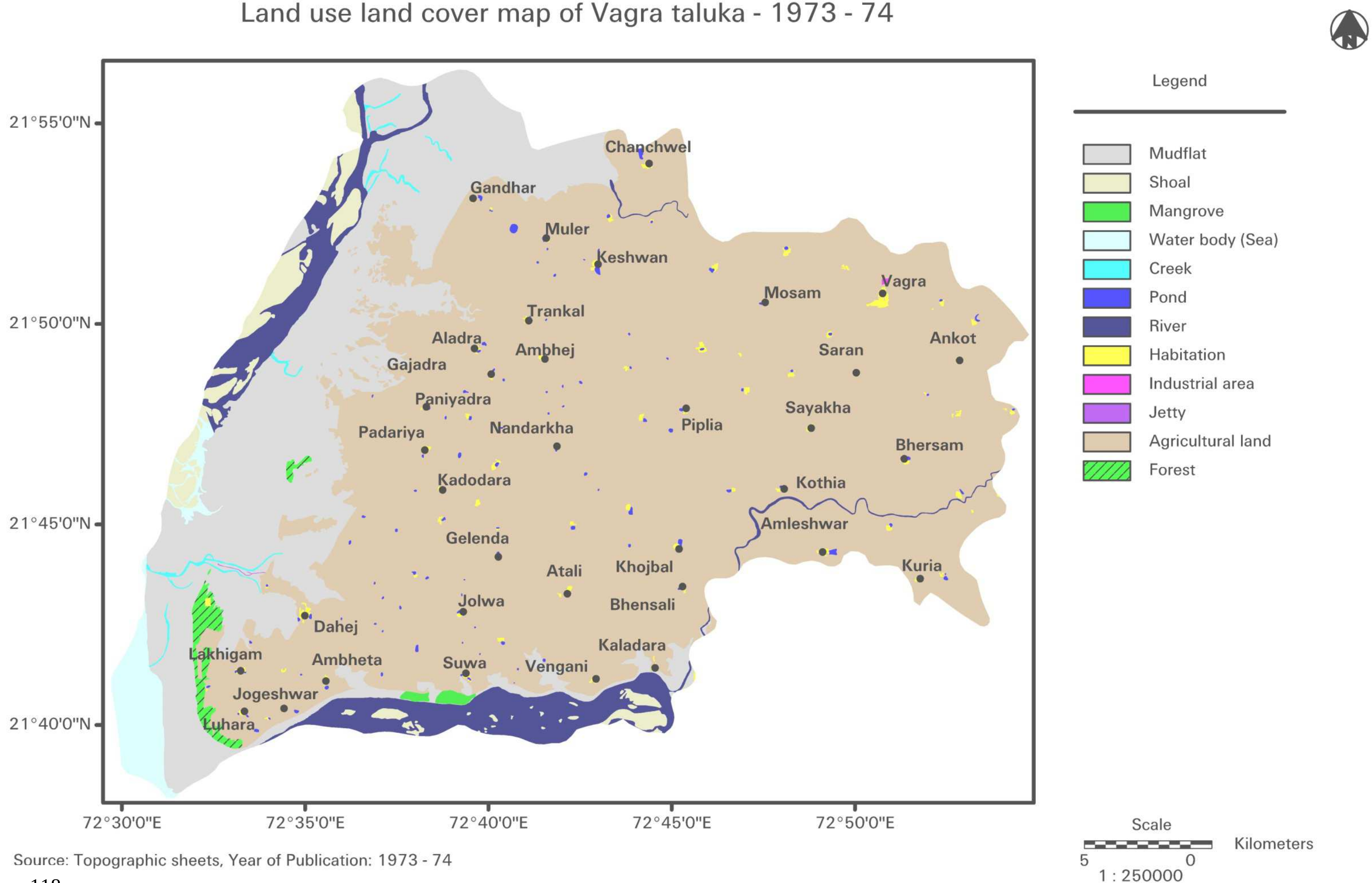
	Year					
Categories	**1978**	**1987**	**1997**	**2001**	**2004**	**2012**
	(Area in %)					
Coastal wetland	22.36	23.04	19.01	14.47	14.34	15.33
Water body	11.60	7.46	7.53	10.62	9.27	8.18
Barren land	1.05	4.15	1.92	2.85	1.86	1.57
Scrub	3.52	2.24	5.01	5.48	6.11	6.46
Built-up land	1.00	2.95	7.68	9.61	10.54	14.64
Agriculture land	59.97	59.84	58.54	56.67	57.58	53.53
Forest	0.50	0.32	0.31	0.31	0.30	0.29

Table 5.7 Distribution of major land use land cover categories of Vagra taluka across different years

Year 2012	
Class name	**Area (in ha)**
Mudflat	7670.618
Scrub	4423.132
Water body (Sea+ river)	8446.329
Creek	76.16876
Pond	279.5769
Canal	279.8088
Waterlogged area	428.6743
Barren land	252.9285
Habitation with vegetation	396.0576
Vacant area	784.7603
Industrial area	3092.936
Jetty	22.23432
Agriculture land	18562.48
Aquaculture industry	40.76381
Saltpan industry	7154.394
Oil well	840.8985
Road	105.0573
Total area	52856.82

Table 5.8 Area of various land use land cover categories demarcated from the satellite image of Cartosat-1

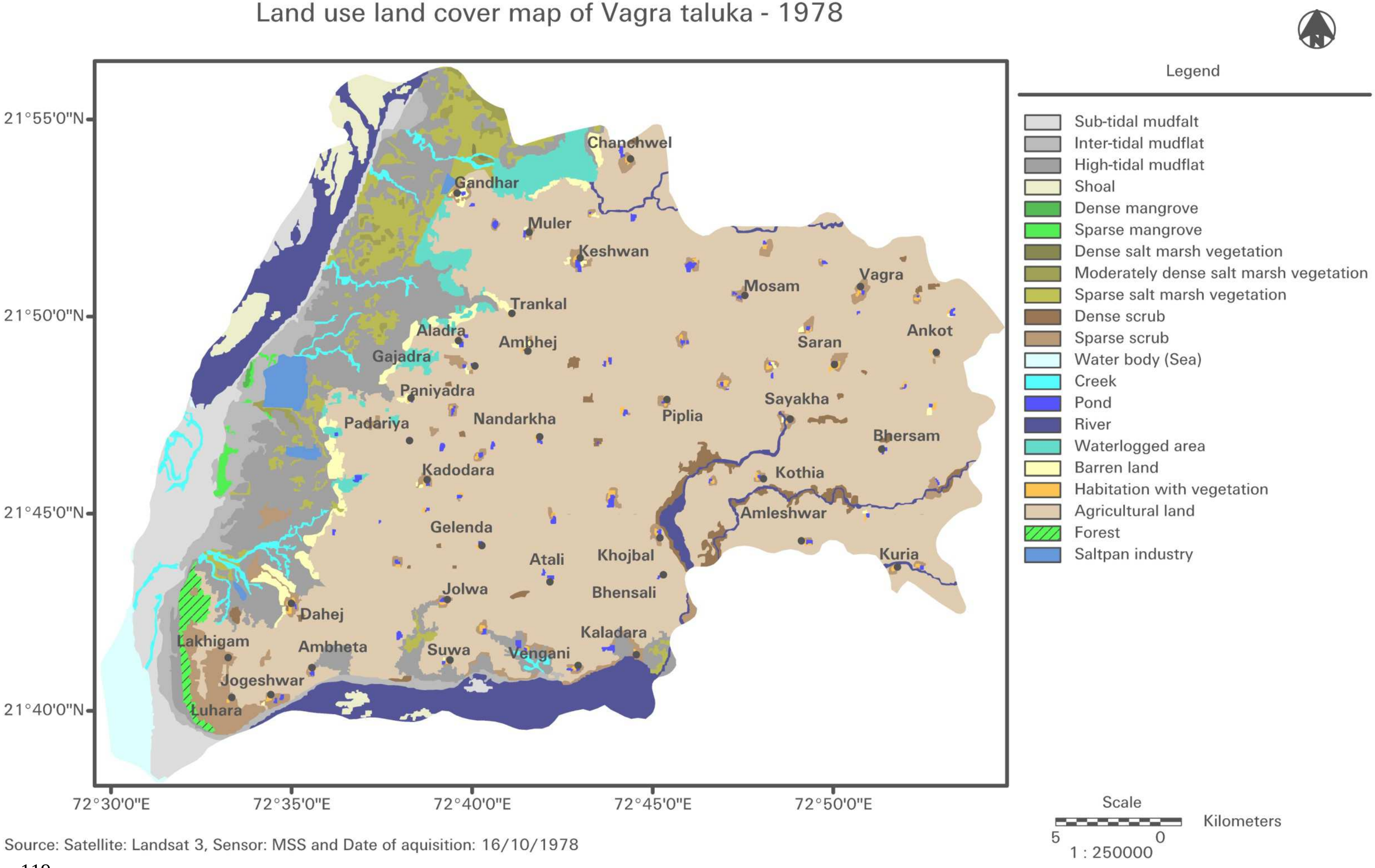
Land use land cover map of Vagra taluka - 1973 - 74



Source: Topographic sheets, Year of Publication: 1973 - 74

Plate : 5.9

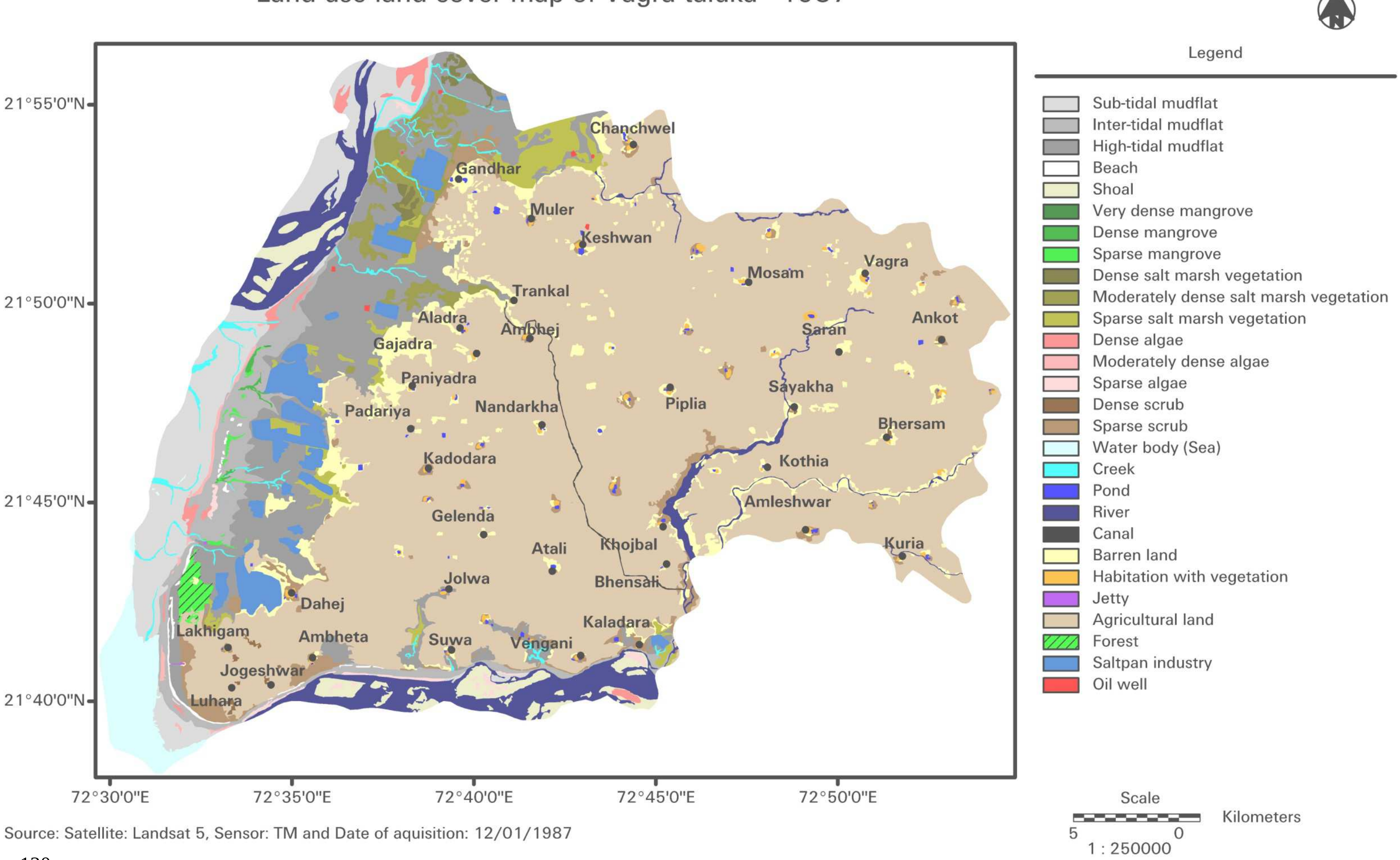
Land use land cover map of Vagra taluka - 1978



Source: Satellite: Landsat 3, Sensor: MSS and Date of aquisition: 16/10/1978

Plate : 5.10

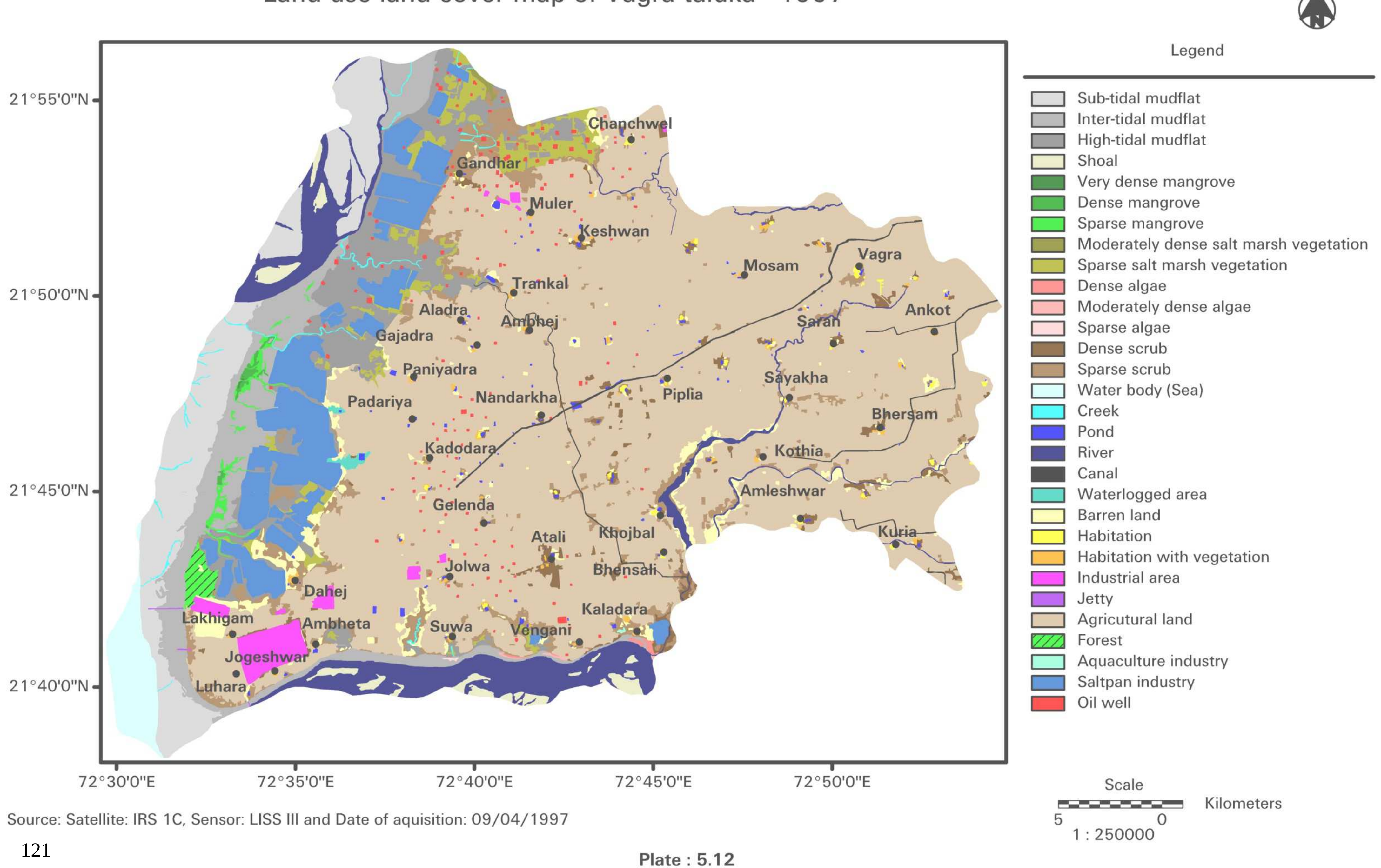
Land use land cover map of Vagra taluka - 1987



Source: Satellite: Landsat 5, Sensor: TM and Date of aquisition: 12/01/1987

Plate : 5.11

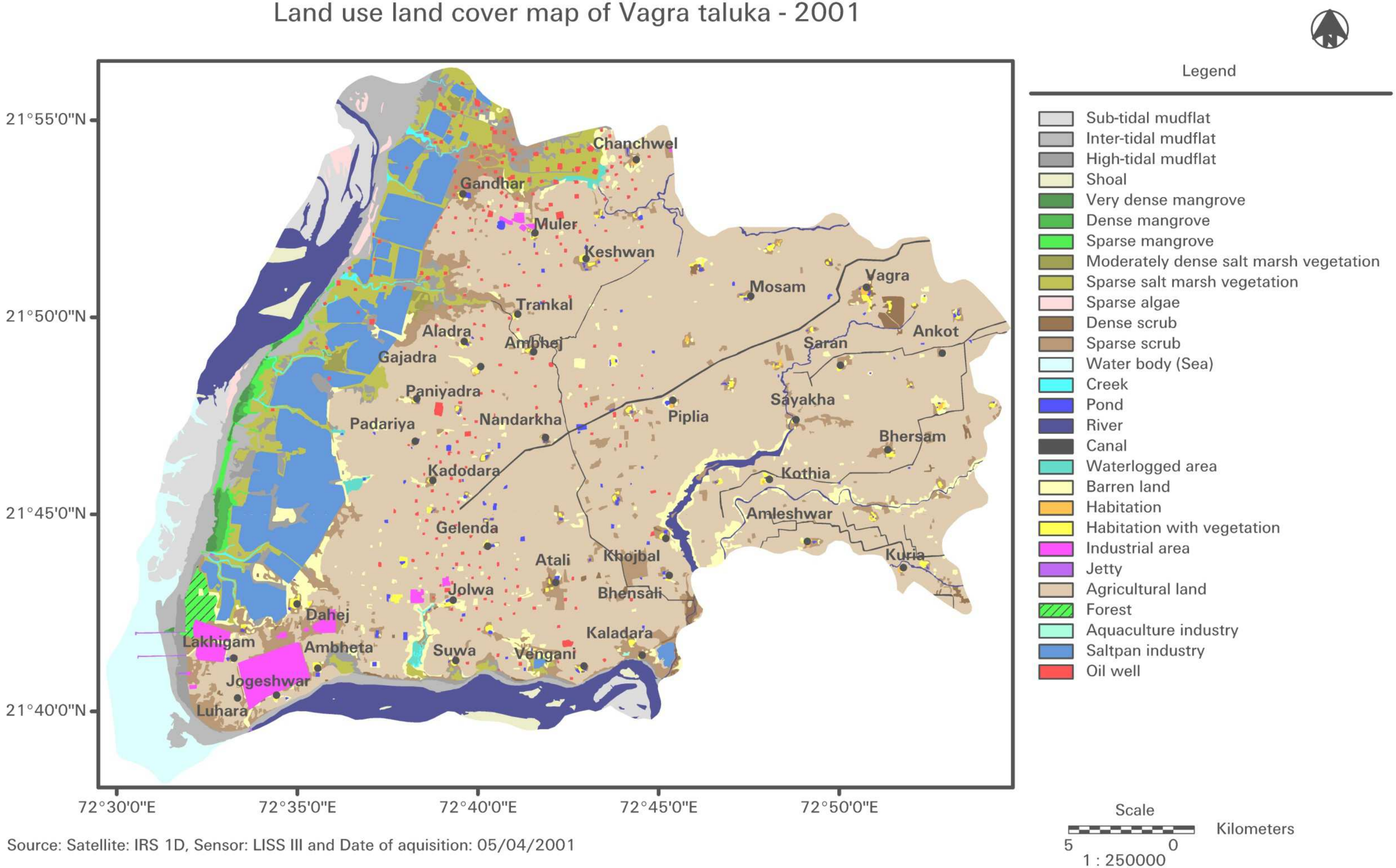
Land use land cover map of Vagra taluka - 1997



Source: Satellite: IRS 1C, Sensor: LISS III and Date of aquisition: 09/04/1997

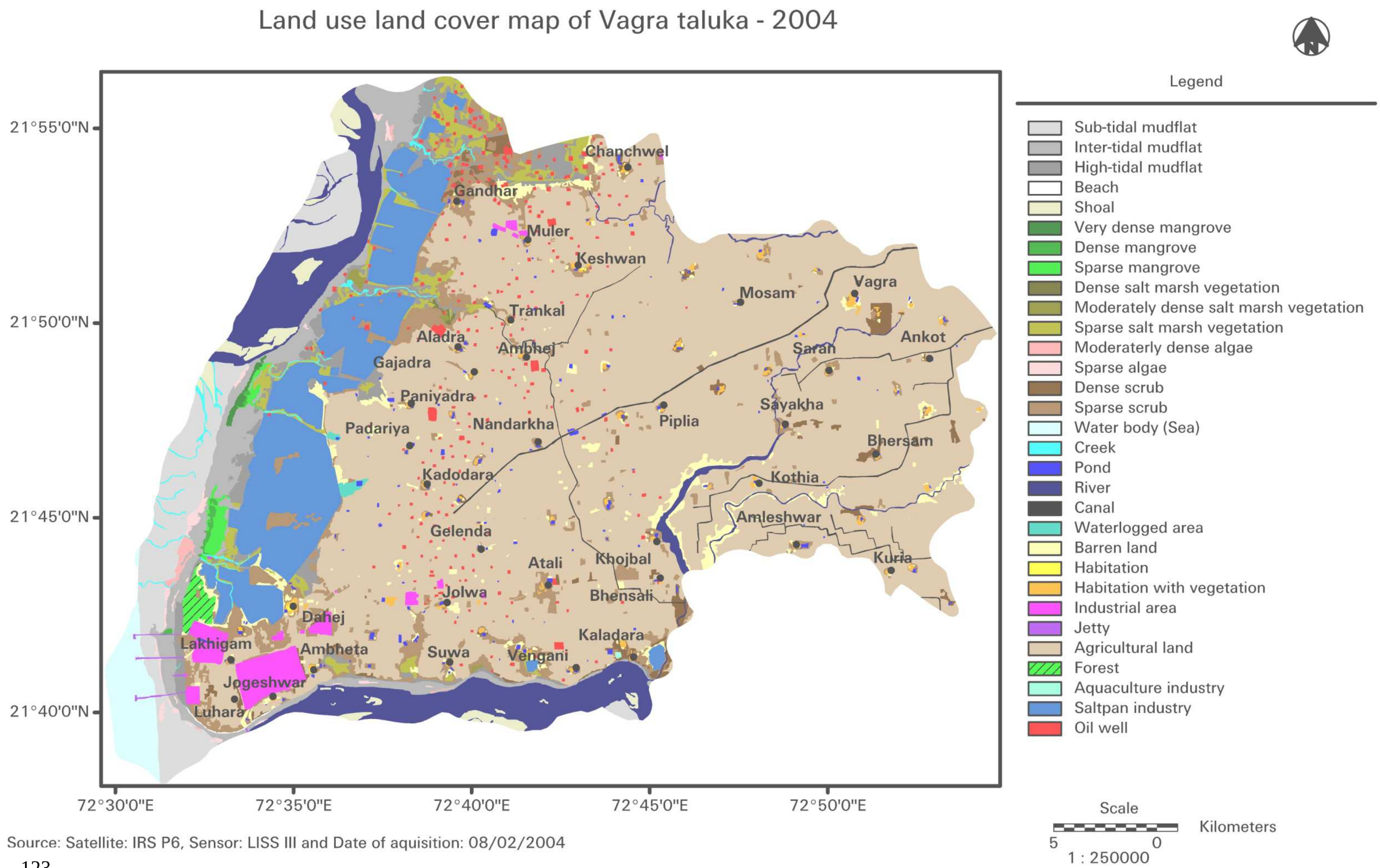
Plate : 5.12

Land use land cover map of Vagra taluka - 2001



Source: Satellite: IRS 1D, Sensor: LISS III and Date of aquisition: 05/04/2001

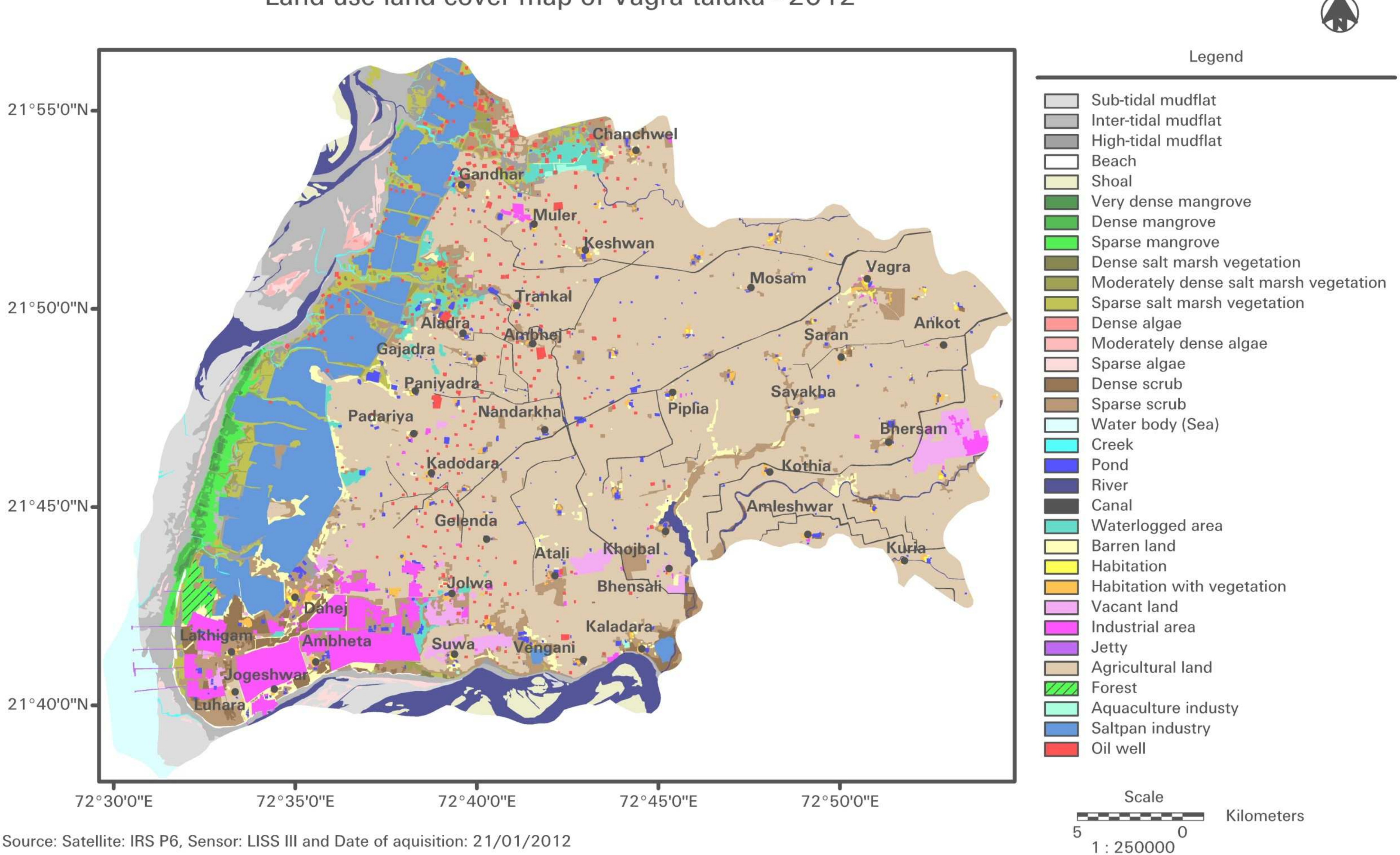
Plate : 5.13



Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 08/02/2004

Plate : 5.14

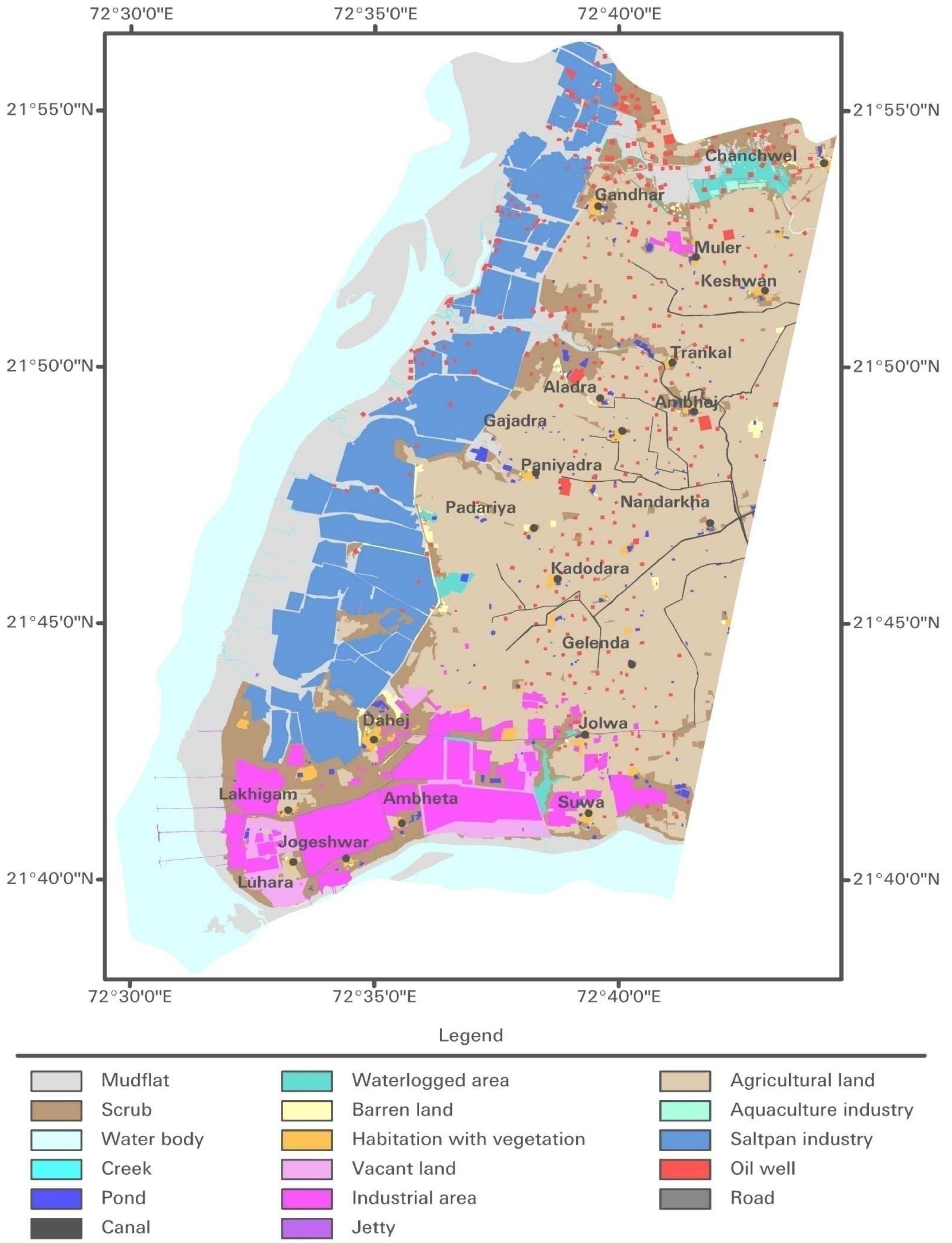
Land use land cover map of Vagra taluka - 2012



Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 21/01/2012

Plate : 5.15

Land use land cover map of Vagra taluka - 2012



Scale

5 0 Kilometers

1 : 200000

Source: Satellite: Cartosat-1, Sensor: PAN-F
Date of aquisition: 17/02/2012

Plate : 5.16

5.1.2.1 Trend in Areal Extent of Different Land Use Land Cover Categories From 1978-2012

A. Coastal wetland: Mudflats, shoal, beach, mangrove, salt marsh vegetation, algae were the categories observed in Vagra taluka and variations observed in them are discussed below.

A.1 ***Mudflat:*** The industrial activites in the mudflat area had increased from 1978 to 2012. Figure 5.17 shows area covered by barren mudflat, vegetated mudflat and mudflat taken up by the industries. Each of these three categories is discussed in detail below.

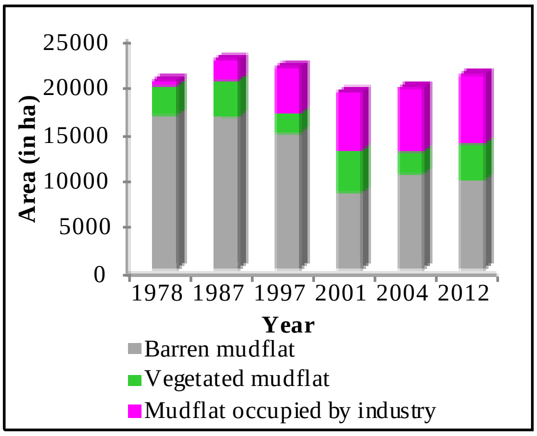


Figure 5.17 Area of mudflat in Vagra

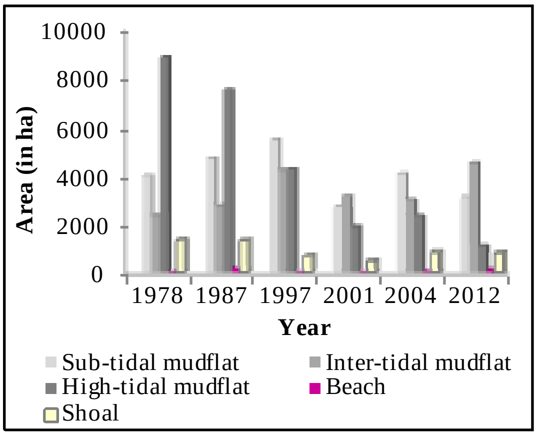


Figure 5.18 Areal extent of different barren mudflat categories in Vagra

A.1.1 Barren mudflat: The sub-tidal mudflat, inter-tidal mudflat, high-tidal mudflat, beach and shoal were the types of barren mudflat observed in this taluka. The areal extent of each of these categories over a period of time is shown graphically in Figure 5.18. Variation in low tide condition across different years was the major reason for the change observed in the area under sub-tidal mudflat and shoal for different years.

A.1.2 Vegetated mudflat: It comprised of the part of mudflat covered by mangrove, salt marsh vegetation or algae. The mangrove vegetation in this taluka was also represented by *Avicennia marina* only. Mangroves were observed along the west coast of taluka between Paniyadra and Dahej. A small patch of mangrove was observed in the south of Gandhar village. Figure 5.19 shows the variation in mangrove cover of the area over time. A small drop was observed in year 2004. The salt marsh vegetation showed increase in its areal extent (Figure 5.20) and was observed along the entire coastline of taluka. Among the different densities, sparse salt marsh vegetation covered the maximum area. Figure 5.21 shows the area covered by algae.

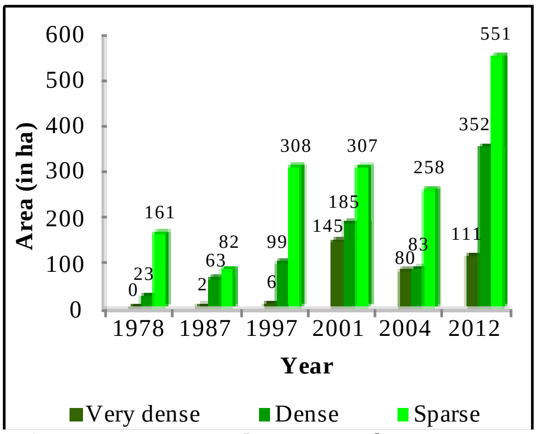


Figure 5.19 Areal extent of mangrove in Vagra

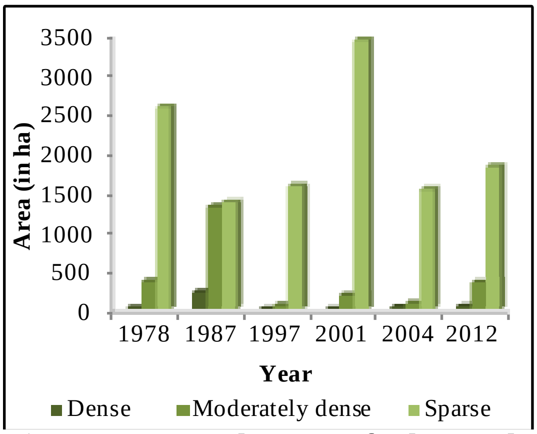


Figure 5.20 Areal extent of salt marsh vegetation in Vagra

B. Scrub: Figure 5.22 shows the increasing trend in the scrub area. This category had a wide distribution and was present in coastal wetland, near water bodies and even in agricultural areas.

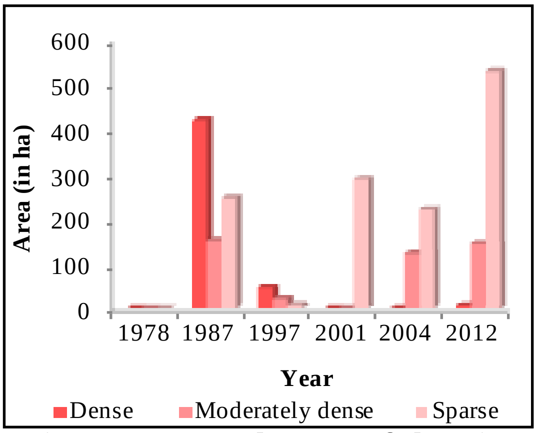


Figure 5.21 Areal extent of algae in Vagra

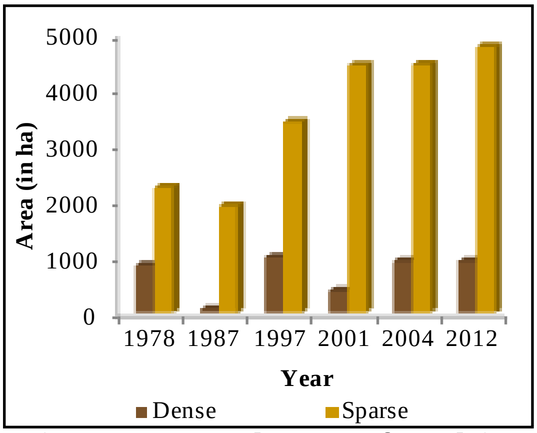


Figure 5.22 Areal extetn of scrub in Vagra

C. Water bodies: Sea, creek, pond, river, water logged area as well as man-made features such as canal were the categories observed in Vagra. The area covered by each of these categories is shown graphically in Figure 5.23. The variation in the areal extent of sea, creek and river was due to variation in the low tide conditions of the satellite images. The pond and canal showed the increasing trend in terms of area as well as in numbers from year 1978-2012.

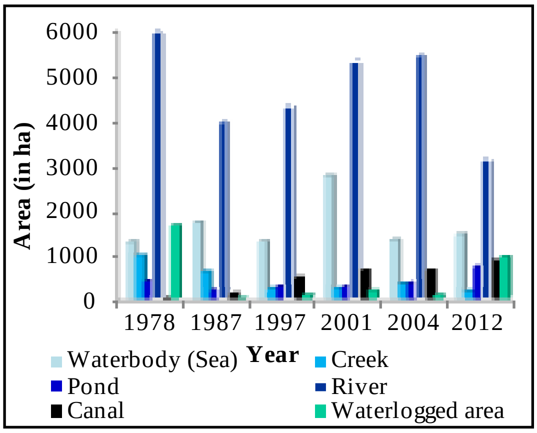


Figure 5.23 Areal extent of various types of water bodies in Vagra

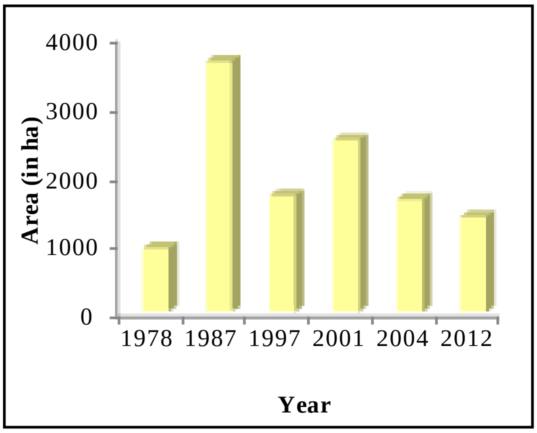


Figure 5.24 Areal extent of barren land in Vagra

D. Barren land: This category was mainly observed towards the landward side of the saltpan or waterlogged area and around river. Besides these, it was also found in agriculture area and around built-up area especially habitation. The graphical representation in Figure 5.24 shows that this category fluctuates considerably. These fluctuations were mainly due to its conversion into another category.

E. Built-up land: In Vagra, habitation, habitation with vegetation, vacant land, industrial area and various transportation features like road, jetty or port were categories observed in built up area.

E.1 ***Habitation:*** This included both the categories i.e. habitation and habitation with vegetation. The area of habitation for different years is represented graphically in Figure 5.25.

E.2 ***Industrial area:*** Sea dependent industries included saltpan industry, aquaculture industry and jetty/port industry where as land based industries included all the industries located beyond the high water line towards the land ward side. In addition to these, oil well (including exploratory sites for oil and natural gas) was a category distributed both in mudflat (high-tidal mudflat) as well as on land. The areal extent of all these categories is given in Table 5.9 and represented graphically in Figure 5.26. It shows an increase in the extent of all types of industries from 1978 to 2012.

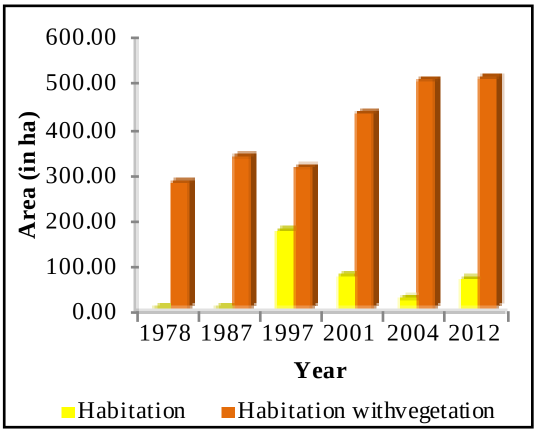


Figure 5.25 Area of habitation in Vagra

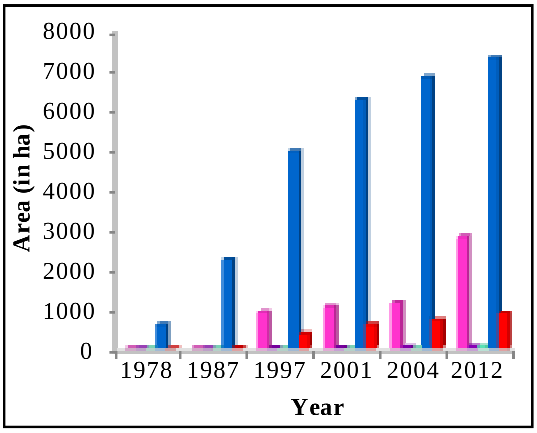


Figure 5.26 Area occupied by various types of industries in Vagra*

*Legends of the Figure are given in Table 5.9

Types of Industry	Symbol	1978	1987	1997	2001	2004	2012
		Area (in ha)					
Land based Industrial area	■ (pink)	0	0	919	1064	1160	2807
Jetty	■ (purple)	0	6	15	27	36	52
Aquaculture industry	■ (aqua)	0	0	3	4	8	54
Salt industry	■ (blue)	607	2226	4961	6240	6817	7297
Oil industry	■ (red)	0	28	372	608	723	886
Total industrial area		607	2260	6271	7943	8744	11095

Table 5.9 Variation in areal extent of various industries in Vagra taluka

During 1978-2012, the nuber of jetties increased in number from 1 to 7. They were concentrated in the south west corner of taluka specifically from the west of Dahej, Lakhigam, Luhara to the south of Jogeshwar village. The aquaculture industry which was located near Kaladara village had also expanded in its area over the period. In addition to this, a few more aquaculture ponds were observed in waterlogged area to the north of Muler village. Saltpan was the dominant sea based industry which had almost covered the entire western coastal stretch of the taluka. The land based industries were concentrated more around Dahej, Lakhigam, Luhara, Ambheta and Jolwa villages. In addition to these, a few more were observed near Muler and Bhersam villages. The development of the oil wells was mostly restricted to a braod belt between Gandhar – Chanchwel in the north and between Suwa and Vengani villages in the south. A large number of oilwells were also observed in the mudflats from north of Gandhar to the west of Padariya village. The graph (Figure 5.26) indicates that it was the year 1997 when all the different types of industries were observed in this area and since then have showed an increasing trend in their areal extents. Among the five different types of industries the highest area was occupied by the saltpan industry. This was followed by land based industry, oil wells, aquaculture and jetty/port industry respectively. These changes have been discussed later.

E.3 ***Vacant land:*** This particular category was not observed in the satellite images till 2012. This category came into existence with the allotment of space for the SEZs and different developmental schemes. Under these schemes, different plots were allotted for the developmental activities. These plots were demarcated by the regular border based on which they could be easily identified from the satellite image. These large numbers of regular patches were identified in the satellite images of 2012 and verified during the ground truth. The area occupied by this category was 1195 ha in the year 2012.

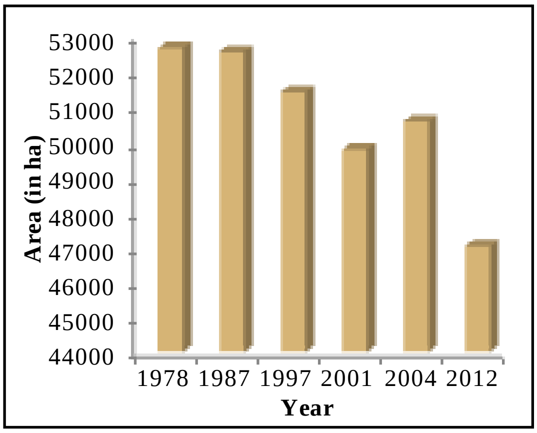


Figure 5.27 Area of agricultural land in Vagra

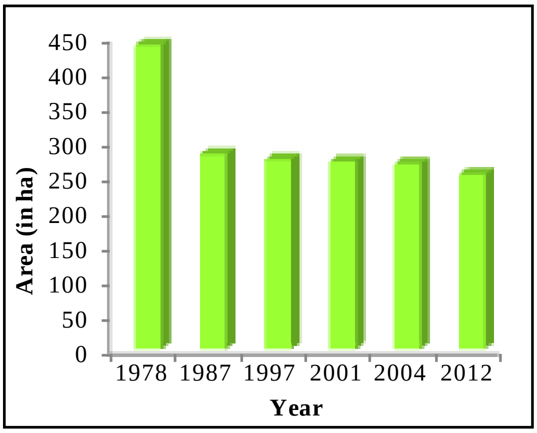


Figure 5.28 Area of forest in Vagra

F. Agriculture land: It was the major land use category. It showed a decreasing trend in its areal extent (Figure 5.27) from 1978-2012. The increase in the built-up area in the landward side of taluka was a major reason for the loss of agricultural land. An increase was observed in 2004 possibly due to a temporary conversion of barren land or scrub to agricultural land.

G. Forest: This category was found in the western side of Vagra taluka between Lakhigam and Luhara village and was demarcated as reserved forest area. Figure 5.28 shows change in this category over a period of time. The area was initially converted to agricultural land and later with the increasing developmental activities in the area was later converted to either built-up area or in to sparse scrub categories. The satellite image of the year 2012 showed only a small patch of forest existing to the north of Lakhigam village.

5.1.2.2 Accuracy Assessment

The highest value of accuracy was reported for the year 2012 while the lowest value was obtained for year 1978. The coarse resolution of the satellite image (79 m) and the misclassification of the sparse scrub category at few locations were the main reasons for the low accuracy of the 1978 map. The values of overall accuracy and Kappa statistics for all the maps are given in Table 5.10.

Year	Overall accuracy	Kappa statistics
1978	84 %	0.7586
1987	88 %	0.8043
1997	88 %	0.8276
2001	86 %	0.794
2004	85 %	0.7611
2012	90 %	0.8519

Table 5.10 Accuracy statistics for Vagra

5.1.2.3 Change Detection of Vagra Taluka

The change detection process had resulted in 464 change classes for Vagra taluka. For reasons described earlier, the change analysis was restricted to mangrove and industrial areas.

***Mangrove Change Analysis*:** The changes observed in the mangroves were grouped under no change, mangrove improvement and mangrove degradation areas. Plate 5.17 and 5.18 shows the change in mangrove vegetation while Table 5.11 shows the change in areal cover for the different categories.

The change analysis over a period of 34 years showed an increasing trend in the mangrove cover. The improvement of the mangrove was due to their growth on the barren mudflat and even in the salt marsh zone. Their improvement in the water body was due to their growth along the creeks. Table 5.11 shows that along with improvement, degradation had also increased during 2001-2012 as compared to 1978-2001. Among the different degradation classes, density wise degradation was much high followed by mangrove to industry and mangrove to mudflat area. These degraded mangrove area were mainly concentrated nearby the industrial area and reduction in the mangrove was due to the cutting of the mangrove area. The map (Plate 5.18) clearly depicts that during 2001-2012, the degradation of mangrove was more around the industrial area. The industry mainly responsible for the degradation of mangroves in this taluka was the saltpan industry. Besides this, other major reason for degradation was conversion of mangrove to water body. This was due to the high rate of erosion prevailing at some locations along the north western coast of the taluka and was the main reason for the reduction of mangroves in the 2004. Thus, although there was increase in the mangrove area, degradation rates were also high during 2001-2012.

Change in the industrial area: Major changes have occurred in industrial environment of the taluka. As seen earlier Vagra has the highest rate of industrialization among all the three talukas under study. The expansion of the areal extent of these industries either in mudflat or in land area is shown in Table 5.12 while the change detection maps for the years 1978-2001 and 2001-2012 are shown in Plate 5.19 and 5.20 respectively.

The saltpan industry had boomed during the period 1978-2001 and had covered most of the mudflat, leaving only a small area for its further expansion. Hence, the expansion of the saltpan industry in mudflat area was much less during 2001-2012. The categories that were converted to saltpan industry are shown in the form of pie charts as Figure 5.29 and 5.30.

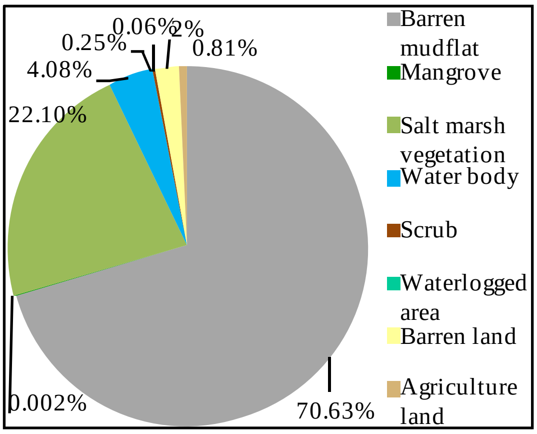


Figure 5.29 Categories converted to saltpan industry during 1978-2001

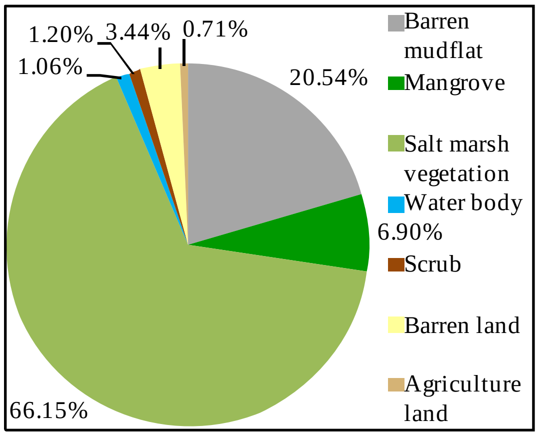


Figure 5.30 Categories converted to saltpan industry during 2000-2012

As indicated in Figure 5.29, a large area of barren mudflat and a small part of salt marsh vegetation was converted to saltpan area during 1978-2001 whereas the categories which were converted to saltpan during 2001-2012 included a large area of salt marsh vegetation, mangrove and the available area of barren mudflat (Figure 5.30).

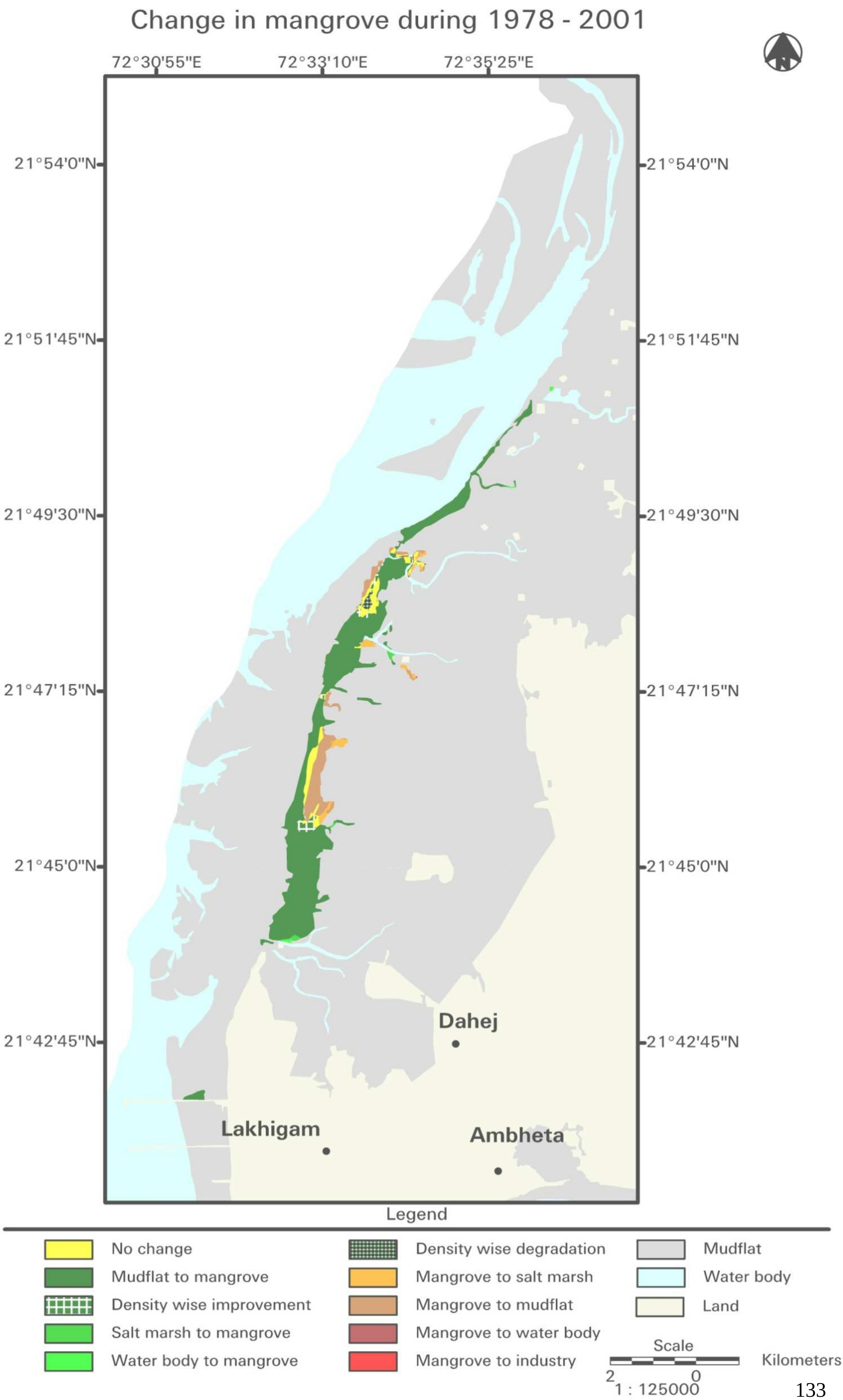

Change in mangrove during 1978 - 2001
72°30'55"E
72°33'10"E
72°35'25"E
21°54'0"N
21°51'45"N
21°49'30"N
21°47'15"N
21°45'0"N
21°42'45"N
Dahej
Lakhigam
Ambheta
Legend
No change
Mudflat to mangrove
Density wise improvement
Salt marsh to mangrove
Water body to mangrove
Density wise degradation
Mangrove to salt marsh
Mangrove to mudflat
Mangrove to water body
Mangrove to industry
Mudflat
Water body
Land
Scale
2
0
Kilometers
1 : 125000

Plate : 5.17

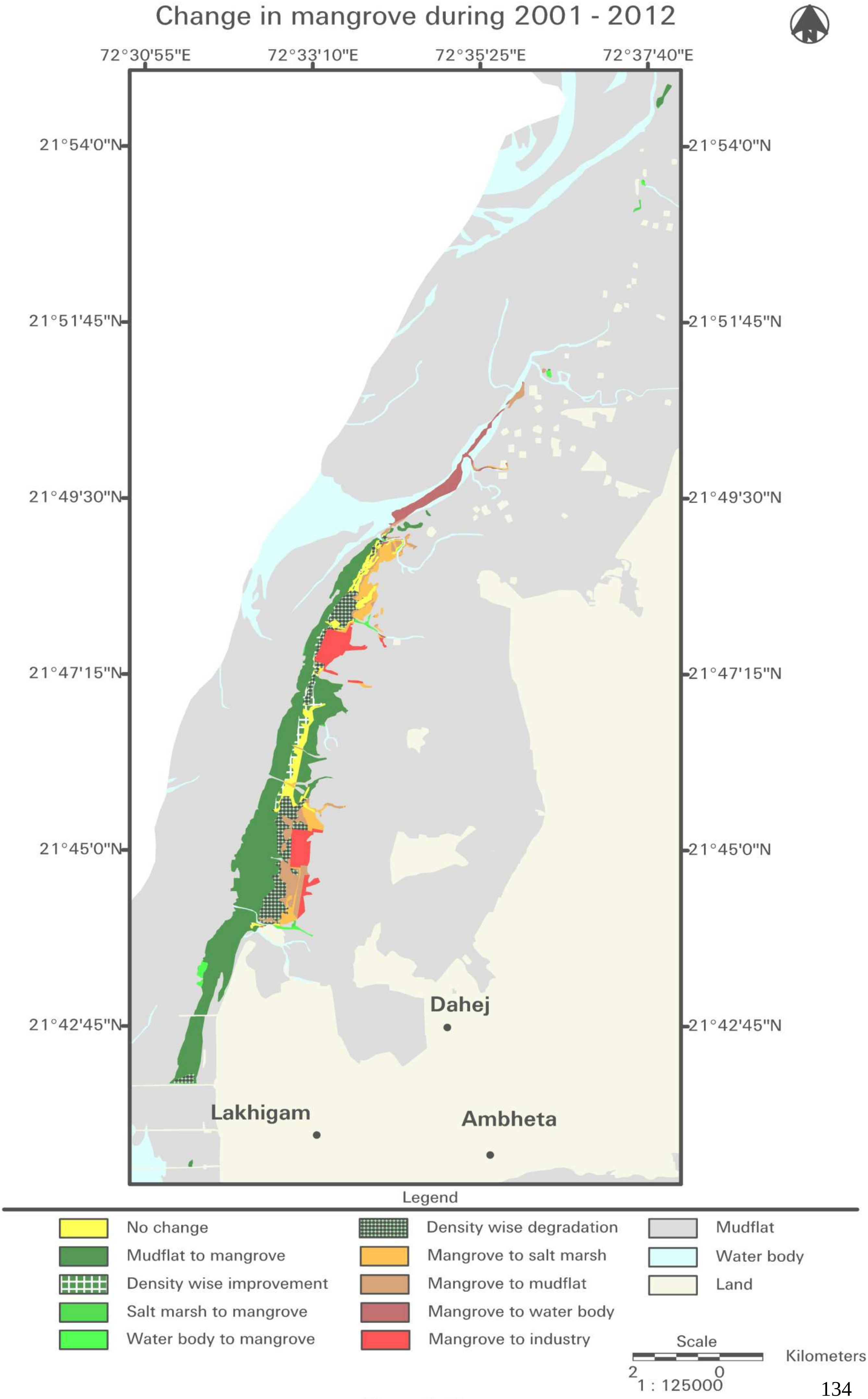

Change in mangrove during 2001 - 2012
72°30'55"E
72°33'10"E
72°35'25"E
72°37'40"E
21°54'0"N
21°51'45"N
21°49'30"N
21°47'15"N
21°45'0"N
21°42'45"N
Dahej
Lakhigam
Ambheta
Legend
No change
Mudflat to mangrove
Density wise improvement
Salt marsh to mangrove
Water body to mangrove
Density wise degradation
Mangrove to salt marsh
Mangrove to mudflat
Mangrove to water body
Mangrove to industry
Mudflat
Water body
Land
Scale
Kilometers
2
0
1 : 125000

Plate : 5.18

Change in industries during 1978 - 2001

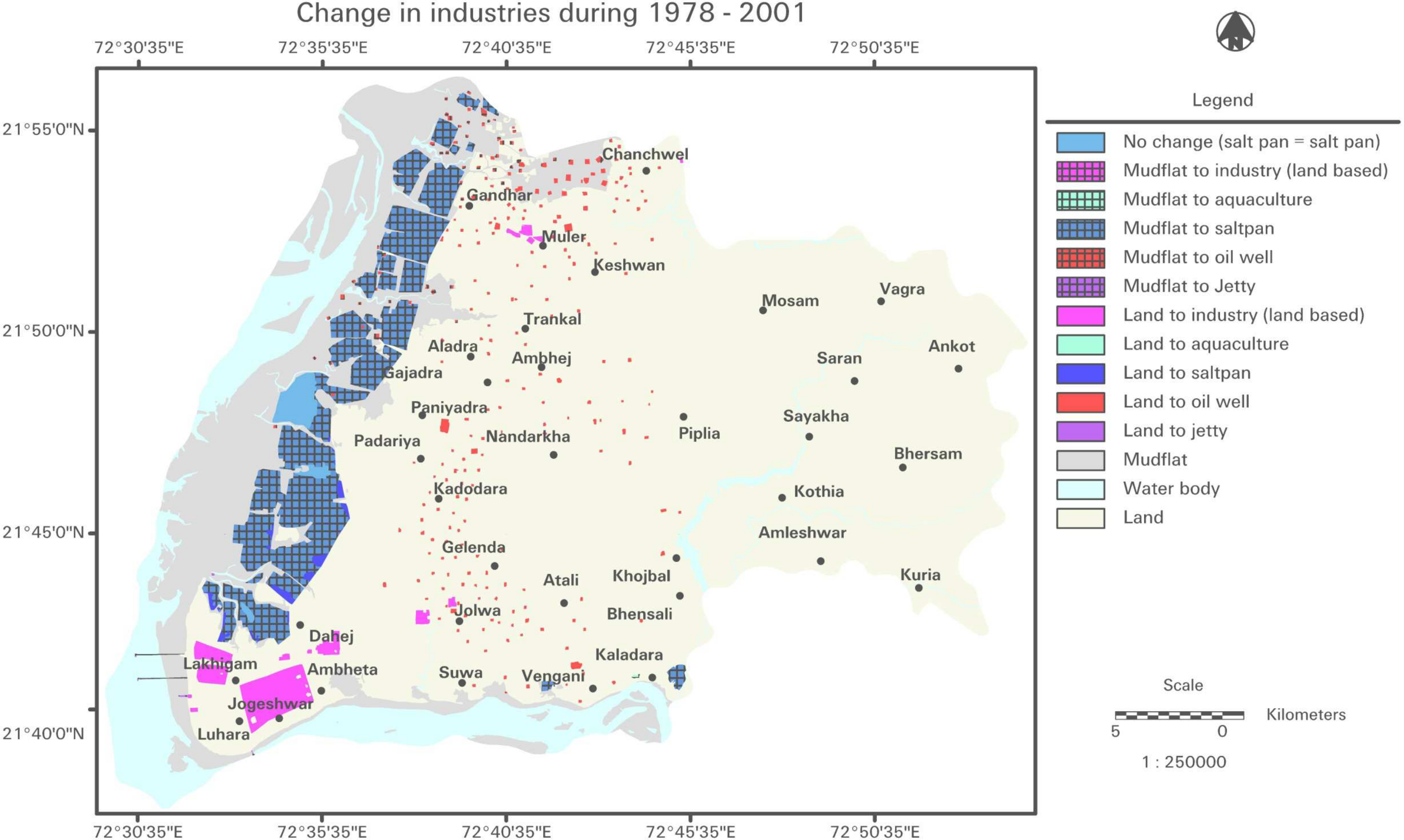
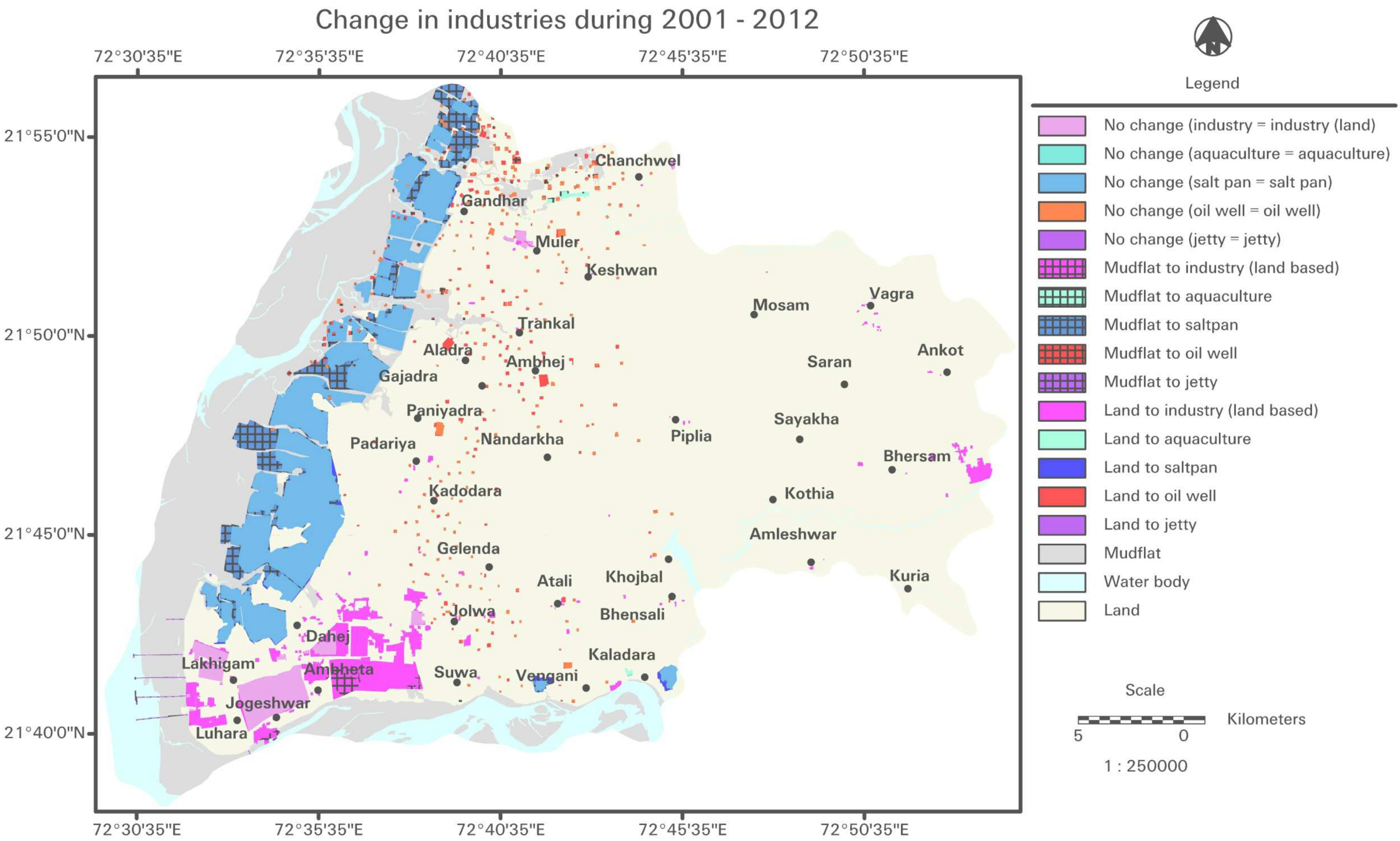


Plate : 5.19



Change in industries during 2001 - 2012
72°30'35"E
72°35'35"E
72°40'35"E
72°45'35"E
72°50'35"E
21°55'0"N
21°50'0"N
21°45'0"N
21°40'0"N
Chanchwel
Gandhar
Muler
Keshwan
Mosam
Vagra
Trankal
Aladra
Ambhej
Gajadra
Saran
Ankot
Paniyadra
Padariya
Nandarkha
Piplia
Sayakha
Bhersam
Kadodara
Kothia
Amleshwar
Gelenda
Atali
Khojbal
Kuria
Jolwa
Bhensali
Dahej
Lakhigam
Ambheta
Suwa
Vengani
Kaladara
Jogeshwar
Luhara
Legend
No change (industry = industry (land)
No change (aquaculture = aquaculture)
No change (salt pan = salt pan)
No change (oil well = oil well)
No change (jetty = jetty)
Mudflat to industry (land based)
Mudflat to aquaculture
Mudflat to saltpan
Mudflat to oil well
Mudflat to jetty
Land to industry (land based)
Land to aquaculture
Land to saltpan
Land to oil well
Land to jetty
Mudflat
Water body
Land
Scale
Kilometers
5
0
1 : 250000

Plate : 5.20

Categories	**Changed categories**	**1978-2001**	**2001-2012**
		Area (in ha)	
No Change	Very dense mangrove	0.00	3.12
	Dense mangrove	7.54	9.50
	Sparse mangrove	44.66	70.11
	Total	52.20	82.72
Improvement	Mudflat to Mangrove	552.82	709.93
	Density wise improvement in mangrove	17.94	40.19
	Salt marsh to Mangrove	5.34	4.70
	Water body to Mangrove	3.18	17.54
	Total	579.28	772.37
Degradation	Mangrove to Mudflat	84.13	95.67
	Density wise degradation of mangrove	5.62	158.74
	Mangrove to Salt marsh	22.99	87.24
	Mangrove to Water body	1.37	62.20
	Mangrove to Industry	0.13	110.35
	Total	114.25	514.19

Table 5.11 Change in mangroves of Vagra

Duration	**1978-2001**				**2001-2012**			
Type of industry	(Area in ha)							
	No Change	Mudflat	Land	Total area	No Change	Mudflat	Land	Total area
Industry (Land based)	0.00	0.55	1064.29	1064.83	914.26	164.11	1728.67	2807.04
Jetty	0.00	26.65	0.24	26.90	13.08	34.84	3.78	51.70
Aquaculture industry	0.00	4.48	0.00	4.49	1.82	22.75	29.04	53.61
Saltpan industry	454.76	5599.99	185.22	6239.97	5702.35	1518.13	76.03	7296.52
Oil based industry	0.00	157.65	449.99	607.64	402.79	150.40	333.23	886.42
Total area	454.76	5789.33	1699.74	7943.83	7034.31	1890.23	2170.75	11095.29

Table 5.12 Change in industrial area of Vagra

The aquaculture industry grew almost equally in the mudflat as well as in the land area. The development of this industry was much more during 2001-2012 compared to 1978-2001.

The development of jetties or port has been one of the main reasons for the development of several other industries in Vagra taluka. The construction of jetties has been mostly at the cost of the barren mudflat and to a very little extent of the salt marsh vegetation.

The land based industries developed considerably during the period of 1978-2001 and continued in 2001-2012. These industries developed by the conversion of agricultural land, scrub land, barren land and waterlogged areas.

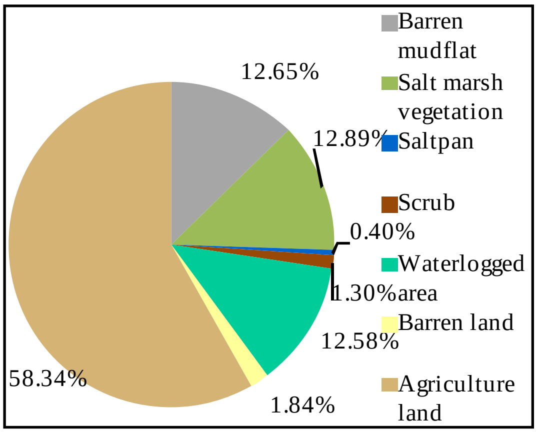


Figure 5.31 Categories converted to oil well during 1978-2001

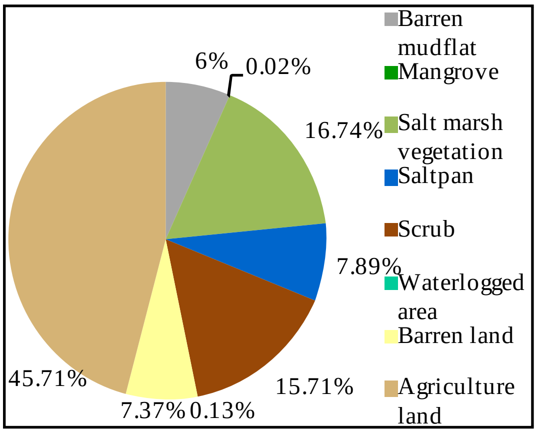


Figure 5.32 Categories converted to oil well during 2001-2012

The oil industry was one of the most devloping industries in the taluka. The area converted to oil wells and associated structures during 1978-2001 and 2001-2012 has been graphically depicted in Figure 5.31 and 5.32. Agricultural land was the major category which got converted. In addition, a large part of the waterlogged area in the north of Muler was also converted to oil well in 1978-2001. During 2001-2012 in addition to agriculture land, barren land and scrub were also converted to oil wells. Although an increase was observed in the areal extent of this category, the rate of increase had slowed down in 2001-2012 as compared to 1978-2001(Table 5.12). In coastal wetland, the oil wells developed by change in the mangrove, salt marsh vegetation and saltpan area.

Thus, large scale development of industries was observed in the mudflat and land during 1978-2001 and the same trend continues even during 2001-2012. The drivers responsible for the development of the area are discussed later.

5.1.3 LAND USE LAND COVER MAPS OF HANSOT TALUKA

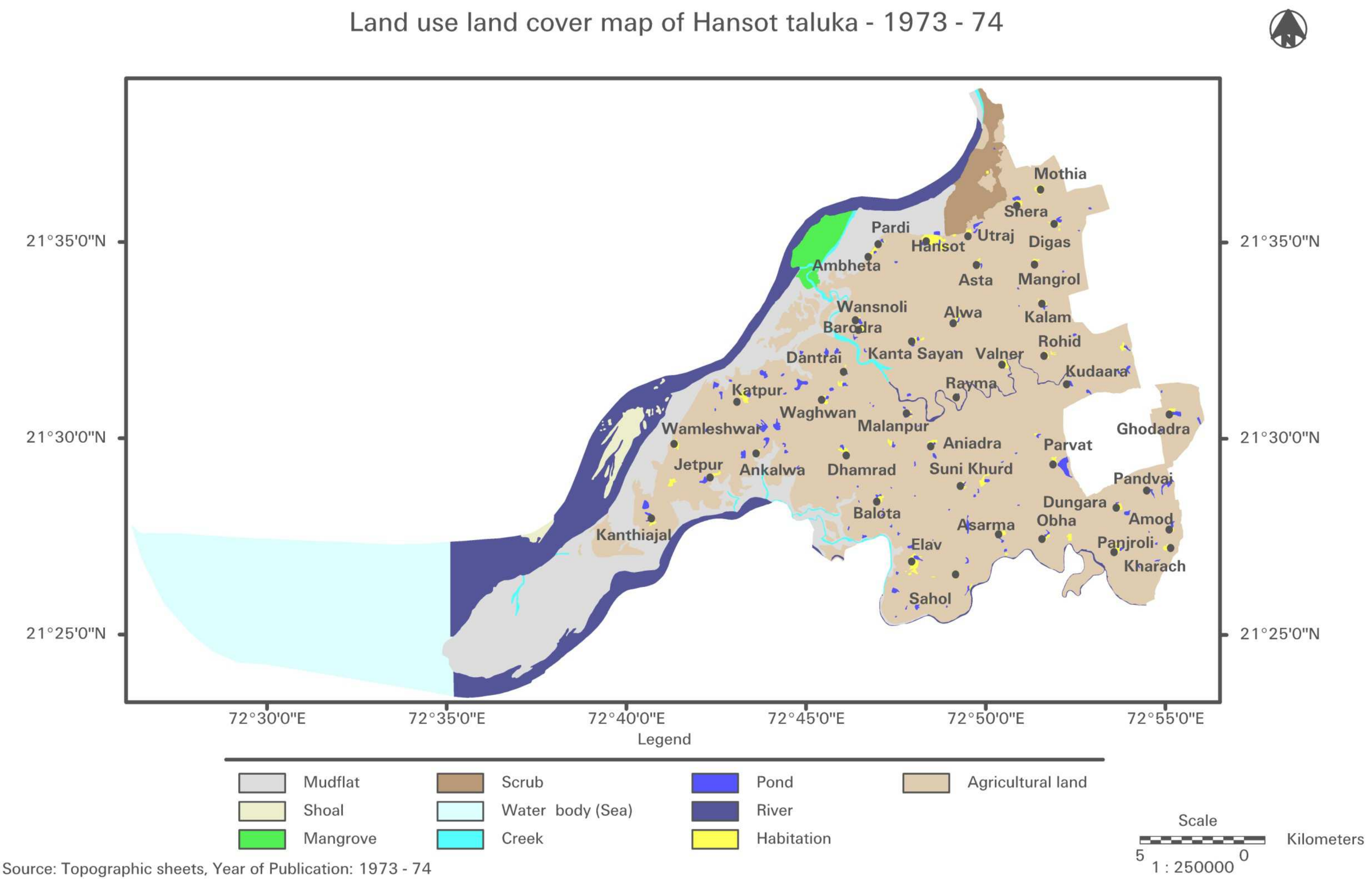
The maps for Hansot taluka were prepared using topographic sheets and satellite images of the year 1978, 1987, 1997, 2004 and 2012. The base map was prepared from topographic sheets published during 1973-74. Hansot taluka falls under the topographic sheet numbers 46C/11, 46C/14 and 46C/15. Plate 5.21 shows the land use land cover map of Hansot taluka prepared from the topographic sheets. Various categories demarcated from the topographic sheets include mudflat, shoal, mangrove, scrub, different types of water bodies, habitation and agricultural land. Agriculture was the major land use category of Hansot taluka contributing about 55.18 % of the total area. Waterbodies which included sea (23.60%), creek (0.56%), pond (0.72%) and river (2.52%) followed next. The areal extent of each of these categories is given in Table 5.13.

Class Name	Area (in ha)
Mudflat	6901.37
Shoal	424.86
Mangrove	462.23
Scrub	857.15
Water body (Sea)	12243.56
Creek	289.06
Pond	373.08
River	1305.18
Habitation	400.29
Agriculture land	28628.54
Total area	51885.32

Table 5.13 Area covered by various land use land cover categories demarcated from topographic sheets of Hansot

The land use land cover maps for the year 1978, 1987, 1997, 2004 and 2012 are given in Plates 5.22, 5.23, 5.24, 5.25 and 5.26 respectively. The different categories which have been demarcated from satellite images included different types of mudflats (sub-tidal, inter-tidal and high-tidal), shoal, beach, mangroves, salt marsh vegetation, algae, *Porteresia coarctata* (grass), scrub, different types of natural and artificial water bodies, barren land, habitation, various types of industries and agricultural land. A summary of the extent of major categories is given in Table 5.14. Agriculture was the major land use throughout the time series. As shown in the Table 5.14 the extent of the coastal wetland categories showed a decreasing trend while the built up area showed an increasing trend.

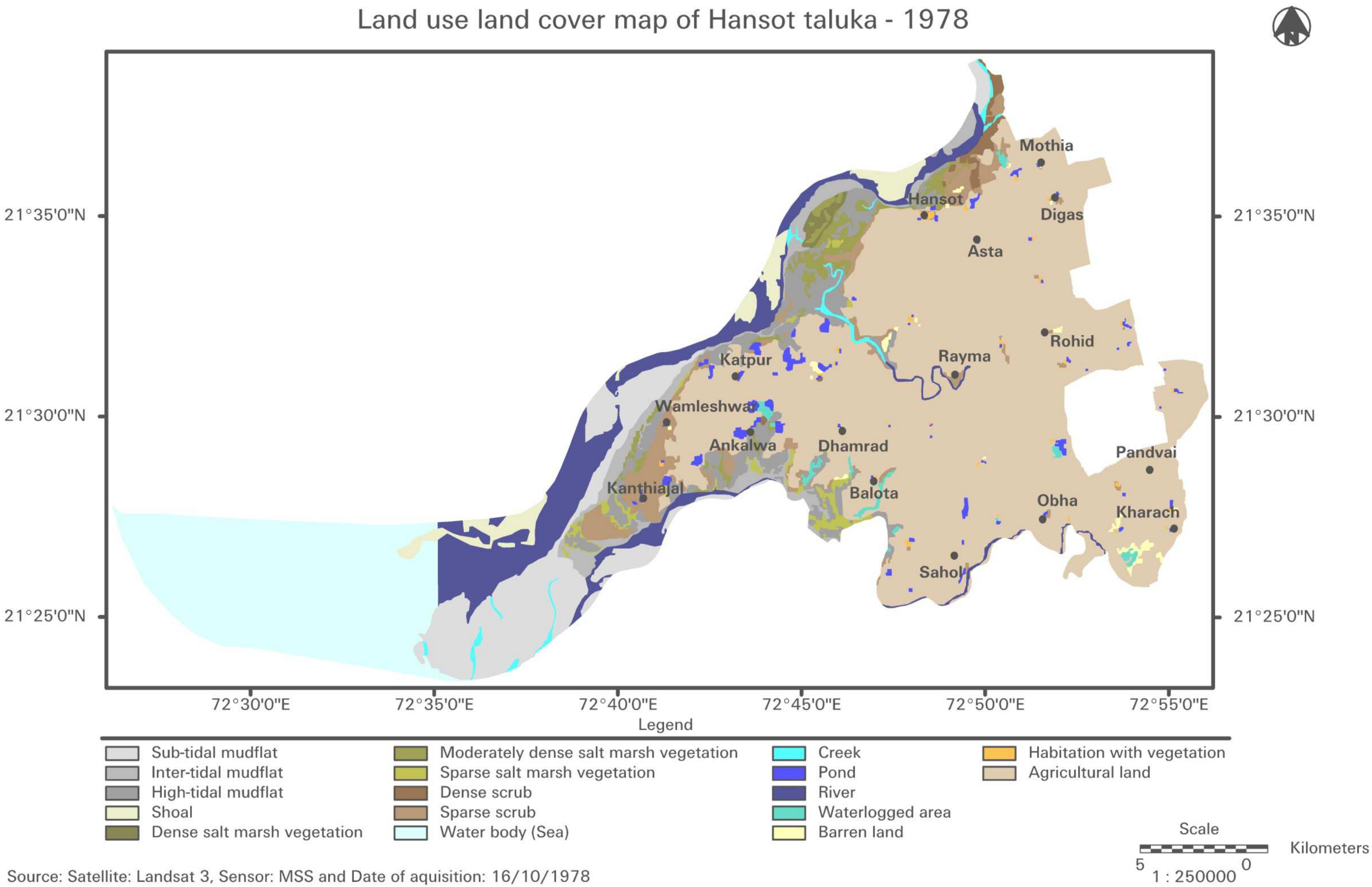
Land use land cover map of Hansot taluka - 1973 - 74



Source: Topographic sheets, Year of Publication: 1973 - 74

Plate : 5.21

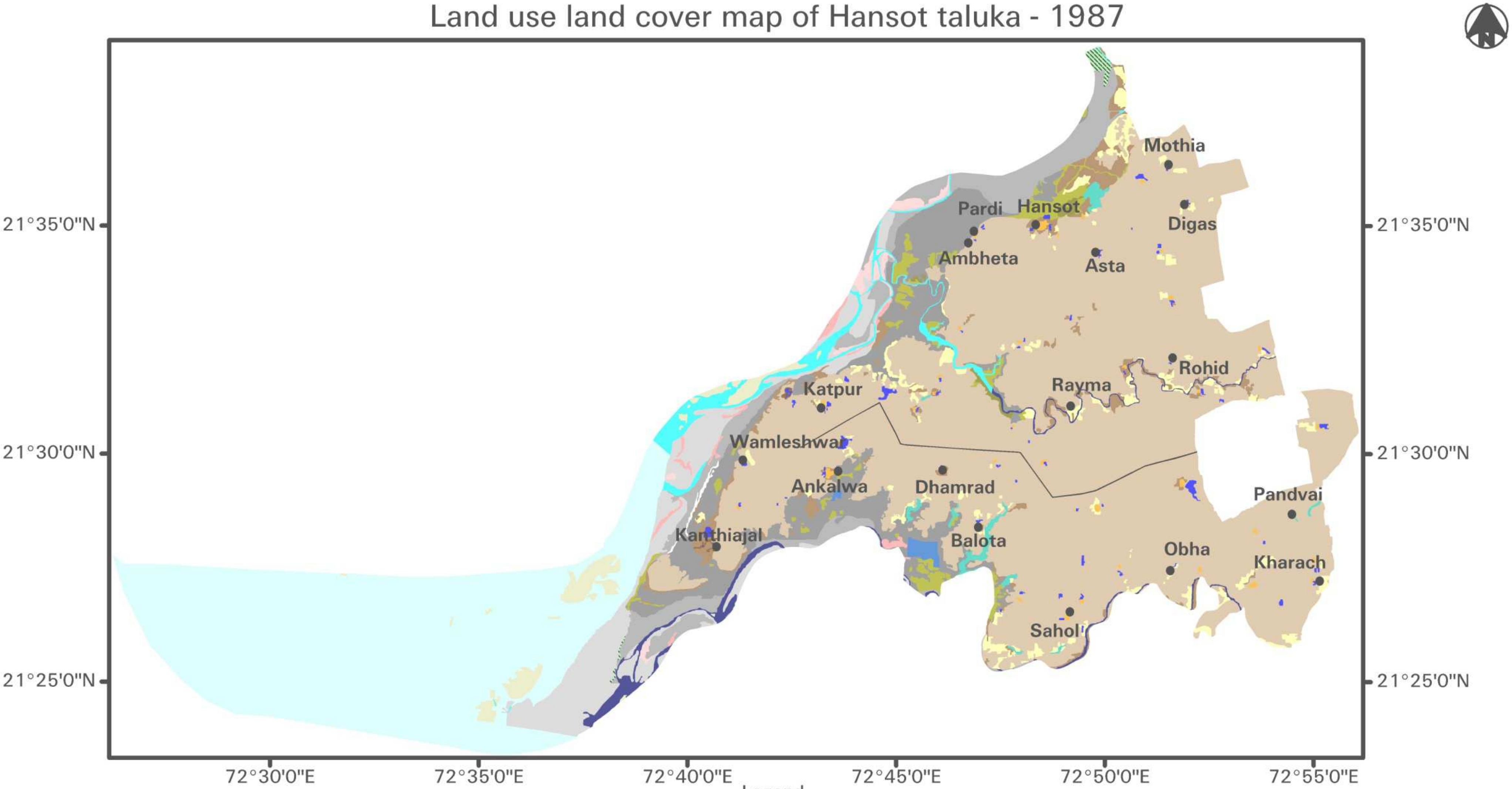
Land use land cover map of Hansot taluka - 1978



Source: Satellite: Landsat 3, Sensor: MSS and Date of aquisition: 16/10/1978

Plate : 5.22

Land use land cover map of Hansot taluka - 1987



Legend

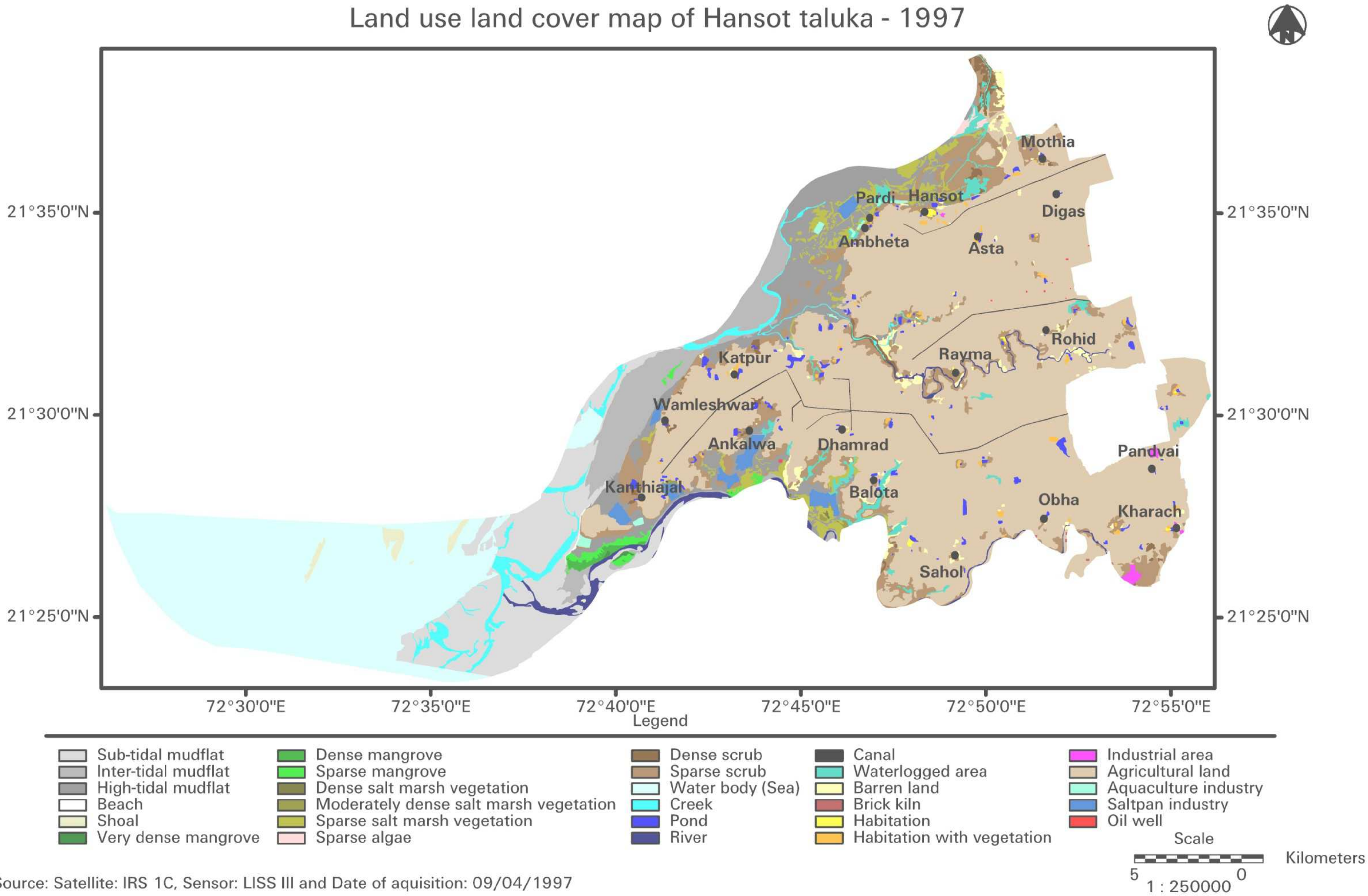
- Sub-tidal mudflat
- Inter-tidal mudflat
- High-tidal mudflat
- Beach
- Shoal
- Moderately dense salt marsh vegetation
- Sparse salt marsh vegetation
- Moderately dense algae
- Sparse algae
- *Porteresia coarctata*
- Dense scrub
- Sparse scrub
- Water body (Sea)
- Creek
- Pond
- River
- Canal
- Barren land
- Waterlogged area
- Habitation with vegetation
- Agricultural land
- Saltpan industry

Scale
5 0 Kilometers
1 : 250000

Source: Satellite: Landsat 5, Sensor: TM and Date of aquisition: 12/01/1987

Plate : 5.23

Land use land cover map of Hansot taluka - 1997



Source: Satellite: IRS 1C, Sensor: LISS III and Date of aquisition: 09/04/1997

Plate : 5.24

Land use land cover map of Hansot taluka - 2004

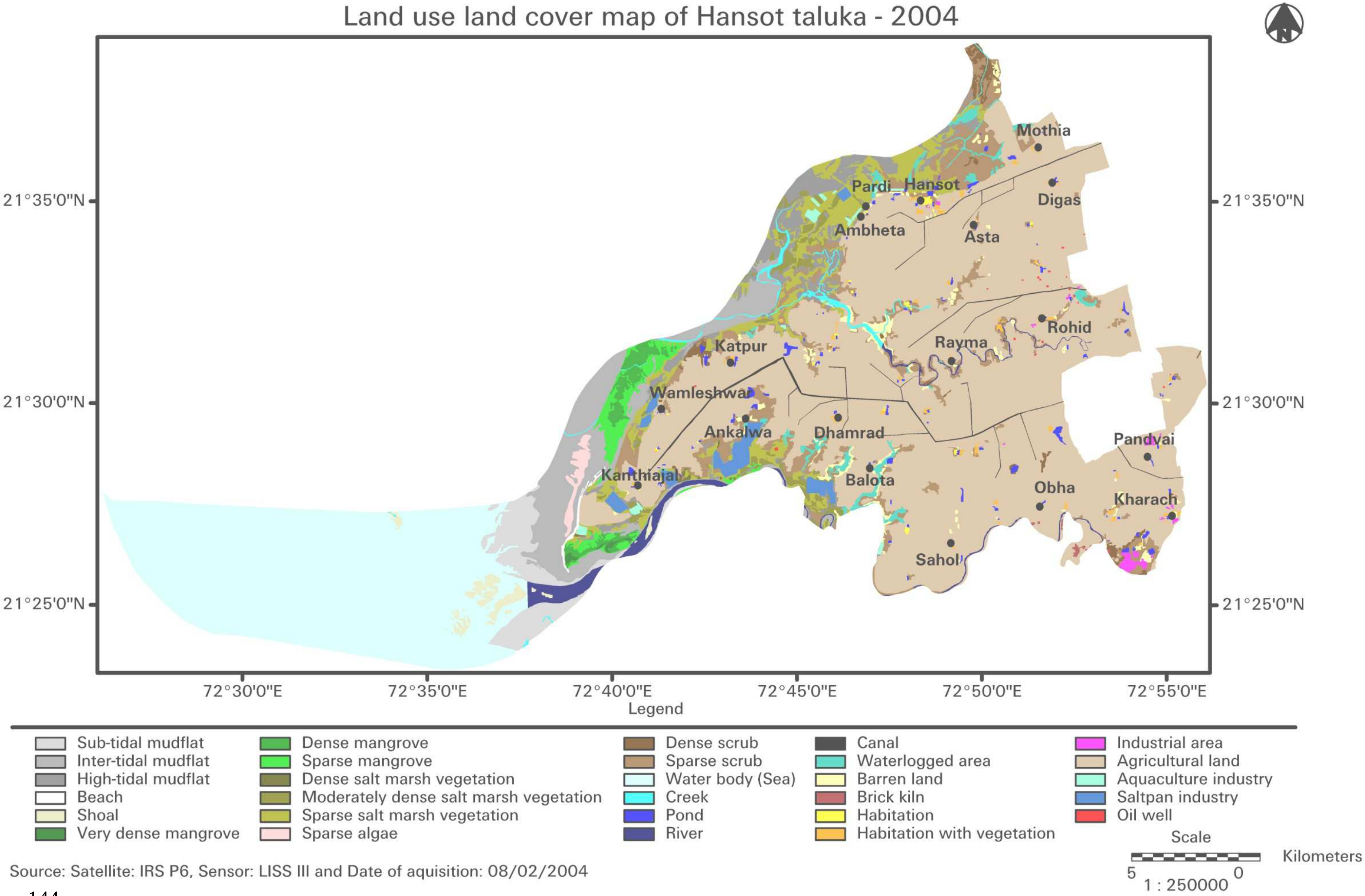
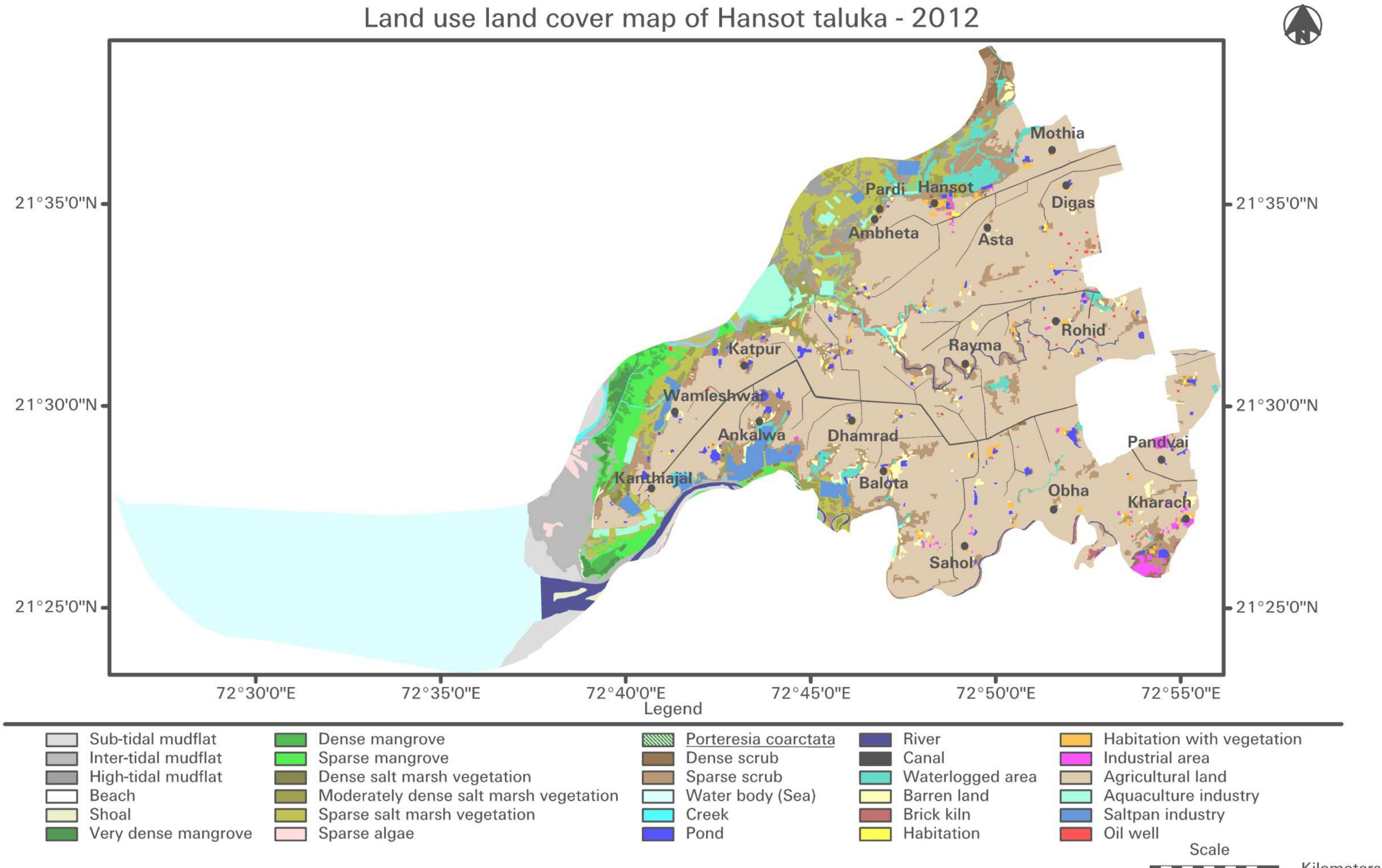


Plate : 5.25



Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 21/01/2012

Plate : 5.26

	Year				
Categories	**1978**	**1987**	**1997**	**2004**	**2012**
	Area in %				
Coastal wetland	20.23	19.75	20.76	18.15	14.80
Water body	25.32	25.92	22.59	24.70	26.91
Barren land	0.37	2.04	0.91	0.87	1.04
Scrub	4.04	2.10	6.54	5.85	6.71
Built-up land	0.27	0.48	1.65	2.06	4.19
Agriculture land	49.77	49.72	47.55	48.38	46.36

Table 5.14 Distribution of manjor land use land cover categories of Hansot talukas across different years

5.1.3.1 Trend in Areal Extent of Different Land Use Land Cover Categories From 1978-2012

A. Coastal wetland: Mudflats, beach, shoal, mangrove, salt marsh vegetation and algal vegetation were the coastal wetland categories observed in this taluka.

A.1 *Mudflat:* The area covered by barren mudflats, vegetated mudflats and mudflats occupied by industries is represented graphically in Figure 5.33. From 1978 to 2012, the area of barren mudflat had decreased as it was either taken up by vegetation or by industries. Thus, vegetated mudflats and industries in the mudflat area showed increase in their area over a period of time.

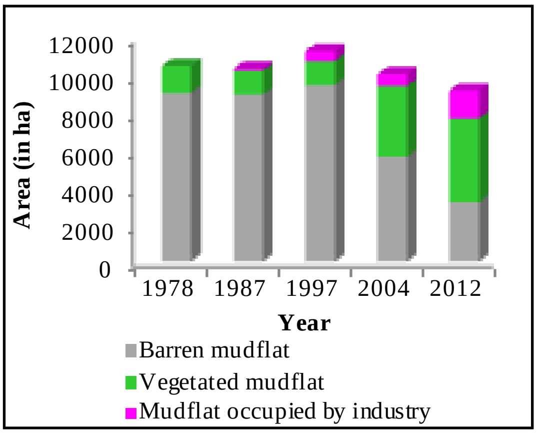


Figure 5.33 Area covered by mudflat category in Hansot

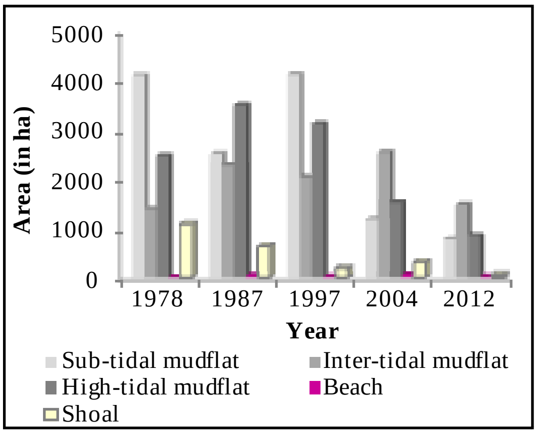


Figure 5.34 Area covered by different barren mudflat categories in Hansot

A.1.1 *Barren mudflat:* The area of sub-tidal mudflat and shoal varied based on the tidal condition of the satellite image. The decrease in the high tidal mudflat from 1987 to 2012 was due to their conversion in to other category such as vegetated mudflat or industrial area (Figure 5.34).

A.1.2 <u>*Vegetated mudflat:*</u> The mudflats covered by mangrove, salt marsh, algae or by grass like *Porteresia coarctata* came under this category. Figure 5.35 shows the variation in the areal extent of mangrove vegetation. The mangroves were found to the west of Katpur, south of Kanthiajal and Ankalwa villages. The graph depicts an increase in the area as well as density of mangrove cover. Figure 5.36 gives an idea about extent of salt marsh vegetation. While Figure 5.37 shows the change in area of algal vegetation. Figure 5.38 shows the area covered by the pioneer grass *Porteresia coarctata*. In 1987 it was found in the north of Hansot taluka where Aliabet merged over a period of time. In 2012 this category was found in the south of Ankalwa village where due to the change in the course of Kim River, a new patch of mudflat was formed. Thus, in the most of the cases this vegetation was closely associated with recently formed mudflats (Bhatt *et al.*, 2008).

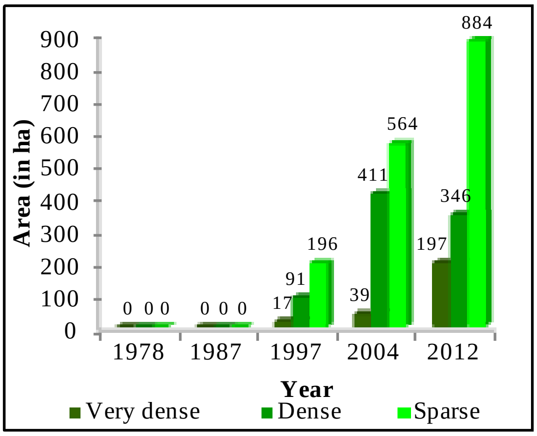


Figure 5.35 Areal extent of mangrove in Hansot

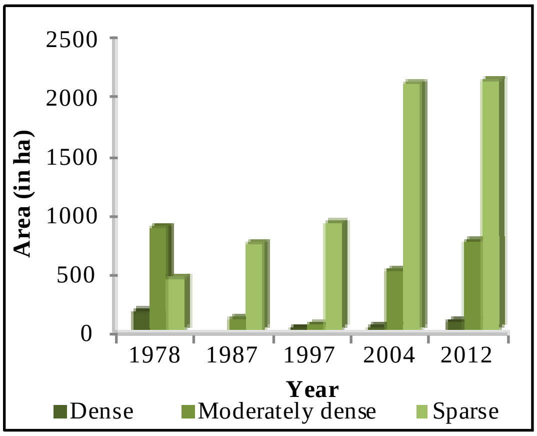


Figure 5.36 Areal extetnt of salt marsh vegetation in Hansot

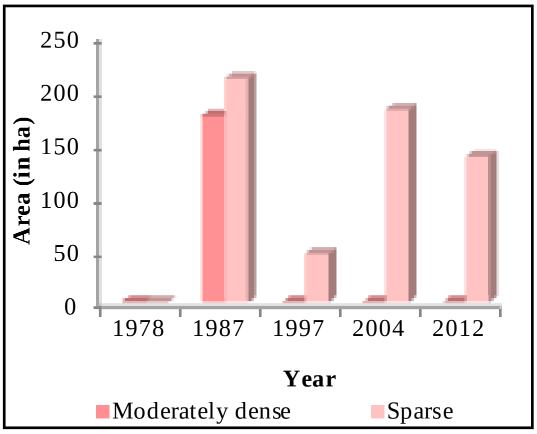


Figure 5.37 Areal extent of algae in Hansot

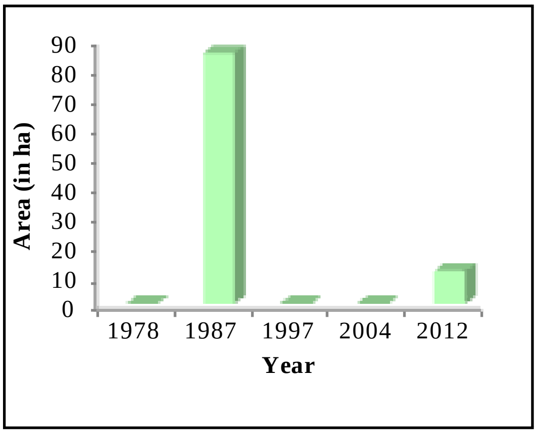


Figure 5.38 Areal extent of *Porteresia coarctata* in Hansot

B. Scrub: Scrub vegetation was found in north of Hansot town, along the river side as well as along the coastline. A few scattered patches were also observed within agricultural land. The area covered by scrub is shown in Figure 5.39.

C. Water bodies: Among the different water bodies the area covered by sea was highest. The extent of different water bodies is graphically represented in Figure 5.40. The area covered by canal has gradually increased over time.

D. Barren land: Barren land was found near water bodies and adjoining the coastline and scrub. Figure 5.41 shows the area covered by barren land.

E. Built-up land: An areal extent of this category was relatively less as compared to Jambusar and Vagra talukas.

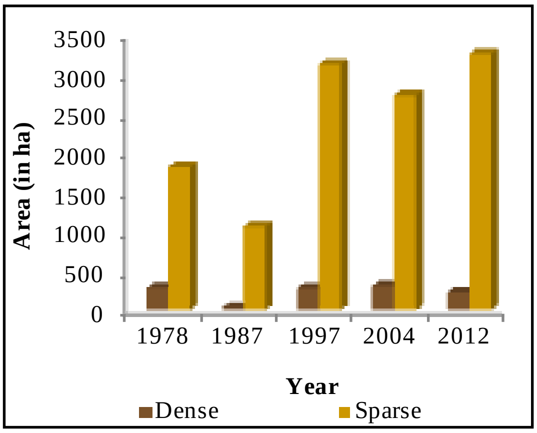


Figure 5.39 Area covered by scrub in Hansot

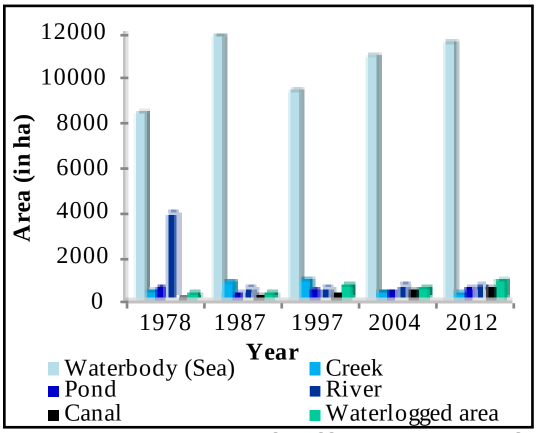


Figure 5.40 Area of different types of water bodies in Hansot

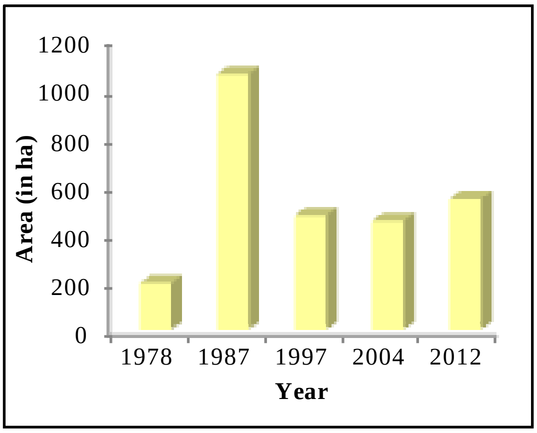


Figure 5.41 Area of barren land in Hansot

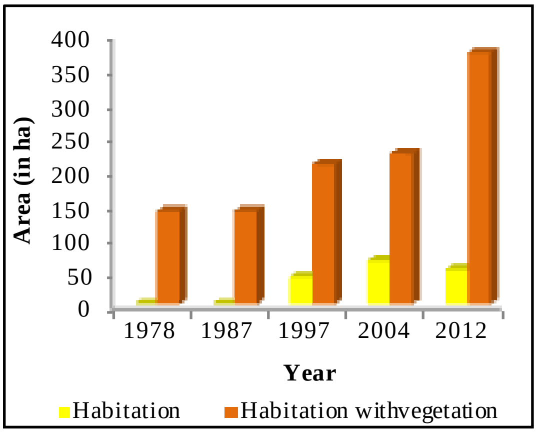


Figure 5.42 Area of habitation in Hansot

E.1 ***<u>Habitation:</u>*** Habitation and habitation with vegetation showed an increase in the area over a period of time (Figure 5.42).

E.2 *Industrial area:* The area covered by industries has steadily increased since 1987 (Figure 5.43). Among them, the area covered by aquaculture was the highest and was progressively followed by saltpan, land based industries, oil industry and the brick kiln industry. Saltpans were found to the north of Hansot, west of Wamleshwar and south of Kanthiajal, Ankalwa and Dhamrad villages. Aquaculture industry had developed mostly at Pardi (to the north of Katpur), to the south and west of Kanthijal and to a very small extent to the south of Dhamrad village. Brick kilns had developed south of Obha and Panjroli villages whereas land based industries had extensively developed near Pandvai, Kharach and Sahol villages and Hanost town. The oil wells were concentrated more in the land ward region as compared to mudflats. They were found in large numbers between Digas and Rohid villages. Besides these a few oil wells were also observed to the east and west side of Katpur and to the south of Ankalwa village.

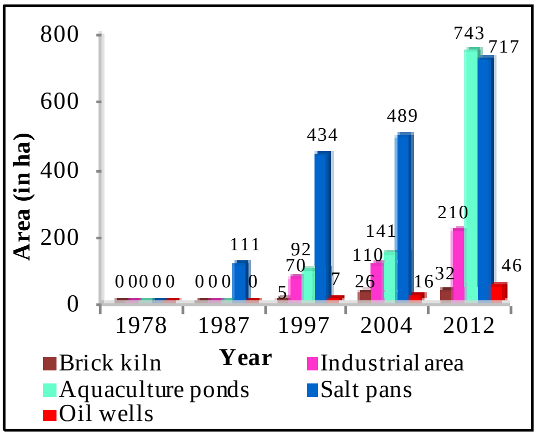


Figure 5.43 Area occupied by different industries in Hansot

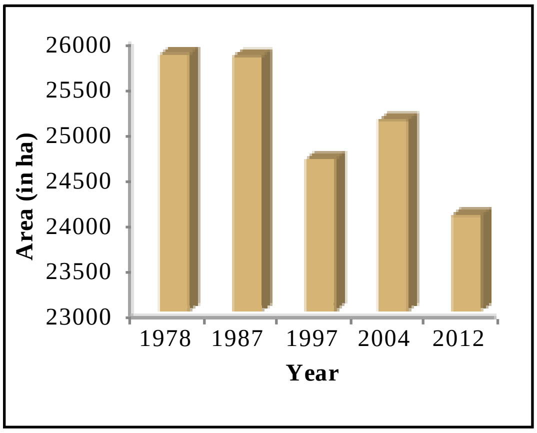


Figure 5.44 Area of agricultural land in Hansot

F. Agriculture land: Like Jambusar and Vagra this category occupied the maximum areal extent. Figure 5.44 shows the variation in the extent of agricultural land over time. Except for the year 2004 it has been showing a gradual decrease in extent. The increase in 2004 could be attributed to the temporary conversion of either barren land or scrub land to agriculture category.

5.1.3.2 Accuracy Assessment

The overall accuracy and Kappa statistics that were generated for each of these maps have been given in Table 5.15. The lowest value was obtained for the year 1978. The lower spatial resolution and the misclassification of sparse scrub at a few locations were the reasons for the low accuracy of the map.

Year	Overall accuracy	Kappa statistics
1978	87%	0.8578
1987	91%	0.8999
1997	93%	0.8995
2004	93%	0.8341
2012	91%	0.8720

Table 5.15 Accuracy statistics for Hansot

5.1.3.3 Change Detection of Hansot Taluka

Change detection analysis of Hansot for the durations 1978-1997 and 1997-2012 had resulted in 370 changed categories. Of these, the categories associated with changes in mangrove and industries have been discussed in detail in the successive text.

***Mangrove Change Analysis*:** Plate 5.27 and 5.28 show the mangrove change maps for the durations 1978-1997 and 1997-2012 respectively. The extent of changes within different categories has been given in Table 5.16. During 1978-1997, major improvement in mangrove area was observed to the south of Kanthiajal. Improvement was also seen south of Ankalwa and in the west of Katpur villages. This improvement was mostly due to colonization of mudflats and creeks by mangrove vegetation. This improvement continued during 1997-2012. In addition to mudflats and creeks, mangroves also colonized areas occupied by salt marsh. They also showed an increase in density at several places. During 1997-2012, marked improvement was seen in areas to the west of Katpur, Wamleshwar and Kanthialjal villages. Degradation of mangrove was also observed during this duration in locations south of Kanthiajal and Ankalwa villages. The conversion of mangrove to salt marsh vegetation represented the largest degradation class closely followed by density wise degradation, and then conversion to mudflat area to industrial area (aquaculture and salt pan industry) and to a very small extent to the water body. Thus, this taluka witnessed increase as well as degradation of mangrove distributed over different areas during the study period.

Change in the industrial area: Aquaculture, saltpan, land based industries, oil industry and brick kiln were the major industries observed in Hansot. Change in the areal extent of these industries during 1978-1997 and 1997-2012 is represented in form of thematic maps in Plates 5.29 and 5.30. Table 5.17 shows areal extent of the changed categories. An increase in the areal extent was observed for all the industries. The development in the brick kiln industry was about seven times during 1997-2012 compared to 1978-1997. This increase was due to the conversion of agricultural land, barren land and scrub land to brick kiln area.

Land based industries expanded substantially in the south eastern part of the taluka near Kharach and Pandvai villages. This increase came at the cost of agricultural land, scrub and barren land.

Aquaculture industry showed the highest quantum of growth during this period. Its increase in area during 1997-2012 (742.70 ha) was about 8 times more than that during (91.71 ha) 1978-1997. The categories that were converted to aquaculture during 1978-1997 and 1997-2012 have been represented in the form of pie charts as Figure 5.45 and 5.46. During 1978-1997 aquaculture ponds were mainly build on barren mudflat, salt marsh vegetated mudflat, creek (water body) and scrub to a small extent. Whereas during 1997-2012, along with the above, parts of mangrove, waterlogged area and barren land were also converted to aquaculture industry. Thus, there is a need to regularly monitor the growth of this industry in the area if the mangrove vegetation is to be conserved.

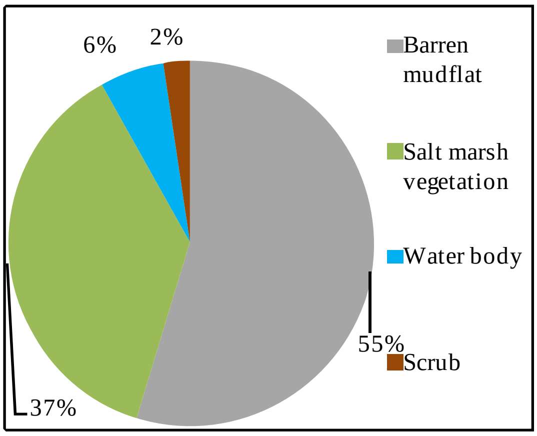


Figure 5.45 Categories converted to aquaculture industry during 1978-1997

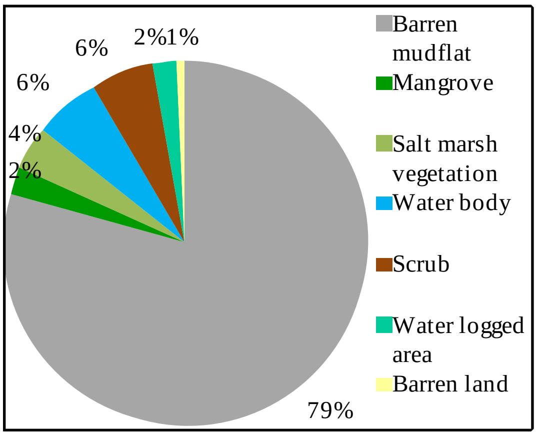


Figure 5.46 Categories converted to aquaculture industry during 1997-2012

During 1978-1997 and 1997-2012 barren mudflats represented the major class that was taken upby the developing saltpan industry (Figure 5.47 and 5.48). Interestingly a small part of land has also been taken up for the construction of saltpans.

Change in mangrove during 1978 - 1997

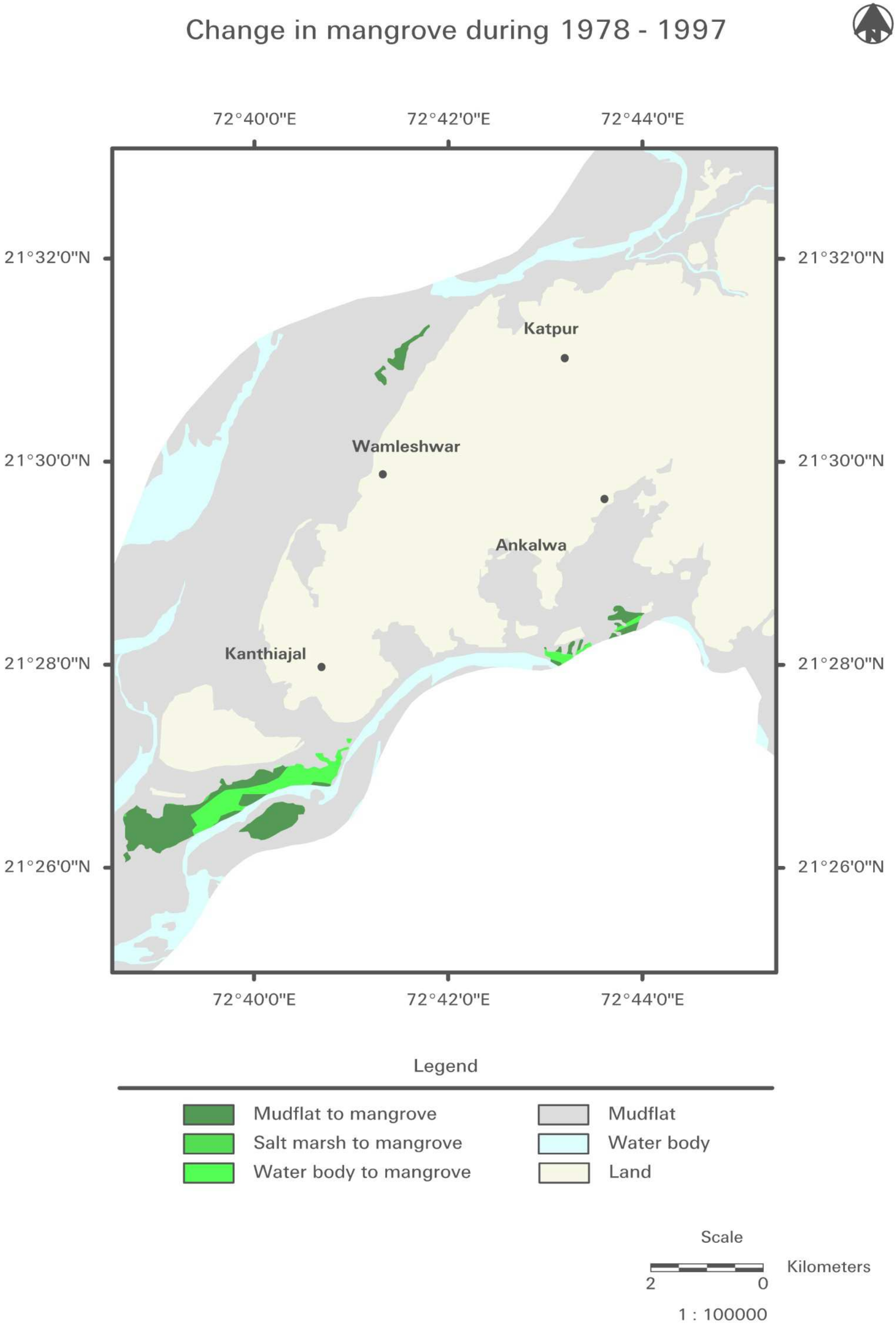


Plate : 5.27

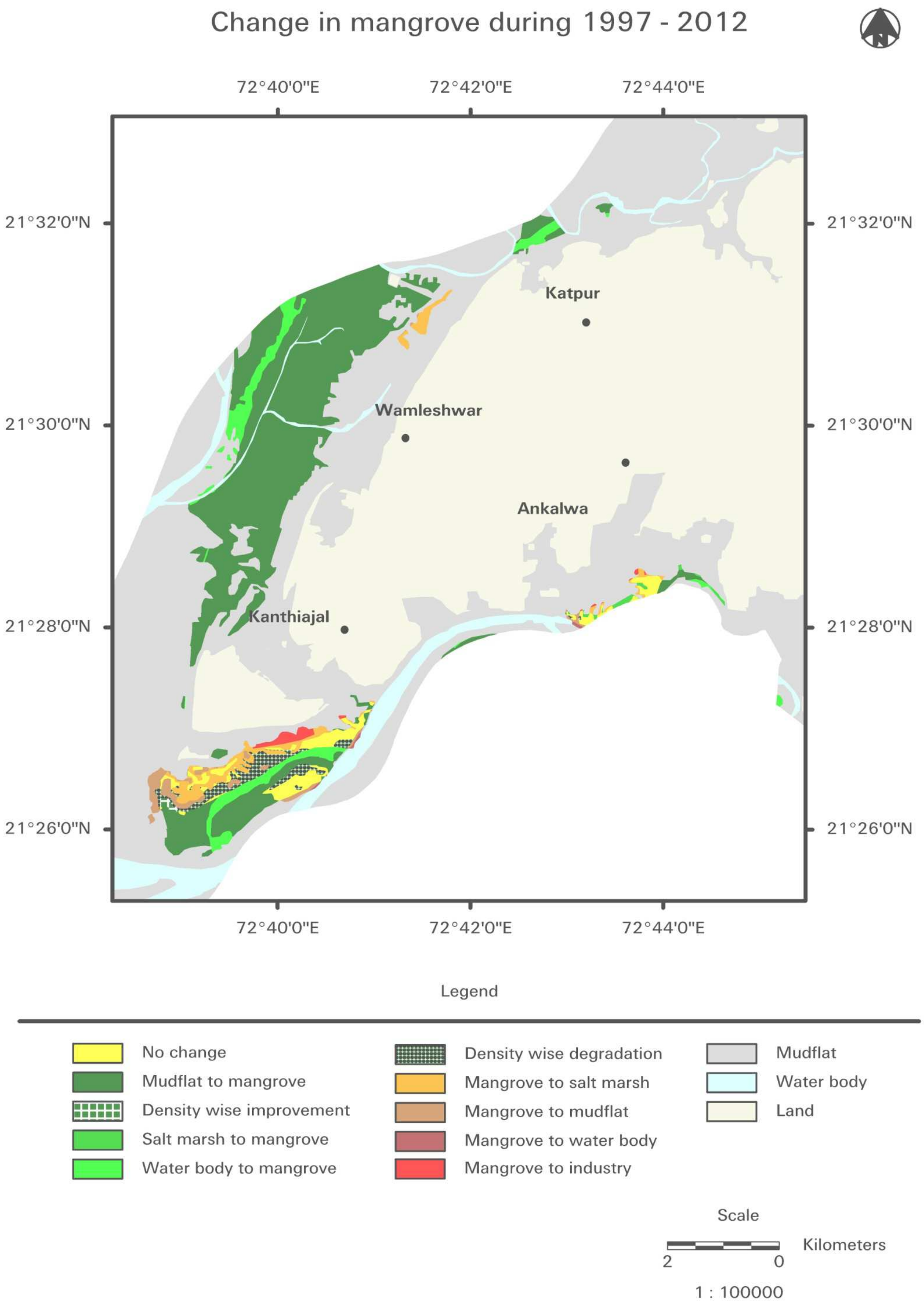

Change in mangrove during 1997 - 2012
72°40'0"E
72°42'0"E
72°44'0"E
21°32'0"N
21°30'0"N
21°28'0"N
21°26'0"N
Katpur
Wamleshwar
Ankalwa
Kanthiajal
Legend
No change
Mudflat to mangrove
Density wise improvement
Salt marsh to mangrove
Water body to mangrove
Density wise degradation
Mangrove to salt marsh
Mangrove to mudflat
Mangrove to water body
Mangrove to industry
Mudflat
Water body
Land
Scale
Kilometers
2
0
1 : 100000

Plate : 5.28

Change in industries during 1978 - 1997

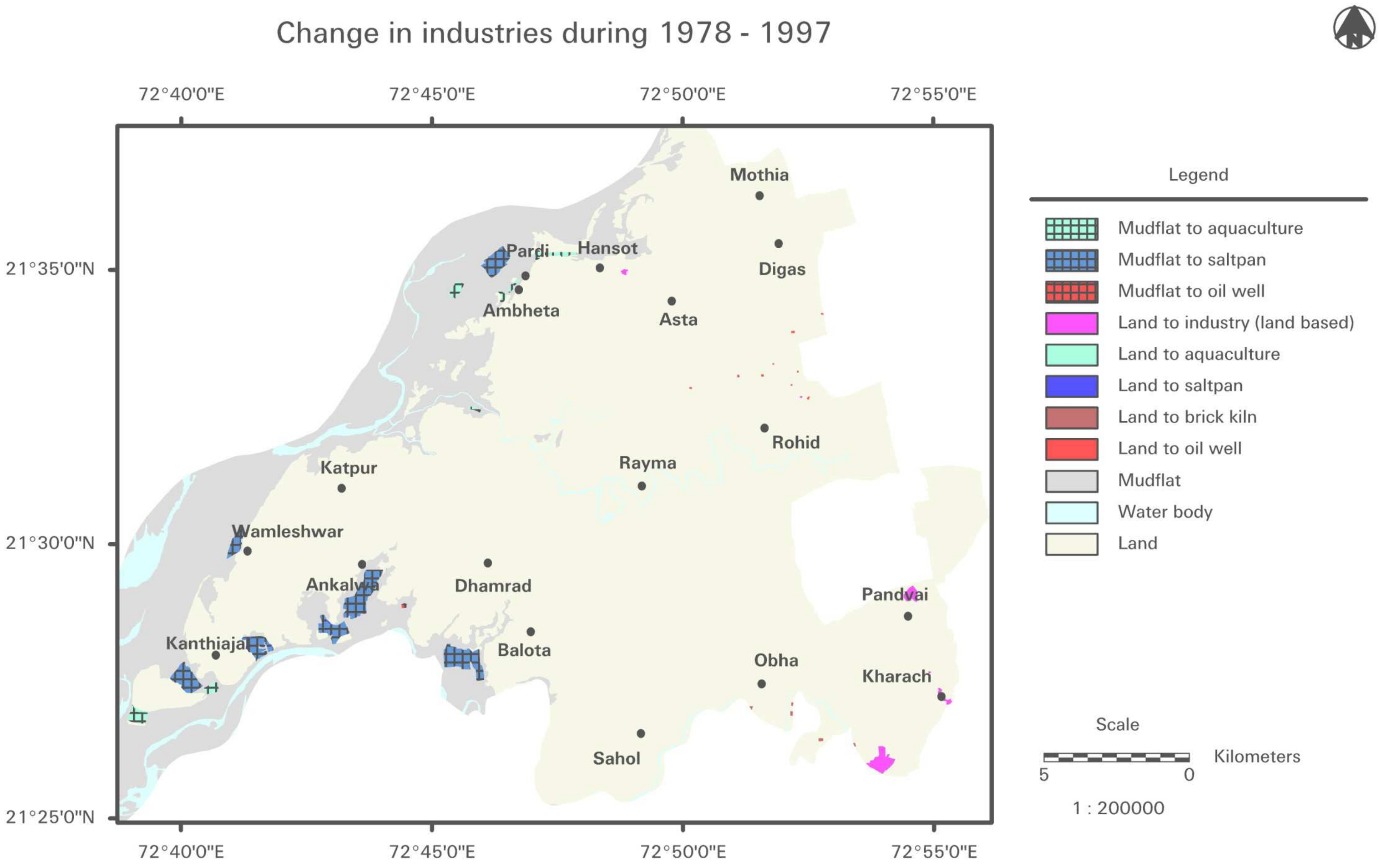


Plate : 5.29

Change in industries during 1997 - 2012

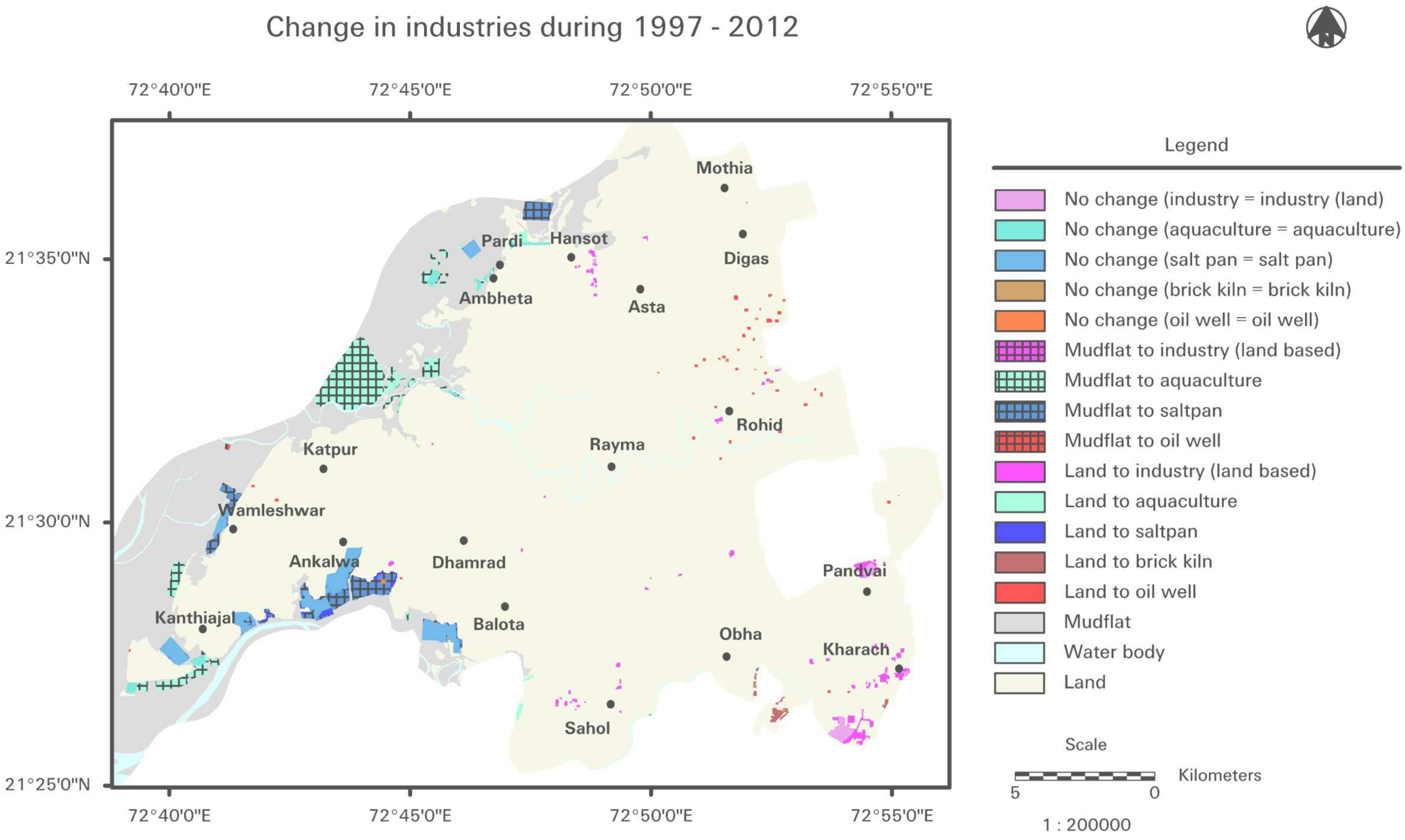


Plate : 5.30

Categories	Changed categories	1978-1997	1997-2012
		Area (in ha)	
No Change	Dense mangrove	0.00	1.80
	Sparse mangrove	0.00	90.93
	Total	0.00	92.73
Improvement	Mudflat to Mangrove	203.10	1125.31
	Density wise improvement in mangrove	0.00	3.99
	Salt marsh to Mangrove	0.82	8.28
	Water body to Mangrove	99.40	134.08
	Total	303.32	1271.66
Degradation	Mangrove to Mudflat	0.00	43.84
	Density wise degradation of mangrove	0.00	63.02
	Mangrove to Salt marsh	0.00	79.30
	Mangrove to Water body	0.00	2.95
	Mangrove to Industry	0.00	17.48
	Total	0.00	206.60

Table 5.16 Change in mangroves of Hansot

Duration	1978-1997				1997-2012			
Type of industry	Area (in ha)							
	No Change	Mudflat	Land	Total area	No Change	Mudflat	Land	Total area
Brick kiln	0	0	4.81	4.81	3.05	0.00	28.75	31.79
Industry (Land based)	0.00	0.00	69.85	69.85	64.52	0.04	145.72	210.28
Aquaculture industry	0.00	89.40	2.30	91.71	68.59	616.74	57.38	742.70
Saltpan industry	0.00	431.34	2.72	434.06	376.37	311.75	29.26	717.38
Oil well	0.00	2.52	4.42	6.94	6.42	3.26	36.20	45.87
Total area (in ha)	0.00	523.26	84.10	607.36	518.94	931.79	297.31	1748.03

Table 5.17 Change in industrial area of Hansot

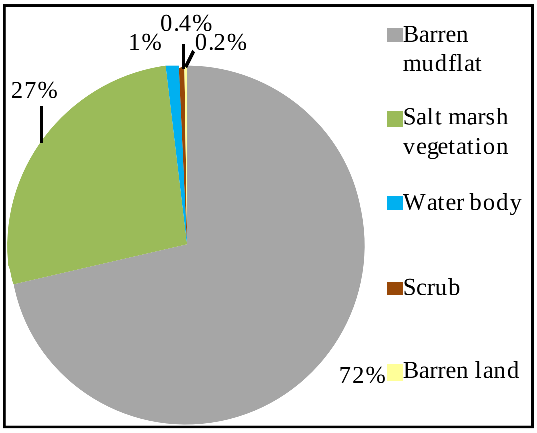


Figure 5.47 Categories converted to saltpan industry during 1978-1997

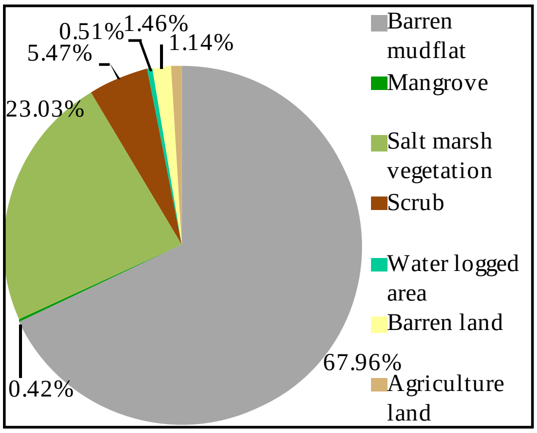


Figure 5.48 Categories converted to saltpan industry during 1997-2012

Oil industry had grown more than five times during 1997-2012 (45.87 ha) as compared to (6.94 ha) 1978-1997. The categories converted in to oil well industry in 1978-1997 and 1997-2012 is represented graphically in Figure 5.49 and 5.50. As seen below oil wells have develoed more on land compared to interitdal areas.

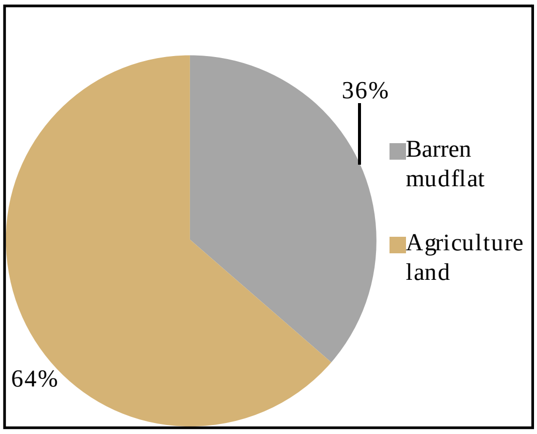


Figure 5.49 Categories converted to oil well during 1978-1997

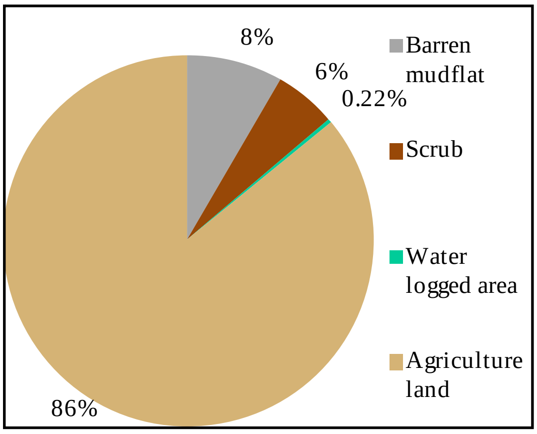


Figure 5.50 Categories converted to oil well during 1997-2012

5.1.4 LAND USE LAND COVER MAPS OF ALIABET

Aliabet was an island in the Narmada River and fell under the administrative boundary of Vagra taluka. However over a period of time due to substantial changes in its geomorphology, it lost its identity as an island and got merged with the mainland along its southern and eastern boundaries i.e. with the Hansot taluka. Thus, practically, the approach of Aliabet was from Hansot and should be studied along with this taluka. However, in order to avoid any administrative boundary conflicts, Aliabet was considered as a separate entity for the study of land use land cover categories, change detection and geomorphology. For Aliabet land use land cover maps were prepared from the topographic sheets and from the satellite images for the year 1978, 1987, 1997, 2001, 2004 and 2012. The base map was prepared from the topographic sheets published during 1973-74. Aliabet comes under the topographic sheet number 46C/10, 46C/11 and 46C/14. Plate 5.31 shows land use land cover map of Aliabet prepared from them. The different categories marked from the topographic sheets were mudflat, shoal, mangrove, scrub and different types of water bodies. Aliabet being an island was covered by water from all the sides. The different types of water bodies (sea, river, creeks) had a combined areal extent of 50.54%. During this period, Narmada River was flowing along the northern side as well as from the eastern side of the island whereas in the western side it was delimited by the Gulf of Khambhat. The island was basically a coastal wetland (30.76%) which got criss-crossed by a number of creeks. The topographic sheets showed large patches of mangrove (18.45%) on the island and a small patch of scrub (0.22%) in the north-east side of Aliabet. The areal extent of these categories is given in Table 5.18. It is important to note here that the agricultural area (0.03%) mentioned in Table 5.18 and demarcated in the Plate 5.31 is not on the island area but along the northern bank of Narmada River. As this part falls within the boundary fixed for Aliabet, the mapping and area calculation was done accordingly.

Class Name	Area (in ha)
Mudflat	13573.95
Shoal	2892.76
Mangrove	9876.28
Scrub	119.64
Water body (Sea)	14577.05
Creek	1722.37
River	10517.73
Waterlogged area	239.71
Agriculture land	16.74
Total area	53536.23

Table 5.18 Area of various land use land cover categories demarcated from topographic sheets of Aliabet

Aliabet showed relatively large homogenous land cover classes as compared to other talukas under study. Hence, this area was classified using unsupervised classification technique followed by contextual editing. Plate 5.32, 5.33, 5.34, 5.35, 5.36 and 5.37 shows the land use land cover maps for the year 1978, 1987, 1997, 2001, 2004 and 2012 respectively. The contribution of the major categories in terms of percentage is depicted in Table 5.19. Throughout the time series, the water body has been the major category followed by coastal wetland category, scrub, barren land and built-up land.

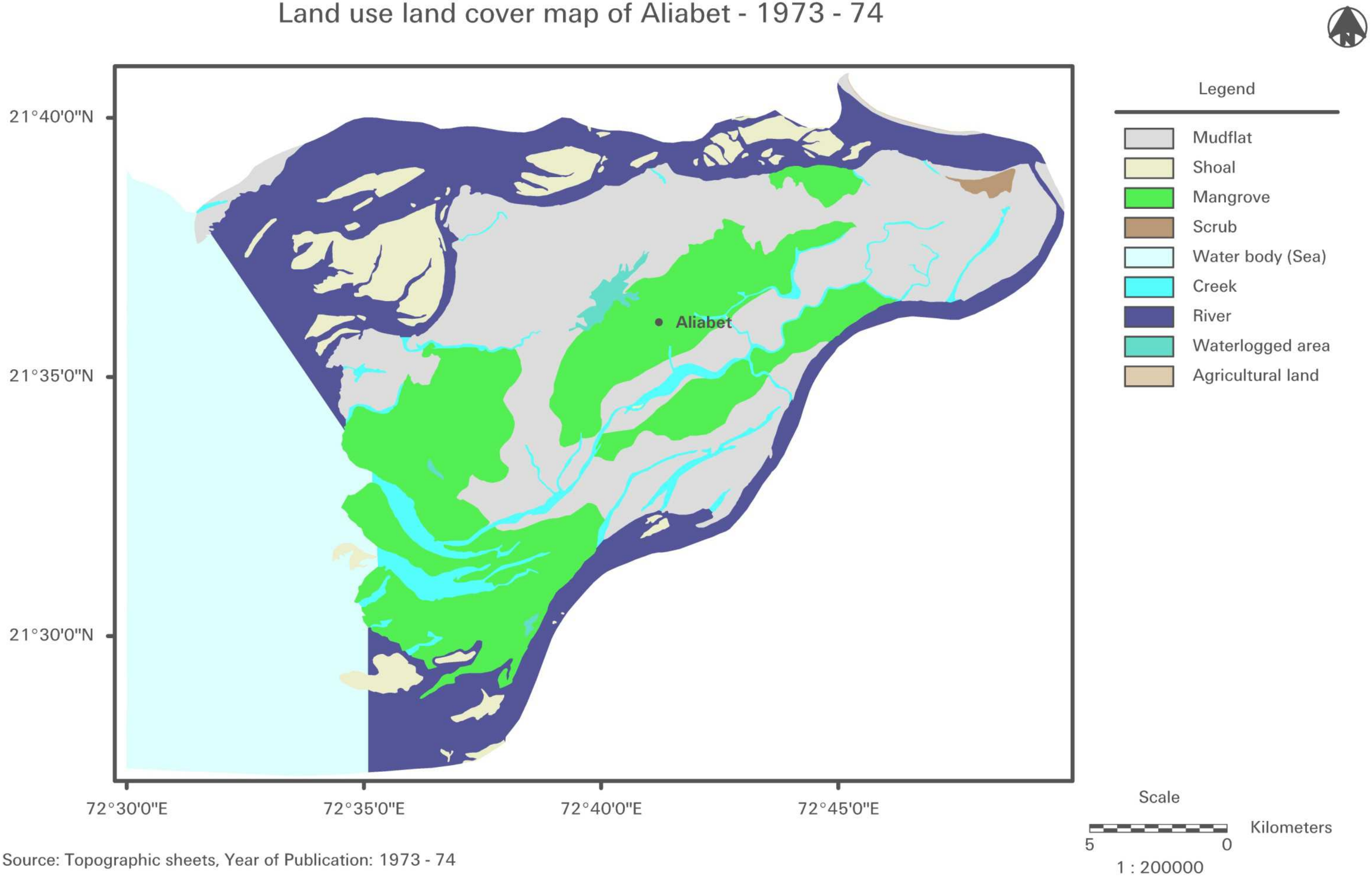
The sequence of the thematic maps of Aliabet clearly indicates the progressive merging of an island with the mainland. In 1978, Narmada River flowed from the northern as well as eastern direction of an island. By 1987, the channel flowing from the eastern side was filled by sediments and the satellite image showed presence of grass-like (probably *Porteresia coarctata*) vegetation along the mouth of channel.

	Year					
Categories	**1978**	**1987**	**1997**	**2001**	**2004**	**2012**
	Area (in %)					
Coastal wetland	39.43	45.80	51.73	39.98	45.44	42.03
Water body	60.11	52.55	45.94	58.10	51.86	52.18
Barren land	0.00	0.05	0.07	0.29	0.10	0.03
Scrub	0.42	1.54	2.20	1.57	2.47	4.84
Built-up land	0.00	0.00	0.00	0.00	0.07	0.85
Agriculture land	0.04	0.06	0.06	0.06	0.06	0.07

Table 5.19 Distribution of major land use land cover categories of Aliabet across different years

Apart from this the image also indicated algae as well as salt marsh vegetation at places where the island merged with the mainland. With the filling of this channel, water from the river no longer flowed along the southern part of the island. Hence, the channel which was demarcated as river in 1978 was later marked as creek. The entire coastal wetland was well dissected by creeks which brought considerable tidal water in to Aliabet. A small patch of scrub observed in the north east side of Aliabet also expanded considerably over time. Earlier Aliabet was not accessible during monsoon and even for a few months after monsoon. Thus, the entire wetland area was undisturbed for considerable period of time. But, the construction of the oil well (industrial development) along the northern side of Aliabet (in 2004) and the development of a road along with it had large impact on the use of the coastal wetland. This facilitated the development of the aquaculture industry and substantially changed the land use land cover characteristics of this coastal wetland. Recent visits

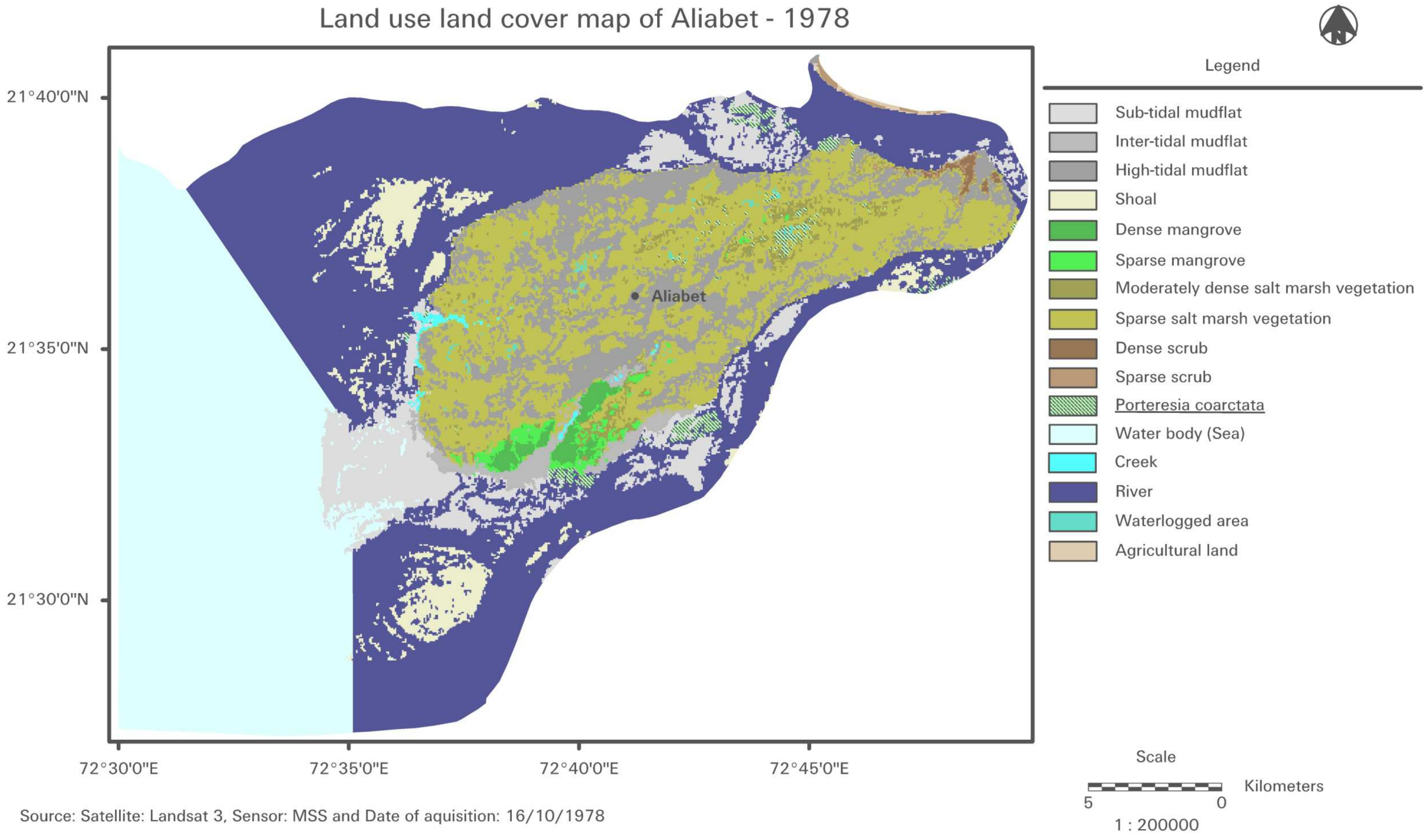
Land use land cover map of Aliabet - 1973 - 74



Source: Topographic sheets, Year of Publication: 1973 - 74

Plate : 5.31

Land use land cover map of Aliabet - 1978



Source: Satellite: Landsat 3, Sensor: MSS and Date of aquisition: 16/10/1978

Plate : 5.32

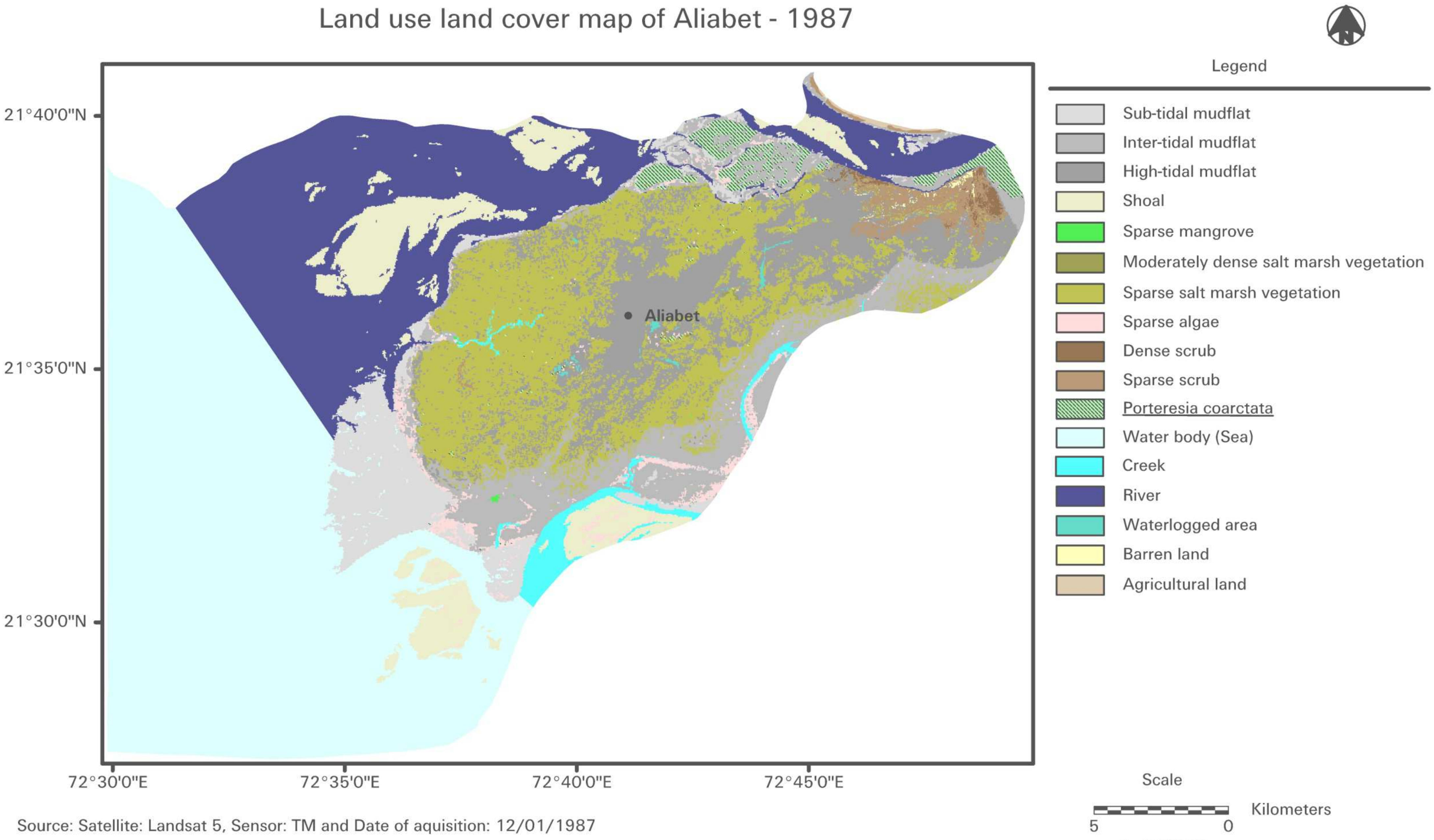
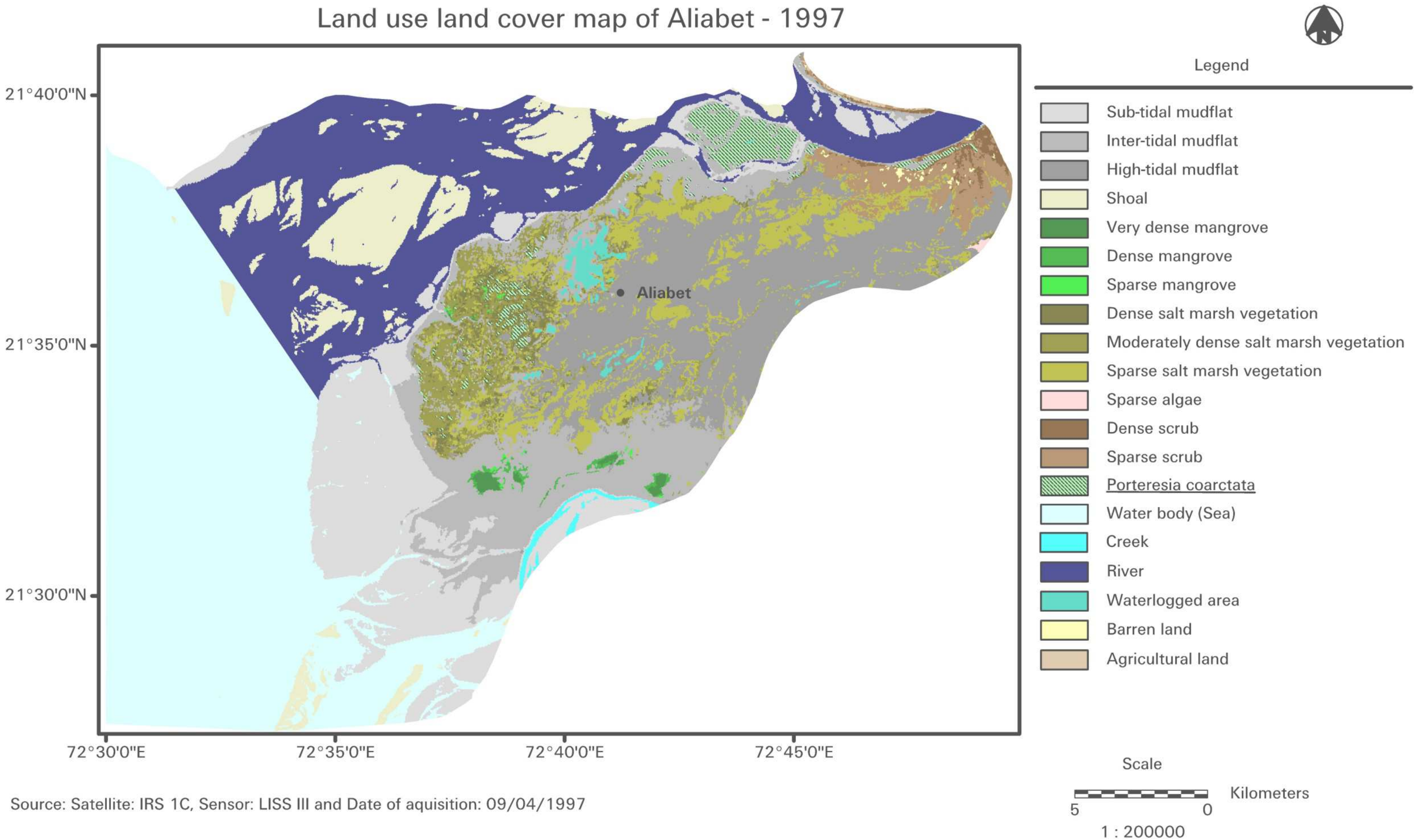

Land use land cover map of Aliabet - 1987
Legend
Sub-tidal mudflat
Inter-tidal mudflat
High-tidal mudflat
Shoal
Sparse mangrove
Moderately dense salt marsh vegetation
Sparse salt marsh vegetation
Sparse algae
Dense scrub
Sparse scrub
Porteresia coarctata
Water body (Sea)
Creek
River
Waterlogged area
Barren land
Agricultural land
Aliabet
21°40'0"N
21°35'0"N
21°30'0"N
72°30'0"E
72°35'0"E
72°40'0"E
72°45'0"E
Scale
Kilometers
5
0
1 : 200000
Source: Satellite: Landsat 5, Sensor: TM and Date of aquisition: 12/01/1987

Plate : 5.33

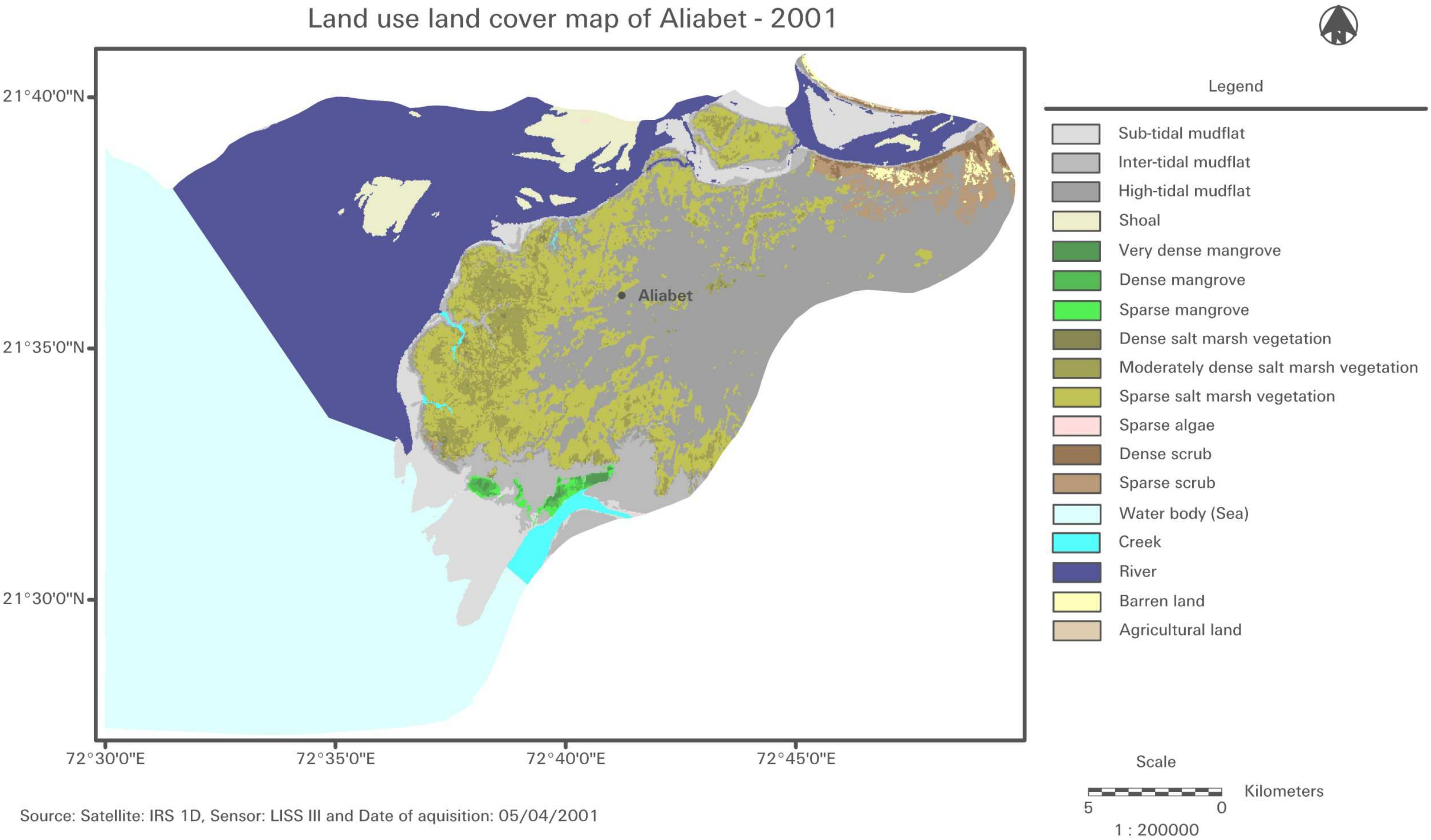
Land use land cover map of Aliabet - 1997



Source: Satellite: IRS 1C, Sensor: LISS III and Date of aquisition: 09/04/1997

Plate : 5.34

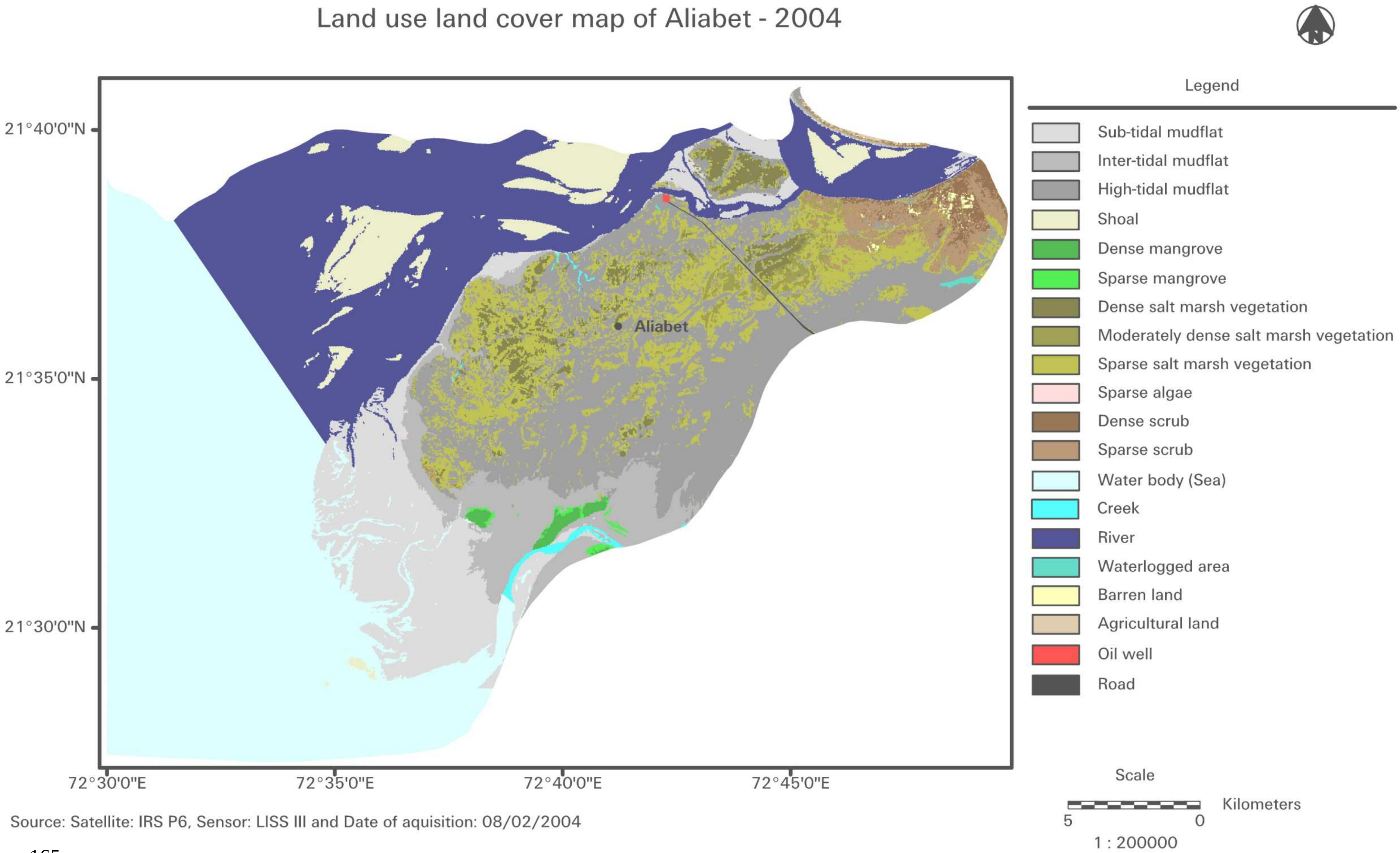
Land use land cover map of Aliabet - 2001



Source: Satellite: IRS 1D, Sensor: LISS III and Date of aquisition: 05/04/2001

Plate : 5.35

Land use land cover map of Aliabet - 2004



Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 08/02/2004

Plate : 5.36

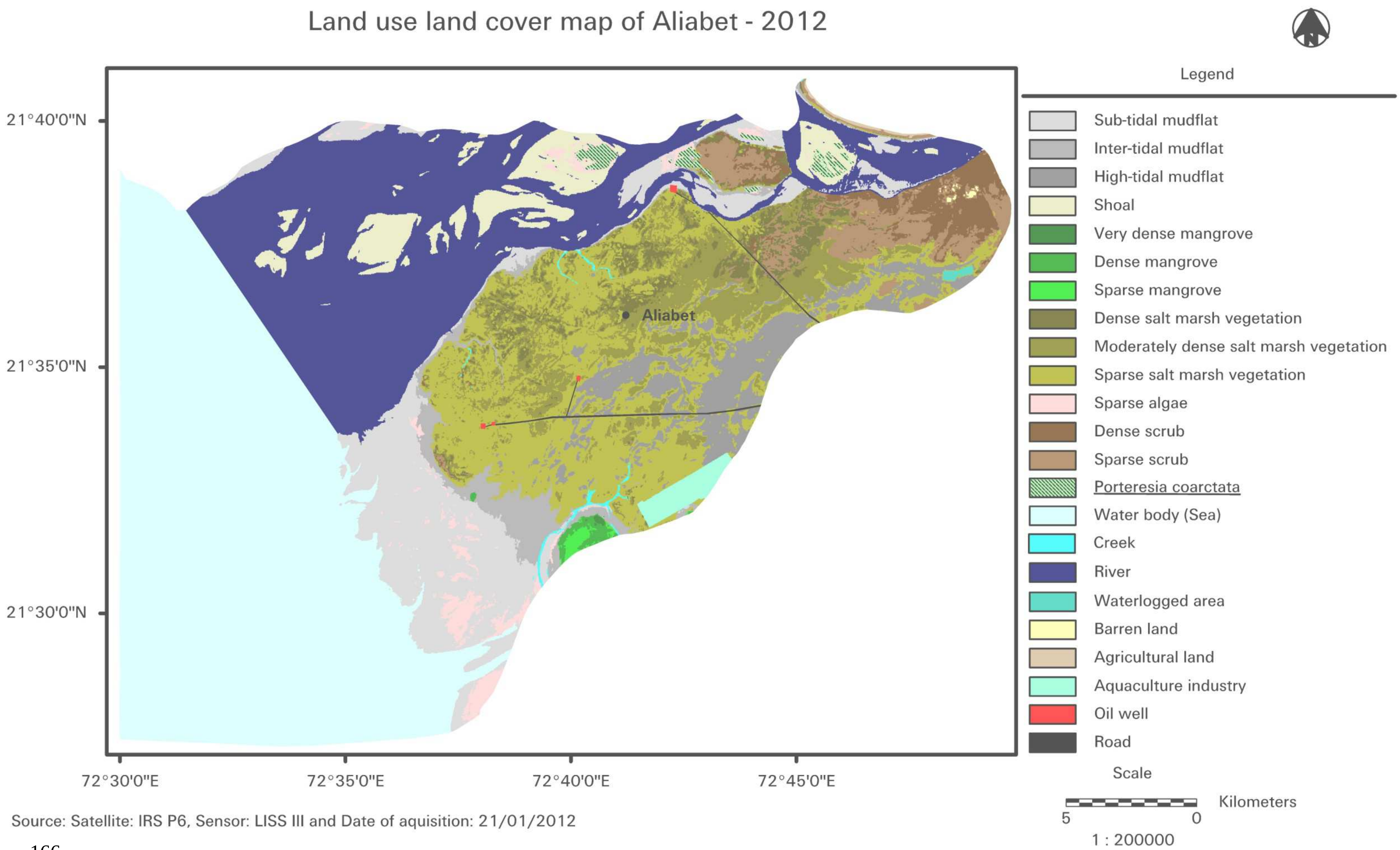

Land use land cover map of Aliabet - 2012
Legend
Sub-tidal mudflat
Inter-tidal mudflat
High-tidal mudflat
Shoal
Very dense mangrove
Dense mangrove
Sparse mangrove
Dense salt marsh vegetation
Moderately dense salt marsh vegetation
Sparse salt marsh vegetation
Sparse algae
Dense scrub
Sparse scrub
Porteresia coarctata
Water body (Sea)
Creek
River
Waterlogged area
Barren land
Agricultural land
Aquaculture industry
Oil well
Road
Aliabet
21°40'0"N
21°35'0"N
21°30'0"N
72°30'0"E
72°35'0"E
72°40'0"E
72°45'0"E
Scale
Kilometers
5
0
1 : 200000
Source: Satellite: IRS P6, Sensor: LISS III and Date of aquisition: 21/01/2012

Plate : 5.37

to this area have shown that the aquaculture industry has developed to such a large extent that most of Aliabet has now become accessible.

5.1.4.1 Trend in Areal Extent of Different Land Use Land Cover Categories From 1978-2012

A. Coastal wetland: Mudflats, shoal, mangrove, salt marsh and algal vegetation were the categories observed in Aliabet.

A.1 ***<u>Mudflat:</u>*** The area covered by barren mudflat, vegetated mudflat and mudflat taken up by industries and scrub is graphically depicted in Figure 5.51.

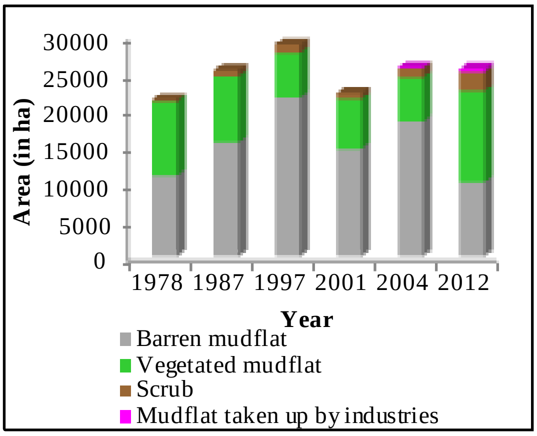


Figure 5.51 Area covered by mudflat in Aliabet

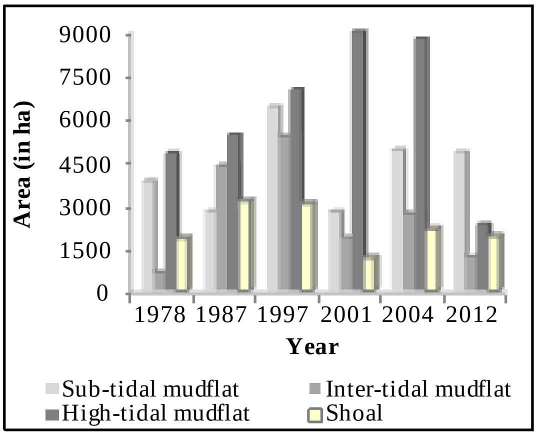


Figure 5.52 Area covered by different barren mudflat categories in Aliabet

A.1.1 *<u>Barren mudflat:</u>* Aliabet had undergone lots of changes in its geomorphology. It witnessed considerable accretion and to a small extent erosion as well. The variation observed in the extent of barren mudflat category was mainly due to the accretion observed in this area and variation in the tidal conditions of the satellite images. The areal extent of each of these is shown in Figure 5.52.

A.1.2 *<u>Vegetated mudflat:</u>* Figure 5.53 shows variation the area covered by mangrove vegetation over the priod of study. The area of mangrove was highest for the year 1978, which dropped substantially in 1987. The mangrove cover almost remained constant during 1997, 2001 and 2004. There were however change in its density. A drop was observed in the area of mangrove area in 2012. Figure 5.54 shows the area covered by salt marsh vegetation and Figure 5.55 shows the area covered by algal vegetation from 1978-2012. Figure 5.56 shows the area covered by *Porteresia coarctata* (grass) on and around Aliabet. This particular vegetation flourished well on the newly formed mudflats and according to Jagtap *et al.*, (2006) and Bhatt *et al.*,

(2008) it is also an indicator of stabilization of the new formed mudflats. The increase in its areal extent in the 1978, 1987 and 1997 supports the changes observed in Aliabet.

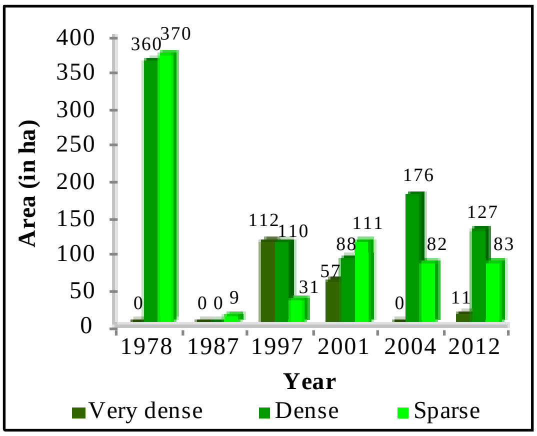


Figure 5.53 Areal extent of mangrove in Aliabet

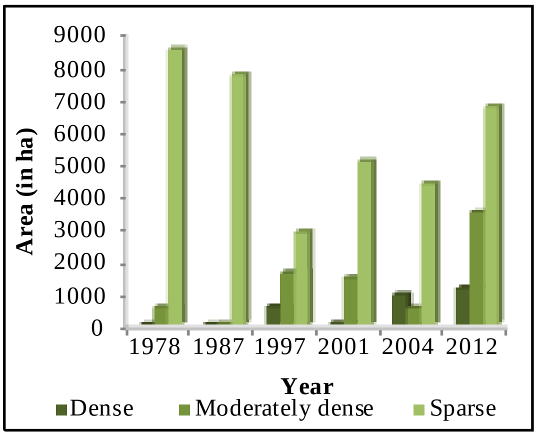


Figure 5.54 Areal extent of salt marsh vegetation in Aliabet

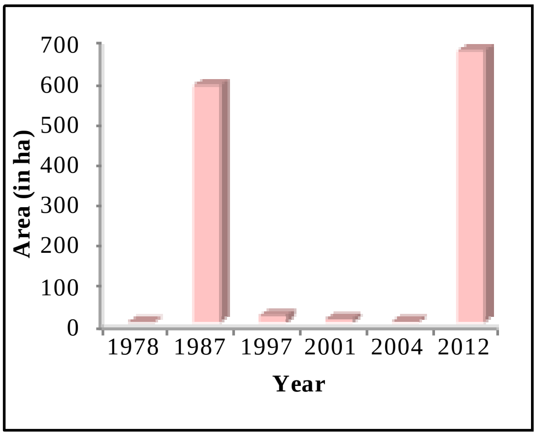


Figure 5.55 Areal extent of algae in Aliabet

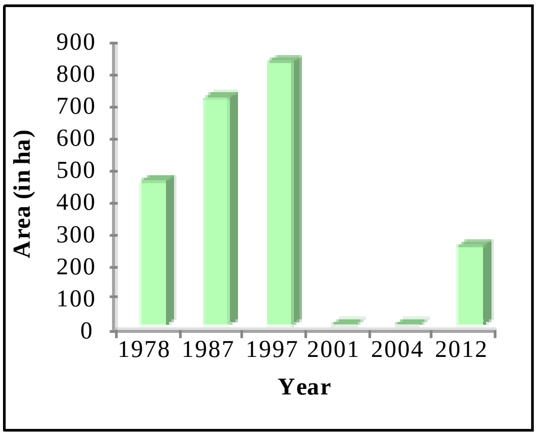


Figure 5.56 Areal extent of *Porteresia coarctata* in Aliabet

B. Scrub: *Prosopis juliflora* was the dominant plant species in this category. Figure 5.57 depicts the gradual increase in extend of scrub vegetation over time. A small patch of scrub found in the northern eastern part of the island in 1978 has expanded considerably over time. The scrub vegetation has also established itself on the newly formed island north of Aliabet indicating that the substratum of the island had stabilized.

C. Water bodies: Along with sea and river which are the major water bodies in the area, creeks and water logged areas have also been delineated in the area. Their areal extent and variation over time have been depicted in Figure 5.58.

D. Barren land: This was found as small patches on the north eastern side of Aliabet in between scrub vegetation. Extent of this category had increased from 1978 to 2001 but then decreased in 2004 and 2012 (Figure 5.59) mainly due to its conversion into scrub.

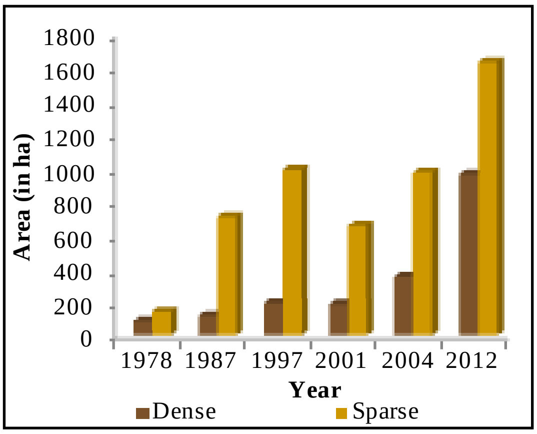


Figure 5.57 Areal extent of scrub in Aliabet

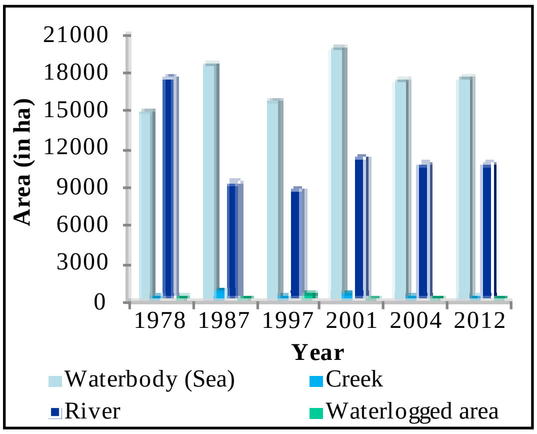


Figure 5.58 Areal extent of different types of water bodies in Aliabet

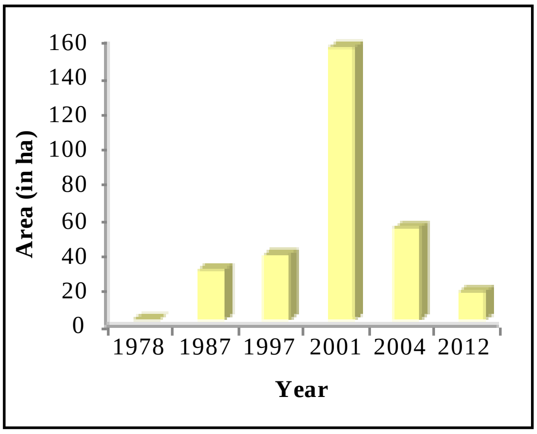


Figure 5.59 Area of barren land in Aliabet

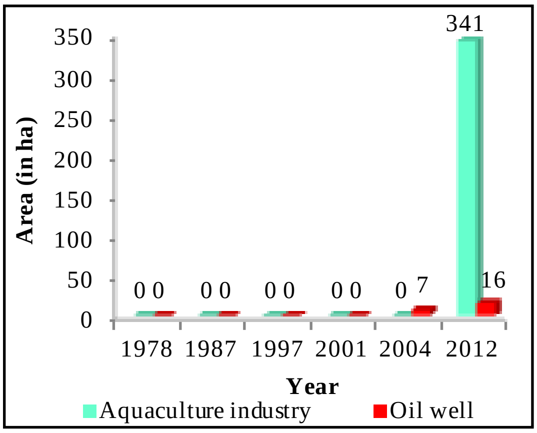


Figure 5.60 Area occupied by industries in Aliabet

E. Built-up land: Industrial area and roads were the only built-up categories found in Aliabet.

E.1 *Industrial area:* This category was first observed in the image of 2004 and since then they have shown continuous increase in their areal extent (Figure 5.60). The first industry that developed was an exploratory rig for oil and natural gas. With time their numbers on Aliabet had increased from 1 to 4. Another industry that flourished lately in this area was the aquaculture industry. It covered an area of about 341 ha in 2012. Field visits to the area indicated that the extent of this industry increased substantially even after 2012.

E.2 ***<u>Transportation:</u>*** The road network in aliabet had also improved from 2004 to 2012 (Figure 5.61).

F. Agriculture land: As indicated earlier a small land area on the mainland adjoining Vagra taluka fell within the boundary of aliabet. The extent indicated in Figure 5.62 falls within this area. The small variation that we can see has been due to the conversion of scrub vegetation to agricultural land.

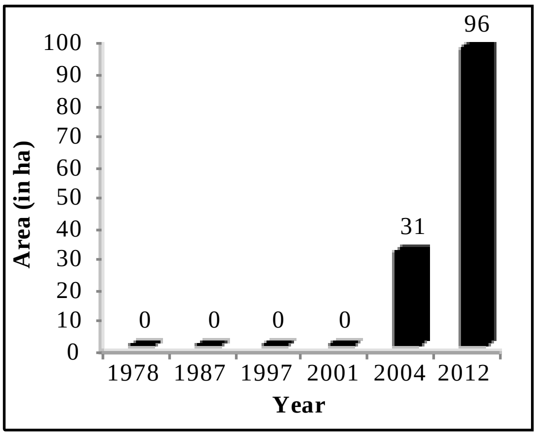


Figure 5.61 Area of road in Aliabet

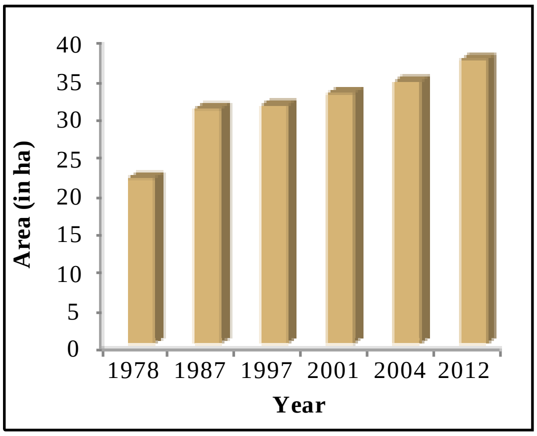


Figure 5.62 Area of agricultural land in Aliabet

5.1.4.2 Accuracy Assessment

The value of overall accuracy and kappa statistics calculated for the maps is given in Table 5.20.

Year	Overall Accuracy	Kappa Statistics
1978	88%	0.8560
1987	88%	0.8501
1997	90%	0.8760
2001	94%	0.9183
2004	86%	0.8158
2012	92%	0.9032

Table 5.20 Accuracy statistics for Aliabet

The maps prepared for Aliabet were through unsupervised classification followed by contextual editing. This was one of the reasons for the low accuracy of the maps compared to other talukas. The lowest value of accuracy was found for the year 2004. The misclassification in the sparse salt marsh category at few locations with high tidal mudflat was the major reason for the relatively lower accuracy of the map.

5.1.4.3 Change Detection of Aliabet

The change detection analysis of Aliabet resulted in 245 change classes. As indicated in the change detection analysis of other taluka the analysis was restricted to the mangrove and industrial category only.

Mangrove Change Analysis**:** The change detection maps are depicted in Plate 5.38 and 5.39. The list of change categories with respect to mangrove is given in Table 5.21. It shows the degradation of mangrove was relatively higher in the case of Aliabet compared to all the other regions. During 1978-2001, improvement in mangrove vegetation was mostly due to the colonization of mangroves on the newly formed mudflats on the souther part of Aliabet. A similar trend was observed during 2001-2012. Degradation of mangrove was mainly due to conversion of mangrove in to mudflat and salt marsh vegetation and to a little extent in to water body (in 2012). Another important observation was displacement of mangrove vegetation. From the year 1978-2012, area of mangrove had shifted in southward direction of Aliabet, towards the creek. The main reason for this was change in geomorphology of area. Thus, natural factors were mainly responsible for degradation of mangrove vegetation in Aliabet.

Change in the industrial area: The first industry in Aliabet was established after 2001 and hence the change analysis has been restricted to the duration from 2001-2012. This change map has been depicted on Plate 5.40. The aquaculture and oil industries that developed on Aliabet have done so at the cost of barren mudflats and mudflat covered with salt marsh vegetation. The area converted in to aquaculture

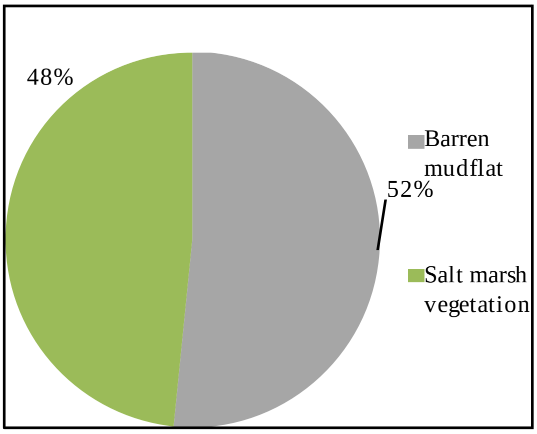


Figure 5.63 Categories converted to aquaculture industry during 2001-2012

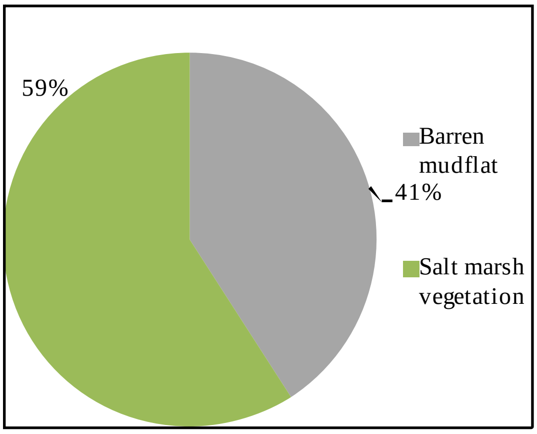


Figure 5.64 Ctegories converted to oil well during 2001-2012

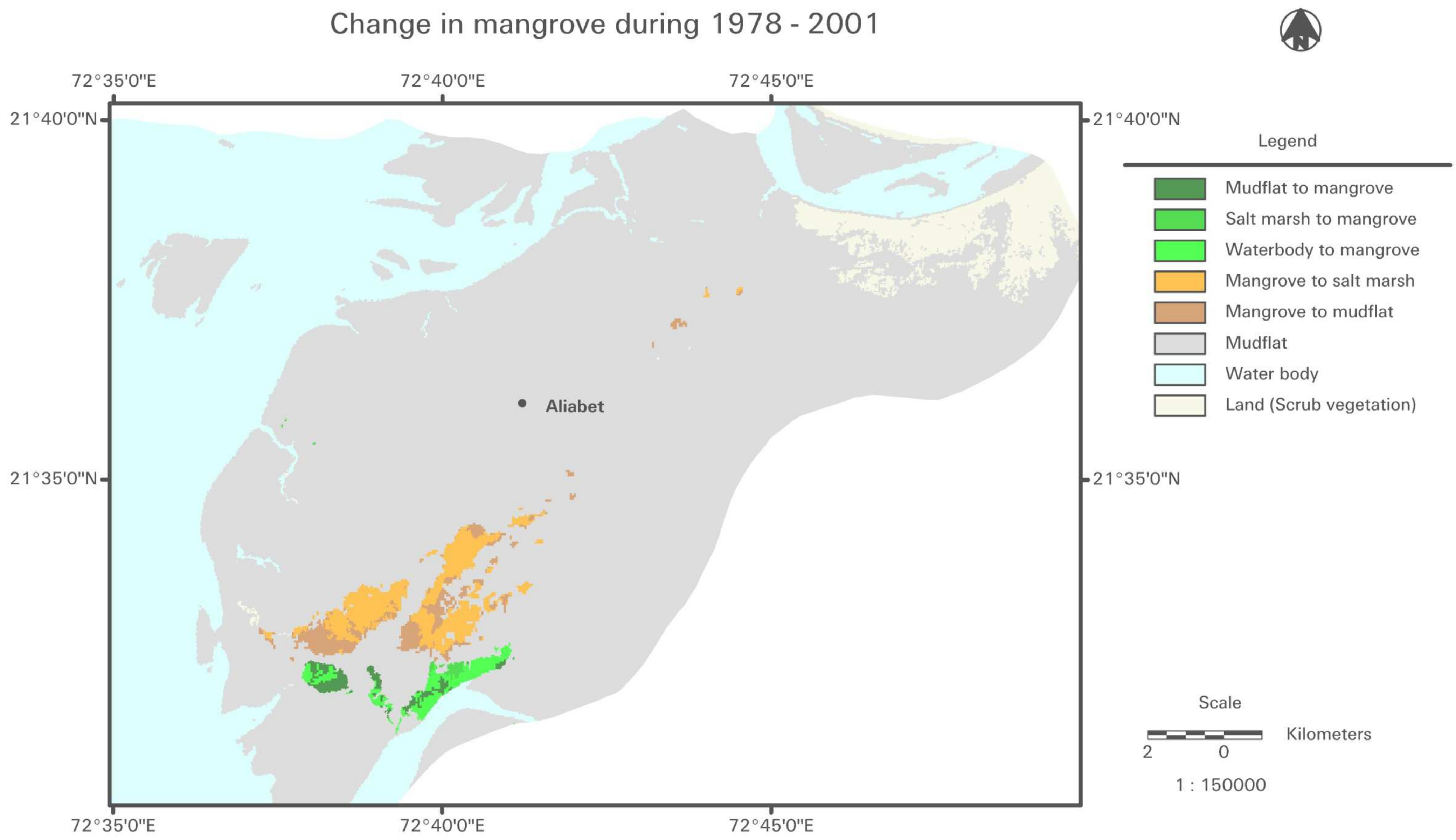

Change in mangrove during 1978 - 2001
72°35'0"E
72°40'0"E
72°45'0"E
21°40'0"N
21°35'0"N
Aliabet
Legend
Mudflat to mangrove
Salt marsh to mangrove
Waterbody to mangrove
Mangrove to salt marsh
Mangrove to mudflat
Mudflat
Water body
Land (Scrub vegetation)
Scale
Kilometers
2
0
1 : 150000

Plate : 5.38

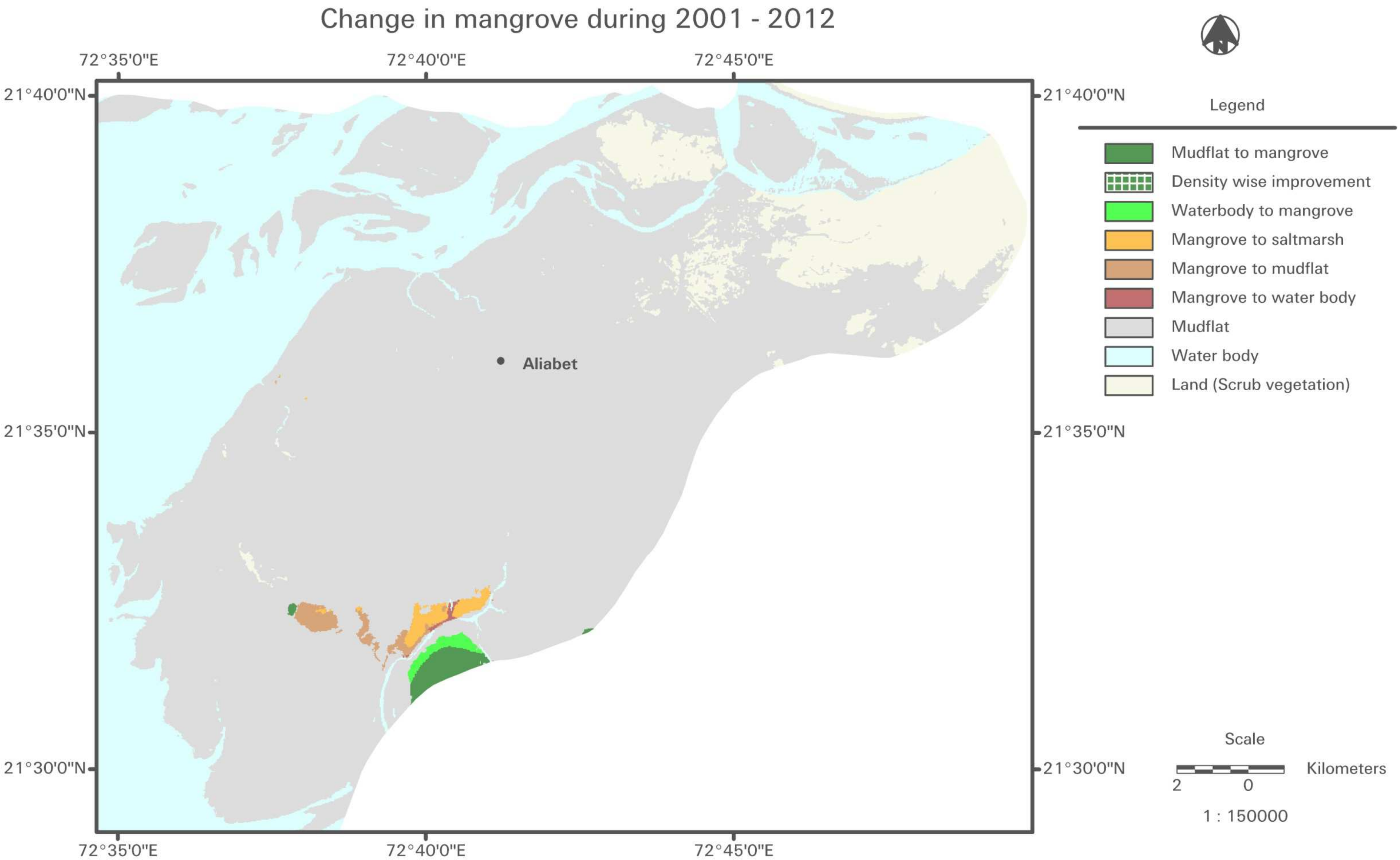

Change in mangrove during 2001 - 2012
72°35'0"E
72°40'0"E
72°45'0"E
21°40'0"N
21°35'0"N
21°30'0"N
Aliabet
Legend
Mudflat to mangrove
Density wise improvement
Waterbody to mangrove
Mangrove to saltmarsh
Mangrove to mudflat
Mangrove to water body
Mudflat
Water body
Land (Scrub vegetation)
Scale
2
0
Kilometers
1 : 150000

Plate : 5.39

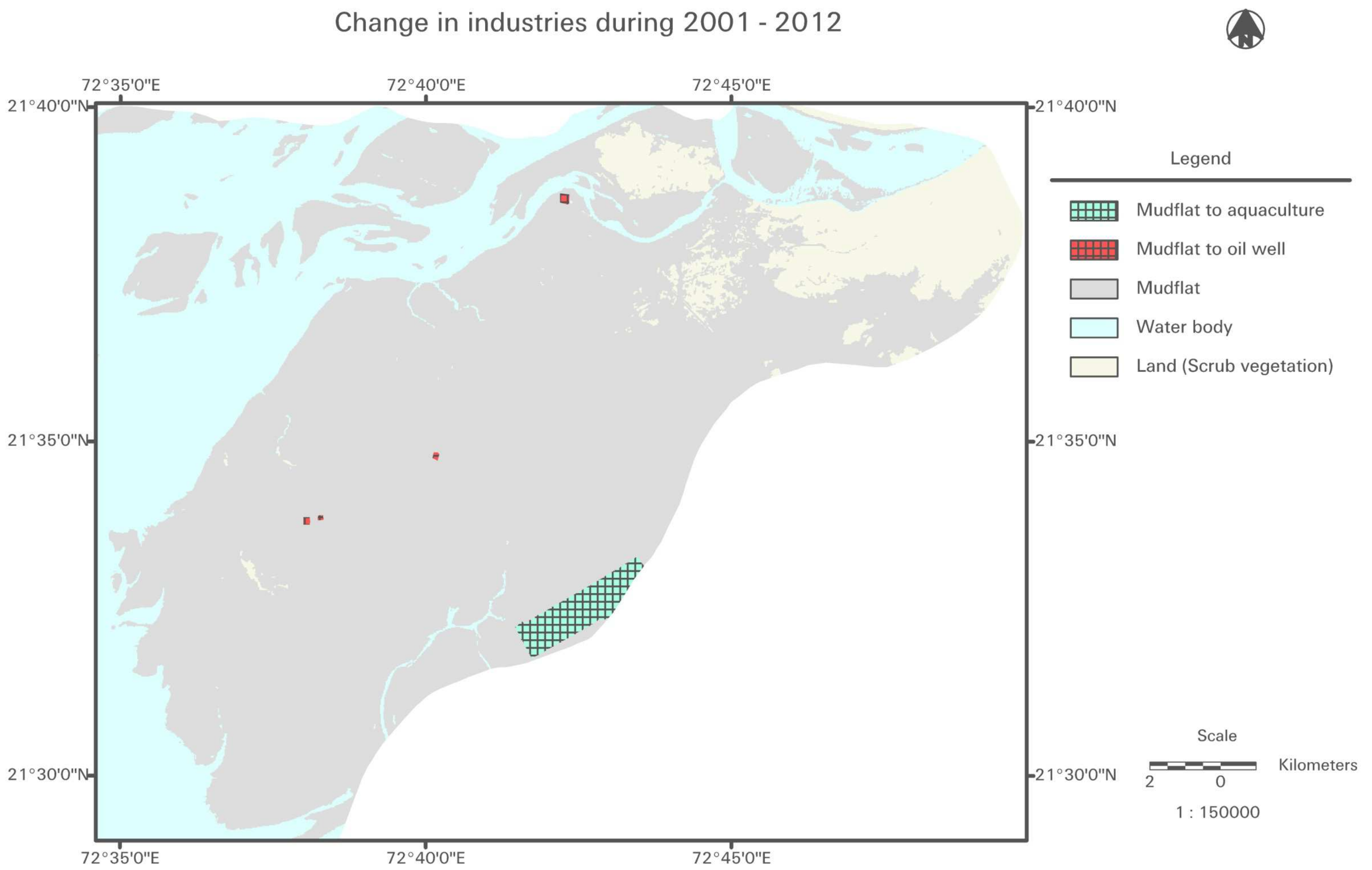

Change in industries during 2001 - 2012
72°35'0"E
72°40'0"E
72°45'0"E
21°40'0"N
21°35'0"N
21°30'0"N
Legend
Mudflat to aquaculture
Mudflat to oil well
Mudflat
Water body
Land (Scrub vegetation)
Scale
Kilometers
2
0
1 : 150000

Plate : 5.40

Categories	Changed categories	1978-2001	2001-2012
		Area (in ha)	
No Change	Sparse mangrove	0.01	0.00
	Total	0.01	0.00
Improvement	Mudflat to Mangrove	87.03	156.49
	Density wise improvement in mangrove	0.00	0.01
	Salt marsh to Mangrove	0.95	0.00
	Water body to Mangrove	149.53	64.24
	Porteresia coarctata to Mangrove	18.56	0.00
	Total	256.07	220.74
Degradation	Mangrove to Mudflat	248.12	131.37
	Density wise degradation of mangrove	0.00	0.00
	Mangrove to Salt marsh	482.04	111.53
	Mangrove to Water body	0.00	13.17
	Mangrove to Industry	0.00	0.00
	Total	730.16	256.06

Table 5.21 Change in mangrove of Aliabet

Duration	2001-2012		Total area
Type of industry	Category on which industry developed Area (in ha)		
	Barren mudflat	Mudflat covered by salt marsh vegetation	
Aquaculture industry	176.13	165.00	341.13
Oil well	6.42	9.28	15.70
Total area (in ha)	182.55	174.28	356.83

Table 5.22 Change in industrial area of Aliabet

industry and oil well in the year 2001-2012 have been graphically depicted in the form of pie charts in Figure 5.63 and 5.64 respectively. Among the two industries, aquaculture industry had occupied a substantial part of Aliabet. The extent of areal changes in Aliabet has been given in Table 5.22.

5.1.5 DISCUSSION

Land is one of the most limiting factors in coastal areas and hence is generally subjected to more than one use (Chauhan, 2007). Analysis of land use has become a pre-requisite before development of any region because the unsustainable use of land and its resources are considered as one of the key factors for the degradation of the environmental quality on earth (Varghese *et al.*, 2010). The equilibrium of nature can be mainted by maintaining all type of land uses such as wetland, agriculture land and built up land in a balanced way (Nagarajan and Poongothai, 2011). The use of coastal areas in a sustainable manner requires its proper management in which ecological and economic benefits can be obtained in an integrated manner (Chauhan, 2007). The study of land use land cover and their changes in the coastal areas of Bharuch district from 1978 to 2012 have indicated major changes. To understand and analyse these changes in an efficient manner, it is necessary to divide them in to homogenous units. Thus theses changes have been discussed separately for coastal wetlands, water bodies and terrestrial areas.

5.1.5.1 Coastal Wetland Area

The coastal wetland area includes unvegetated mudflats, vegetated wetlands and the industries that had developed within the wetland area. Changes in the course of rivers Dhadhar and Kim, change in alignment of Aliabet and the dynamic coastal as well as fluvial processes operating in the present study area were major factors responsible for the accretion and erosional activities prevailing in this area. In addition to this, the study area is structurally controlled by the Cambay rift trending NNW-SSE as well as the Narmada-Son rift trending ENE-WSW (Chandra and Chowdhary, 1969). The important role played by this tectonics in the modification of the coastal configuration cannot be ruled out. The role played by these factors have been discussed along with the geomorphology later.

A correlation matrix was generated to understand the relationship between the different categories of coastal wetland with respect to the variation in their areal extent. Table 5.23 shows correlation matrix for Jambusar, Vagra, Hansot while Table 5.24 shows the correlation matrix for Aliabet.

The LULC maps of 1978 for all the talukas showed that unvegetated mudflats and salt marsh vegetation were the two major categories that existed in the coastal wetland area. A look at the data in Table 5.23 and 5.24 showed that mudflat showed a strong to weak negative correlation with all the other categories viz., mangrove, salt marsh vegetation and industries. This was expected as most of the area that was colonised or occupied by any other category was originally an unvegetated mudflat to a large extent. As seen in the results earlier it was the mangrove vegetation which had colonized the mudflats first and then they were occupied by different industries.

The overall extent of the mangrove vegetation in Bharuch district had shown an increase from about 1194.43 ha in 1978 to 3960.23 ha in 2012. Plantation activity taken up by the various government and non-government agencies (Vishwanathan *et al.*, 2011; Mahapatra *et al.*, 2014) and good regeneration capability of *Avicennia marina* were major reasons for increase in the areal extent. There were however major variations in the change across the four different areas. Aliabet has actually seen a large fall in the mangrove cover. The mangrove area in 2012 was less than a third of what it was in 1978. Another interesting feature regarding the coastal wetland area was that the mangrove vegetation had mostly colonized the intertidal mudflats while most of the industries came up in the hightidal mudflat. The positive correlation of mangrove and industrial area indicated a simultaneous increase in mangrove vegetation as well as in industrial area in Jambusar, Vagra and Hansot. The availability of space for the growth of both categories was the reason for this. But, as most of barren mudflats were later occupied by vegetation (mangrove or salt marsh) or industry (salt pan, aquaculture and oilwell), any further increase in industry would mostly be with the loss of coastal vegetation. The development of industries with loss of salt marsh vegetation can be observed from the negative correlation between the industry and salt marsh vegetation in Jambusar and Vagra talukas. In Hansot however a strong positive correlation is seen which can be explained by the fact that a large area of the mudflat was formed during the study period and the colonization of it by salt marsh was taking place at the same time as the establishment of industry in the hightidal mudflats. Also the development of the industries in the wetland area of Hansot is much less compared to the other two talukas.

Categories	Taluka											
	Jambusar				Vagra				Hansot			
	MF	MN	SM	IN	MF	MN	SM	IN	MF	MN	SM	IN
MF	1				1				1			
MN	-0.92	1			-0.80	1			-0.96	1		
SM	-0.23	-0.17	1		-0.03	-0.11	1		-0.95	0.93	1	
IN	-0.54	0.83	-0.69	1	-0.89	0.81	-0.37	1	-0.89	0.93	0.78	1

Table 5.23 Correlation matrix for coastal wetland categories for three coastal talukas

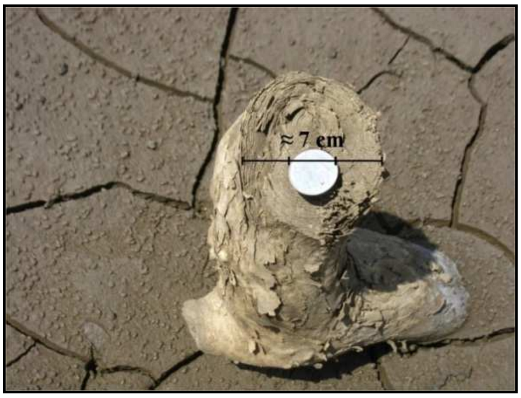
Abbreviations: MF: Mudflat, MN: Mangrove vegetation, SM: Salt marsh vegetation and IN: Sea based industries

Categories	Mudflat	Mangrove	Salt marsh vegetation	Scrub	Barren land	Sea based Industries
Mudflat	1					
Mangrove	-0.37	1				
Salt marsh vegetation	-0.23	-0.13	1			
Scrub	-0.15	-0.44	0.91	1		
Barren land	0.20	-0.26	-0.07	-0.13	1	
Sea based Industries	-0.55	-0.15	0.89	0.90	-0.29	1

Table 5.24 Correlation matrix for coastal wetland categories of Aliabet

After 2001, industries such as saltpan, aquaculture and oilwell had slowly started to encroach on mangrove areas. The mangroves were either directly cut or they were allowed to die by stopping the movement of water by filling up the creeks. This area was then reclaimed for the construction of saltpans or aquaculture ponds. A large patch of mangrove to the south of Kanthiajal (Hansot taluka) and next to an aquaculture pond was cut. The extent of cutting and the age of mangroves that were cut can be seen from the diameter of the stem of a cut mangrove plant shown in Figure 5.65. The destruction of mangrove areas due to development of saltpan and aquaculture industries has been reported in several parts of the world including India (Macintosh, 1996; TERI, 2000; Anon, 2001a; Jorge *et al.*, 2002; Jayanthi *et al.*, 2010; Nguyen *et al.*, 2013). The destruction of mangroves due to its conversion to aquaculture ponds was very well documented by Valiela *et al.*, 2001; Lewis *et al.*, 2003; Giri *et al.*, 2008 and Ponnambalam *et al.*, 2012. Loss of mangroves due to the development of saltpans has been documented by Taylor *et al.*, 2003; Nagi, 2008, Ilman *et al.*, 2011 and Lakshmi *et al.*, 2012. Though the mangrove cover had showed an increase in Bharuch district in recent times, it is also facing degradation as well as destruction.

Cutting of mangroves in south of Kanthiajal, Hansot



Diameter of stem of *Avicennia mairna*

Figure 5.65 Destruction of mangrove in Hansot taluka

5.1.5.2 Water Bodies

The area of pond and canal showed a marked increase in their areal extent. In the study area, the main sources of potable water were surface water (pond/ tank), canal or ground water (well) (Anon, 2011c). With the increase in built-up area and to fulfill increasing demand for water, various tasks such as deepening of ponds, development of few new ponds, repairing of wells and canals were taken up by the local government bodies (Anon, 2012a). In addition to this, as the north part of the study area came under the command area of the Sardar Sarovar Narmada project, construction of several minor and sub-minor canals took place. Hansot taluka fell within the command area of the Ukai Dam where construction of several minor canals took place. This is in line with the present finding which showed an overall increase in the canal network throughout the district. A strong positive correlation between built-up area and canal also supports the above findings (Table 5.25). Increase in the extent of canal was at the cost of agriculture land and barren land. This observation is supported by the negative correlation of either barren land (Table 5.25) or agriculture land (Table 5.25) with canal category in the respective taluka.

5.1.5.3 Terrestrial Area

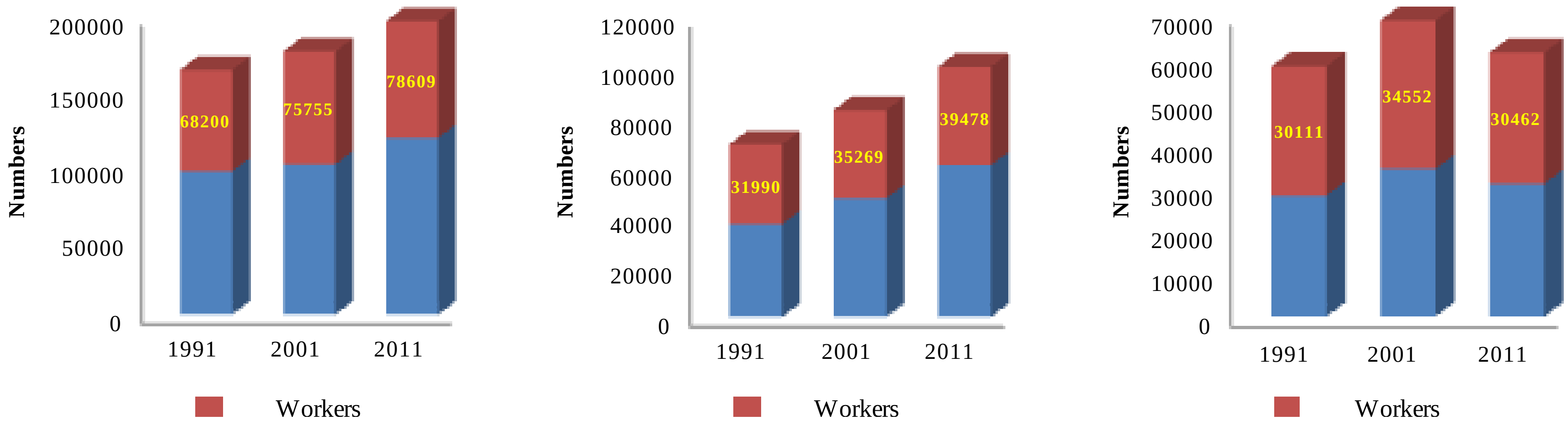
Agriculture was the major land use for all three coastal talukas. The major agricultural products were cereals (wheat, rice, jowar, bajara, maize), pulses (mung, math, udad, tur), ground nut, castor, sugar cane, cotton etc (Pandya, 2009). The correlation matrix for some major terrestrial categories is given in Table 5.25.

Agriculture land showed a negative correlation with habitation as well as with industrial area (Table 5.25). A very strong negative correlation is seen for Hansot and Vagra talukas. When seen in the light of change detection analysis it was observed that most of the industries as well as habitation had come up at the coast of agricultural land. The conversion of any category to habitation or industrial area became a significant transformation because these conversions were generally non-reversible (Fan *et al.*, 2007). The industrial development of this area was thus at the cost of agricultural land over the period of study. These results are in line with the findings of other similar studies around the globe (Aragrande and Argenti, 2001; Seto *et al.*, 2002; Mundia and Aniya, 2005; Tattu *et al.*, 2008b; Forkuor and Cofie, 2011 and Mahapatra *et al.*, 2014). Breaking away from this decreasing trend, in some areas like Jambusar (in 2000), Vagra and Hansot (in 2004) and Aliabet (1978-2012) a small increase in agricultural land was seen due to conversion of barren land or scrub to agriculture. With development, the price of agricultural land in this area had increased (Shah *et al.*, 2012). This was one of the main reasons for selling off land specifically to make a large income at one go. The belief that the income generated by selling off agricultural land for industrial development and the subsequent income from the developed industry would be much higher than agricultural activity, prompted the farmers as well as the local government bodies to sell off their land (Fan *et al.*, 2007). In this way, large tracts of fertile agriculture land were gradually developed into

Taluka	Jambusar						Vagra						Hansot					
Category	SC	CN	BL	HB	IN	AL	SC	CN	BL	HB	IN	AL	SC	CN	BL	HB	IN	AL
SC	1						1						1					
CN	0.76	1					0.93	1					0.72	1				
BL	-0.99	-0.85	1				-0.52	-0.19	1				-0.54	0.00	1			
HB	0.84	0.99	-0.91	1			0.91	0.99	-0.16	1			0.81	0.97	-0.15	1		
IN	0.72	1.00	-0.81	0.98	1		0.89	0.95	-0.33	0.92	1		0.76	0.97	-0.13	0.99	1	
AL	0.18	-0.50	-0.03	-0.38	-0.56	1	-0.82	-0.91	0.25	-0.85	-0.98	1	-0.87	-0.87	0.14	-0.95	-0.91	1

Table 5.25 Correlation matrix for different land categories for three coastal talukas

Abbreviations: SC: Scrub, CN: Canal, BL: Barren land, HB: Habitation, IN: Land based industries, AL: Agricultural land



(a) (b) (c)

Figure 5.66 Trend in population and workers in (a) Jambusar, (b) Vagra and (c) Hansot talukas (Generated based on Census data)

industrial areas. It is however important to note while this change would promote economic growth, it would also cause a gradual decline in the availability of land required to produce food for an ever increasing population.

The extent of habitation and industrial area had a strong positive correlations (Table 5.25) indicating their development hand in hand. An increase in industries attracts people resulting in an increase in population and as well as habitation (Forkuor and Cofie, 2011). Population data retrieved from the 2011 census supports above observation. The data collected for the year 1991 (Varsani, 1991), 2001 (Anon, 2001b) and 2011 (Anon, 2011b) showed consistent increase in the population for Jambusar and Vagra talukas (Figure 5.66). Hansot also showed an increase in the population for the duration 1991 to 2001 however a small drop in population was observed in 2011. The population data could be correlated with industrial development. The higher industrial development in Vagra and Jambusar was higly correlated with increase in population as well as number of workers from 1991-2011. The relatively lesser development of industries in Hansot along with the higher development of industries in other talukas of Bharuch district as well as adjoining Surat district could have resulted in migration of the population. This could probably be one of the reasons for the small decrease in population during 2001 to 2011.

A reserved forest existed in Vagra taluka near Lakhigam and Luhara villages. This area has been very dynamic and several changes were seen in it. A large part of it was first convereted to scrub and then to agriculture land. It was subsequently converted in to built up area used by industry with a small area getting converted back to scrub. The demarcation of this and its adjoining land under special schemes such as SEZ had been the major reason for its conversion to industrial area. In Vagra, there existed patches of land within SEZ or GIDCs or PCPIR, in which industries had not yet developed. These patches gradually got converted to scrub. This was one of the reasons for the increase in the scrub category. Scrub vegetation which is mostly dominated by *Prosopis juliflora* has gradually colonized most of the barren land near the coast. Some of the high tidal flats have also been colonized by scrub vegetation. This result is in line with the findings of Mahapatra *et al.*, (2014) who reported increase in the scrub area over a period of time.

The barren land showed a negative correlation with scrub and built-up category. The development of industries in Vagra and Jambusar talukas have mostly been near the coast. As indicated earlier they have mostly come up in areas occupied by barren land as well as agricultural areas. All these have resulted in a gradual decline in the area occupied by barren land.

Thus, the development of the industries has been the major cause for changes observed in land use land cover categories of the area under study.

5.1.5.4 Drivers for the Industrialization

Bharuch district had been on of the fastest industrial developing district in the state from 1983 to 2014 (Anon, 2014a). The drivers responsible for the massive industrialization that the study area has undergone are mentioned below.

1. Presence of "Black gold"
2. Construction of jetties
3. Passing of Delhi-Mumbai Industrial Corridor (DMIC) through the district
4. Development of SEZs and PCPIR region
5. Provision of subsidies and special concession for the development of specific coastal industries

Gujarat had been ranked first in production of crude oil (onshore 55.10%) and natural gas (32.3%) in India (Anon, 2010c). In Gujarat, major oil and gas reserves are located at Ankleshwar, Mehsana, Tapti, Hazira, Bharuch, Gandhar, Dahej, Jambusar, Palej and Kalol (Anon, 2010c) (Figure 5.67). In addition to these, a few isolated gas fields are located in Dholka and Khambhat and around Ahmedabad. Of the 11 major locations, 6 came under Bharuch district. Thus, the district possesses a huge reservoir of hydrocarbons. This presence of "Black gold" (oil and natural gas) in its crust was the major reason for development of petroleum and petroleum based industries in this district. The availability of natural gas had triggered rapid industrialization in this region. The gas produced by ONGC wells in Gandhar provided feedstock to the adjoining petrochemical based industry. This was initially developed by Indian Petrochemical Corporation Limited (IPCL) and was later on taken over by Reliance Industries Limited (RIL) (Anon, 2011d). The establishment of an LNG re-gasification terminal by Petronet LNG Limited at Dahej further strengthened the availability of natural gas (Anon, 2011d). The setting up of the Petroleum, Chemicals and Petrochemicals Investment Region (PCPIR), specifically for establishment of manufacturing facilities for domestic and export-oriented production of petroleum, chemical and petrochemicals had enhanced the rate of industrialization in this area. The PCPIR was spread over 453 sq. km of which 371 sq. km fell under Vagra taluka and 82 sq. km in Bharuch taluka (Anon, 2009). Its close vicinity to other existing GIDC chemical estates, viz. Jhagadia, Ankleshwar and Panoli has also boosted its development.

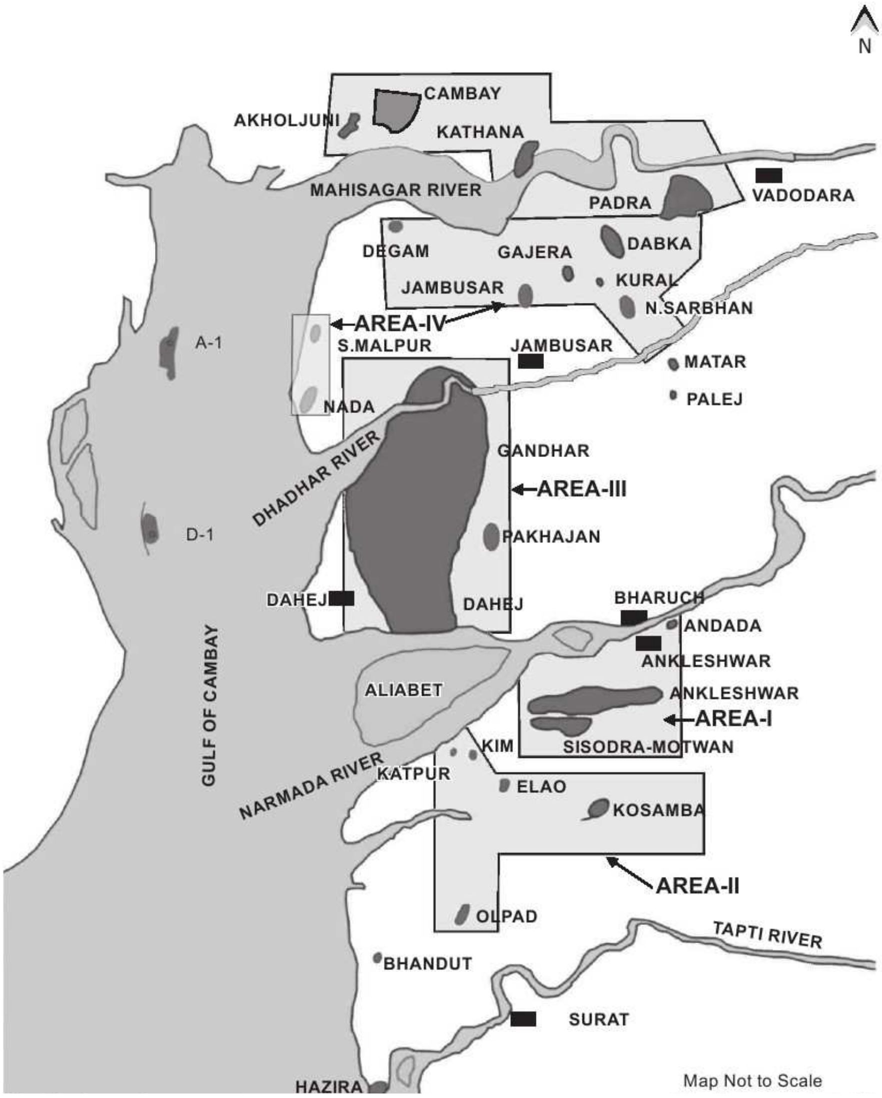


Figure 5.67 Hydrocarbon bearing fields in Ankleshwar asset (south Cambay basin) (Source: Anon, 2012b)

The Government of Gujarat had promoted Special economic Zones (SEZs) in different districts which were considered as growth engines that can boost manufacturing, augment export and generate employment. Till March 2014, a total 57 SEZs had been approved in Gujarat, which were spread over 10 districts. Bharuch district had 8 SEZs of which 5 fell under Vagra taluka, 1 under Jambusar, Jhagadia and Ankleshwar talukas respectively. The SEZs located at Jambusar and Dahej were multi-product SEZs whereas Vilayat in Vagra had various sectors such as hydrocarbon (1), pharmaceutical (1) and chemicals (2). The development of Dahej SEZ limited as a joint venture of ONGC and GIDC was among the top 25 economic zones in the world (as per survey of Financial Times, Vibrant Gujarat-2013). Besides this, the world's largest copper smelter was established at Dahej in SEZ part-II (Anon, 2010d). Thus, development of SEZs had contributed extensively to the economy of Bharuch district.

As per the Government of Gujarat report on Industries in Gujarat (Anon, 2014a), Bharuch stood third in number of large units implemented in Gujarat from 01/01/1983 to 31/03/2014 and second in terms of investment and employment in Gujarat state (Figure 5.68). In addition to this, micro, small and medium scale enterprises (MSME) had played a pivotal role in industrial dispersal and overall industrial development of the state. They have proved to be major contributors to the economy of state especially in terms of value addition, employment generation, entrepreneurship development and inclusive growth (Joti, 2010). Bharuch possess 12 GIDCs and 5431 units of MSME with an investment of 219020 lakhs and employment of 64041 (Anon, 2014a). The numbers of MSME units in Bharuch district has also increased continuously from February 2006 to March 2014 (Anon, 2014a).

In 2007, the Government of India had announced the establishment of the Multi-modal High Axel Load Dedicated Freight Corridor (DFC) between Delhi and Mumbai, covering an overall length of 1483 km and passing through six states. These six states were Uttar Pradesh, NCR of Delhi, Haryana, Rajasthan, Gujarat and Maharashtra. Distribution of length of the corridor indicated that among these states Rajasthan (39%) and Gujarat (38%) together constituted major part of total length of freight corridor. The main objective of DFC was to optimize the present potential, enhance investment climate and promote the economic development of the region (Anon, 2007b). The government of India had further proposed establishing, promoting and facilitating "Delhi Mumbai Industrial Corridor (DMIC) along the alignment of DFC between Delhi and Mumbai. The vision for DMIC was to create a strong economic base with globally competitive environment and state-of-the-art infrastructure to activate local commerce, enhance foreign investments and attain sustainable development. On the basis of the potential for growth and inherent strengths of various locations along the DMIC influenced area, 11 investment regions and 13 industrial areas were identified from seven states viz., Uttar Pradesh, Haryana, Rajasthan, Gujarat, Madhya Pradesh and Maharashtra. In Gujarat, 2 investment regions and 3 industrial areas were identified in consultation with state government. The two proposed investment regions in Gujarat were Bharuch-Dahej and

Ahemdabad-Dholera (Anon, 2007b). Thus, the selection of the Bharuch-Dahej area as an investment region and its close proximity (50 km) to the Dedicated Freight Corridor in southern Gujarat was a major driver for the development of this area.

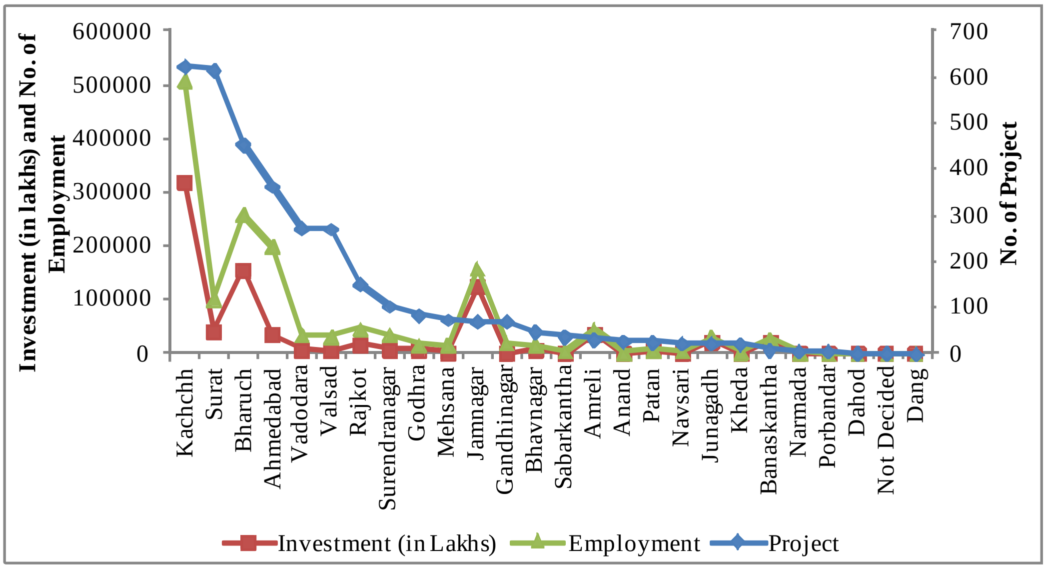


Figure 5.68 District wise projects under implemtation in Gujarat (IEM+LOI+LOP) from 01/01/1983 to 31/03/2014 (Source: Graph based on data obtained from Anon., 2014a)

Dahej is strategically located centrally within the industrial belt to serve north, west and central India and international destinations such as Middle East, Africa, Europe and North America. It acts as a gateway to landlocked states of India especially north-central India. Besides this, its distance of around 400 km north of Mumbai and with excellent access to entire North West Indian hinterland is a major reason for the development of this area (Anon, 2013a). Dahej port and development of new jetties had made significant contribution to accelerate the industrial growth in the Bharuch district. The old Dahej port operated by Guajrat Maritime Board was located to the west of Dahej village. The industries involved in the construction of the private jetties (from north to south) were Birla Copper, Gujarat Chemical Port Terminal Company Limited (GCPTCL), Adani, LNG Petronet and Reliance Dahej Marine Terminal (RDMT). Among these, the jetties developed by GCPTCL and LNG Petronet were the first chemical and LNG terminals of India (Anon, 2013a).

In addition to this, presence of vast coastal wetland area along Bharuch district had promoted development of salt and aquaculture industry in the state. Among different types of industries mentioned above, saltpan was the first established industry in present study. In Gujarat, the production of salt had increased substantially (Lakshmi *et al.*, 2012) and accounts for 78.61% of total salt production in India

(Anon, 2014a). Jamnagar, Surendranagar, Bhavnagar, Rajkot, Kutch and Bharuch were major salt producing districts of the state. In Gujarat, Bharuch ranked 5^{th} and contributed 8.42% of its total salt production. In Bharuch the highest number of salt industries were observed in Vagra (47 units with 4500 salt workers) followed by Jambusar (43 units with 2700 salt workers) and Hansot (7 units with 380 salt workers). Amod, an adjoining taluka of Vagra also possessed a few saltpans (4 units with 300 salt workers) (Anon, 2014b). This type of industry had provided livelihood to significant number of families which were economically backward and mostly illiterate (Lakshmi *et al.*, 2012). This huge production of salt in district had also promoted the development of chemical industries based on this natural resource. The industries depending on this resource were Grasim Ind. Ltd. at Vilayat, GACL (at Dahej), Gujarat Flourochem (at Dahej), Nirma Ltd.(at Dahej), Reliance India Ltd. (at Dahej), Shri Ram Alkali & Chemical (at Jhagadiya) and United Phosphorous Ltd (at Jhagadiya) (Anon, 2014c).

The brackish water aquaculture industry first developed in Guajrat during 1991-1992. As per statistics available from Commissioner of Fishers (Gandhinagar, (Anon, 2011e)), Gujarat state possessed 89340.91ha area spread over 10 districts, suitable for the development of the brackish water aquaculture. Of these 10 districts, seven districts had allotted land for the development of aquacultures. Among these seven districts, Bharuch (1436.00 ha) stood second in area allotment after Navsari (1522.44 ha). The introduction of a simplified land lease policy for this industry, special subsidy and infrastructure facilities by the government had boosted the development of aquaculture industry in the various districts (Anon, 2011e). In Bharuch, the maximum aquaculture ponds were observed in Hansot taluka followed by Vagra taluka (including Aliabet). Earlier, the development of aquaculture pond was started in the land which was unfit for any other agriculture purposes (TERI, 2000). But, as results discussed earlier indicate its development expanded in to the mangrove area and has caused degradation of mangroves in Hansot. Development of aquaculture has been responsible for the destruction of vast area of mangroves the world over (Jorge *et al.*, 2002).

In addition to the above, shipbuilding is an important shore based industry which can flourish with matching infrastructure in terms of rail/road connectivity, availability of skilled manpower, proximity to supporting industries/institutions. Gujarat Maritime Board (GMB) had proposed the development of a cluster of Marine

Shipbuilding Parks (MSP) along four locations in Gujarat state. One of those sites was the Northern Bank of River Narmada near Dahej which fell under Vagra taluka. Various companies had proposed shipbuilding units at south of Jolva village (Sinha, 2010). In addition to this, two companies namely ABG Shipyard at Jogeshwar village (in SEZ area) and Soft Shipyard at Kaladara had staterd functioning in Vagra taluka.

Along with this vast industrial development, the transportation facilities as well as social infrastructure had improved markedly in the district. Bharuch had 2838 km of metal roads connecting all villages in the district. All the villages were well connected by the state road transport facilities. With the development at Dahej and its surrounding area and to overcome the vehicular traffic problems, a 50 km six lane state highway connecting Dahej to Bharuch and the national highway No. 8 was developed. The district is connected by broad gauge with all the major cities such as Vadodara (in north) and Surat (in south). A narrow gauge train network was available between Bharuch-Samni-Dahej and Samni-Jambusar-Kavi stations. Of these, the track between Bharuch-Samni-Dahej was converted to broad gauge railway track to cope-up with the freight traffic movement between Bharuch and Dahej (Anon, 2015a). Along with this the social infrastructure of the district had also improved. Number of primary schools (887), secondary and senior secondary school (285), colleges (15) showed improvement in the education sector compared to last decade (Anon, 2013a). There was improvement in the education sector and the literacy rate in 2011 stood at 83.03% from 74.41% in 2001. The numbers of primary health centers (38), community health centers (14), dispensaries (44), sub health centers (200), allopathic hospitals (12) and private hospitals (22) for the year 2010-2011 suggested improvement in public health facilities.

Thus, looking at overall development in the three coastal talukas, Vagra witnessed the maximum industrial development and there by maximum land use land cover changes, followed by Jambusar and Hansot talukas. The types of industries developed in each of this taluka differ considerably. In Vagra because of availability of plenty of “black gold” petroleum, chemical, petrochemical, port and salt based industries developed substantially. In Jambusar saltpan was the major industry followed by brick kiln and other (land based industries) and oil wells. Whereas in Hansot aquaculture was the major industry followed by saltpan, other (land based) industry, oil wells and brick kilns.

5.2 STUDY OF COASTAL VEGETATION

Coastal vegetation is considered as an ecological storehouse that is rich in biodiversity and has high ecological value (Untawale, 1994; Banerjee, 1994). This vegetation is dominated by a few species that have adapted to the rigors of this environment (Zahran, 1977). Mangroves, mangrove associates, salt marsh vegetation, beach or strand vegetation are different types of coastal vegetation. Each of this type of vegetation has acquired unique features to survive in the harsh coastal environment. In the present study two different aspects, the diversity of coastal vegetation and the structural attributes of mangroves have been investigated.

5.2.1 DIVERSITY OF COASTAL VEGETATION

The diversity of coastal vegetation was studied using extensive field surveys. The sites selected for the study of the coastal vegetations are shown in Figure 5.69. The vegetation types observed in the present study were mangrove, mangrove associates & salt-marsh vegetation, sand vegetation and land vegetation. Details of each of these classes are given below.

Mangroves: These are the group of plants which have complete fidelity to the mangrove environment; that is they occur only in mangal and do not extend into terrestrial communities (Tomlinson, 1986). A single mangrove species *Avicennia marina* was reported from the study area.

Mangrove associates and salt marsh vegetation: Mangrove associate includes the plants which are not inhabitants of strict mangrove communities and could occur in terrestrial areas as well (Tomlinson, 1986). Whereas salt-marsh vegetation includes the group of plants which can tolerate high salinity and are under the influence of occasional tidal inundation (Daly, 2013). The salt-marsh vegetation generally occupies the high tide zone i.e. towards the landward side of the coastal area. Salt marsh vegetation covered the maximum area of such tidal mudflats throughout the study area. *Salvadora persica*, *Tamarix indica* and *Tamarix dioica* were the common mangrove associates observed in the present study. Whereas *Aeluropus lagopoides*, *Cressa cretica* and *Suaeda maritima* were the common salt marsh vegetation observed in the present study.

Sand strand vegetation: The geomorphological setting of the present study area restricted the development of prominent beach features. However, a narrow strip of

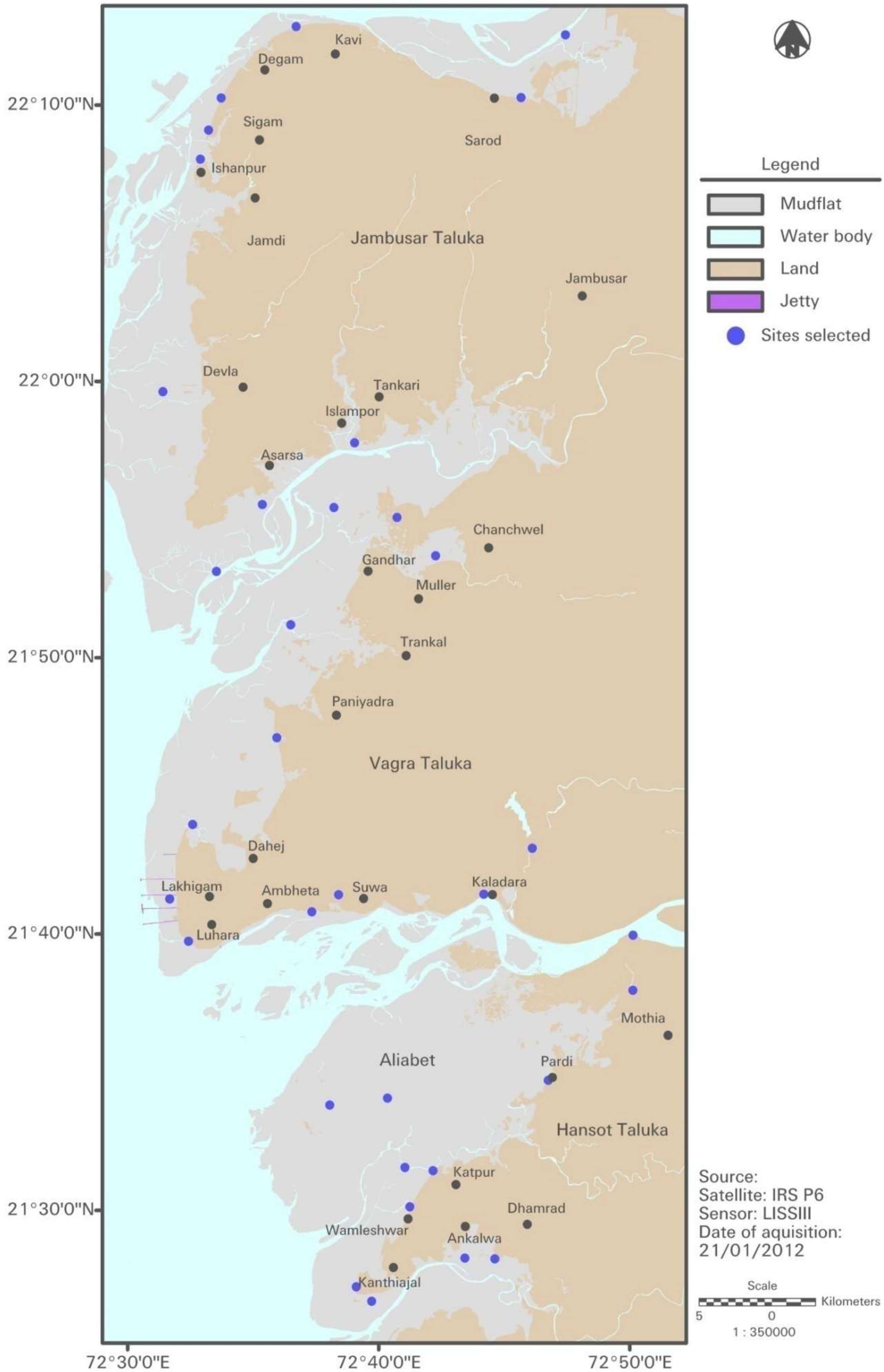


Figure 5.69 Map showing sites selected for the study of coastal vegetation

sandy beach was observed to the west of Lakhigam (Vagra) as well as Kanthiajal (Hansot). Beach vegetation was completely absent at Vagra while at Hansot, individuals belonging to *Ipomoea pes-caprae*, *Cyperus rotundus*, *Cressa cretica*, *Borassus flabellifer* and *Alhagi pseudalhagi* were observed. Among these *Ipomoea pes-caprae*, *Cyperus rotundus* and *Borassus flabellifer* were exclusively found in sandy area whereas *Cressa cretica* and *Alhagi pseudalhagi* were found in other habitats as well.

Land vegetation: This comprised of vegetation present on land adjoining the coastal wetlands and within 500m area from the high water line. This region represented the highest number of plants enumerated in the present study.

The list of plants observed in the present study and their details are given in Table 5.26. Selected plants are shown in Plates 5.41 to 5.48.

Each of the above mentioned vegetation types form a specific community. *Porteresia coarctata* was observed towards the sea ward side of mudflat and especially on the newly formed mudflats. Pure patches of *Avicennia marina* was observed towards the sea ward side whereas towards land it grew in association with either salt marsh vegetation such as *Aeluropus lagopoides*, *Sesuvium portulacastrum* and *Suaeda maritima* or in association with *Salvadora persica* and *Tamarix*. In addition to these, the high tidal mudflats showed the presence of pure as well as mixed patches of salt marsh throughout the coast of Bharuch district. Among the different species of salt marsh vegetation *Aeluropus lagopoides* grew most abundantly, followed by *Suaeda maritima*. Although *Sesuvium portulacastrum* was found in all the talukas but its distribution was relatively restricted to some areas. This was followed by the growth of *Cressa cretica*, and few grasses like *Aeluropus lagopoides*, *Bolboschoenus maritimus*, *Sporobolus ioclados* and *Sporobolus virginicus*. They grew towards the landward margin of the high-tidal mudflat and showed wide distribution. This was followed by the land vegetation. Among the different species of land vegetation *Prosopis juliflora* grew abundantly all along the coastline and at places was observed in the high-tidal mudflat area as well.

No.	List of vegetation observed in the present study	Family	Jambusar	Vagra	Hanost	Habit	Vernacular name
	Mangrove						
1	*Avicennia marina* (Forssk.) Vierh.	Verbenaceae	√	√	√	S/sT	Tivar
	Mangrove associates						
2	*Salvadora oleoides* Decne.	Salvadoraceae	√			S/sT	Piludi
3	*Salvadora persica* L.	Salvadoraceae	√	√	√	T	Piludi, Pilvo
4	*Tamarix dioica* Roxb. ex Roth	Tamaricaceae	√	√	√	T	Achhilaijo Paras, Bhuri Paras, Lai Jo Zad
5	*Tamarix indica* Willd.	Tamaricaceae		√		S/T	Lai, Ratilai, Panoshi
6	*Tamarix aphylla* (L.) H.Karst.	Tamaricaceae	√	√		T	Lai
	Salt marsh vegetation						
7	*Aeluropus lagopoides* (L.) Thwaites	Gramineae	√	√	√	H	Del, Dolari
8	**Cressa cretica* L.	Convolvulaceae	√	√	√	H	Rudanti, Palio, Khariyu
9	*Porteresia coarctata* (Roxb.) Tateoka	Gramineae		√	√	H	Dhani Ghas
10	*Sesuvium portulacastrum* (L.) L.	Ficoideae	√	√	√	H	Khariyu
11	*Suaeda vermiculata* Forssk. ex J.F.Gmel.	Chenopodiaceae		√		S	Moras, Khari Luni-ni-Bhaji
12	*Suaeda maritima* (L.) Dumort.	Chenopodiaceae	√	√	√	H/US	Moras, Morad
13	*Urochondra setulosa* (Trin.) C.E.Hubb.	Gramineae	√			H	Nodi
	Beach-strand/ sand strand vegetation						
14	*Borassus flabellifer* L.	Palmae			√	T	Tad
15	*Cyperus rotundus* L.	Cyperaceae			√	H	Kaluro, Mutha, Moth
16	*Ipomoea pes-caprae* (L.) R. Br.	Convolvulaceae			√	H	Maryad vel, Dariani Vel
	Land vegetation						
17	*Abelmoschus angulosus* Wall. ex Wight & Arn.	Malvaceae			√	H	Agado, Kandhero
18	*Abelmoschus manihot* (L.) Medik.	Malvaceae		√		US	Ran Bhindi, Jangli Bhindi
19	*Abutilon pannosum* (G.Forst.) Schltdl.	Malvaceae	√	√	√	US	Balbij
20	*Abutilon indicum* (L.) Sweet	Malvaceae	√		√	US	Khapat, Dabaliar
21	*Acacia nilotica* (L.) Delile	Mimosaceae	√			T	Baval, Kalo Baval, Ram Baval

No.	List of vegetation observed in the present study	Family	Jambusar	Vagra	Hanost	Habit	Vernacular name
22	*Achyranthes aspera* L.	Amaranthaceae		√	√	H	Anghedi, Anghedo, Aghado
23	*Adansonia digitata* L.	Malvaceae			√	T	Sampu-Dizo Zad, Rukh, Rukhdo, Gorakh ambli, Chor Ambli
24	**Alhagi pseudalhagi* (M. Bieb.) Desv. ex B. Keller & Shap.	Papilionaceae		√	√	US	Kantalo Gochar
25	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae			√	H	Jar bhaji, Jar Bhangaro
26	*Antigonon leptopus* Hook. & Arn.	Polygonaceae		√		C	Icecream val
27	*Apluda mutica* L.	Gramineae	√	√		H	Bhungario Ga, Fulari Ga
28	*Aristolochia bracteolata* Lam.	Aristolochiaceae	√	√		H/US	Kidamari
29	*Azadirachta indica* A.Juss.	Meliaceae	√			T	Limdo
30	*Bergia suffruticosa* (Delile) Fenzl	Elatinaceae			√		Ropatri, Lavariu, Vithi Kharsan, Gandharo-okhrad
31	*Boerhavia plumbaginea* Cav.	Nyctaginaceae	√			H	Zeri Satodo, Vasedo, Punarnava
32	*Bolboschoenus maritimus* (L.) Palla	Cyperaceae	√	√	√	H	Kasuru
33	*Calotropis gigantea* (L.) Dryand.	Asclepiadaceae		√		S	Akado
34	*Calotropis procera* (Aiton) Dryand.	Asclepiadaceae		√		S	Akado, Nano Akado, Nani Rui
35	*Capparis decidua* (Forssk.) Edgew.	Capparidaceae	√	√	√	S	Kerdo, Kera
36	*Capparis sepiaria* L.	Capparidaceae			√	S	Kanthar, Kantharo
37	*Celosia argentea* L.	Amaranthaceae	√		√	H	Lambdi, Lampdi
38	*Cenchrus ciliaris* L.	Gramineae			√	H	Anjan, Dhaman, Jhinu Dhamnu
39	*Chionachne gigantea* (J.Koenig) Veldkamp	Gramineae	√			H	Garolu
40	*Chloris barbata* Sw.	Gramineae		√		H	Mindadiu
41	*Chloris quinquesetica* Bhide	Gramineae			√	H	Rushad Ghas
42	*Chrozophora plicata* (Vahl) A.Juss. ex Spreng.	Euphorbiaceae		√		H	Kalo Okharad

No.	List of vegetation observed in the present study	Family	Jambusar	Vagra	Hanost	Habit	Vernacular name
43	*Citrullus colocynthis* (L.) Schrad.	Cucurbitaceae		√		H	Indravarna, Kokadvaran, Kadva Indravaran
44	*Clerodendrum phlomidis* L.f.	Verbenaceae	√		√	S/sT	Arni
45	*Clitoria annua* J.Graham	Papilionaceae			√	H	Garni,Gokarn
46	*Colocasia esculenta* (L.) Schott	Araceae		√	√	H	Alavi, Patarveliya
47	*Commelina benghalensis* L.	Commelinaceae		√		H	Gokanalo,Sishmuliyu
48	*Commelina ramulosa* (C.B.Clarke) H.Perrier	Commelinaceae	√			H	Shishmuliyu
49	*Corchorus olitorius* L.	Tiliaceae		√	√	US	Kag Gisodi, Gunpat
50	*Corchorus tridens* L.	Tiliaceae	√	√		H	Kadavi Chuchdi
51	*Cuscuta reflexa* Roxb.	Convolvulaceae	√			H	Amarvel, Anantvel
52	*Cyanthillium cinereum* (L.) H.Rob.	Compositae		√	√	H	Sahadevi, Sadedi
53	*Cymbopogon martini* (Roxb.) W.Watson	Gramineae	√			H	Roicha Ghas, Rosha Ghas
54	*Cyperus esculentus* L.	Cyperaceae	√	√	√	H	Chichada
55	*Cyperus pangorei* Rottb.	Cyperaceae		√	√	H	Lahul
56	*Datura innoxia* Mill.	Solanaceae		√		US	Dhantura, Kantalo, Dhanturo, Kalo Dhanturo
57	*Dichanthium annulatum* (Forssk.) Stapf	Gramineae	√			H	Zinzvo
58	*Dinebra retroflexa* (Vahl) Panz.	Gramineae			√	H	Khariyu
59	*Echinochloa colona* (L.) Link	Gramineae		√		H	Samo, Jiriu, Motujiriu
60	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae			√	H	Kanphutti
61	*Enicostema axillare* subsp. *littorale* (Blume) A.Raynal	Gentianaceae	√			H	Zinku Kariyatu, Kadvinai, Mamejevo
62	*Eragrostis japonica* (Thunb.) Trin.	Gramineae	√			H	Chiksi
63	*Euphorbia hirta* L.	Euphorbiaceae			√	H	Vadi Dudheli
64	*Euphorbia neriifolia* L.	Euphorbiaceae	√			S	Thor
65	*Euphorbia indica* Lam.	Euphorbiaceae	√			H	Dudhiyal, Dudhali
66	*Euphorbia tirucalli* L.	Euphorbiaceae			√	S	Kharsani
67	*Fimbristylis quinquangularis* (Vahl) Kunth	Cyperaceae		√		H	-

No.	List of vegetation observed in the present study	Family	Jambusar	Vagra	Hanost	Habit	Vernacular name
68	*Glinus lotoides* L.	Ficoideae	√			H	Mitho okharad
69	*Hibiscus obtusilobus* Garcke	Malvaceae		√		H/US	Van Bhindo
70	*Hygrophila auriculata* (Schumach.) Heine	Acanthaceae		√	√	H	Kantashelio, Akharo, Talimkhana
71	*Hyptis suaveolens* (L.) Poit.	Labiatae		√		H	Vilayti Tulsi
72	*Indigofera oblongifolia* Forssk.	Papilionaceae		√	√	S	Zil, Ziiladi, Zildo
73	*Indigofera tinctoria* L.	Papilionaceae			√	S	Gali, Nil, Gudi
74	*Ipomoea fistulosa* Mart. ex Choisy	Convolvulaceae		√		S/sT	Behaya, Nafatiyu
75	*Ipomoea aquatica* Forssk.	Convolvulaceae		√	√	H	Nali ni Bhaji, Nada ni vel
76	*Ischaemum rugosum* Salisb.	Gramineae			√	H	Varelu
77	*Jatropha gossypiifolia* L.	Euphorbiaceae		√		S	Ratan Jyot
78	*Justicia procumbens* L.	Acanthaceae	√			H	Kari Andhedi
79	*Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae			√	H	Duthie,Kadri Tunedi
80	*Laggera aurita* (DC.) Sch.Bip. ex Schweinf.	Compositae	√			H	Bhint Mulo
81	*Lindenbergia muraria* (Roxburgh ex D. Don) Brühl	Scrophulariaceae	√			H	Pirsadedi, Zamaval, Patharchati, Bhintchati
82	*Malachra capitata* (L.) L.	Malvaceae		√	√	H/US	Pardeshi Bhindo
83	*Merremia emarginata* (Burm. f.) Hallier f.	Convolvulaceae	√	√		H	Undardi, Undarkani, Undari
84	*Nothosaerva brachiata* (L.) Wight	Amaranthaceae	√			H	Bhaji
85	*Oxystelma esculentum* (L. f.) Sm.	Asclepiadaceae		√	√	H	Jal-dudhi, Dudhli
86	*Parkinsonia aculeata* L.	Caesalpiniaceae			√	S/sT	Rambaval
87	*Parthenium hysterophorus* L.	Compositae			√	US	Congrass Ghas
88	*Paspalum vaginatum* Sw.	Gramineae			√	H	Koda
89	*Passiflora foetida* L.	Passifloraceae		√		C	Krishna Kamal
90	*Pedalium murex* L.	Pedaliaceae			√	H	Ubhu Gokharu
91	*Pergularia daemia* (Forssk.) Chiov.	Asclepiadaceae	√			H	Chamar Dudheli, Nagla Dudheli, Amer Dudheli

No.	List of vegetation observed in the present study	Family	Jambusar	Vagra	Hanost	Habit	Vernacular name
92	*Peristrophe bicalyculata* (Retz.) Nees	Acanthaceae	√			H	Adhedi, Lisi Adhedi, Kali Anghedi
93	*Phyllanthus maderaspatensis* L.	Euphorbiaceae	√		√	H	Bakarato, Kanochha
94	*Polygonum plebeium* R.Br.	Polygonaceae	√			H	Ratan Jyot
95	*Prosopis juliflora* (Sw.) DC.	Mimosaceae	√	√	√	S/sT	Gando Baval
96	*Senna auriculata* (L.) Roxb.	Caesalpiniaceae	√			S	Aval, Avali, Avar
97	*Senna tora* (L.) Roxb.	Caesalpiniaceae		√		H	Kuvandio, Pochandio, Dadhajozad
98	*Sesbania sesban* (L.) Merr.	Papilionaceae		√		S/sT	Shevari, Jayanti
99	*Sida acuta* Burm.f.	Malvaceae			√	US	Bala
100	*Solanum virginianum* L.	Solanaceae	√	√	√	H	Bhoringni, Bhoyringni
101	*Sporobolus coromandelianus* (Retz.) Kunth	Gramineae	√			H	Vimbhdo
102	*Sporobolus ioclados* (Trin.) Nees	Gramineae	√			H	Khevai Ghas
103	*Sporobolus virginicus* (L.) Kunth	Gramineae	√			H	Khari Ghas
104	*Tephrosia purpurea* (L.) Pers.	Papilionaceae		√		US	Sarpankho
105	*Thespesia populnea* (L.) Sol. ex Corrêa	Malvaceae			√	T	Paras Piplo
106	*Tricholepis glaberrima DC.*	Compositae			√	H	Brahm Dandi, Fishiaru
107	*Tridax procumbens* (L.) L.	Compositae		√		H	Pardesi Bhangaro
108	*Triumfetta rotundifolia* Lam.	Tiliaceae		√	√	H	Zipti, Gol Zipti
109	*Typha domingensis* Pers.	Typhaceae	√	√	√	H	Ghabajariu, Ramban
110	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Rhamnaceae	√	√		S	Chani Bor, Palera, Pali, Palia, Chania Bor

Table 5.26 List of vegetation observed in the present study

Abbreviations: H: Herb, S: Shrub, US: Under shrub, T: Tree, sT: Small Tree, C: Climber
Note: 1. Vernacular names were compiled from various sources including field work.
2. Family names in the above table are as per Benthum and Hooker Classification system.
* Plant species also observed in sandy areas of Kanthiajal in addition to their natural habitats.

Avicennia marina and saltmarsh vegetation growing along the creek

Pneumatophores of *Avicennia marina*

Flowers of *Avicennia marina*

Fruits of *Avicennia marina*

Germinating seeds of *Avicennia marina*

Seedling of *Avicennia marina*

Plate 5.41 Mangrove observed in present study area


Salvadora persica


Inflorescence of *Salvadora persica*


Flowers and fruit of *Salvadora persica*

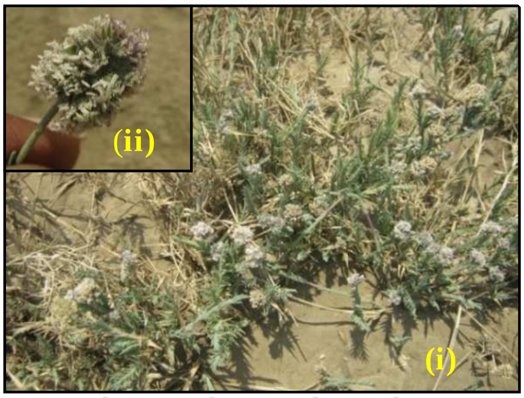

Tamarix in high tidal mudflats


Flowering branch of *Tamarix indica*


Closer view of flowers of *Tamarix indica*

Plate 5.42 Mangrove associates observed in present study area

Salt marsh vegetation growing along creek



(i) *Aeluropus lagopoides* and (ii) its inflorescence

Flowers of *Cressa cretica*

Fruits of *Cressa cretica*

Porteresia coarctata

Flower of *Sesuvium portulacastrum*

Plate 5.43 Salt marsh vegetation observed in present study area


Suaeda maritima


Flower of *Suaeda maritima*


Fruits and dry seeds of *Suaeda maritima*


Fruits of *Suaeda vermiculata*


Urochondra setulosa


Inflorescence of *Urochondra setulosa*

Plate 5.44 Salt marsh vegetation observed in present study area


Flowering branch of *Acacia nilotica*


Alhagi psuedalhagi

(i) Flower and (ii) fruit of *Alhagi psuedalhagi*


Aristolochia bracteolata

(i) Flower and (ii) fruit of *Aristolochia bracteolata*


Flower of *Bergia suffruticosa*


Flowers of *Boerhavia plumbaginea*


Inflorescence of *Bolboschoenus maritimus*

Plate 5.45 Landvegetation observed in present study

(i) Flowering branch and (ii) closer view of flower of *Capparis decidua*

Capparis sepiaria

Chrozophora plicata

Flowers of *Chrozophora plicata*

(i) *Citrullus colocynthis* and (ii) its fruit

Commelina ramulosa

Flower of *Commelina ramulosa*

Flower of *Corchorus olitorius*

Plate 5.46 Land vegetation observed in present study area


Fruits of *Corchorus olitorius*


Inflorescence of *Cyperus esculentus*


Cyperus rotundus


Hygrophila auriculata


Hyptis suaveolens


Inflorescence of *Indigofera oblongifolia*

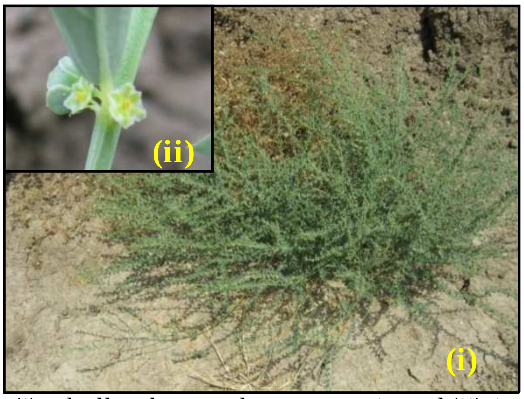

Fruits of *Indigofera oblongifolia*


Ipomoea pes-caprae

Plate 5.47 Land vegetation observed in present study area

(i) *Oxystelma esculentum* and (ii) its flower

Flower of *Passiflora foetida*



(i) *Phyllanthus maderaspatensis* and (ii) its flower

(i) *Polygonum plebeium* and (ii) its branch

Flower of *Senna auriculata*

(i) *Solanum virginianum* and (ii) its flower

Flowers and fruits of *Triumfetta rotundifolia*

Flower and fruit of *Tephrosia purpurea*

Plate 5.48 Land vegetation observed in present study area

A total 110 species belonging to 88 genera and 37 families are being reported in the present study. Among the 37 families, the highest number of species belonged to Gramineae followed by Malvaceae (Figure 5.70). Among the 88 genera, highest numbers of species were reported for the genus *Euphorbia*, followed by *Cyperus*, *Sporobolus* and *Tamarix*. The present study has indicated 45 new records to the coastal flora of Bharuch district. These mainly include *Abutilon pannosum*, *Adansonia digitata*, *Bergia suffruticosa*, *Boerhavia plumbaginea*, *Bolboschoenus maritimus*, *Cenchrus ciliaris*, *Chionachne gigantea*, *Chrozophora plicata*, *Commelina ramulosa*, *Datura innoxia*, *Euphorbia indica*, *Hibiscus obtusilobus*, *Hyptis suaveolens*, *Nothosaerva brachiata*, *Parkinsonia aculeata*, *Paspalum vaginatum*, *Pedalium murex*, *Sesbania sesban*, *Tamarix aphylla* and *Tricholepis glaberrima*. The total number of plants reported for Jambusar, Vagra and Hansot taluka were 50, 55 and 56 respectively. Although the numbers of plants for each of these talukas were nearly same, the plants observed in each of these talukas were quite different. Analysis of the Sorenson index calculated for Jambusar, Vagra and Hansot taluka showed very low values of similarity index. The similarity index provides a quantitative measurement for comparing two populations (Chuang, 2012). This index is very important in showing similarity between two different stands of vegetation (Snyder and Boss, 2002; Ambasht and Ambasht, 2008). Table 5.27 shows the values for similarity index which emphasizes the distinct nature of vegetation in all three coastal talukas.

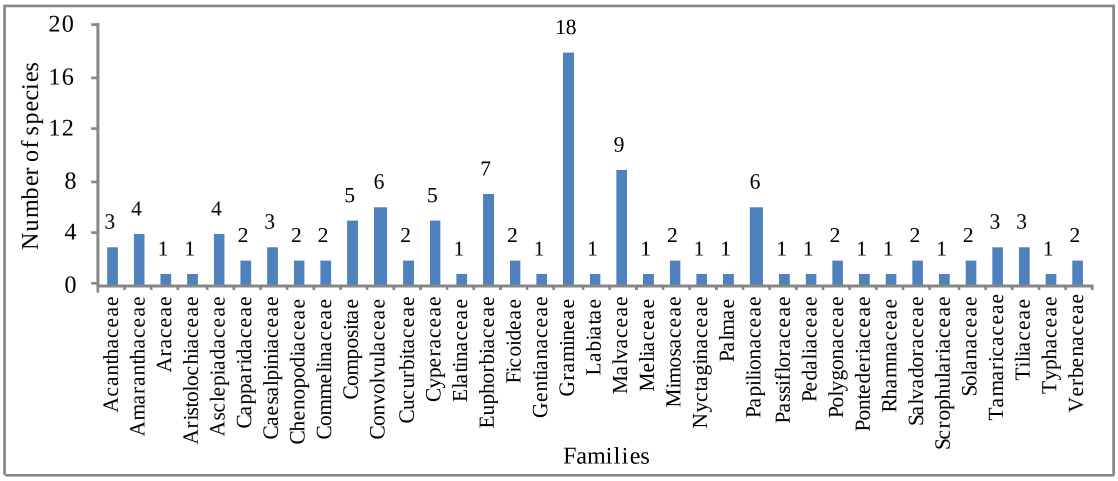


Figure 5.70 Distribution of diversity across different families

Bhagwanani (1980) had conducted a study of vegetation present in the coastal area from Khambhat to Umargam. She had reported total 671 species belonging to

415 genera and 109 families. The large coastal stretch from Khambhat to Umargam and consideration of all observed plants within this area seems to be the major reasons for higher numbers of plants reported by her. A study conducted by GEC (Anon, 2011c) had reported 313 plants for the coastal talukas of Bharuch. Their list not only included the diversity of the coastal region but also incuded the entire terrestrial area.

Taluka	Jambusar	Vagra	Hansot
Jambusar	1.0000		
Vagra	0.3810	1.0000	
Hansot	0.3396	0.4865	1.0000

Table 5.27 Sorenson Similarity Index matrix for coastal talukas of Bharuch district

The fact that the present study restricted the listing of plants to 500m from the high water line could be one of the reasons for 110 species to be listed in present study. Among these, a few plants such as *Alhagi pseudalhagi* (Gujarat, Goa and Maharashtra), *Suaeda fruticosa* (Gujarat and Andhra Pradesh), *Suaeda maritima* (Gujarat and West coast) and *Tamarix aphylla* (Gujarat and Andhra Pradesh) has been listed as restricted plants (Anon, 2015b). *Urochondra setulosa* was earlier listed as indigenous plant for West coast and specifically to Gujarat (Stanley, 2004; Rana and Ranade (2009) and Giri *et al.*, 2015). *Bergia suffruticosa*, *Nothosaerva brachiata* and *Tamarix dioica* have been reported as rare plants (Anon, 2015b). Besides this, *Tricholepis glaberrima* has been reported as endemic and rare plant for Gujarat state (Shah, 1978; Nagar, 2015).

5.2.2 MANGROVE PHYTOSOCIOLOGY

Avicennia marina was the only true mangrove observed in the study area. Transects were laid down in the mangrove area of Jamdi, Devla, Vagra, Katpur and Kanthiajal villages of Bharuch district and their details are given in Table 5.28. In case of Vagra, transects were laid along the west coast between Trankal and Aladra villages. The length of transects was variable on account of dense creek network as it was not possible to cross some creeks even in low tide. This was one of the reason why transects were not possible in some areas. It is important to note here that although importance was given to mangrove vegetation at places where salt marsh vegetation were encountered in the quadrates, it was also taken in to consideration.

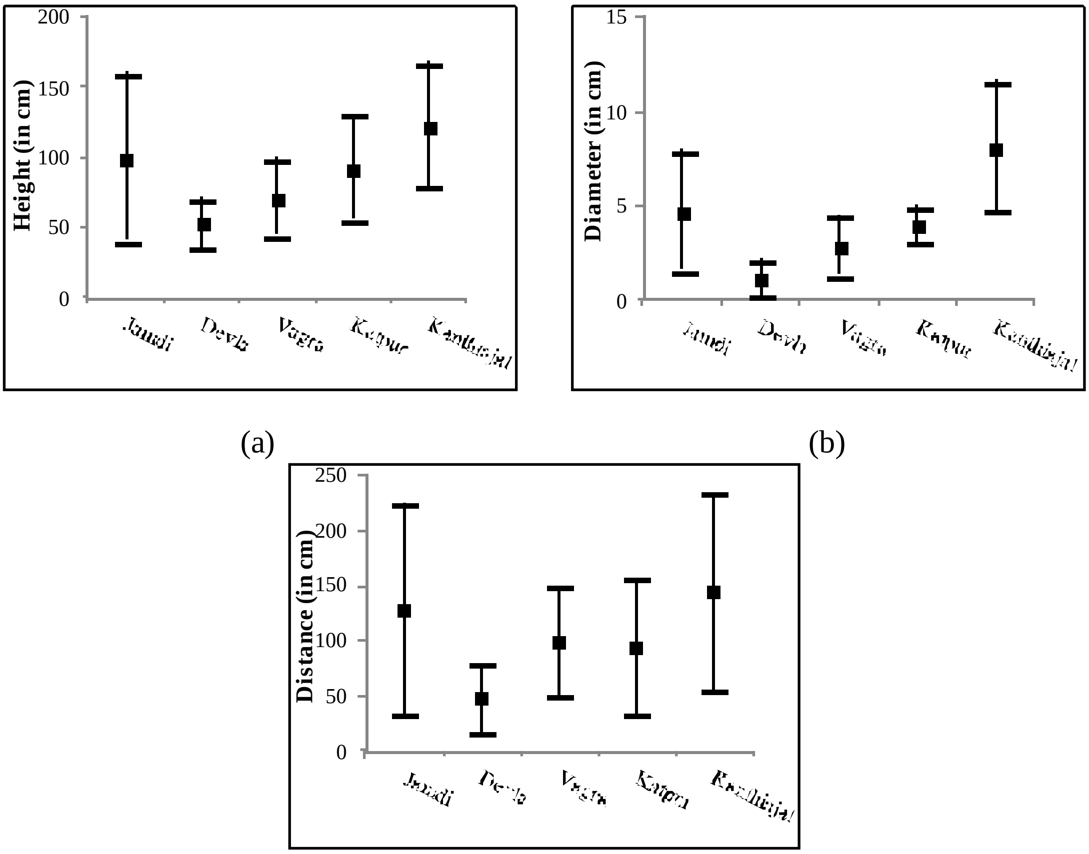
Sr. No.	Location		Start Lat. / Long.	End Lat. / Long.	Length (m)
1	Jamdi (Isanpura)	Jambusar	22° 08' 03".00 N 72° 32' 47".02 E	22° 08' 07".06 N 72° 32' 41".26 E	300
2	Devla		21° 59' 46".02 N 72° 31' 10".00 E	21° 59' 47".96 N 72° 31' 01".97 E	200
3	Vagra	Vagra	21° 51' 09".99 N 72° 36' 21".99 E	21° 51'09".99N 72° 36' 16".00 E	170
4	Katpur	Hansot	21° 31' 23".99 N 72° 41' 25".99 E	21° 31' 23".00 N 72° 41' 19".99 E	150
5	Kanthiajal		21° 26' 46".04 N 72° 39' 44".01 E	21° 26' 39".98 N 72° 39' 40".99 E	200

Table 5.28 Details of transects along the coast of Bahruch district

5.2.2.1 Structural Attributes of Mangrove

This included collection of data for height, diameter and distance between the individual plants. Data showed much variation in attributes such as height, diameter and distance across the villages as well as in talukas. Among the five sites the mangrove of Kanthiajal showed the highest values for height (250 cm) diameter (16.18 cm) and distance (450 cm). The lowest value of height (30 cm), diameter (4.85 cm) were observed for Devla where as the least distance (10 cm) was recorded for Vagra. Figure 5.71 shows the variation in height (a), diameter (b) and distance between two plants (c) respectively. Among five different villages, Kanthiajal showed much higher value while Devla showed relatively lower value for all three parameters.

The data was statistically analyzed with help of Fisher's test (F-test) to know the significance of variation between the villages of Jambusar and Hansot talukas and ANOVA to know overall variation among the five villages respectively. The results of F test suggested that there was significant difference in the height ($F_{(103,58)} = 11.77$, $p<0.05$), diameter ($F_{(103,58)} = 20.65$, $p<0.05$) and distance ($F_{(103,58)} = 9.52$, $p<0.05$) of mangroves of Jamdi and Devla villages of Jambusar taluka. Similar results were obtained for diameter ($F_{(79,59)} = 13.35$, $p<0.05$) and distance ($F_{(79,59)} = 2.03$, $p<0.05$) for the villages of Hansot taluka. However there was no significant difference in the height ($F_{(79,59)} = 1.42$, $p>0.05$) mangroves of Kanthiajal and Katpur. A significant variation was observed within and across the different villages and talukas (Figure 5.71) and could be viewed from the results obtained from ANOVA test for the parameters like height ($F_{(4, 366)} = 27.09$, $p<0.05$), diameter ($F_{(4, 366)} = 72.37$, $p<0.05$) and distance ($F_{(4, 366)} = 17.86$, $p<0.05$).



(a) (b)

(c)

Figure 5.71 Variation in different structural attributes of mangrove across five different sites

The above data was also used to calculate other various variables such as absolute frequency, tree density per hectare, basal area, mean distance, complexity index and their results are summarized in Table 5.29 and 5.30. Among the five sites, the highest basal area was observed at Kanthiajal followed by Katpur, Jamdi, Vagra and Devla. Whereas reverse was the case in terms of absolute density. The present finding showed a density of 5189 - 30795 stems/ha for Jambusar taluka, 10197 for Vagra taluka and 4777 - 11178 stems/ha for Hansot taluka. An earlier study by GEC (Anon, 2011c) on the mangrove density for Jambusar, Vagra and Hansot taluka had reported a density of 6440.1, 4620.0 and 5400.1 stems per ha respectively. Findings of the present study showed a much higher density for all the three talukas.

Village	Sampling point	Total Quarters	Absolute density (no. of stems/ha)	Mean distance (In cm)	Basal area (In m^2/ha)	Mean stand diameter (In cm)	Mean height (In cm)	Complexity Index
Jamdi	30	120	5189.23	129.23	13.19	5.68	100.10	0.69
Devla	20	80	30794.88	48.94	7.54	1.77	53.17	1.23
Vagra	17	68	10196.98	99.03	8.74	3.31	71.78	0.64
Katpur	15	60	11178.17	94.58	14.93	4.12	92.83	1.55
Kanthiajal	20	80	4776.81	144.69	29.41	8.86	123.00	1.73

Table 5.29 Different variables calculated for study area

No.	Name of species	Absolute frequency (In %)		Absolute density (no. of stems/ha)		Relative frequency (In %)		Relative density (In %)	
		Jamdi	Devla	Jamdi	Devla	Jamdi	Devla	Jamdi	Devla
1	*Aeluropus lagopoides*	13.33	5.00	648.65	521.95	12.90	4.76	10.83	1.25
2	*Suaeda nudiflora*	3.33	25.00	149.69	10438.94	3.23	23.81	2.50	25.00
3	*Avicennia marina*	86.67	75.00	5189.23	30794.88	83.87	71.43	86.67	73.75

Table 5.30 Absolute and relative frequency and density values for Jambusar taluka

The mean distance among the plants was highest at Kanthiajal followed by Jamdi, Vagra, Katpur and Devla. The Mean height of mangrove was very high for Kanthiajal followed by Jamdi, Katpur, Vagra and Devla areas.

These structural variables have strong relationship with each other and same is represented in form of a correlation matrix in Table 5.31. It shows significant negative correlation of density with mean distance, basal area and height whereas a significant positive correlation is observed between basal area and mean distance, mean height and mean distance, mean height and basal area. This relationship was apparent because, as the density decreases, the competition for the nutrients or resources would decrease. As a result of which an individual could get more nutrients or resources compared to the dense vegetated area and thereby showed high value of basal area and height parameters. Same was the case with the mean distance as mean distance increased between the plants, competition would be less for the nutrients or resources and therefore basal area and height would be increased. These variables are very important to predict the age of a vegetation stand (Maia and Coutinho, 2012). As the age of the plant increases there can be two possibilities for their growth or survival. These are (1) the number of individuals per unit area decreases and (2) the number of individuals remains same by not increasing their mass with age (Chapman and Reiss, 1995). In the first case, with the age, due to competition for the resources, some plants are out-competed and die. This process is known as self-thinning. In the second case with the age number of plants remains the same and their competition for the resources continues. In such circumstances, the plants avoid self-thinning process by not increasing their mass with age. Thus, in the second case the plants would show stunted growth.

Parameter	Absolute density	Mean distance	Basal area	Mean stand diameter	Mean height
Absolute density	1				
Mean distance	-0.94	1			
Basal area	-0.59	0.76	1		
Mean stand diameter	-0.77	0.92	0.94	1	
Mean height	-0.84	0.93	0.90	0.96	1

Table 5.31 Correlation matrix for different variable

In the present study self-thining may have been responsible for the less number of stems/ha and high values of height as well as basal area at Kanthiajal as well as Jamdi. The high numbers of stems/ha at Devla with relatively very low values of height, basal area and mean distance, suggest that those mangrove plants might be young in age and may not have reached maturity. For Vagra and Katpur, the number of individuals were relatively less (as compared to Devla) and their relatively high values for the mean distance, basal area and mean height suggest that they were of an intermediate age.

Complexity index is an important parameter that defines the complexity or the structural development of a stand. Several studies had been carried out wherein the type of mangrove is defined based on the values of basal area, density and complexity index of a mangrove stand (Pool *et al.*, 1977; Flores-Verdugo *et al.*, 1987; Arreola-Lizárraga *et al.*, 2004; Jayakody *et al.*, 2008; Bosire *et al.*, 2014). The values of complexity index were very low for all the selected villages of Bharuch district. The values of basal area, density and complexity index indicate that the mangroves of Bharuch district are of fringe and dwarf type. These are in line with the results obtained by Flores-Verdugo *et al.*, (1987) and Arreola-Lizárraga *et al.*, (2004) wherein they obtained similar values for the complexity index for mangroves of El Verde Lagoon on the coast of Mexico and Gulf of California, Mexico respectively. Among the five sites the highest complexity index was observed for Kanthiajal followed by Katpur, Devla, Jamdi and Vagra. These high values at Kanthiajal and Katpur were greatly influenced by its high basal area. From the size class distribution, mangroves of Katpur were younger as compared to Kanthiajal. The complexity index also indicates the disturbances in the mangrove area. According to Kairo *et al.*, (2002); Obade *et al.*, (2004); Walters (2005); Bandeira *et al.*, (2009) and Bosire *et al.*, (2014) stand stem density, basal area and complexity indices tend to be lower in disturbed forests and the low values of basal area with low values of complexity index reflected human pressure in the area. In the present study, high disturbance in mangrove area was observed at Vagra and Kanthiajal based on field survey and from change detection studies. The low values of basal area and complexity index observed for mangroves of Vagra also confirm their high disturbance. In addition to phytosociology, satellite images can also be used to retrieve the age of mangrove stands. A comparison of the available satellite images of different years starting from 1978 to 2012 showed that among these five sites, mangroves were observed first at Kanthiyajal (very dense patch), Katpur (very sparse) and Devla (very sparse) in the year 1997. This was followed by their appearance at Jamdi and Vagra in the year

2003 and 2010 respectively. This indicated the older age of mangroves of Kanthialjal and Katpur followed by the mangroves of Jamdi, Devela and Vagra areas.

Maps prepared from the satellite image of 2012 (IRS P6 LISS III) showed that mangroves of Bharuch district covered an area of 39.60 sq. km of which 3.49 sq. km was very dense mangrove, 9.72 sq. km was dense mangrove and 26.39 sq. km was of sparse mangrove. The above mentioned area was considered as per the administrative boundary of present study. But, due to the change in the course of the river Kim, new mudflats were observed in the south of Hansot taluka (Figure 5.72). These mudflats fell outside the administrative boundary of Hansot taluka but were attached to the terrestrial area of Hansot rather than Olpad taluka of Surat district. These areas were later occupied by the mangrove. Hence, if these mangroves were considered the total mangrove area of the district would increase to 40.62 sq. km of which 3.50 sq. km of very dense mangrove, 9.97 sq. km of dense mangrove and 27.15 sq. km of sparse mangrove area.

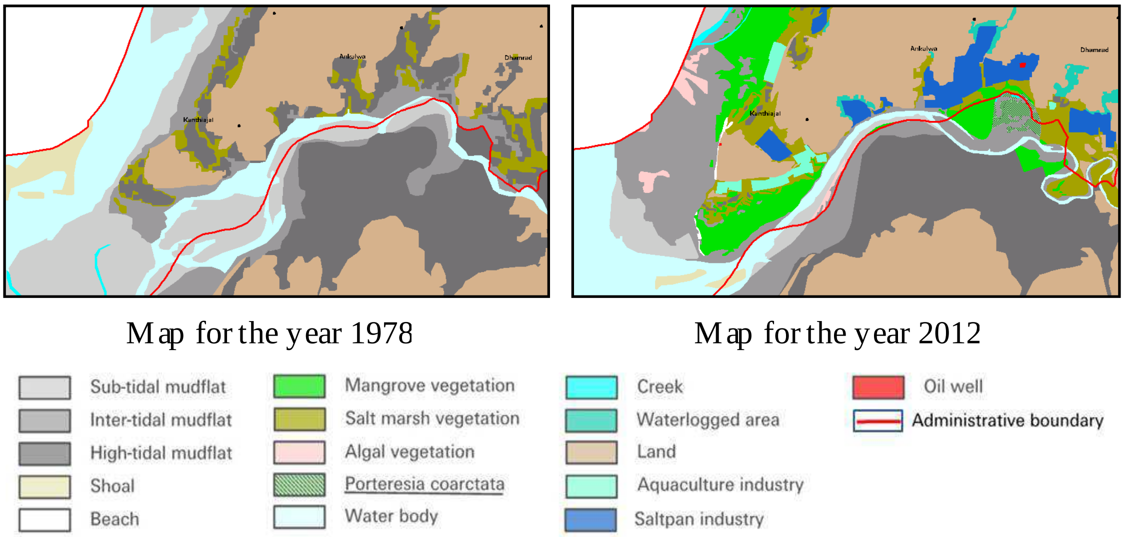


Figure 5.72 Change in the course of Kim river

GEER (2009) had used Landsat 3 (year-2005) data to quantify the mamgroves of Gulf of Khambhat and South Gujarat coast (Pandey and Pandey, 2009). According to their results, the total area of mangrove of Bharuch was 50.70sq. km of which area of 39.50 sq. km of dense mangrove and 11.20 sq. km of sparse mangrove. This value was far away from the findings of present study as well as from the number depicted in FSI report for the year 2013. Patel *et al.*, (2014) had used LISS III data of 28th Jan-2006, for the analysis of mangrove area. They found 42.46 sq. km area of mangrove of which 15.47 sq. km of dense mangrove and 26.99 sq. km of sparse mangrove. Forest survey of India had assessed the mangrove cover of India since 1987. These reports for the last several years indicated the continuous increase in the mangrove cover of Bharuch district.As per their recent report "India state of Forest report 2013" Bharuch possessed total 44 sq. km of mangrove area of which 16 sq. km area of dense mangrove and 28 sq. km of sparse mangrove (Anon, 2013b). Figure 5.73 depicts the comparison of the results of present study with these reports.

Thus, present study area was represented by one mangrove, five mangrove associates, seven salt marsh plants, three sand vegetation and ninety four plants of land vegetation. This showed increase in diversity of the species as one move from seaward to landward side. This is similar to the findings of Nebbia and Zalba (2002) and Monserrat *et al.*, (2012) which showed higher biodiversity along the cliff or dune

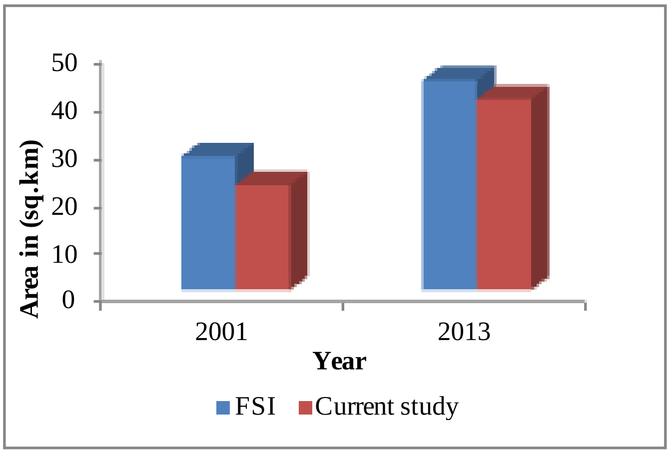


Figure 5.73 Comparison of mangrove cover

region as compared to tidal mudflats in Argentina. The analysis of structural parameters of mangroves for Bharuch district showed much variation in values of height, diameter and distance between the two plants among all the sites and talukas. The variation observed in vegetation across three talukas could be due to age of stand, variation in rainfall, geomorphology and sediment characteristics of these areas. These parameters play an important role in variation observed in the vegetation stand (Pool *et al.*, 1977; Kathiresan, 2010; Bhatt, 2013). Among these parameters, rainfall is discussed here whereas geomorphology and physico-chemical characteristics of sediments are discussed later. The rainfall data collected for the present study area (2003-2013) is represented graphically as Figure 5.74.

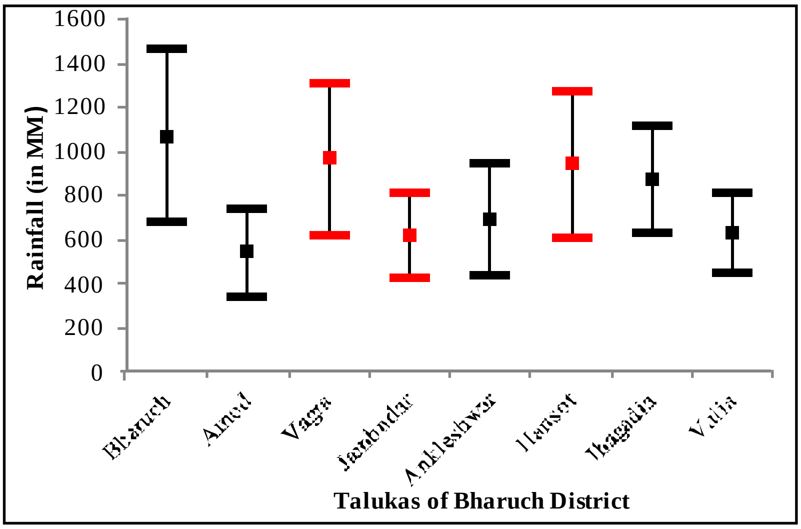


Figure 5.74 Rainfall pattern across different talukas of Bharuch district from 2003-2013 (source: Anon, 2014b)

Among the three talukas (indicated by red lines) Jambusar showed relatively less rainfall compared to Vagra and Hansot. This could be one of the reasons for the variation observed in the vegetation pattern. This observation about data of rainfall was also in agreement with the results obtained for similarity index which showed the vegetation of Vagra and Hansot to be more similar compared with Jambusar.

5.3 PHYSICO-CHEMICAL ANALYSIS OF COASTAL SEDIMENTS

Granulometric as well as chemical analysis of coastal sediments were carried out under the present study. Figure 5.75 shows sites selected for the collection of coastal sediments. The detail of each of these parameters is discussed below.

5.3.1 GRANULOMETRIC ANALYSIS OF COASTAL SEDIMENTS

The results obtained from grain size analysis are shown in Table 5.32 and their graphical representation in form of triangular diagram is given in Figure 5.76. It is important to note here that the sample number indicated at several places that follows pertain to the sample number incated in Table 5.32.

Taluka		Sample No.	Silt (in %)	Clay (in %)	Sand (in %)	Texture Class
Jambusar	1	Sarod	93.87	4.7	1.43	Silt
	2	Kavi 1	72.27	27.52	0.21	Clayey silt
	3	Kavi 2	74.53	24.82	0.65	Clayey silt
	4	Kavi 3	69.13	30.47	0.4	Clayey silt
	5	Kavi 4	18.8	7.55	73.65	Silty sand
	6	Degam	56.8	32.46	10.74	Clayey silt
	7	Jamdi 1	64.93	34.34	0.72	Clayey silt
	8	Jamdi 2	69.67	23.52	6.81	Clayey silt
	9	Devla 1	64.37	35.29	0.34	Clayey silt
	10	Devla 2	49.6	49.69	0.71	Silty clay
	11	Tankari 1	76.87	14.72	8.42	Silt
	12	Tankari 2	66.47	33.18	0.35	Clayey silt
Vagra	13	Muler	68.87	28.75	2.39	Clayey silt
	14	Gandhar 1	69.13	29.95	0.92	Clayey silt
	15	Gandhar 2	71.53	26.64	1.83	Clayey silt
	16	Lakhigam 1	0	4.82	95.72	Sand
	17	Lakhigam 2	53	33.86	13.14	Clayey silt
	18	Luhara	1.13	3.42	95.45	Sand
	19	Ambheta sez 1	71.8	16.3	11.9	Sandy silt
	20	Ambheta sez 2	31.33	46.55	22.11	Sand-silt-clay
	21	Kaladara 1	61.13	38.12	0.74	Clayey silt
	22	Kaladara 2	48.8	47.3	11.9	Clayey silt
	23	Kaladara 3	34.4	60.38	5.22	Silty clay

Taluka		Sample No.	Silt (in %)	Clay (in %)	Sand (in %)	Texture Class
	24	Aliabet 1	79.8	17.91	2.29	Silt
	25	Aliabet 2	56.8	42.94	0.26	Clayey silt
Hansot	26	Katpur	58.53	41.27	0.2	Clayey silt
	27	Kanthiajal 1	0	2.67	98.13	Sand
	28	Kanthiajal 2	57.4	42.52	0.08	Clayey silt
	29	Kanthiajal 3	50.4	49.44	0.16	Clayey silt
	30	Ankalwa 1	50.8	48.49	0.71	Clayey silt
	31	Ankalwa 2	46.23	53.53	0.24	Silty clay
	32	Dhamrad 1	43.93	55.83	0.24	Silty clay
	33	Dhamrad 2	49.93	49.83	0.24	Clayey silt

Table 5.32 Details of textural classes for various samples

The textural soil triangular diagram gives an idea of the proportion of three components i.e. silt, sand and clay in a soil sample. The result showed that most of the sediments fell in the clayey silt textural class followed by silty clay, sand, silty sand, silt and Sand-silt-clay (Sansicl) (Figure 5.76). This triangular diagram gives an overall picture about the textural class, but to have information at individual village level along with the weight percentage of different fractions of sediments; data was represented in form of histogram. The histogram with a single peak (with high weight percentage of single class) shows unimodal nature whereas with two or more than that shows bimodal or polymodal nature respectively (Folk and Ward, 1957). The histograms of the current samples indicated a clear asymmetrical nature for distribution of grain size and showed dominance of finer particles as compared to coarser particles. Table 5.33 depicts unimodal or bimodal nature of sediments whereas Figure 5.77 shows (a) unimodal and (b) bimodal nature of sediments respectively.

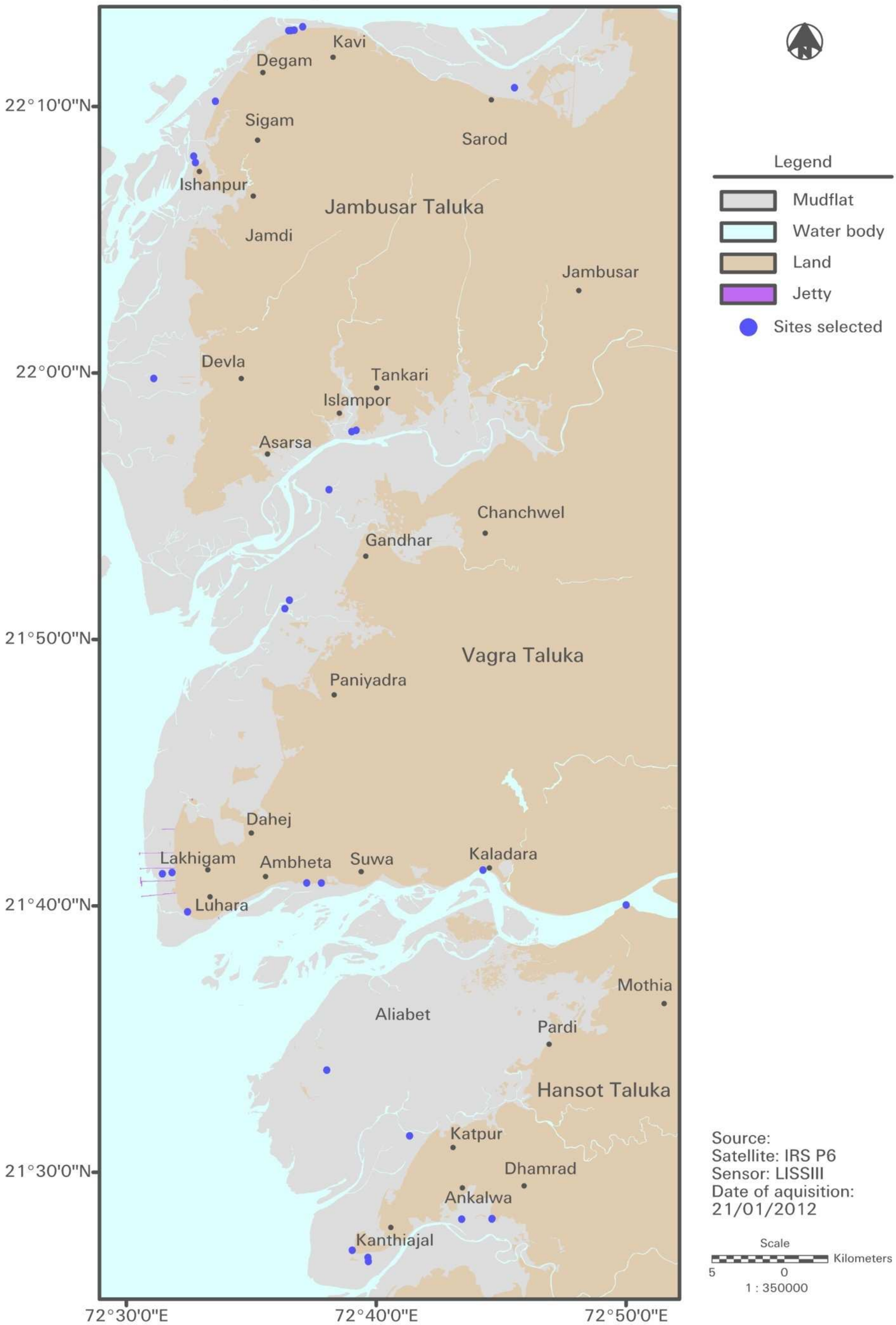
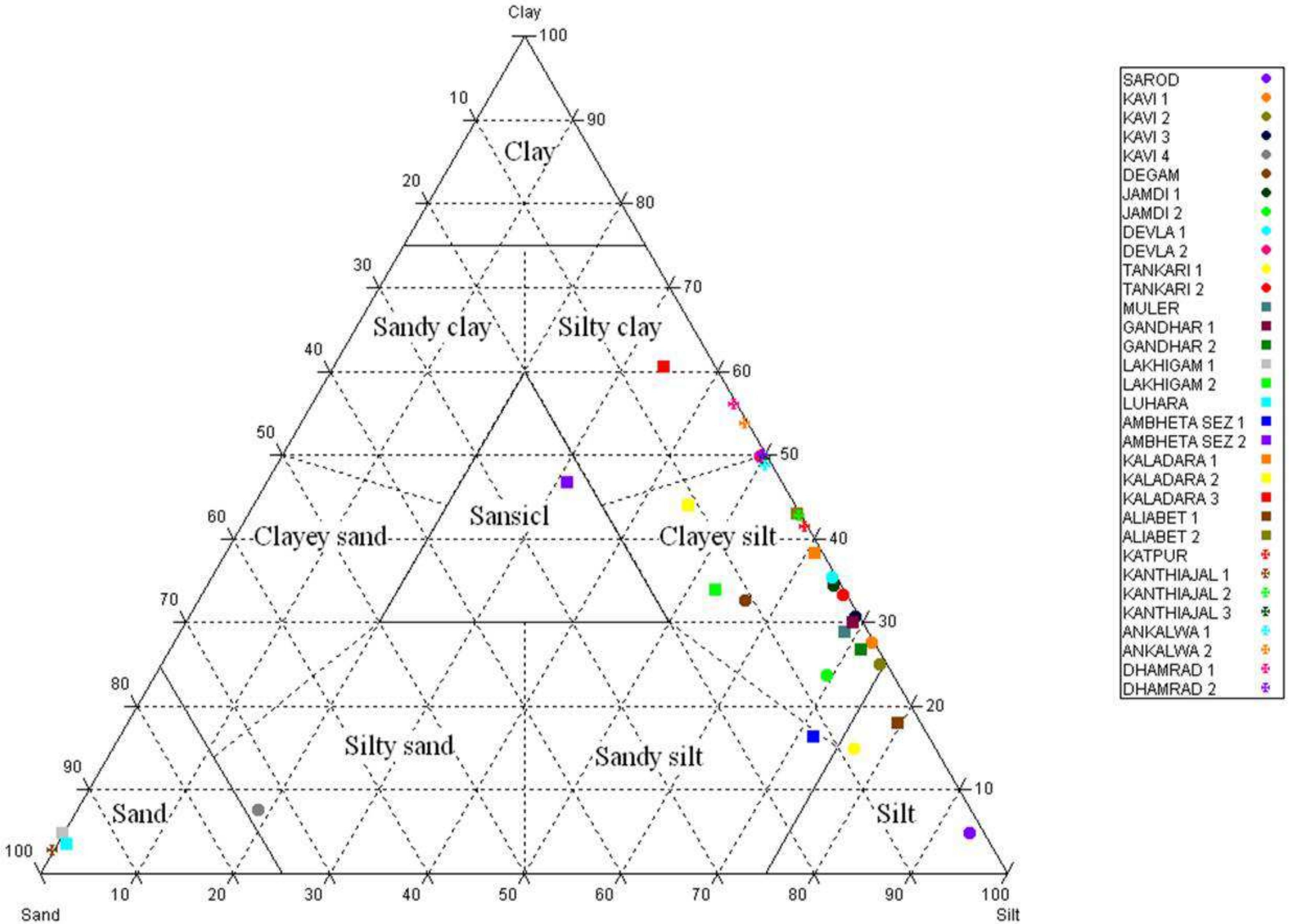


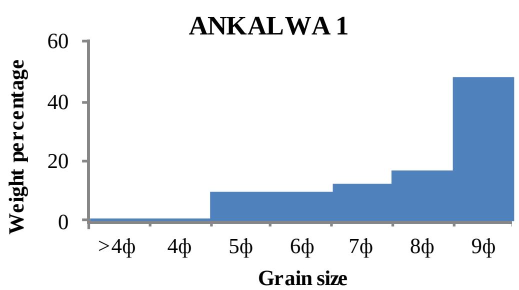
Figure 5.75 Location map showing sites of sediment collection



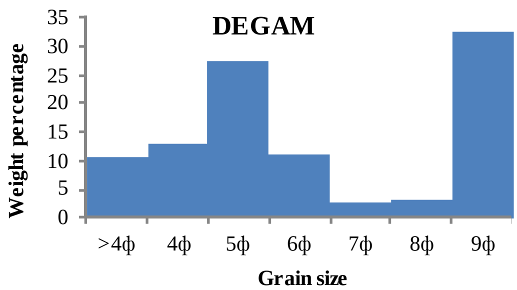
Figue 5.76 Triangular diagram showing textural characteristics of coastal sediments

Taluka		Sample No.	Histogram type
Jambusar	1	Sarod	Bimodal
	2	Kavi 1	Bimodal
	3	Kavi 2	Bimodal
	4	Kavi 3	Bimodal
	5	Kavi 4	Unimodal
	6	Degam	Bimodal
	7	Jamdi 1	Bimodal
	8	Jamdi 2	Bimodal
	9	Devla 1	Bimodal
	10	Devla 2	Bimodal
	11	Tankari 1	Bimodal
	12	Tankari 2	Bimodal
Vagra	13	Muler	Bimodal
	14	Gandhar 1	Bimodal
	15	Gandhar 2	Bimodal
	16	Lakhigam 1	Unimodal
	17	Lakhigam 2	Unimodal
	18	Luhara	Unimodal
	19	Ambheta sez 1	Bimodal
	20	Ambheta sez 2	Unimodal
	21	Kaladara 1	Bimodal
	22	Kaladara 2	Unimodal
	23	Kaladara 3	Bimodal
	24	Aliabet 1	Bimodal
	25	Aliabet 2	Bimodal
Hansot	26	Katpur	Unimodal
	27	Kanthiajal 1	Unimodal
	28	Kanthiajal 2	Unimodal
	29	Kanthiajal 3	Unimodal
	30	Ankalwa 1	Unimodal
	31	Ankalwa 2	Unimodal
	32	Dhamrad 1	Unimodal
	33	Dhamrad 2	Unimodal

Table 5.33 Interpretation of histogram type for sediments of various samples



Unimodal



Bimodal

Figure 5.77 Graphical representation of percentage of various grain size indicating (a) unimodal and (b) bimodal nature of sediments

5.3.1.1 Statistical Analysis of Grain Size Data

Various statistical parameters such as graphic mean size, standard deviation, graphic skewness and kurtosis were used to analyse the grain size data. The individual analysis of each parameter is described first and then their interpretation is discussed later.

Graphic Mean size:

Graphic mean size gives an idea about central tendency or the average size of sediments (Irudhayanathan *et al.*, 2011). It is influenced by the source of supply of sediments, velocity of transporting agent, shape and specific gravity, composition, durability, resisting nature of sediments and amount of tossing during the transportation (Singarasubramanian *et al.*, 2006; Kumar and Patterson, 2008). The values of mean size for different villages and their average, minimum and maximum values are given in Table 5.34 and their graphical representation is given in Figure 5.78.

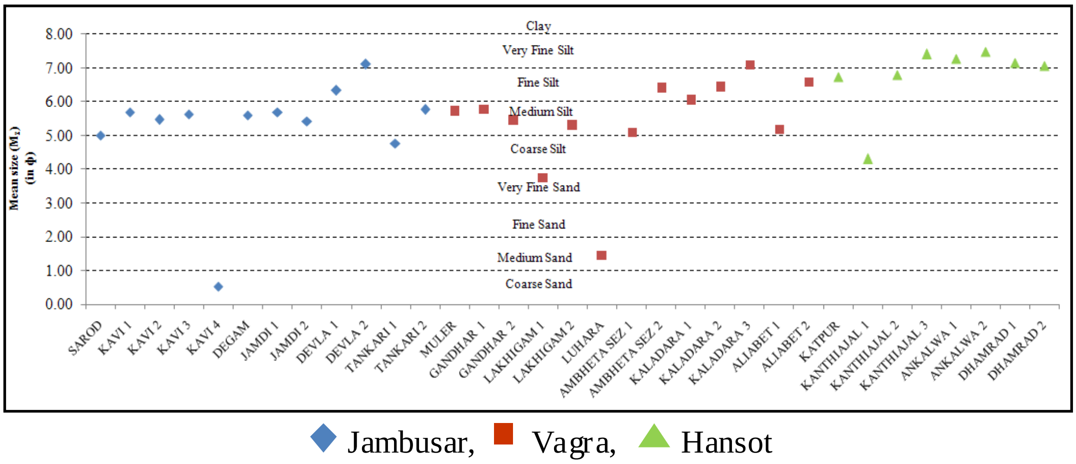
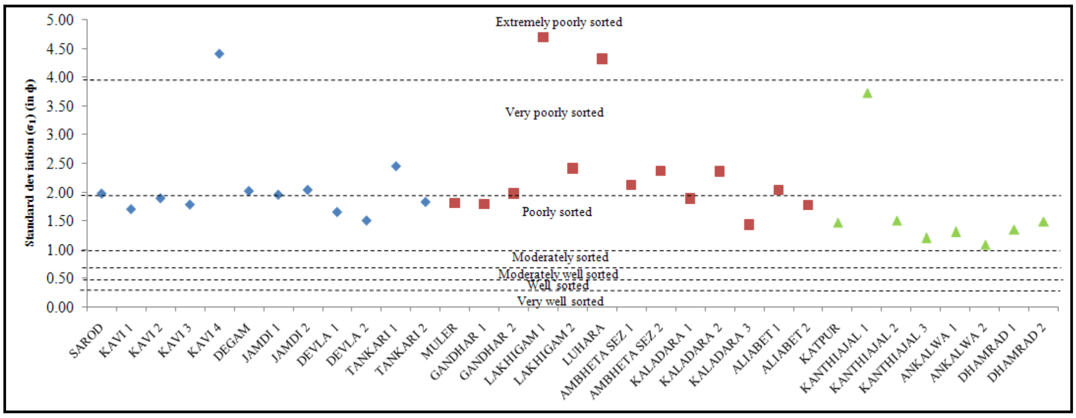


Figure 5.78 Graphical representation of mean size for the coastal talukas

Standard deviation:

Graphic standard deviation measures the sorting of sediments. Sorting has an inverse relation with the standard deviation. Sorting of sediments is influenced by degree of turbulence, velocity of transporting agent, hydrodynamic properties, nature of sediments supplied to the depositional environment and rate of supply of detritus (McKinney and Friedmann, 1970). Sediments collected in present study showed poorly sorted nature followed by very poorly to extremely poorly sorted nature of sorting (Figure 5.79).

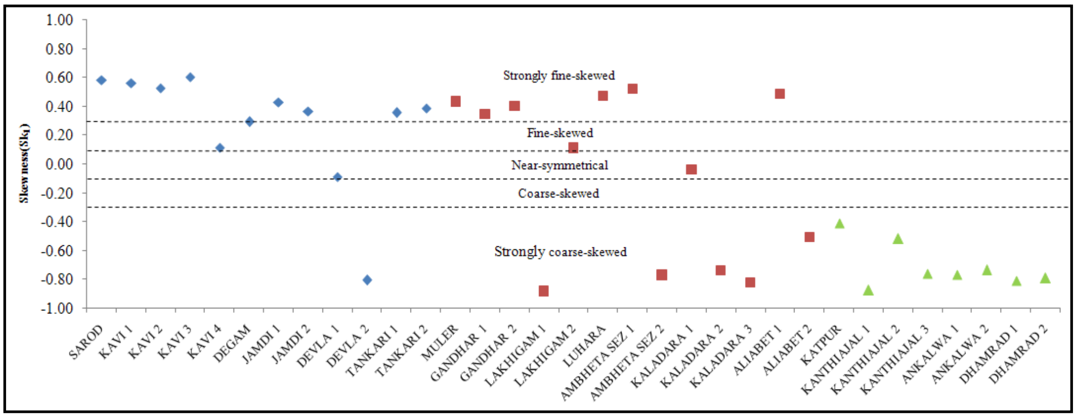


Jambusar, Vagra, Hansot

Figure 5.79 Graphical representation of standard deviation for the coastal talukas

Skeweness:

Graphic skewness is a measure of symmetry of the grain-size distribution curve. It gives an idea of predominance of the coarser or finer sediments (Goswami and Ghosh, 2011). Data for the skewness is shown in Figure 5.80 and Table 5.34. Comparison of skewness values with the classification system proposed by Folk and Ward (1957) and Cadigan (1961) showed that skewness values of samples fall in strongly fine skewed, fine skewed, near symmetrical and strongly coarse skewed classes.



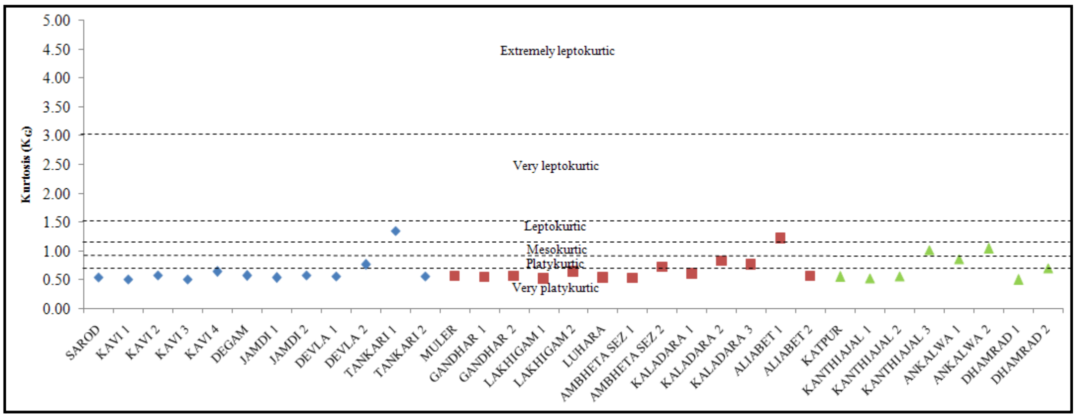
Jambusar, Vagra, Hansot

Figure 5.80 Graphical representation of skewness for the coastal talukas

Kurtosis:

Graphic kurtosis (K_G) is the peakedness of distribution. It is a quantitative measure used to describe departure from normality of distribution. Kurtosis is a measure of concentration of frequencies within the central part of distribution relative to the concentration in the flanks. Thus, it is a ratio between the sorting in 'tails' and central portion of the curve. If sorting in central portion is better than tails, the curve is excessively peaked and termed as leptokurtic. If tails are better sorted than central portion, then the curve termed as platykurtic and if sorting is uniform both in tails and central portion then termed as mesokurtic (Goswami and Ghosh, 2011).

The values of kurtosis for the different stations are shown in Table 5.34 and represented in the form of scatter plot in the Figure 5.81. The majority of the samples were very platykurtic, followed by platykurtic, mesokurtic and leptokurtic condition (Table 5.35).



Jambusar, Vagra, Hansot

Figure 5.81 Graphical representation of Kurtosis for the coastal talukas

Bivariant plots:

The inter-relationship of specific size-parameters are significant in the interpretation of various aspects of depositional environment (Folk and Ward, 1957; Passega, 1957; Friedman, 1961, 1967; Moiola and Weiser, 1968; Visher, 1969). Scatter plots convey important information for understanding geological significance of grain size parameters (Karudu *et al.*, 2013). Scatter plots between certain grain size parameters are helpful to interpret the energy conditions, medium of transportation, mode of deposition etc (Ganesh *et al.*, 2013). In present study, various combinations such as mean size vs standard deviation, mean size vs skewness, mean size vs kurtosis, skewness vs standard deviation, skewness vs kurtosis, kurtosis vs standard deviation and skewness vs normalized kurtosis were used to understand the relationship between different size parameters. Here the samples from all the three talukas were plotted on a single bivariate plot to understand the relationships more clearly

Taluka	Village	M_z	σ_1	Sk_1	K_G	Verbal term of Parameter			
		(in Φ)				M_z	σ_1	Sk_1	K_G
Jambusar	Sarod	5.00	1.97	0.59	0.54	Csl	PS	SFS	VPK
	Kavi 1	5.68	1.70	0.56	0.51	Msl	PS	SFS	VPK
	Kavi 2	5.47	1.89	0.53	0.58	Csl	PS	SFS	VPK
	Kavi 3	5.63	1.78	0.60	0.50	Msl	PS	SFS	VPK
	Kavi 4	0.53	4.40	0.12	0.64	Csa	EPS	FS	VPK
	Degam	5.60	2.01	0.29	0.57	Msl	VPS	FS	VPK
	Jamdi 1	5.68	1.95	0.43	0.53	Msl	PS	SFS	VPK
	Jamdi 2	5.42	2.03	0.37	0.57	Csl	VPS	SFS	VPK
	Devla 1	6.33	1.65	-0.09	0.55	Msl	PS	NSy	VPK
	Devla 2	7.10	1.50	-0.81	0.76	Fsl	PS	SCS	PK
	Tankari 1	4.77	2.45	0.36	1.35	Csl	VPS	SFS	LK
	Tankari 2	5.77	1.82	0.39	0.56	Msl	PS	SFS	VPK
	Average	5.25	2.10	0.28	0.64	Csl	VPS	FS	VPK
	Minimum value	0.53	1.50	-0.81	0.50	Csa	PS	SCS	VPK
	Maximum value	7.10	4.40	0.60	1.35	Fsl	EPS	SFS	LK
Vagra	Muler	5.72	1.80	0.43	0.56	Msl	PS	SFS	VPK
	Gandhar 1	5.78	1.79	0.35	0.55	Msl	PS	SFS	VPK
	Gandhar 2	5.45	1.97	0.40	0.56	Csl	PS	SFS	VPK
	Lakhigam 1	3.77	4.69	-0.88	0.51	VFsa	EPS	SCS	VPK
	Lakhigam 2	5.30	2.41	0.11	0.64	Csl	VPS	SFS	VPK
	Luhara	1.47	4.32	0.47	0.53	Csa	EPS	SFS	VPK
	Ambheta sez 1	5.10	2.12	0.52	0.53	Csl	VPS	SFS	VPK
	Ambheta sez 2	6.40	2.37	-0.77	0.72	Msl	VPS	SCS	PK
	Kaladara 1	6.05	1.88	-0.04	0.61	Msl	PS	NSy	VPK
	Kaladara 2	6.43	2.35	-0.74	0.83	Msl	VPS	SCS	PK
	Kaladara 3	7.10	1.43	-0.82	0.76	Fsl	PS	SCS	PK
	Aliabet 1	5.20	2.03	0.49	1.22	Csl	VPS	SFS	LK
	Aliabet 2	6.60	1.77	-0.51	0.56	Fsl	PS	SCS	VPK
	Average	5.41	2.38	-0.08	0.66	Csl	VPS	NSy	VPK
	Minimum value	1.47	1.43	-0.88	0.51	Csa	PS	SCS	VPK
	Maximum value	7.10	4.69	0.52	1.22	Fsl	EPS	SFS	LK
Hansot	Katpur	6.73	1.47	-0.41	0.55	Fsl	PS	SCS	VPK

Taluka	Village	M_z	σ_1	Sk_1	K_G	Verbal term of Parameter			
		(in Φ)				M_z	σ_1	Sk_1	K_G
	Kanthiajal 1	4.30	3.74	-0.88	0.53	VFsa	VPS	SCS	VPK
	Kanthiajal 2	6.80	1.51	-0.52	0.56	Fsl	PS	SCS	VPK
	Kanthiajal 3	7.40	1.20	-0.76	1.01	Fsl	PS	SCS	MK
	Ankalwa 1	7.27	1.31	-0.77	0.86	Fsl	PS	SCS	PK
	Ankalwa 2	7.47	1.09	-0.74	1.04	Fsl	PS	SCS	MK
	Dhamrad 1	7.15	1.35	-0.81	0.50	Fsl	PS	SCS	VPK
	Dhamrad 2	7.07	1.49	-0.79	0.70	Fsl	PS	SCS	PK
	Avereage	6.77	1.64	-0.71	0.72	Fsl	PS	SCS	PK
	Minimum value	4.30	1.09	-0.88	0.50	VFsa	PS	SCS	VPK
	Maximum value	7.47	3.74	-0.41	1.04	Fsl	VPS	SCS	MK

Table 5.34 Results of various grain size parameters

Note: Coasrse silt: Csl, Medium silt: Msl, Fine silt: Fsl, Coarse sand: Csa, Very fine sand: VFsa. Details of other abbreviations are given in table below.

Standard deviation (σ_1)		Skewness		Kurtosis	
σ_1 Value	Verbal Term	Sk_1 Value	Term	K_G Value	Term
Under 0.35 ϕ	Very well sorted(VWS)	+1.00 to +0.30	Strongly fine-skewed(SFS)	<0.67	Very platykurtic (VPK)
0.35 - 0.50 ϕ	Well sorted(WS)	+0.30 to +0.10	Fine skewed(FS)	0.67 - 0.90	Platykurtic(PK)
0.50 - 0.71 ϕ	Moderately well sorted(MWS)	+0.10 to -0.10	Near-symmetrical(NSy)	0.90 - 1.11	Mesokurtic(MK)
0.71 - 1.00 ϕ	Moderately sorted(MS)	-0.10 to -0.30	Coarse-skewed(CS)	1.11 - 1.50	Leptokurtic(LK)
1.00 - 2.00 ϕ	Poorly sorted(PS)	-0.30 to -1.00	Strongly coarse-skewed(SCS)	1.50 - 3.00	Very leptokurtic(VLK)
2.00 - 4.00 ϕ	Very poorly sorted(VPS)			> 3.00	Extremely leptokurtic(ELK)
Over 4.00 ϕ	Extremely poorly sorted(EPS)				

Table 5.35 Values of different paramteres and their verbal terms (Source: Folk, 1974)

Mean size vs Standard deviation:

A scatter plot of mean size (Y axis) against standard deviation (X axis) showed a negative linear trend, clearly indicating a decrease in the grain size with increase in the standard deviation (Figure 5.82) which was similar to the results obtained from the studies of Reddy *et al*., (2008) and Karudu *et al*., (2013).

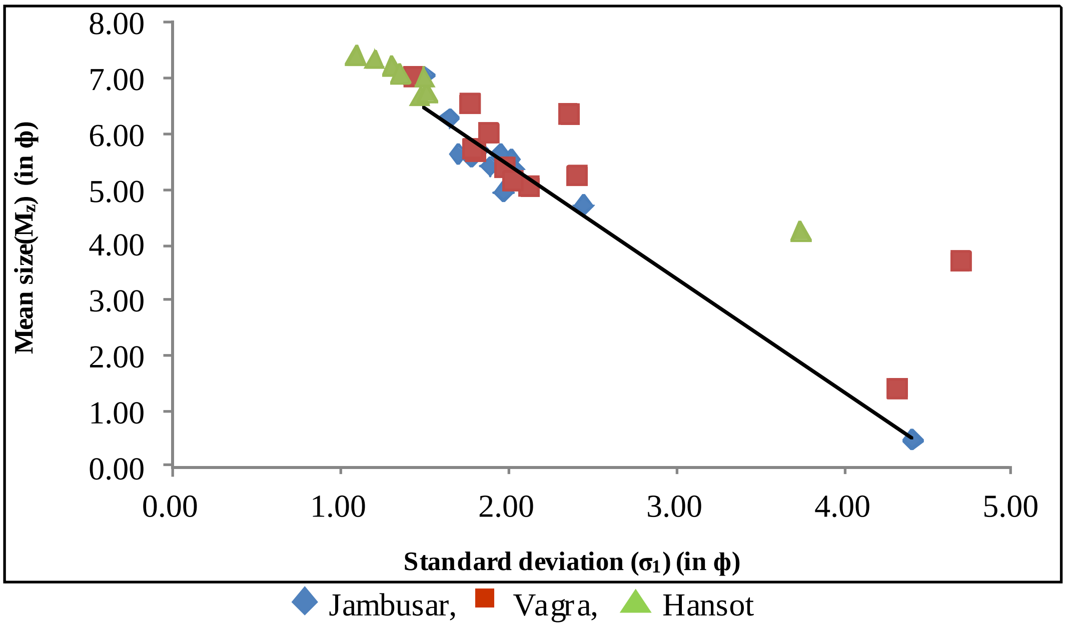


Figure 5.82 Scatter plot of Mean size vs Standard deviation

Mean size vs Skewness:

A scatter plot of Mean size vs Skewness is one of the best techniques for understanding the type of modality. Figure 5.83 shows the sinusoidal curve which is similar to the standard graph of Folk and Ward (1957). The sinusoidal nature was because of the proportionate admixture of two size-classes of the sediments i.e. silt and clay with little fraction of sand.

Skewness vs Standard deviation:

Figure 5.84 shows relation between the standard deviation and skewness. It showed that majority of samples were poorly sorted and showed their clustering towards strongly fine as well as coarse skewness. The poorly sorted and fine skewed sediments indicated deposition of sediment under low energy condition where as the strongly coarse skewed sediments showed deposition of sediments under high energy condition.

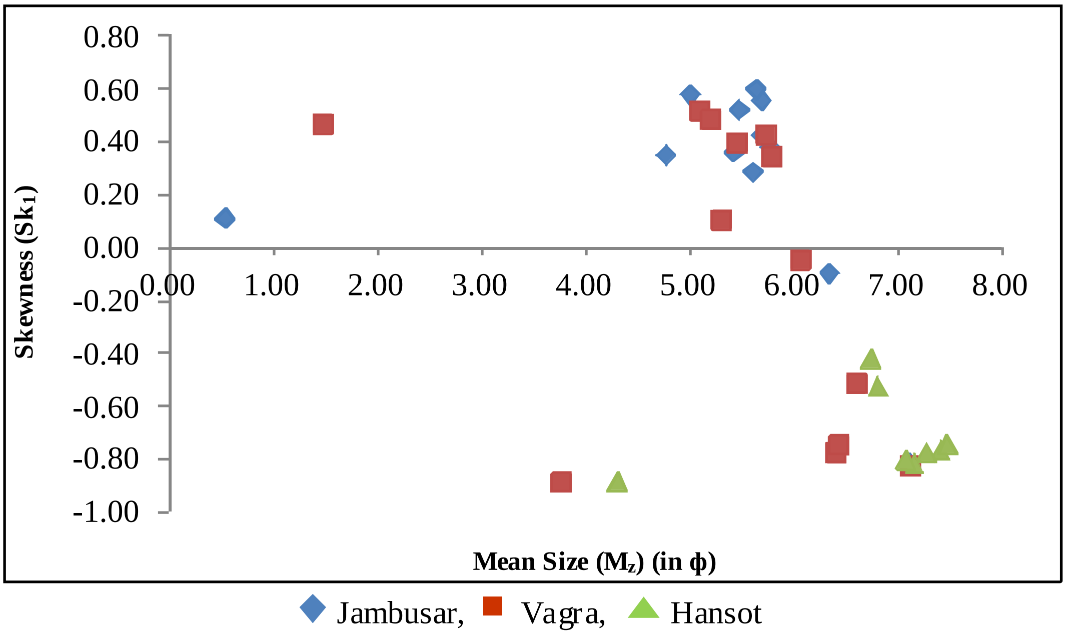


Figure 5.83 Scatter plot of Mean size vs Skewness

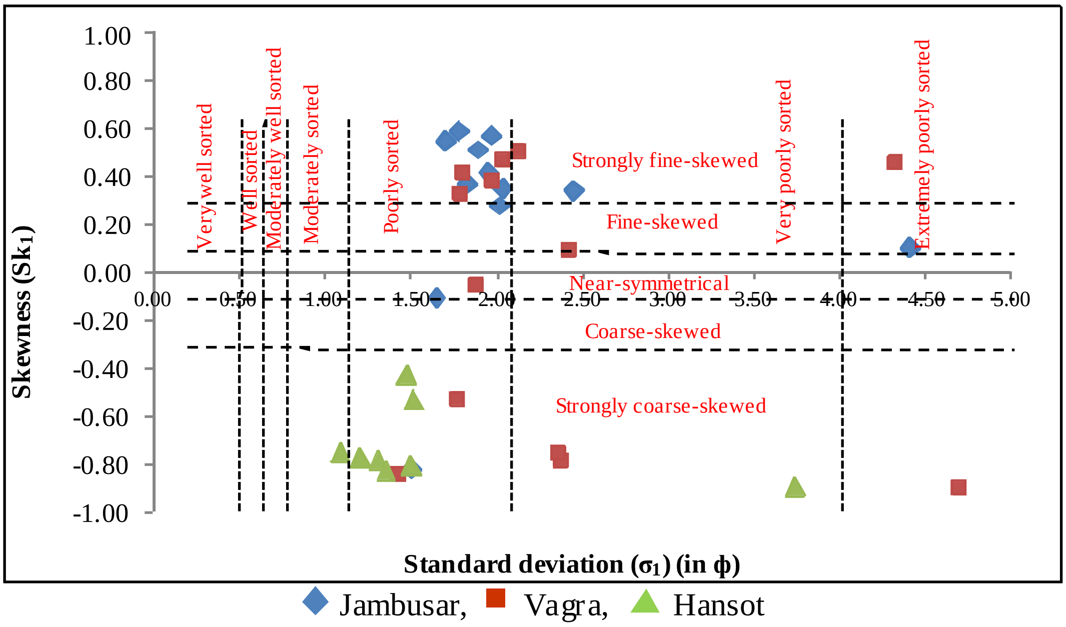


Figure 5.84 Scatter plot of Skewness vs Standard deviation

Skewness vs Kurtosis:

Figure 5.85, a plot of skewness vs kurtosis showed that majority of the sediments were found within positvely skewed with very platykurtic to leptokurtic range. This was followed by sediments showing negatively skeweness with very platykurtic to platykurtic range for the values of kurtosis. This suggested that the dominance of medium grain size (medium silt) population followed by fine grain size (fine to very fine silt) acting as secondary population.

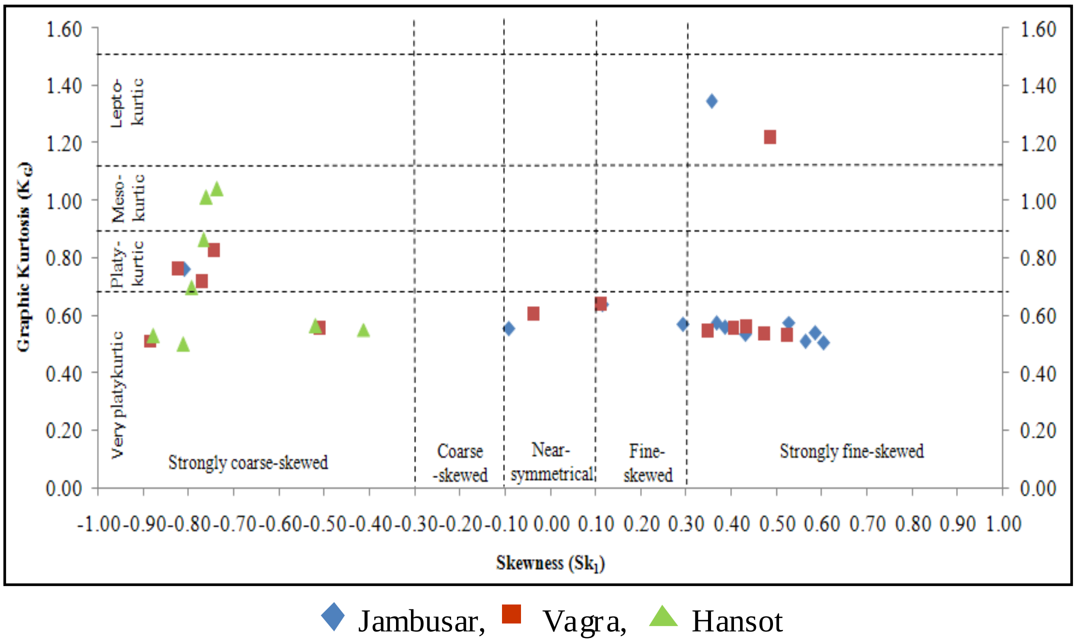


Figure 5.85 Scatter plot of Skewness vs Kurtosis (After Folk and Ward, 1957)

Thus, the sediments collected from Jamubsar taluka showed dominance of medium silt particles, which were strongly fine skewed, poorly sorted and very platykurtic in nature. Whereas sediments collected from Hansot taluka showed dominance of fine silt, which were poorly sorted, strongly fine skewed and very platykurtic to mesokurtic in nature. The sediments of Vagra taluka showed admixture of medium and fine silt particles, with their skewness value ranged from strongly fine to strongly coarse. They showed the extreme values of sorting (very poorly to poorly sorting) and kurtosis (very platykurtic to platykurtic).

Results showed considerable variation in sediments collected from all three coastal talukas. It showed distinct variation in the sediments collected from Jambusar and Hansot talukas whereas Vagra acts as a transitional zone, which possessed sediments with characteristics of both talukas (of Jambusar as well as Hansot talukas.) Information about energy conditions, depositional environment, type and direction of transportation medium derived from the grain size analysis are discussed here.

5.3.1.2 Discussion

Textural study of the samples suggested that silt was dominant constitute with clay as subordinate followed by little fraction of sand. This was represented well in histogram in form of weight percentage of different size particles. The sediments showed two different modal class namely unimodal or bimodal. The collection sites located in riverine environment (towards the landward side in the river channel) (such as

Ankalwa and Dhamrad) and those facing the gulf region (Lakhigam and Luhara) showed unimodal nature. Whereas sites located at the mouth of river i.e. in estuarine area (Sarod, Kavi, Devla, Tankari, Gandhar, Ambheta, Kaladara and Aliabet) mostly showed bimodal nature of sediments. The reason for the unimodal nature of sediment could be the single source of sediments which could be river in most of samples, except for the samples from Lakhigam 1, Luhara and Kanthiajal 1 where the source of sediment could be beach or sea. The bimodal nature of sediment indicated that sediments were brought by two different sources which could be river and sea in this case. Bimodality of sediment can be viewed from the scatter plot of mean size vs skewness which suggested the sinusoidal shape of the curve (Figure 5.83). Even very platykurtic nature of sediments indicates bimodal condition (Goswami and Ghosh, 2011). Thus, non-normal values of skewness and kurtosis suggested mixing of two or more modal fractions (Folk and Ward, 1957).

Information about the size of particles was derived from mean size. The sediments collected in present study were majorly fine (silt) in nature with little variation in their size. They ranged from coarse-medium-fine-very fine silt as one moved from Jambusar to Hansot. Although silt made major contribution, at a few locations (Kavi, Luhara and Lakhigam) coarse, medium and very fine sand sediments were observed. Mean size is mainly used as an index of energy conditions and gives idea about the nature of depositional conditions of the sediments (Ganjoo and Kumar, 2012; Ganesh *et al.*, 2013; Karudu *et al.*, 2013). In the present study area, dominance of finer sediments (at Kavi, Jamdi, Muler, Gandhar, Kaladara, Katpur and Kanthiajal) indicated the low energy conditions prevailing in the area. At few locations the presence of coarser particles indicated the high energy conditions at those specific sites e.g. Luhara and Lakhigam.

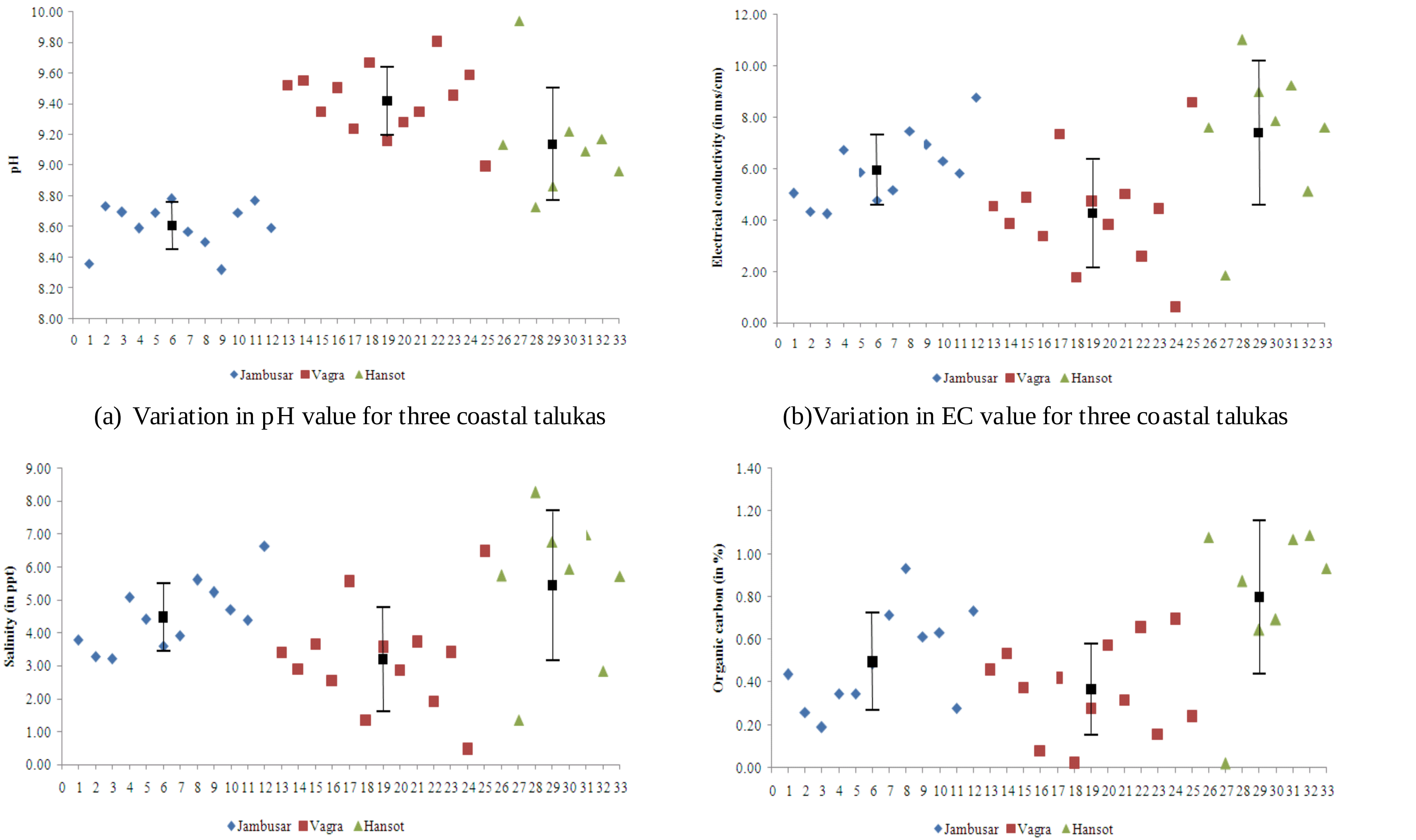
Skewness also gives idea about the direction of transportation medium. The positive value of transportation indicated unidirectional flow of transporting medium where as negative value signified to and fro motion of transporting medium (Friedman, 1961). In the present study, the unidirectional motion was observed in Sarod, Kavi, Jamdi, Tankari, Muler, Gandhar, Lakhigam and Luhara regions where there was influence of either the river or sea (tidal water). But in the transitional area (estuarine area) at Ambheta, Kaladara, Kanthiajal, Ankalwa and Dhamrad wherein the sediments of fine and coarse nature were mixed together, to and fro motion of the transporting medium was responsible for transportation of sediment (Blaeser and Ledbetter, 1980).

Sorting is another statistical parameter that serves as a measure to decipher energy or depositional environment and to know the presence or absence of coarse and fine grained fractions (McKinney and Friedmann, 1970). Extremely poor sorting, very poor sorting and poor sorting characteristic of the current samples revealed that deposition must have been fluviatile (Ganjoo and Kumar, 2012). The variations in its value were likely due to continuous addition of finer/coarser material in various proportions (Rao *et al.*, 2001; Ramanathan *et al.*, 2009) and due to difference in water turbulence and variability in the velocity of depositing currents (Casshyap and Khan, 1982). Even strongly fine skewed (Sarod, Kavi, Jamdi, Tankari, Muler, Gandhar and Alaibet1) and fine skewed (Degam) nature of sediments suggested introduction of finer material and excessive riverine input (Singarasubramanian *et al.*, 2006). Very low value of kurtosis and very platykurtic (Sarod, Kavi, Degam, Jamdi, Muler, Gandhar and Kanthiajal) to platykurtic (Devla, Kaladara and Ankalwa) nature of sediment suggested fluvial (riverine) characteristics of the sediments (Karudu *et al.*, 2013).

So, in brief as one moved from north to south in the study area, there was reduction in grain size and an increase in energy condition. The depositional environment was mainly riverine except for sediments collected from Lakhigam, Luhara and Kanthiajal wherein sea or tidal water was the depositional medium.

5.3.2 CHEMICAL ANALYSIS OF COASTAL SEDIMENTS

pH, electrical conductivity, salinity and organic carbon were the parameters analyzed in present study. Results showed considerable variation among three coastal talukas. Figure 5.86 showed variation observed for each parameter at taluka level whereas Figure 5.87 showed variation in individual parameter at vegetated mudflat and barren mudflat area. The results derived from one way ANOVA test for three different talukas revealed significant variation in pH ($F_{(2,30)} = 35.59$, $p<0.05$), electrical conductivity ($F_{(2,30)} = 5.92$, $p<0.05$), salinity ($F_{(2,30)} = 5.05$, $p< 0.05$) and organic carbon ($F_{(2,30)} =6.91$, $p<0.05$). Similarly significant variation were obtained for sediments collected from mangrove, salt-marsh vegetation and barren mudflat area



(a) Variation in pH value for three coastal talukas

(b)Variation in EC value for three coastal talukas

(c) Variation in salinity for three coastal talukas

(d) Variation in content of organic carbon for three coastal talukas

Figure 5.86 Variation in (a) pH, (b) electrical conductivity, (c) salinity and (d) organic carbon across three coastal talukas

where in values of pH ($F_{(2,30)}$ = 4.55, $p<0.05$), electrical conductivity ($F_{(2,30)}$ = 10.46, $p<0.05$), salinity ($F_{(2,30)}$ = 9.65, $p<0.05$) and organic carbon ($F_{(2,30)}$ =5.42, $p<0.05$).

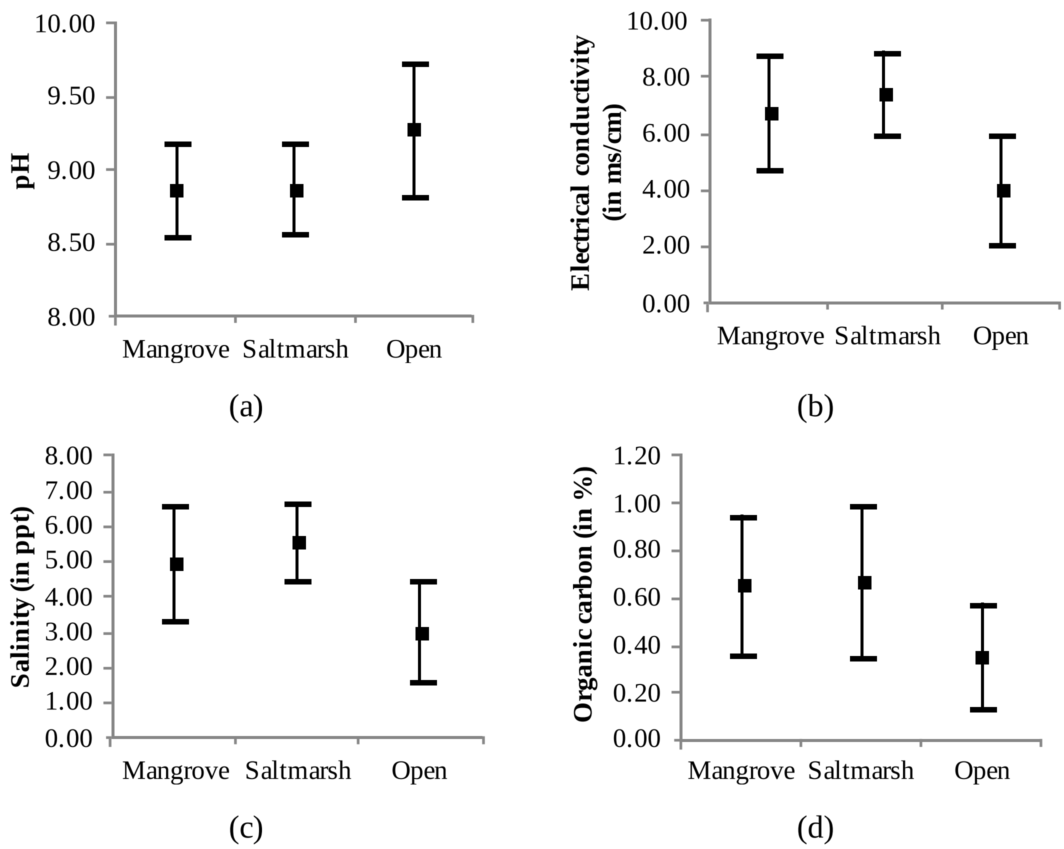


Figure 5.87 Variation in (a) pH, (b) electrical conductivity (EC), (c) salinity and (d) organic carbon (OC)for area covered by mangrove and salt marsh vegetation and open/barren mudflat area

5.3.3 DISCUSSION

The results showed apparent variation among three different talukas and between sediments collected from vegetated (mangrove and salt-marsh vegetation) and barren or open mudflat area.

Among three talukas, higher range of pH was observed at Hansot followed by Vagra and Jambusar taluka. pH of soil plays an important role in the growth of mangroves (Venugopal *et al.*, 2008). Results of pH of soil showed high pH value ranging from 8.78 - 9.50 with an average value of 9.14 for Hansot taluka. This was the range at which mangroves achieved maximum shoot growth (Venugopal *et al.*, 2008). Thus, this very alkaline nature of sediments of Hansot taluka could be the reason for high values of height for mangroves of Hansot taluka. The alkaline nature of sediments observed in this area was due to their vertisols type of soil, for which high pH value was one of its characteristics (Virmani *et al.*, 1982). Values of electrical conductivity and salinity showed relatively high values for sediments collected from Hansot followed by Vagra and Jambsar taluka. The values of electrical conductivity were mostly 2 ms/cm or more than 4ms/cm indicating their sodic nature of sediments (Chichmalatpure and Rao, 2009). Values of organic carbon were relatively higher for Hansot taluka followed by Jambusar and Vagra taluka. High values of electrical conductivity, salinity and organic carbon observed for Hansot taluka was due to presence of mangrove or salt marsh vegetation as well as their finer size of sediments. Finer sediments such as silt and clay are characterized by compact arrangement of soil particles. This could be the reason for the high value of organic carbon and salinity for the silt and clay particles. Whereas in case of sand, the coarser particle size, large intercellular space and less water holding capacity were the reason for the low value of organic carbon and salinity (Dessai *et al.*, 2009). Another reason for increase of organic carbon in finer particles was similarity in settling velocity of both organic constituents and finer particles (Trask, 1939; Girap *et al.*, 1994). The values observed for pH, electrical conductivity, salinity and oragnic carbon were in line with findings of Sajish (2012), Patel (2014) and Shukla (2014) where they had studied the above mentioned parameters for sediments collected from estuarine area of Mahi and Dhadhar and Gulf of Khambhat region. They found relatively high pH (alkaline) value and low electrical conductivity, salinity and organic carbon values for this region. Similar values were also observed in mangroves area of Tamil Nadu and Pondicherry states of India (Venugopal *et al.*, 2008).

		Clay (%)	Silt (%)	Sand (%)
Mangrove	Minimum	14.72	43.93	0.08
	Average	38.46	60.26	1.28
	Maximum	55.83	76.87	8.42
Salt marsh vegetation	Minimum	16.30	46.23	0.24
	Average	34.38	60.89	4.73
	Maximum	53.53	71.80	13.14
Open mudflat	Minimum	2.67	0.00	0.21
	Average	26.34	46.21	28.08
	Maximum	60.38	93.87	98.13

Table 5.36 Range of clay, silt and sand in vegetated and unvegetated mudflat area

The sediments of mangrove area and saltmarsh (vegetated areas) and open mudflats were compared to know difference in the textural parameters of soils from two different types of coastal vegetation as well as open mudflat. The analysis of grain size showed a small variation in silt and clay content of mangrove and salt marsh vegetation area whereas considerable difference was observed in the open (unvegetated) area (Table 5.36). In mangrove the amount of silt and clay was much higher as compared to sand fraction. Whereas in saltmarsh vegetation along with silt and clay, relatively more content of sand was obsereved. The high content of sand in salt marsh vegetation could be due to its proximity to the cliff region. Figure 5.87 showed that similar pH conditions were seen in mangrove and salt marsh vegetated areas whereas of the pH values were much higher for open mudflat area. One of the possible reason for this could be the prevalence of microbial activity in vegetated area, which may have released acidic components and lowered pH the especially in mangrove area (Kathiresan, 2010). This could also be the cause for the high values of electrical conductivity in vegetated area in comparison to open area. Mangrove and salt-marsh area are considered as sink for organic carbon and produce more organic carbon than can be stored within the system and this excess material is exported to coastal water (Odum, 1968, 1980; Hazelden and Boorman, 1999; Kathiresan, 2003). Present findings showed relatively higher value of organic carbon for mangrove and salt marsh vegetated mudflat area as compared to open mudflat area. Also the value of organic carbon was slightly higher for salt marsh vegetated mudflat area compared to mangrove areas. Difference in inundation of tidal water in mangrove (inter-tidal mudflat) and salt marsh vegetated (high-tidal) mudflat area and variation in daily flooding area could be some of the factors responsible for observed variation in quantity of organic carbon. Amount of organic carbon could get washed out easily from mangrove areas falling under the influence of daily tidal cycles. Whereas compared to this, salt marsh area (high-tidal mudflat) would get less inundated and its area under tidal flood would vary based on spring and neap tidal cycles. So, mangrove area (inter-tidal mudflat) which flooded twice in a day could have high removal of organic carbon as compared to salt marsh vegetated mudflat area. This could be the possible reason for high content of organic carbon observed in salt marsh vegetated area as compared to mangrove area. This could also be the cause for variation observed in salinity in mangrove and salt marsh vegetated mudflat area.

Thus, values of chemical parameters showed much variation along three coastal talukas as well as among vegetated and open mudflat area.

5.4 COASTAL GEOMORPHOLOGY OF THREE COASTAL TALUKAS OF BHARUCH DISTRICT

Geographically, Bharuch district is located within the Gulf of Khambhat and showed much variation in geomorphic features. Landforms observed in the north of Narmada were quite distinct from southern region. In the northern segment, river Mahi and Dhadhar dumped their sediments which were constantly redistributed by unique combination of tidal currents and velocity of river waters entering in to the gulf (Islam and Merh, 1988). Combination of ebb and flood tide with incoming water from rivers in the gulf produced interesting patterns of sediment transport. Wave action was not well pronounced in the gulf area (northern part of Narmada) and entire sediment distribution was dependent on river water flow and tidal currents (Desai *et al.*, 1992). Coastal segment to the south of Narmada had coastal environment where effects of open sea and those of the gulf combined with each other. In this area, height of tide was much less as compared to that in the gulf of Khambhat. Effects of tidal currents especially during the ebb flow provide substantial south-ward long shore drift of the sediments (Merh and Vashi, 1984).

The major landforms observed in the present study area and their taluka wise distribution is given below.

Estuarine river mouth: The estuarine river mouths of Mahi, Dhadhar, Narmada and Kim were of funnel shaped and muddy in nature. The width of mouths of Mahi, Dhadhar and Naramada were considerably broad whereas of Kim was relatively narrow. During high tides, sea water entered through their inlets to fairly long distances, as a result of which extensive tidal mudflats were encountered along all the estuaries. The mouth of Mahi, Dhadhar and Narmada, in the low tide revealed vast patch of muddy shoals across which river flowed through network of braided channels.

Foreshore mudflats and offshore mud banks: The entire coastal segment was marked by wide foreshore mudflat all along its length. All estuaries except Narmada showed extensive mudflats (Nayak *et al.*, 1986). These mudflats were classified further in to high tide flats, inter-tidal flats and sub-tidal flats (Davies, 1972). The mudflats based on presence or absence of vegetation were divided in to vegetated or barren/open mudflat (Plate 5.49). The high tidal and inter-tidal mudflats were mostly covered by halophytes (mangrove and saltmarsh vegetation) where as sub-tidal mudflats were mostly barren. Width of intertidal zone varied from 500 m to 3 km and narrowed down from north to south direction of the study area. The mudflats were traversed by numerous named and unnamed tidal creeks and channels which meandered through tidal mudflat (Plate 5.49).

Occurrence of offshore mud banks and shoal was another characteristic feature of the northern coastal block. Mahi, Dhadhar and Narmada River showed silty and sandy banks of varying dimension and shape in the mouth region (Plate 5.50). These vast quantities of sediments, brought by various rivers and reworked by tidal currents, were seen deposited as mouth bars, foreshore mudflats and offshore mudbanks (Merh and Vashi, 1984). Most of these mudbanks got submerged during high tide, though parts of some of larger ones remained dry during the normal high tide. These mudbanks frequently change their configurations in course of time or even seasonally, depending on sediment supply and pattern and intensity of depositional and erosional processes operating within the Gulf (Patel *et al.*, 1984).

Backshore alluvial cliffs: Backshore coastal plains were made up of alluvium and these rose abruptly above the tidal flats forming a cliff. This feature was more pronounced at mouths of the rivers where height of cliff was considerably high. This was striking feature of Mahi and Narmada estuary (Plates 5.50). Cliffs were observed in the river basins of Dhdahdar and Kim. But as they fell in area that was beyond taluka boundary of the present study area and hence not included in this study.

Behind the cliffs, extend the alluvial plains which comprised a featureless flat terrain. The alluvial plains between the Mahi and Dhadhar i.e. of Jambusar taluka showed gradual southwesterly slope (Patel *et al.*, 1984).

Alluvial islands within mudflat: Within mudflats, occurred numerous ‘bets’ or ‘islands’ of alluvium, projecting a few meters above the high waterline. These were highly irregular in shape and of variable sizes. They represented an alluvial topography of past when strand line was much lower and when various coastal streams eroding the alluvium flowed for several kilometers further west before meeting sea. The immediate/successive transgression resulted into drowning of river valley and encirclement of elevated portions of a dissected alluvial coast by tidal waters (Patel *et al.*, 1982). These alluvial islands supported considerable vegetation and larger ‘bets’ were even cultivable.

Exposed sub-tidal mudflat at low tide, Kavi (Jambusar)

Vast stretch of inter-tidal mudflat at Ambheta (Vagra)

Mangrove and salt marsh vegetation in high-tidal mudflat, Devla (Jambusar)

Salt marsh vegetation in high-tidal mudlfat, Katpur (Hansot)

Large creek at south of Aliabet

Meandering of creek in high-tidal mudflats, Ankalwa (Hansot)

Plate 5.49 Various coastal landforms observed in present study area

Exposure of shoal with receding tide, Narmada river

Exposed shoal in low tide, Narmada River

High cliffs at Kavi (Jambusar)

High cliffs to south of Suwa (Vagra)

Sandy ridge at Lakhigam (Vagra)

Beach at Lakhigam (Vagra)

Plate 5.50 Various coastal landforms observed in present study area

Sandy ridges: Sandy ridges were characteristic feature of coastline to south of Narmada River. But, some aeolian sand formation was observed only between the mouth of Dhadhar and Narmada. An ill-defined ridge composed of fine sand and high silt content was observed at Lakhigam i.e. south of Dahej. This ridge showed a good vegetation cover which mostly included forest of Acacia and other xerophytic flora (Plate 5.50) (Patel *et al*., 1984).

5.4.1 GEOMORPHOLOGICAL SET UP OF JAMBUSAR TALUKA

The geomorphic features observed in Jambusar taluka were estuarine river mouths, mudflats, mangrove vegetation, saltmarsh vegetation, creeks, shoals and alluvial plains. Estuarine river mouth of Mahi River was quite broad as compared to the river Dhadhar. The mouth of river Dhadhar showed extensive mud accumulation. This accumulation was to such an extent, that the river meanders, bifurcates and then joins again while flowing within muddy deposits. This was a good example of choking of river due to increasing mud accretion in the area (Patel *et al.*, 1982). Mahi and Dhadhar both estuaries showed an extensive patch of mudflats. The width of mudflat varies from a kilometer to maximum up to 8 km. The sub-tidal mudflats were mostly barren whereas at places, intertidal and high tidal mudflats were covered by mangrove or saltmarsh vegetation. But, major area of the high tidal mudflat had taken up by saltpan industry. High tidal mudflats were followed by alluvial cliffs that rose abruptly above the alluvial plain. Height of the cliffs decreased from Sarod to Kavi to Degam. Very high height of the cliff was noticed at Sarod, followed by Kavi and was decreasing further at Degam and its south. The comparison of satellite images over a period of more than 30 years suggested considerable changes in flow of Dhadhar River (Plate 5.51). Due to which erosional features were observed near Asarsa village (right bank of Dhadhar River) where as deposition was observed on the left bank of Dhadhar River (along vagra taluka).

5.4.2 GEOMORPHOLOGICAL SET UP OF VAGRA TALUKA

The geomorphic features observed along Vagra taluka included estuarine river mouth, mudflats, saltmarsh, mangrove vegetation, creeks, shoals, alluvial cliffs and sandy ridges (Plate 5.52). Among Mahi, Dhadhar, Narmada and Kim rivers, Narmada had the broadest river mouth. As per the satellite image of 2012, width of mouth of Narmada River was approximately 10 km. A number of offshore mud banks and shoals were observed at the mouth as well as in main channel (Narmada River). Vast stretch of mudflats were observed along the western side of taluka whereas along the southern side of taluka (i.e. along northern side of the Narmada River) width of mudflat decreased considerably. The width of mudflat ranged from few hundred of meters to 8 km. Mudflats along the western side were covered by dense mangrove as well as salt marsh vegetation whereas relatively open vegetation was observed along the southern side of taluka. Most of the high tidal mudflats of this taluka were occupied by the saltpans and some area was taken up by the oil wells. In the north of Dahej, a 'bet' like raised feature was observed within mudflat. The major area of this alluvial island was covered with scrub (*Prosopis juliflora*) vegetation and some part of this island was under cultivation. The backshore alluvial cliffs were observed in south of taluka. The height of the cliff was considerably high at mouth region. Besides this a sandy ridge was observed along the western side of Lakhigam which was extending up to the light house near Luhara village. Patel *et al.*, (1984) and Merh and Vashi (1984) had recorded the length of sandy ridge as 5 km, width 200-500 m and height 5 to 8 m above alluvial plain. A narrow strip of beach was observed to the west of Dahej near Lakhigam (Plate 5.52).

5.4.3 GEOMORPHOLOGICAL FEATURES OF ALIABET

One of the important feature in mouth of river Narmada was presence of gigantic mouth bar "Aliabet". In the name Aliabet term "bet" means an island. Aliabet was an upturned liver shaped island with a stabilized central part which represents long linear mouth bar parallel to the tidal flow (Ganapathi and Pandey, 1991). Comparison of multi-date satellite images and toposheets of various years suggested substantial changes in size and shape of Aliabet. Earliest image of the year 1978 showed flow of Narmada along the eastern side of Aliabet. But, successive satellite images showed filling of the channel (east of Aliabet) and growth of Aliabet on the southern side. A new patch of mudflat was observed along the northern side of Aliabet. Although rate of deposition was higher in Aliabet, erosion was also observed along the northern side. Mudflats, creek, mangrove and salt marsh were the major geomorphic features observed in Aliabet (Plate 5.53). This area received considerable tidal water through dense network of creeks which criss-crossed the entire area. High tidal mudflats were mostly covered with salt marsh vegetation but at places found barren. In the recent years, substantial area of high tidal mudflats was taken up by aquaculture industry.

Geomorphological maps of Jambusar taluka

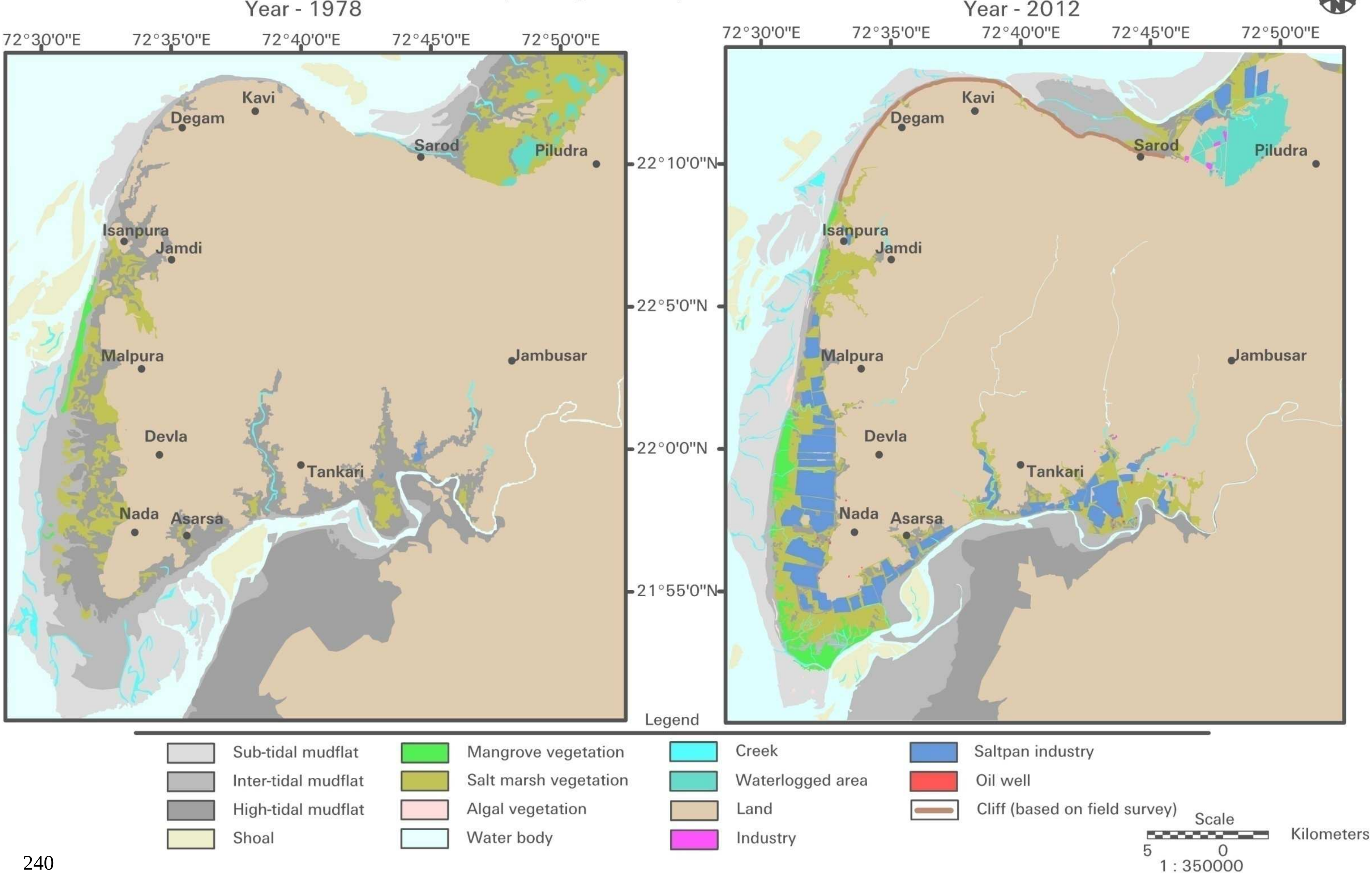


Plate : 5.51

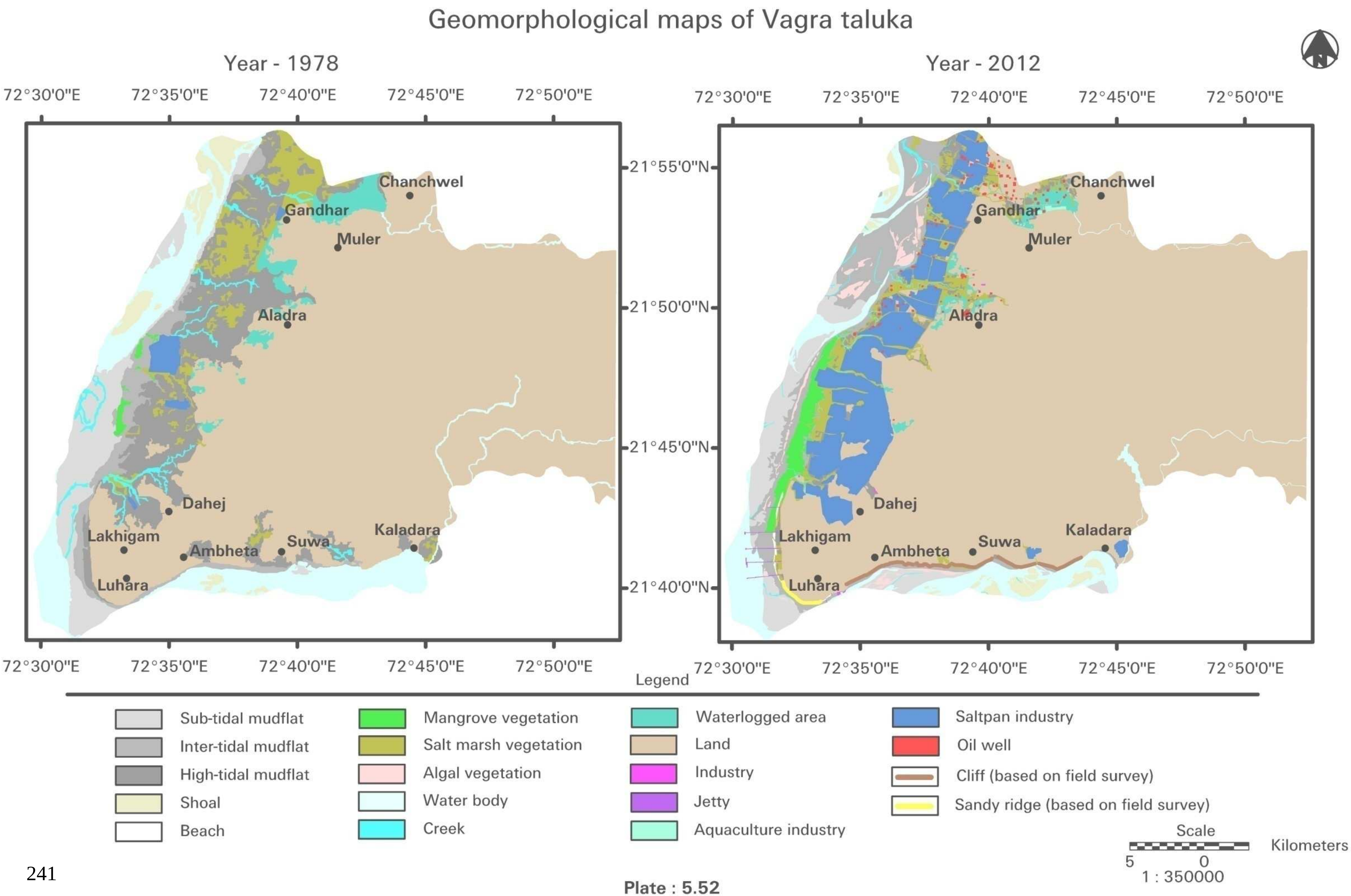

Geomorphological maps of Vagra taluka
Year - 1978
Year - 2012
72°30'0"E
72°35'0"E
72°40'0"E
72°45'0"E
72°50'0"E
21°55'0"N
21°50'0"N
21°45'0"N
21°40'0"N
Chanchwel
Gandhar
Muler
Aladra
Dahej
Lakhigam
Ambheta
Suwa
Kaladara
Luhara
Legend
Sub-tidal mudflat
Inter-tidal mudflat
High-tidal mudflat
Shoal
Beach
Mangrove vegetation
Salt marsh vegetation
Algal vegetation
Water body
Creek
Waterlogged area
Land
Industry
Jetty
Aquaculture industry
Saltpan industry
Oil well
Cliff (based on field survey)
Sandy ridge (based on field survey)
Scale
5 0 Kilometers
1 : 350000

Plate : 5.52

Geomorphological maps of Aliabet

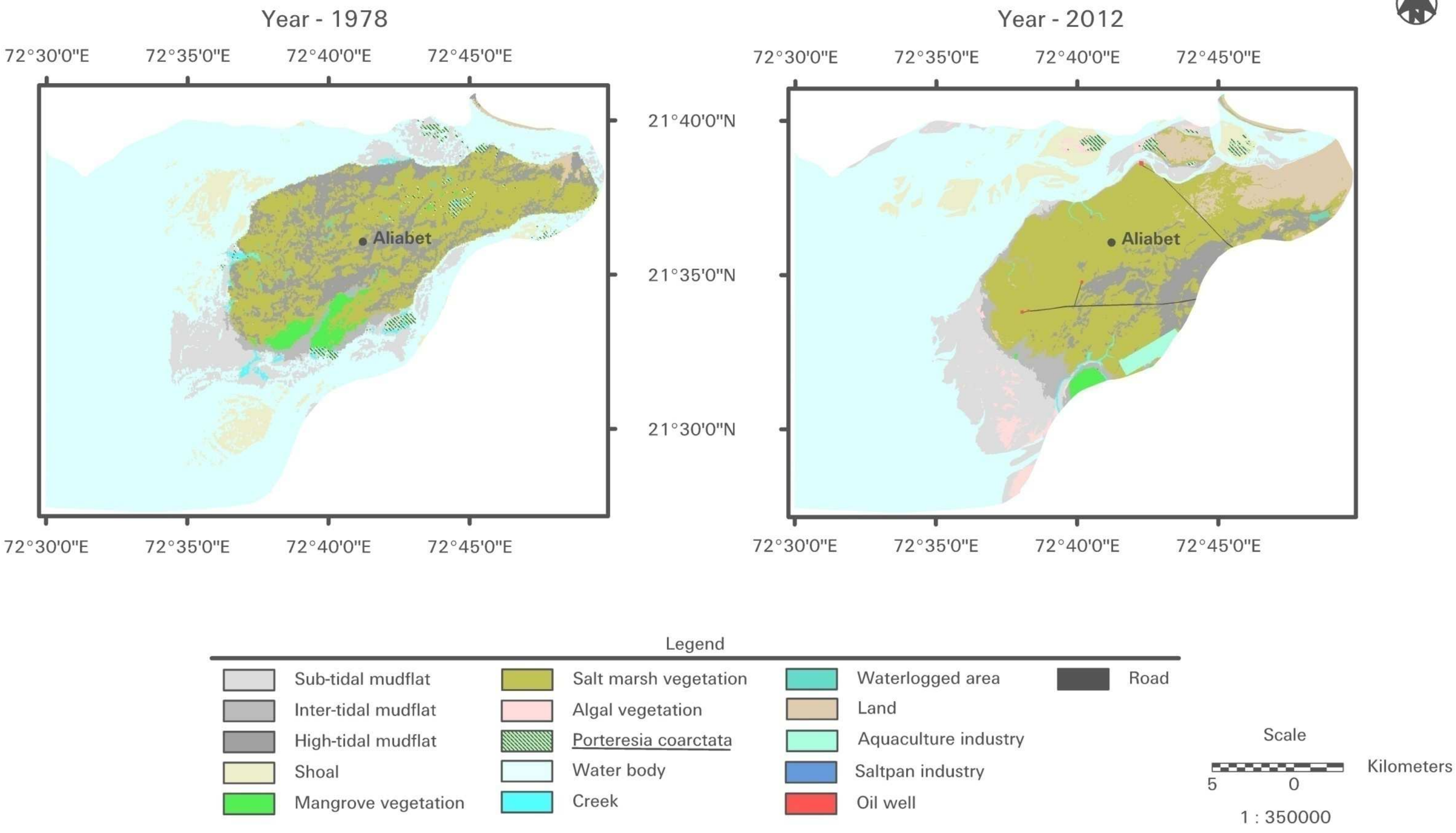


Plate : 5.53

Geomorphological maps of Hansot taluka

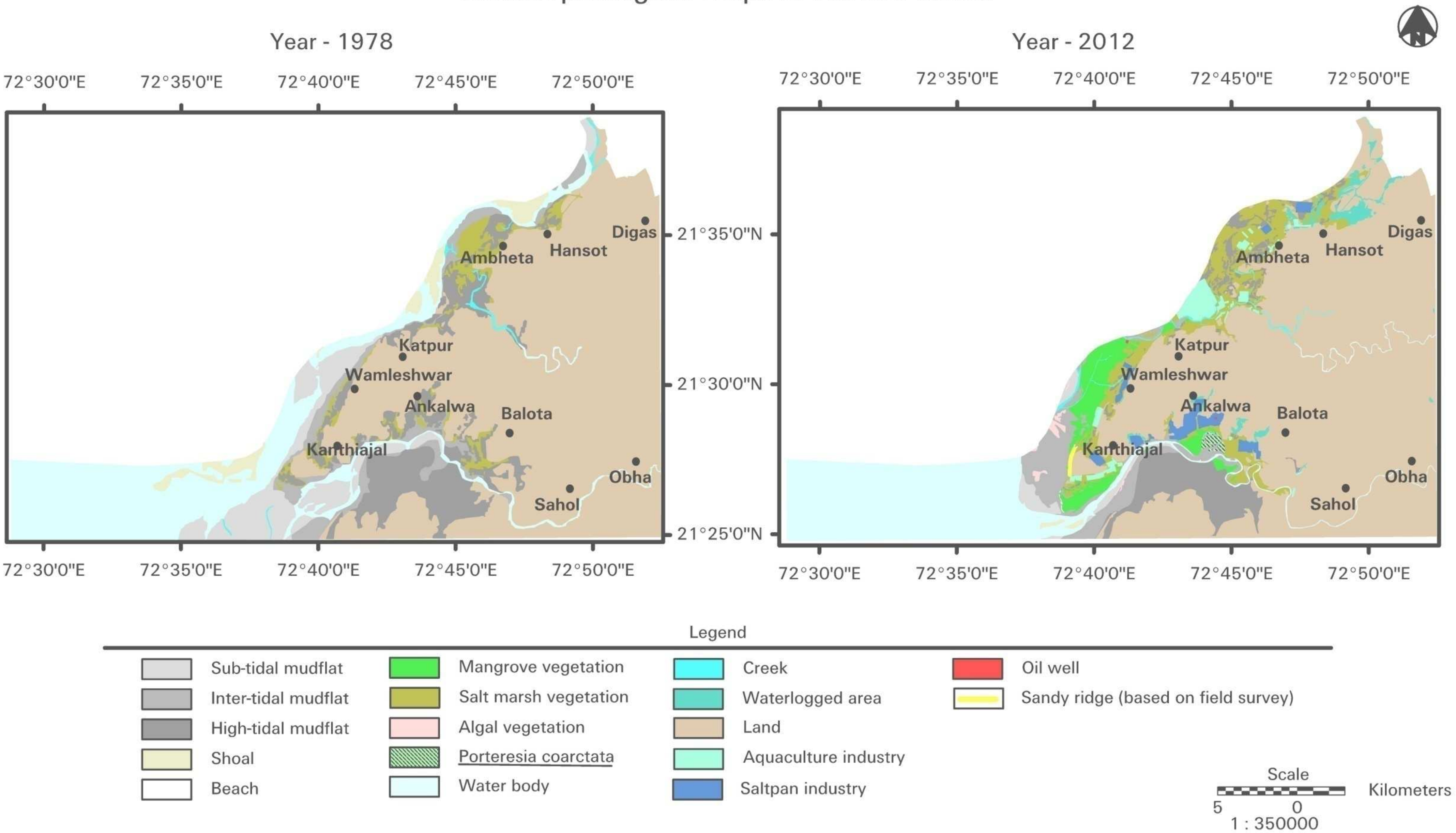


Plate : 5.54

5.4.4 GEOMORPHOLOGICAL SET UP OF HANSOT TALUKA

This taluka comprised of geomorphic features such as estuarine river mouth, mudflats, saltmarsh, mangrove vegetation, creek and sandy ridges (Plate 5.54). Mouth of the River Kim was considerably narrow. The River Kim meandered for several kilometers within mudflats before meeting the sea. Geomorphic map of the year 1978 showed channel of Narmada River flowing from the north-west direction of taluka. This channel over a period of time was filled by sediments and only a small, narrow creek brought tidal water during high tide. The widths of mudflats decreased considerably and were observed along western side as well as along southern side of taluka. The mudflats were dissected by numerous creeks and were covered by salt marsh and mangrove vegetation. In this area, some parts of high tidal mud flat were converted in to saltpan and aquaculture industry. The alluvial island namely “Motimor bet” was observed within mudflats. The major area of island was under agricultural practice. A sandy ridge was observed in the west of Motimor bet. According to Merh and Vashi (1984) and Patel *et al.*, (1984) the ridge had a length of 1½ km, width of ½ km and a height of 5 - 6 m. A narrow strip of beach was observed at the west of Motimor bet. This alluvial island showed few erosional features which could be retrieved from the comparison of satellite data and from field evidences.

5.4.5 DISCUSSION

The study revealed number of depositional as well as erosional features in this study area. The Gulf was characterized by the highest tidal amplitude along the west coast which could be due to its narrow configuration, its shallowness and its location in widest portion of the west coast continental shelf. In the gulf, strong tidal action and water brought by major rivers namely Sabarmati, Mahi and Narmada were main sources of sediments. Shallow continental shelf, relatively calm water of Cambay region, large sediment discharge by rivers and low altitude of coastal plains were the possible reason for vast mudflats and marshy tracts occurring near mouth of estuaries (Ahmad, 1972).

Increase in number of shoals along mouth of Mahi, Dhadhar and Narmada indicated deposition in the mouth region. Nayak and Sahai (1985a) had observed similar observation in Mahi River. According to them the changes were due to the construction of Kadana dam on Mahi River and a dam on Panam River. The dam restrained floods which were removing sediments from mouth region. These sediments got deposited at mouth of estuary and formed shoals that indicated weak and regulated discharge which was unable to carry sediments further in to the gulf (Nayak and Sahai, 1985 b). This deposition at the mouth had created sediment drought near head of the gulf. Thus, the dynamic equilibrium of the estuary had got disturbed and to maintain this, probably the northern bank of Mahi River was being eroded by strong tidal forces. In case of Dhadhar, the construction of Deo Dam could be reason for reduction in sediments supply and same could be reason for erosion along the northern bank. Erosion was also observed at Nada and Asarsa villages of Jambusar taluka. Damaged walls of oil wells at Asarsa (Plate 5.55) and eroded mangroves at Nada clearly revealed the erosion prevailing in this area.

Problem of erosion was observed along the west coast of Vagra taluka starting from Gandhar to Gajadra villages. In this area, due to the high rate of erosion several oil wells were washed out. Large patch of mangrove present in this area was washed out due to severe erosion. Construction of sea wall and plantation of mangrove around oil well were the measures taken up for protection of oil well (Plate 5.55). At places the energy of water current was so high and that in order to protect mangrove, fencing of iron pipes was done towards the seaward side of mangroves (Plate 5.55). The energy of water was to an extent that at some places mangrove plants cannot withstand against them and washed out along the coast. Absence of any vegetation and presence of scattered washed out mangroves plants along the coast of Lakhigam and Luwara showed the high energy condition prevailing in this area. Similar observation was made for the coast south of Vagra taluka (i.e. northern bank of Narmada River). Here the force of water current was so high that very few and small mangroves were scattered towards high tidal mudflats. Erosion became more pronounced as one move from mouth of Narmada River towards the eastern side. Construction of sea wall for protecting electric tower and its nearby temple at Ambheta village (Plate 5.55) and sharp cutting of cliffs were the evidence of severe erosion observed along northern bank of Narmada River (south of Vagra taluka). As we move eastwards erosion was to such an extent that a metal road near Kaladara was eroded (Tattu *et al.*, 2008a). Effect of Erosion is further indicated by damage of wall constructed to protect cliff bank against the erosion. Plate 5.56 shows the damaged caused by severe erosion at Kaladara. These evidences of severe erosion at Kaladara were supplemented by migration of fishing community towards the inland areas. Thus, entire northen bank of Narmada witnessed high erosional activity.

Broken wall of oil well at Asarsa village, Jambusar

Eroded oil well at Asarsa, Jambusar

Construction of sea wall and plantation of mangrove for protecting oil wells at west of Trankal, Vagra

Fencing of iron pipes for protecting mangroves at Vagra

Washed out mangroves at Lakhigam, Vagra

Construction of sea wall for protection of coast at Ambheta, Vagra

Plate 5.55 Field evidences of erosion prevailing in study area

Sharp cutting of cliffs at south of Ambheta (Vagra)

Erosion of road at Kaladara (Vagra)

Board indicating damage to road Kaladara (Vagra)

Board indicating damage to road Kaladara (Vagra)

Damaged sea wall at Kaladara (Vagra)

Erosion of road at Aliabet

Plate 5.56 Erosional features observed in present study area

Mahapatra *et al*., (2013) had also observed sever erosion along northern bank of Narmada and northwest portion of the Dahej area. They reported loss of 2.49 km^2 area of land due to erosion. Ajai *et al*., (2013a) and Mahapatra *et al*., (2013) had prepared inundation model based on predicted values (Nicholls *et al*., 2007) for global sea level rise by the 2100. Ajai *et al*., (2013a) modeled sea level rise for Dahej and surrounding area for the interval of 25, 50 and 100 years of interval. Mahapatra *et al*., (2013) estimated that 0.49 m rise in sea level would inundate approximately 18.8 km^2 of Dahej and its surrounding area (Mahapatra *et al*., 2013). Recently, Mahapatra *et al*., (2015) had prepared coastal vulnerability assessment of Gujarat coast due to sea level rise wherein they classified present study area (Jambusar, Vagra, Aliabet and Hansot) as moderate vulnerable to low vunerable region.

Possible reason for depositional as well erosional landforms observed at Narmada River could be construction of the Sardar Sarovar Dam in 1979. This dam had restrained huge amount of river water in its reservoir and thus controlled flow of water. With this, flow of the river became regulated and sediments which were earlier removed by the river water were now unable to move further and hence, they accumulated at the mouth and formed number of shoals in the mouth of Narmada River. Thus construction of dam had disturbed the sediment cycle operating in this area. In order to maintain this cycle, probably the northern bank of Narmada River was being eroded by strong tidal forces. Another reason for erosion along the northern bank of Narmada could be increase in number of shoals. This feature had acted as barrier to the normal flow of flood tide as well as river. Due to this water (from river or of flood tide) bifurcated around shoals and hit and carved the northern bank. Comparison of recent satellite images showed increase in number of shoals which indicated that problem of erosion would become more pronounced in the future. Shoals which were considered to be migratory features get stabilized by the development of estuarine grass *Portresia coarcata*. This vegetation had quite different spectral signature in the satellite image. Based on which one can easily identify this grass from other coastal vegetation. This grass acts as a pioneer in the development of mangrove ecosystem (Jagtap, 1985b; Bhatt *et al*., 2008; Harekrishna *et al*., 2013; Zaman *et al*., 2014). This species generally grows on newly deposited sediments and help in enhancing the sedimentation and there by developing favourable substratum for growth of mangroves (Jagtap *et al*., 2006). This stabilization of shoal could further hinder the flow and thus could increase erosion in this area.

Stabilization of shoal can be explained using changes on the island towards the northern side of Aliabet. The gradual stabilization of this island can be seen from comparison of maps of Aliabet. Maps indicated that in 1978, the mudflat showed small patch of *Portresia coarctata* which was increased in successive years (1987 and 1997). This feature was later colonized by salt marsh vegetation and satellite image of 2012 showed growth of *Prosopis juliflora* which itself suggested stabilisation of the substrate. The growth of *Portresia coarctata* on shoal (towards northern side of new island) would stabilize this area and with growth of different types of vegetation would form new landforms.

Aliabet has also witnessed substantial changes in its configuration. The increase in its areal extent showed the predominance of the depositional activities however erosion was observed along Aliabet. Plate 5.56 showed erosion at Aliabet which had washed out road connecting to oil well site in northern side of Aliabet. The growth of new island along the northern side of aliabet could be reason for this erosion. The northern side of Aliabet showed considerable erosion whereas deposition was observed along its southern side. For the growth of the Aliabet, different people had put forth different opinions. According to Bedi and Vaidyanadhan (1982), lateral swinging of water was reflected from the bank and in process erodes them and deposited material at periphery of Aliabet on both the sides. Also during the floods, huge sediment load brought by river was spread over this island. Other possibilities were during the mixing of freshwater with saline water of Gulf of Khambhat in vicinity of Aliabet, clay particles were flocculated and formed aggregates which settled down in island to form mudflats and during high tides these clay aggregates were stirred up again and transported upstream and deposited over Aliabet. Thus, overall seaward growth of Aliabet indicated that rate of deposition was higher than the removal of sediments by sea water and currents. Mukherjee (1985) opined that estuarine islands at the mouths of Narmada and Tapi rivers marked depositional features, perhaps grown on higher topographic surfaces of submerged marine floor. Nayak and Sahai (1985a, 1985b) and Nayak *et al.*, (1987) had explained that increase in the size of Aliabet was due to heavy deposition at estuarine mouth. Further they had not ruled out the possibility of neotectonism for gradual emergence of this island. Nayak *et al.*, (1986) had studied topographic sheets (surveyed in 1955-1956) which suggested that Aliabet during the high tide got submerged. But, their analysis of Landsat satellite image from 1972-1986 revealed that island was not being submerged even during the highest of high tide. Thus, they had postulated emergence of Aliabet and that, this could be the reason for dwindling of mangroves on Aliabet. In addition to this, they also mentioned the excessive grazing by animals in mangrove area could be reason for their reduction. Sundaram *et al.*, (1991) included Aliabet under Dahej surface (tidal mudflats, beach and dunes) and represented it as an active coastal accretionary phase. Ganapathi and Pandey (1991) had collected measurement of Aliabet from toposheets as well as from satellite imageries. This comparison showed its length varied from 19 km (toposheet, 1894) to 29.8 km (imagery, 1990) and width ranges from 1.2-2.0 km (toposheet, 1894) to 5.2-13.1 km (imagery, 1990). Mahapatra *et al.*, (2014) revealed erosion along the northern bank and merging of Aliabet with mainland. According to them, construction of dams on Narmada River had reduced suspended sediment flux which resulted increase in rate of coastal erosion. In addition to reduction in sediment discharge, action of wave and tide played an important role in bringing out the morphological changes observed in Narmada River.

In case of Hansot, the size of Motimor bet had changed a lot over period of time. This area witnessed erosion which can be retrieved from comparison of the maps suggesting reduction in area of Motimor bet. De *et al.*, in 2008 had reported intrusion of sea water along the west of Kanthiajal. They reported loss of more than 1 sq km area of agricultural land. Although erosion was observed along western side of taluka, deposition was observed along the south of Ankalwa village (northern bank of Kim River). Comparison of satellite images showed change in the meandering pattern and thereby change in flow of Kim River. *Portresia coarctata* flourished well on the newly formed mudflat area in the south of Ankalwa village. Even, field visit conducted in October 2014 to this area showed considerable growth of mangrove and salt marsh vegetation on this newly formed mudflat suggesting stabilization of the area.

Thus, all three talukas witnessed substantial changes in their geomorphology and showed evidences of erosional as well as depositional activities prevailing in this area.