Mangrove Cover Dynamics in Kachchh, Gujarat, India

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ABSTRACT

Mangroves are intertidal communities of vegetation. India has nearly 3% of global mangrove vegetation. Gujarat and West Bengal together have approximately 68% of India's mangrove cover. Nearly 70% of mangrove cover in Gujarat is located in Kachchh district. The intertidal areas of Kachchh around Kori Creek, Mundra, Kandla and Satsaida Bet support dense patches of mangrove. In spite of their ecological and economical significance, mangroves today are categorised as an endangered ecosystem. Major threats to them are transformation of mangrove habitats into industrial development zones, human habitations, construction of salt pans, shrimp farming and reduced freshwater availability due to construction of dams in the upland catchment areas. The growing pressures on mangroves require that these coastal habitats be continuously monitored so as to plan a suitable conservation strategy for them. Ground-based monitoring and survey techniques are costly, time-consuming and often difficult to implement as these plants grow in intertidal areas which are difficult to access frequently. With the advent of space-borne remote sensing technologies it has become possible to get a synoptic coverage of a larger area, at cost-effective and repetitive manner which is extremely useful for mangrove mapping and inventorization as well as to identify temporal changes occurring in mangrove environment. In this paper, we report mangrove cover dynamics of Kachchh district of Gujarat state of India using satellite remote sensing techniques. We have mapped mangroves using satellite datasets of 2011 and 2017 period and analysed the changes in mangrove cover. Landsat 8 OLI (Optical Land Imager) and Landsat 5 TM (Thematic Mapper) data were used for the year 2017 and 2011 respectively. Results show that mangrove have increased in 2017 compared to 2011. In particular, the mangrove cover has substantially increased around Satsaida Bet in the inner Gulf of Kachchh.

1. INTRODUCTION

Mangroves are taxonomically diverse associations of woody trees and shrubs, which grow in the intertidal and adjacent communities along tropical and sometimes subtropical coasts (Tomlinson, 1986). They are important for a variety of ecological as well as economical reasons. Ecologically, they act as windbreaker, prevent the hinterland from storm, stabilize the coastline and reduce the coastal erosion. They provide a nursery for a plethora of marine and coastal life-forms. The detritus produced by them helps in recycling of nutrients and thus support benthic marine populations. Economically, they provide fuel, wood, medicine, fodder, food and materials for building the boats and thatching the roofs. In spite of their ecological and economical significance, mangroves today are categorized as an endangered ecosystem. Major threats to them are transformation of mangrove habitats into industrial development zones, human habitations, construction of salt pans, shrimp farming and reduced freshwater availability due to construction of dams in the upland catchment areas (Valiela et al. 2001, Shah et al. 2007, Kumar et al. 2012, Ajai et al. 2013). Because of high ecological and economical values associated with mangroves, there are worldwide efforts going on to study the dynamics of mangrove ecosystem. Earlier studies mostly relied on cumbersome on-field observations. It is extremely difficult to work in inter-tidal, muddy environments along with threats of wild life, therefore there are increasing efforts to utilize satellite data based techniques for mangrove studies, which have obvious advantages of providing more reliable and accurate information due to synoptic view, multispectral and multi-temporal capabilities. Moreover, advancements in digital image processing, availability of GIS techniques and use of GPS while collecting ground truth data at selected locations have further facilitated research work in the mangrove eco-systems.

India has nearly 3% of global mangrove vegetation. Gujarat and West Bengal together have approximately 68% of India's mangrove cover. Nearly 70% of mangrove cover in Gujarat is located along the northern coast of Gulf of Kachchh in Kachchh district. The intertidal areas of Kachchh around Kori Creek, Mundra, Kandla and Satsaida Bet support dense patches of mangrove. In this paper, we report mangrove cover dynamics of Kachchh district of Gujarat state of India studied using satellite remote sensing techniques. Mangrove cover was mapped using satellite datasets of 2011 and 2017 period and the changes were analysed.

2. STUDY AREA

Kachchh is the largest district of India covering an area of 45674 square kilometres (sq km) (https://en.wikipedia.org/wiki/Kutch_district, retrieved on 11/09/2017). Administratively, it comprises of 10 talukas, 1389 villages and 6 municipalities (https://kutch.gujarat.gov.in/about-kutch, retrieved on 11/09/2017). The district lies on northern side of Gulf of Kachchh. The coastal belt of Kachchh district, known as Kachchh coast, spans around 300 km in length (GES, 2014) showing wave as well as tide dominated landforms. Western part of this coast around Kori Creek comprises part of delta built by Indus River. This part has extensive mudflats between Narayan Sarovar-Koteshwar and Jakhau which support dense mangrove vegetation. From Jakhau to Modwa, there are landforms such as sandy beaches and coastal dunes that are formed by coastal processes dominated by waves and currents, whereas from Mundra to Kandla there are wide mudflats and mangroves, indicating the dominance of tides (Shukla et al., 2010). The region between Modwa and Mundra is like a transition zone showing intertidal mangroves as well as beach-dune complex (Shukla et al., 2008). Futher to Kandla, the gulf narrows down abruptly (near Satsaida Bet) into a network of creeks. This region is also called the Little Gulf of Kachchh. The mudflats along these creeks also support sporadic mangrove growth. There are four major mangrove occupying regions along the Kachchh coast *viz*., Kori creek and environs located in the western/north-western side, Mundra and environs located in the middle of this coastal belt, Kandla and environs located along eastern/north-eastern side, and Satsaida Bet and environs located along north-eastern side towards the Little Gulf region (Figure 1).

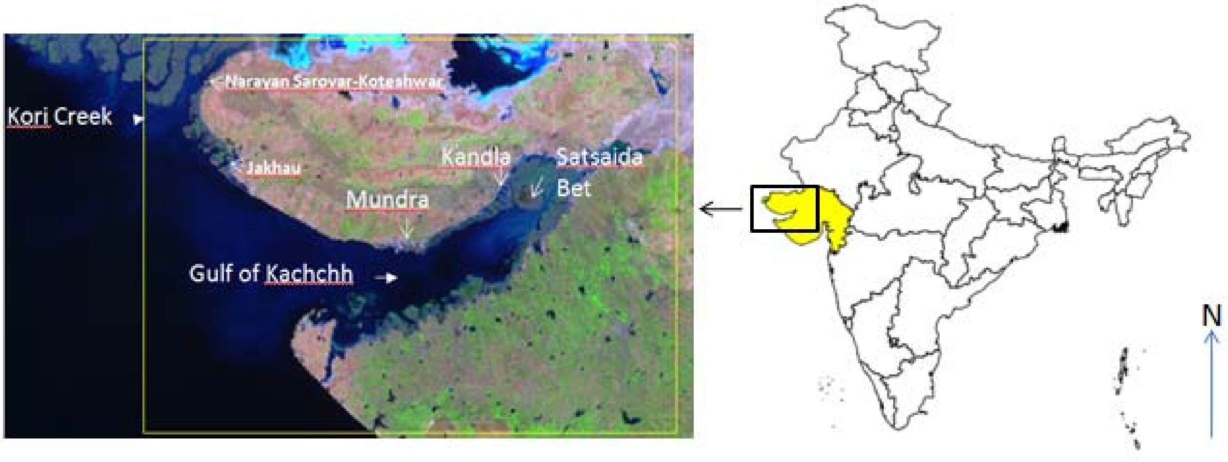

Figure 1: Mangrove occupying regions along the Kachchh coast shown on a natural colour composite prepared by mosaicking Landsat images

3. MATERIALS AND METHODS

3.1 Materials used in this study

Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI (Optical Land Imager) satellite data of the period 2011 and 2017 respectively were used in this study. Table 1 provides the details of the various Landsat data used. Landsat datasets were downloaded from earthexplorer website (http://www.earthexplorer.usgs.gov).

Table 1: Satellite data used in this study

Sr no.	Satellite	Sensor	Path	Row	Date of acquisition
1	Landsat 5	TM	151	44	04 Feb 2011
2	Landsat 5	TM	150	44	13 Feb 2011
3	Landsat 8	OLI	151	44	20 Feb 2017
4	Landsat 8	OLI	150	44	01 March 2017

Characteristics of the two satellite datasets used in this study are summarized in Table 2.

Table 2: Characteristics of the satellite data used in this study

Satellite Data	**Spatial Resolution**	**Spectral Resolution (µm)**	**Temporal Resolution**	**Radiometric Resolution**
Landsat 8 OLI	30 m for B1 to B7, and for B9; 15 m for B8	Band 1 (B1) (Coastal aerosol): 0.43-0.45 B2 (Blue): 0.45-0.51 B3 (Green): 0.52-0.60 B4 (Red): 0.63-0.68 B5 (NIR): 0.84-0.88 B6 (SWIR-1): 1.56-1.66 B7 (SWIR-2): 2.1-2.3 B8 (Pan): 0.5-0.68 B9 (Cirrus): 1.36-1.39	16 days	16 bits
Landsat 5 TM	30 m for B1 to B5, and for B7; data in B6 is acquired in 120 m resolution and then re-sampled to 30 m products	B1 (Blue): 0.45-0.52 B2 (Green): 0.52-0.60 B3 (Red): 0.63-0.69 B4 (NIR): 0.76-0.90 B5 (SWIR-1): 1.55-1.75 B6 (Thermal): 10.40-12.50 B7 (SWIR-2): 2.08-2.35	16 days	8 bits

The ancillary datasets used to support the study include Coastal Zone Information System (CZIS) data base available at Space Applications Centre (SAC) (coastal thematic maps e.g., coastal land use/land cover maps), Survey of India topographical maps, high resolution satellite images available on Google Earth (GE) platform, published and unpublished literature (research papers, articles, project reports etc.) related to the study area collected from various sources, and field data. The study area was visited on-field with Garmin hand-held GPS (Global Positioning System) to collect field data. Ancillary data were used to understand the land cover of the study area, and for identifying pixels for collecting data for training the classifier and for assessing the accuracy of the classified images. Satellite data processing was done using ENVI and QGIS softwares.

3.2 Methodology

The various steps employed for studying mangrove cover dynamics are depicted in Figure 2.

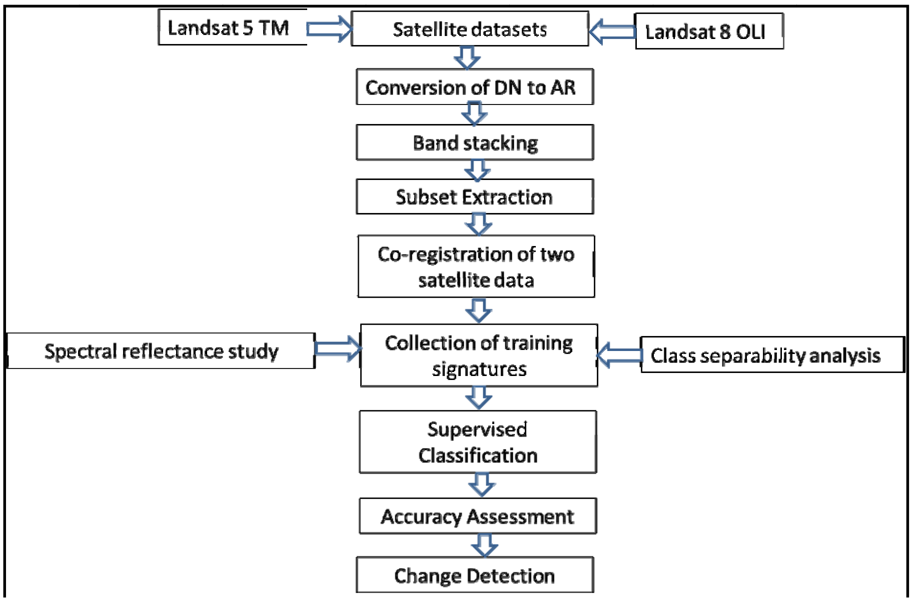

Figure 2: Flowchart depicting methodology adopted to study mangrove cover dynamics

Level 1 data products of both the images (Landsat 5 TM and Landsat 8 OLI) were downloaded from earthexplorer website (https://earthexplorer.usgs.gov/). The DN (Digital Number) values of optical datasets were converted to apparent reflectance (AR) values. Blue, Green, Red, NIR and SWIR bands (SWIR 1 and 2) of both TM and OLI data were used in this study. The AR bands were then stacked together separately for Landsat 8 OLI and Landsat 5 TM, i.e., blue, green, red, NIR and SWIR (1 & 2) bands of Landsat 8 OLI were stacked together and those bands of Landsat 5 TM were stacked together. Such a band composite helps to visualise the terrain features in those regions of electromagnetic spectrum which are invisible to human eyes. For example, a false colour composite (FCC) prepared by displaying NIR, Red and Green bands in the RGB (Red, Green and Blue) colour channels highlights various intertidal features very effectively. The subsets of the different mangrove occupying regions along the Kachchh coast were then extracted from the two datasets separately. Thus we had subset images of the study area corresponding to 2011 and 2017 years, comprising reflectance values in blue, green, red, NIR and SWIR (1 & 2) regions of the electromagnetic spectrum. Corresponding subsets of 2011 and 2017 were then co-registered with each other using 1st order polynomial and at sub-pixel accuracy. Though the two Landsat images were well-aligned with each other, co-registration was done to generate more confidence in change detection analysis. Non-intertidal regions were then masked out from the subsets. Pixels of intertidal features were identified and selected based on field visits, published maps and high resolution GE images. Separate pixels were collected for training the classifier and for accuracy assessment of classified images. The signatures were collected for following intertidal features: Mangrove Dense (MD), Mangrove Sparse (MS), Mangrove Degraded (MDeg), Intertidal Mudflat (IM), Subtidal Mudflat (SM), Salt Encrustation (SE) and Sea Water (SW). Mangroves were classified into dense, sparse and degraded based on the differences in their canopy closure (Mangrove Dense having more than 40% canopy closure, Mangrove Sparse having 10-40% canopy closure and Mangrove Degraded having less than 10% canopy closure). Spectral reflectance profiles of different intertidal features were studied which further aided in selection of training pixels. Class separability analysis was carried out using Transformed Divergence (TD) method to assess statistical separability between various sets of training signatures of intertidal features. Once satisfied with the separability of training signatures, various image subsets were put to supervised classification using maximum likelihood algorithm. Accuracy assessment of classified images was done by calculating Overall Accuracy, User’s Accuracy, Producer’s Accuracy and Kappa Coefficient. Post classification change detection was employed to study the changes in mangrove cover between 2011 and 2017. The changes in the area of the three mangrove categories were computed and a change detection matrix was prepared documenting changes in mangrove cover during 2011 and 2017.

4. RESULTS AND DISCUSSIONS

4.1 Spectral reflectance profiles of intertidal categories

Mangroves form irregular patches, with smooth texture and are associated with dark (if wet) or light (if dry), muddy substratum. Using the field photographs and the maps published by previous studies in this region (SAC, 2012, Kumar et al., 2012) we carefully identified the pixels of intertidal categories in the images and plotted their reflectance in the visible, NIR and SWIR regions. The spectral reflectance of intertidal categories is shown in Figure 3.

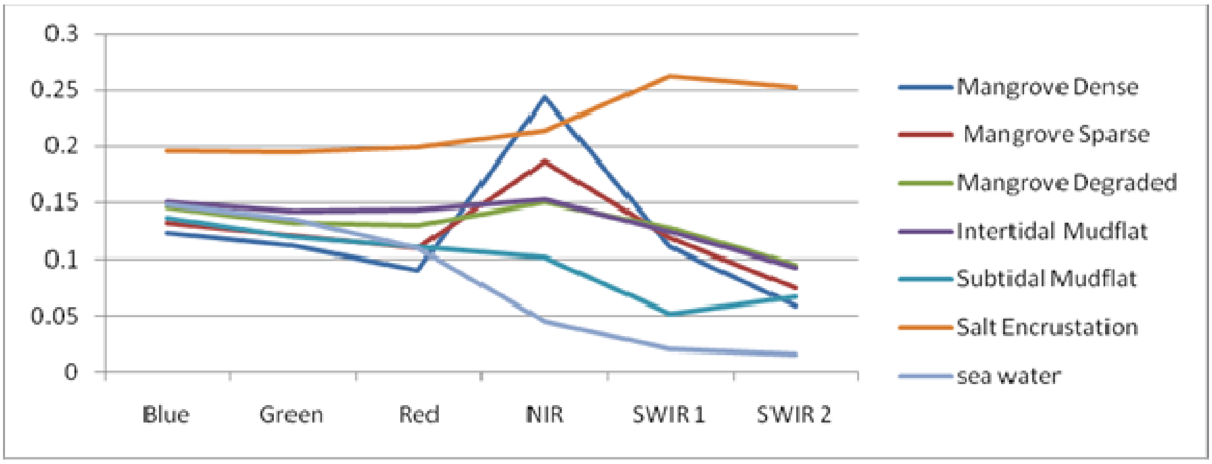

Figure 3: Spectral reflectance of intertidal categories studied

It was observed that the three mangrove categories, *viz*., MD, MS and MDeg are relatively more separable in NIR and SWIR regions of electromagnetic spectrum. Dense mangroves show highest reflectance in the NIR region, followed by MS and then MDeg. Spectral response of vegetation communities, in the visible region of electromagnetic spectrum is affected by leaf pigmentation. In the NIR region, the internal structure of leaves and the stacking of leaves determine the spectral response whereas the leaf moisture content affects the behaviour in SWIR region (SAC, 2003). Sparse and degraded mangroves show higher reflectance values relative to dense mangroves in SWIR regions. In addition, the overall reflectance of three mangrove communities is also influenced by the humidity gradient in soil which in turn varies as per the tide levels (Blasco and Aizpuru, 2002). As the space available among individual plants is more in MDeg and MS, the reflectance from wet ground also influences the overall reflectance of these mangrove communities. Mudflats are differentiated as per their submergence and exposure during tidal conditions. Intertidal mudflat (frequently encountered category of mudflats; regularly inundated by tides; gets exposed after few hours of interval and then gets submerged again) shows higher reflectance than subtidal mudflat (mostly submerged; exposed only during low tides) in all the studied electromagnetic regions. Other categories also show quite contrasting and distinct reflectance patterns.

4.2 Class separability analysis

Another test to determine separability of selected training data of different intertidal categories was conducted through Transformed Divergence (TD) method. TD method computes spectral distance between signatures of categories by taking into account their statistical parameters such as mean, variance and covariance (Kumar et al. 2017). The TD analysis provides separability values ranging from 0 to 2000. A separability value above 1700 indicates fairly good separability between the categories. On the other hand, any value below 1500 is an indication of poor separability between the classes. We found separability values ranging from 1863.74 – 2000 for various sets of training signatures extracted from different subsets of mangrove occupying regions. The separability values mostly were found close to 2000 when contrasting pair of signatures such as mangrove dense and sea water or mangrove dense and salt encrustation were tested for class separability. Lower values were observed when we tested separability between signatures of mangrove categories such as mangrove sparse and mangrove degraded.

4.3 Supervised classification

Once satisfied with the statistical separability of training signatures, the subset images of four mangrove occupying regions pertaining to 2011 and 2017 were classified using maximum likelihood classification (MLC) algorithm. MLC is one of the most popular classification algorithm employed in supervised image classification studies. This algorithm uses a discriminant function to assign a pixel to the class with the highest likelihood. The classified images of four mangrove occupying regions along the Kachchh coast for the period 2011 and 2017 are shown below (Figure 4, 5, 6 and 7).

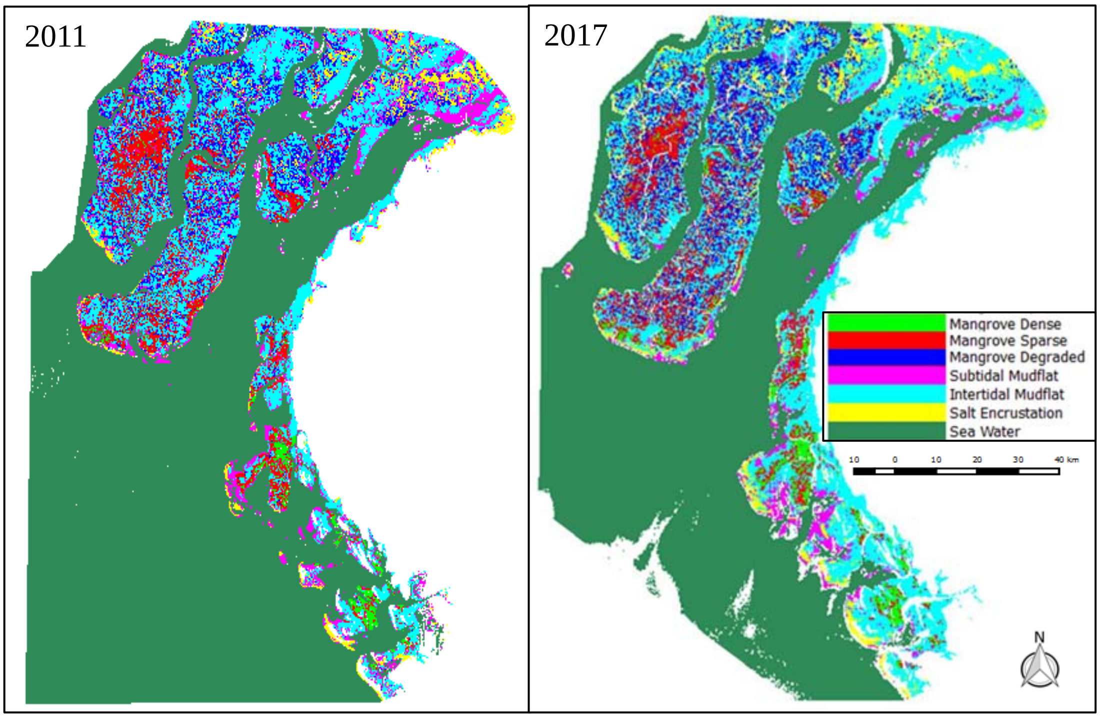

Figure 4: Mangrove and other inter-tidal classes as per supervised classification of Landsat data of 2011 and 2017 covering Kori Creek and environs

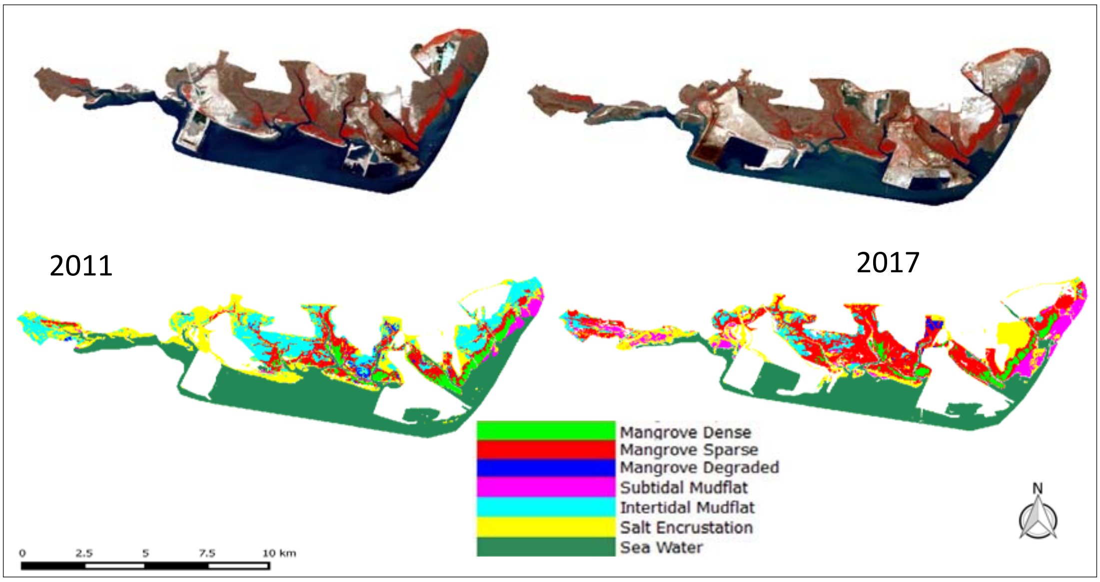

Figure 5: Landsat FCC and corresponding mangrove and other inter-tidal classes as per supervised classification for time frame 2011 and 2017 covering Mundra region and environs in northern parts of the Gulf of Kachchh

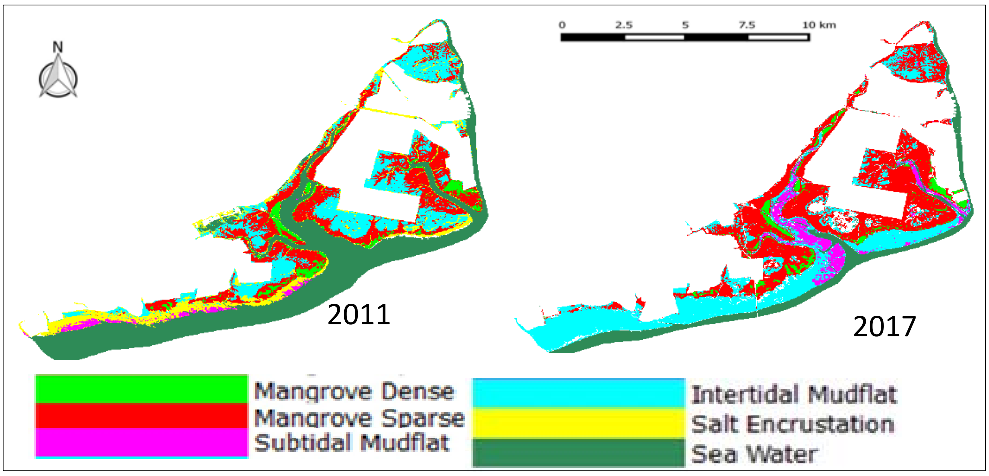

Figure 6: Mangrove and other inter-tidal classes as per supervised classification of Landsat data of 2011 and 2017 covering Kandla Port and environs (Parts of northern coast of Gulf of Kachchh)

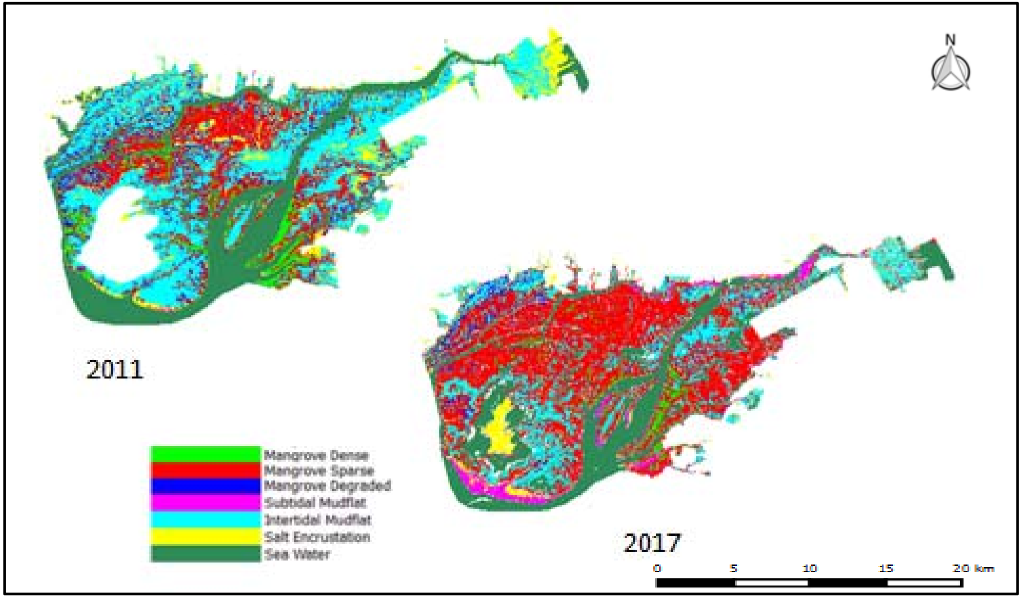

Figure 7: Mangrove and other inter-tidal classes as per supervised classification of Landsat data of 2011 and 2017 covering Satsaida Bet and environs (north-eastern parts of Gulf of Kachchh)

4.4 Accuracy assessment

The data for accuracy assessment were collected from three sources: field visit, published maps (SAC, 2012; Kumar et al., 2012) and high resolution Google Earth images. The accuracy of classified images was evaluated for six classes: MD, MS, MDeg, IM, SM and SE. Sea water was omitted from this exercise as it would have yielded much higher accuracy relative to other land cover classes (Rahman et al., 2013). A minimum of 50 samples for each class is considered sufficient to provide a good classification accuracy estimate (Congalton, 2001, Rahman et al., 2013). Therefore, 50 samples (pixels) for each of the six classes (MD, MS, MDeg, IM, SM, SE) were selected randomly throughout the image. Thus we have a total of 300 pixels for assessing the accuracy of classified images. The accuracy assessment was carried out by computing overall accuracy, user's accuracy, producer's accuracy and kappa coefficient. Accuracy assessment for all the classified images shows overall accuracy range between 89% - 97.64% and corresponding kappa values range between 0.87-0.96. Table 3 summarizes the overall accuracy and kappa coefficient values calculated for classified images of four mangrove occupying regions along the Kachchh coast for 2011 and 2017.

Table 3: Accuracy assessment of classified images of mangrove occupying regions along the Kachchh coast

Classified images of mangrove occupying regions along the Kachchh coast	Accuracy assessment for 2011		Accuracy assessment for 2017	
	Overall Accuracy	Kappa Coefficient	Overall Accuracy	Kappa Coefficient
Classified images of Kori Creek and Environs	93.33%	0.92	97%	0.96
Classified images of Mundra region and Environs	92.67%	0.91	89.13%	0.87
Classified images of Kandla Port and Environs	96.76	0.96	97.64	0.92
Classified images of Satsaida Bet and Environs	90	0.88	89	0.87

4.5 Area computation and change detection

Temporal changes in the extent and condition of mangrove classes during time frame 2011 and 2017 have been quantified based on the corresponding classified Landsat image subsets. Spatial changes in different mangrove covered regions along the Kachchh coast during 2011-2017 are summarized in Table 4.

Table 4: Spatial changes in different mangrove covered regions along the Kachchh coast during 2011-2017

Mangrove occupying regions along the Kachchh coast	**Mangrove dense**		**Mangrove sparse**		**Mangrove degraded**		**Total mangrove cover**	
	2011	**2017**	**2011**	**2017**	**2011**	**2017**	**2011**	**2017**
Kori creek and environs	28.59	46.55	193.56	221.01	211.58	214.08	433.73	481.64
Mundra region and environs	5.44	4.61	12.91	29.63	1.46	0.77	19.81	35.01
Kandla Port and environs	6.23	5.89	35.56	54.57	0	0	41.79	60.46
Satsaida Bet and environs	39.54	19.80	177.29	379.09	60.95	24.50	277.77	423.39
Total	79.8	76.85	419.32	684.3	273.99	239.35	773.1	1000.50

The mangrove area comes out to be 773.11 sq km for 2011 and 1000.50 sq km for 2017 for the entire Kachchh district. There is an increase of 227.39 sq km of mangrove cover during the period 2011-2017.The observed changes in mangrove cover along the four major mangrove occupying regions in Kachchh district are described below:

Kori Creek and environs: There has been an increase of about 48 sq km of mangroves around Kori Creek in 2017 compared to 2011. Dense mangroves have increased by about 18 sq km, sparse mangroves have shown an increase of about 27 sq km and mangroves under degraded class have increased by 2.5 sq km (Table 4). The increase is more in the category of dense mangroves (63% increase) which reflects concomitant improvement of mangrove density in this region (Figure 8). It seems that due to lot of nutrients being brought along with the sediments of Indus River and less anthropogenic activities due to its proximity to International border, growth of mangroves in this region is more due to natural processes rather than plantation efforts. Mangroves around Kori Creek suffered severe degradation by cyclones during 1999 and 2001 (SAC, 2012). Strong winds coupled with storm surges damaged the mangroves considerably by uprooting the trees and depositing thick layer of sediments on them (SAC, 2012). A decline of nearly 190 sq km of mangroves around Kori Creek was reported during the period 1990-2006 (SAC, 2012). In addition, mangroves of this region have also been affected by natural coastal processes such as erosion which damaged the mangroves and changed the topography of the region (Kumar et al., 2012). However, such changes happen over a larger time-scale. Anthropogenic disturbances on the other hand enforce sudden changes (Kumar et al., 2012). Some mangrove patches close to the coast were removed in the past for creation of saltpans (Kumar et al., 2012).

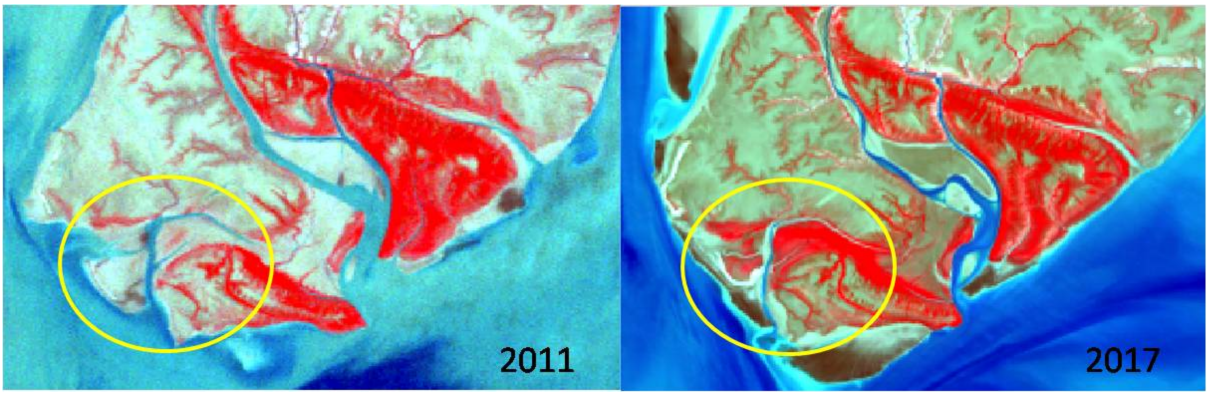

Figure 8: Increase in mangrove cover seen in 2017 Landsat FCC image (parts of north-western region of Gulf of Kachchh around Kori Creek)

Mundra region and environs: The study shows an increase of about 15 sq km of mangroves at Mundra during the period 2011-2017, largely because of approx. 17 sq km of increase in the sparse mangrove category, which is probably result of plantation activities. However, around 1 sq km of dense mangroves and 0.69 sq km of degraded mangroves were destroyed in this region due to expansion of port-related activities.

Kandla Port and environs: In Kandla region, there has been an increase of roughly 19 sq km of sparse mangroves during 2011 and 2017, which is also probably result of plantation activities. However, the study has also observed decline of about half sq km of dense mangroves in this region because of port-related activities and construction of saltpans.

Satsaida Bet and environs: The mudflats around Satsaida Bet showed an increase of 145.62 sq km of mangrove during the mapping period of 2011-2017. Here, the increase is mainly because of increase of 201 sq km of sparse mangroves (Figure 9). This large increase is due to serious plantation efforts carried out by agencies such as Gujarat Forest Department and Gujarat Ecology Commission in collaboration with local communities and organizations. However, the study also observed reduction of approx. 20 sq km of dense mangroves due to construction of saltpans (Figure 10). The area under ‘mangrove degraded’ category declined by about 36 sq km as their condition improved and they were categorized as sparse mangroves in 2017.

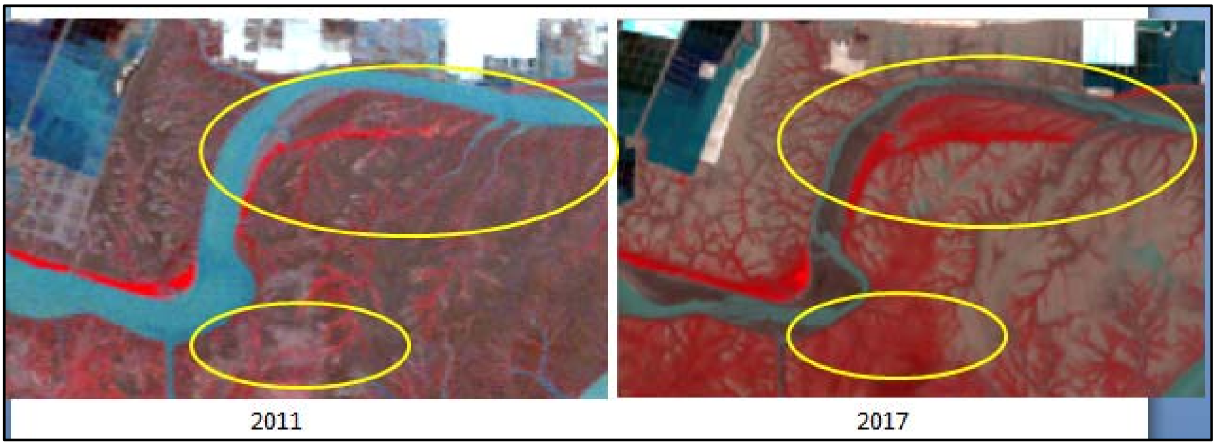

Figure 9: Increase in mangrove cover observed in the encircled area in 2017 in the Landsat FCC image covering Satsaida Bet and environs

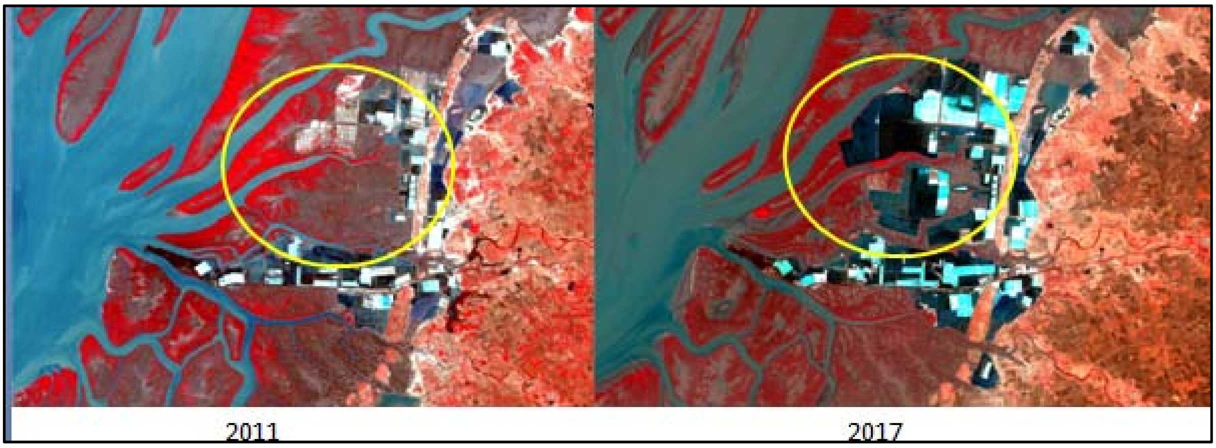

Figure 10: Degradation of mangroves around Satsaida Bet observed in 2017 in the circled area of Landsat FCC image

5. CONCLUSIONS

This study has reported mangrove cover dynamics along the northern coast of Gulf of Kachchh during 2011 and 2017 using satellite remote sensing techniques. There are four major mangrove occupying regions along the Kachchh coast: Kori Creek and environs, Mundra region and environs, Kandla Port and environs, and Satsaida Bet and environs. The results show that mangrove covered area has increased by 227.39 sq km during the time frame 2011-2017. Most of this increase was centred around Satsaida Bet where an increase of 145.62 sq km of mangrove cover was observed during the study period. Primary reason for increase in mangrove cover is serious plantation efforts carried out by various agencies such as Gujarat Forest Department, Gujarat Ecology Commission etc. in collaboration with local communities and organizations.

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