

## Observed changes in extent of mangroves and coral reefs in southern Gulf of Kachchh over ten years using principal component analysis and geo-spatial techniques: a case study

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**Abstract:** The identification of temporal change in the extent of coral reefs and mangroves patches along the Narara and Kalubhar islands was performed using multi-temporal data from 1999 to 2010 (LISS III and LISS IV (MX)). For extracting coral reefs, the reflectances of the feature were studied and using a few sample locations identified by sea-truthing, the reflectances of the corals were observed in different bands. Since these values were not normally distributed, it was considered best to use the modal value of the dataset. The final range was taken as  $\pm 1$  from the mode, which

was used for the extraction of coral pixels. The findings suggested that the coral cover depleted from 19.35 km<sup>2</sup> to 9.11 km<sup>2</sup> in the study area. The second objective of extracting the mangroves was accomplished by employing the technique of Principal Component Analysis (PCA). This technique gave better results as it not only identified the mangrove swamps but also differentiated between the dense and sparse. The greatest variance in the dataset could be identified by this method, thereby making it easier to outline the variations existing within the mangroves. The findings highlighted that out of the total area mangroves covered 38.81 km<sup>2</sup> in 2010 while in 1999, they covered only 30.69 km<sup>2</sup> ascertaining the impact of mangrove restoration projects functioning in the area.

**Keywords:** mangroves, LISS IV, coral reefs, temporal change, PCA

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# Observed Decadal Changes in Extent of Mangroves and Coral reefs in Southern Gulf of Kachchh using Principal Component Analysis and Geo-spatial Techniques: A case study

**Abstract:** The identification of temporal change in the extent of coral reefs and mangroves patches along the Narara and Kalubhar islands was performed using multi-temporal data from 1999 to 2010 (LISS III and LISS IV (MX)). For extracting coral reefs, the spectral behaviour of the feature was studied and by using a few sample locations identified with the help of sea-truth data, the reflectances of the corals were observed in different bands. Since these values were not normally distributed, it was considered best to use the modal value of the dataset. The final range was taken as  $\pm 1$  from the mode, which was used for the extraction of coral pixels. The findings indicate that the coral cover depleted from 19.35 km<sup>2</sup> to 9.11 km<sup>2</sup> in the study area. This depletion may have resulted from the great environmental stress posed by industries situated in the study area. The second objective of extracting the mangroves was accomplished by employing the technique of Principal Component Analysis. This technique gave better results as it not only identified the mangrove swamps but also differentiated between the dense and sparse ones. The greatest variance in the dataset could be identified by this method, thereby making it easier to outline the variations existing within the mangroves. The findings highlighted that out of the total area mangroves covered 38.81 km<sup>2</sup> in 2010, while in 1999 they covered only 30.69 km<sup>2</sup> ascertaining the impact of mangrove afforestation programmes undertaken by Marine National Park authorities.

**Keywords:** mangroves, LISS IV, coral reefs, temporal change, PCA

## 1. Introduction

The Gulf of Kachchh (GoK), which is situated in the north-eastern Arabian Sea, runs in an east-west orientation flanked by the state of Gujarat, India, on both of its edges. It is about 170 km long, 75 km wide at its mouth covering an area of 7300 km<sup>2</sup> (Nair, 2002). There is a marked variation in the northern and southern shores of the Gulf mostly due to tidal variations causing differential sedimentation (Dixit et al., 2010). The southern border of the Gulf is blessed with an extremely varied ecosystem which must be valued and nurtured with utmost care. The intertidal expanse of the Gulf increases upstream and this transitional zone between land and sea covers a wide range of ecosystems. According to Nair (2002), the reasons for this are continuous wave action and littoral sediment transport.

Apart from this region being an ecologically sensitive zone, the primary reason behind its selection as the study area is because it hosts numerous industries along the southern coast which, from the past few decades, seem to be acting as sources of environmental stress. Various industries located along this region like Reliance Industries Limited (petroleum terminal at Sikka), Bharat Oman Refineries Limited (refinery at Vadinar), Essar Oil Refinery (Vadinar) and many others are heavy industrial setups which pose environmental stress. Careful and timely examination of the fragile systems is thus a prerequisite in such locations. The ecosystems of interest which have been studied here are coral reefs and mangroves. Their brief characteristics, parameters for growth etc. have been briefly discussed hereinafter.

## 1.1 Ecosystems in the Gulf of Kachchh

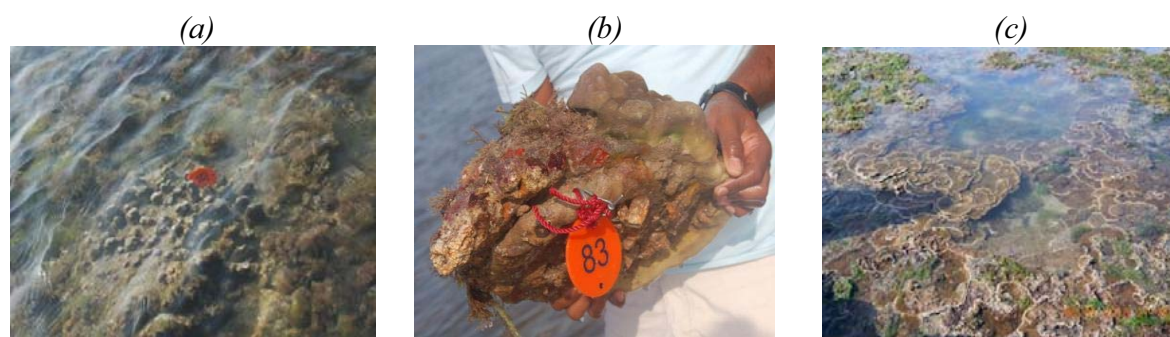
The Marine National Park (MNP) situated in the southern GoK is known to have one of the most diversified marine ecosystems in India. The presence of coral reefs; mangrove swamps; sandy beaches with heterogeneous flora and fauna, makes this region an ecologically sensitive zone needing timely monitoring and management.

### 1.1.1 Coral Reefs

The entire southern shore of the GoK is speckled by coral reef deposits making this belt a major tourist attraction over the past few decades. An area of 270 km<sup>2</sup> stretching from Okha to Jodiya was declared as a Marine Sanctuary in 1980 under the provisions of the Wildlife (protection) Act, 1972, which currently spreads over an area of 457.92 km<sup>2</sup> (website of Jamnagar district). From this, 162.89 km<sup>2</sup> has been declared as the MNP covering 42 islands which are mostly surrounded by coral reefs (Forest and Environment Department, Govt. of Gujarat).

Coral reefs need certain conditions for growth which are duly met with in the southern edges of the Gulf. However, their density and health may vary according to environmental conditions like salinity, temperature, wave actions, turbidity etc.

It has been previously found that the coral reefs around Narara Island and Kalubhar Island are partly of the fringing type and partly patchy (Nair, 2002 and Swaminathan, 2005). Out of the 42 islands, 33 have coral reefs and remaining 20 have mangroves (Dixit et al., 2010). According to the recent studies, both Narara Island and Kalubhar Island have corals existing around them in the intertidal and sub-tidal zones (Figure 1 (a), (b), (c)) (Anonymous, 2011 a). Some of the common species are *Montipora*, *Favia*, *Favites*, *Porites*, *Goniastrea*, *Goniopora*, *Cyphastrea*, *Platygyra*, *Symphyllia* and *Turbinaria* (Anonymous, 2011 b). The present study has been limited to intertidal zone, reasons for which have been stated in the methodology section.



**Fig 1** (a) Corals (*Porites lutea*) found in the middle part of Narara island at 22.475° N 69.706° E (b) Corals (*Porites compressa*) found in the middle part of Narara island (c) Healthy growth of *Montipora* sp in tidal pools at Kalubhar Island located at 22.462° N 69.654° E

### 1.1.2 Mangroves

Mangroves are one of the most productive natural ecosystems and support a rich and diverse flora and fauna. By definition, mangroves can be termed as an assemblage of tropical trees and shrubs that inhabit the coastal inter-tidal zone (Syste, 2014). It has also been stated that mangrove vegetation is found in the tropical and subtropical coasts, which is adapted to survive in the inter-tidal zone (Swaminathan, 2005). Their physiological adaptation to salinity stress helps them to absorb fresh water from saline/brackish water and they can also withstand logged anaerobic mud.

There are several parameters which govern the growth of mangroves and the Indian subcontinent being a typical tropical zone makes an excellent habitat for their growth.

Appropriate temperature of 20 - 35° C, ample rainfall, saline soils, lack of strong winds, tidal fluctuations – all have an impact on their growth. Out of these, rainfall and soil are the most crucial. Repetitive flooding and evaporation from soil substratum results in a thick soil crust on the soil surface which checks the regeneration and growth of mangroves. Also leaching of rain water down the saline soil makes it more suitable for sustaining mangroves (Bioinformatics Centre, 1998).

Soil characteristics in the region have been noted to exhibit very high salinity leading to stunted growth of mangroves. Over the years, hypersalinity of the soil has been recorded due to increased discharge of bittern (discharge from the expanding salt industry in the region) that caused damage to the respiratory roots. As is reported by several researchers (Tam et al., 1995 and Tam and Wong, 1998), mangrove soil is always alkaline and the soil type recorded in southern GoK ranges from calcareous to alkaline with grain size varying from silty-loam to clay (ICMAM Report, 2002) – suitable for sustaining mangroves. Surface run-off is another factor that influences salinity levels which further impact the development of mangroves. Shukla (2011) held that frequently occurring flash floods in the study area carry sizable amounts of water and sediments which erode banks. This, along with weak monsoons and high evaporation makes the land area more arid with increased seawater salinity.

Mangroves occur in variety of configurations. Some species have stunted growth with their roots rising up from the mud (e.g. *A.marina*) while some others send arching prop roots down into the mud (e.g. *R.mucronata*). Observations conducted in the Narara region revealed that *Avicennia marina* had a better average density (20-130 plants/100 m<sup>2</sup>) as compared to other species like *Ceriops tagal*, *Rhizophora mucronata* etc. (Figure 2 (a) and (b)). The heights of these mangroves ranged between 0.5 to 4 m and thus were mostly of the bushy and dwarf type (Anonymous, 2011 a).



**Fig 2** (a) *Avicennia marina* located at 22.481° N 69.227° E along the EOL pipeline corridor in the Narara Island (b) Dense mangroves *Ceriops tagal* located at 22.443° N 69.639° E found in the Kalubhar Island

## 2. Application of remote sensing in coastal ecosystems

Remote sensing techniques have been used to study coastal and marine ecosystems for a long time. With the advent of better quality datasets, in terms of spatial and spectral resolution, it has become possible for analysts to study these systems remotely without taking the trouble of actually going on the site. It is due to the unmatched quality of remotely sensed data that makes it an efficient, cost and time effective medium of procuring data and providing useful outputs.

Coastal ecosystems exhibit a slightly greater degree of complication in the domain of remote sensing mostly because of the complexity of the ecosystem by itself. The spectra of the

features existing on land and those along the coast may vary greatly even if their basic composition is the same. This situation is mostly pertinent to the intertidal zone wherein the advancement and retreat of water could produce totally different reflectances in the satellite data of the same region taken over time.

In this paper, an attempt has been made to present the temporal and spatial variability of the mangrove and coral cover of GoK using Indian Remote Sensing (IRS) data collected in 1999, 2005 and 2010.

### **3. Previous work**

According to Hochberg, Atkinson and Andréfouët (2003), given the 30 year long history of digital coral reef remote sensing, there is surprisingly scanty information available about the spectral reflectance of corals. They attempted to identify the global coral coverage by an intensive ground collection process and predicatively modeled the spectra for other regions. This way the best wavelengths to separate the spectra were produced. Unsupervised classification technique that follows an iterative process for segregation of pixels in different classes is a very commonly used technique for mapping coral reefs. Kakuta et al. (2010) performed a study on the corals of Micronesia wherein they adopted unsupervised method for classification, using ALOS AVNIR-2 and LANDSAT data, with an accuracy of 70%.

Mumby et al., (1997) carried out a study in order to compare digital airborne multispectral imagery (such as Compact Airborne Spectrographic Imager - CASI) with satellite multispectral data (LANDSAT TM and MSS) and drew the conclusion that airborne imagery was able to produce higher accuracy for finer classifications as opposed to satellite data but on the other hand, sensors like LANDSAT proved to be far more cost efficient compared to airborne sensors due to greater coverage per scene. Maximum likelihood method for classification was adopted giving 83% overall accuracy using LANDSAT TM and 93% accuracy using CASI data. The concept of “contextual editing” (Groom, Fuller and Jones, 1996) has also been implemented here, wherein post – classification, the misclassified pixels are re-assigned to classes to which they truly belong. This process normally needs to be applied to the pixels of similar spectral habitats, existing in different physical environments. Benfield et al. (2007) also found contextual editing to improve map accuracy in their study on corals of Pacific Panama. Despite the usefulness in terms of higher accuracy of the airborne sensor data, many researchers favour the use of satellite imagery for mapping coral systems. Vanderstraete and Goosens (2005), in their study on corals of the Red Sea have also highlighted the capability of mapping mangroves by using LANDSAT ETM+ data.

A method followed by many researchers to deal with the issue of poor spectral resolution of satellite data compared to airborne imagery is Image Fusion. Son, Tan and Ransi (2007), fused multispectral satellite bands with high spatial resolution monochromatic airborne data to create new multispectral image with more information. According to the authors, corals detected by these fused images gave better results as compared to those obtained using only either of the two datasets.

Among the Indian satellite sensors, IRS Satellite with Linear Imaging Self Scanner (LISS) sensor has been asserted as a popular choice in many coral studies. Ramachandran (2000) found that merging of high multi – spectral resolution data with PAN data (high spatial resolution) provides detailed spatial information about reclamation, construction activity and ecologically sensitive areas, which are vital for the coastal zone regulatory activities. As previously mentioned, unsupervised classification is a commonly used method for classifying coral zones and this technique has also been applied by Ramachandran (2000). IRS LISS III was divided into 50 classes using unsupervised cluster model technique and by comparing temporal data, change detection was also performed.

IRS LISS II and LISS III data was also employed by Thanikachalam (2010) to map the corals of the Gulf of Mannar using Principal Component Analysis (PCA) giving an accuracy of 93.4% compared to K-means classification (unsupervised) and Maximum Likelihood (supervised parametric) with lower accuracies. PCA was also preferred as it allowed for differentiating between the various coral species existent in the study area.

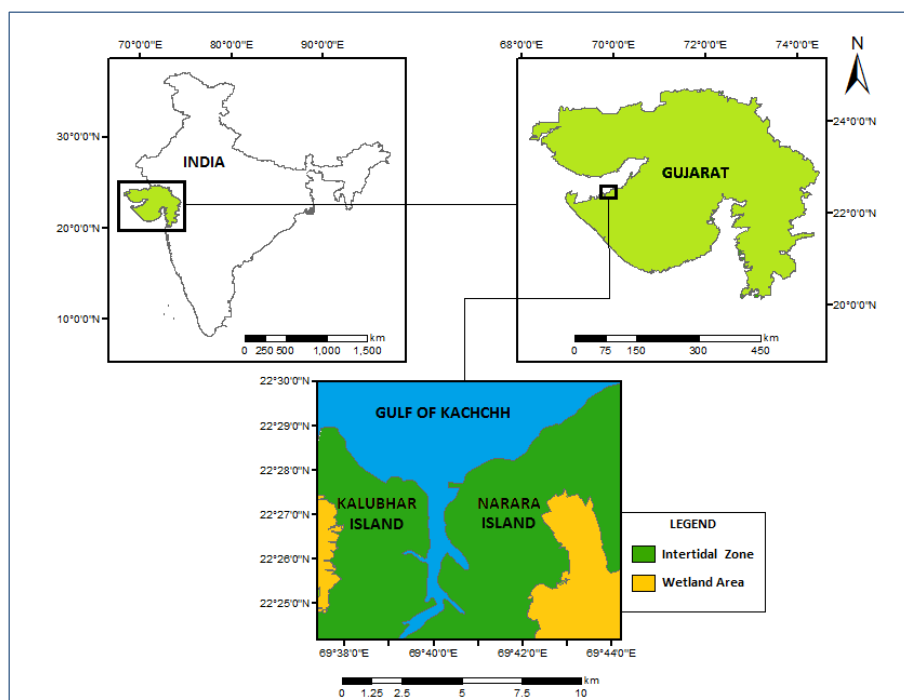
Mangrove classification is another domain of the coastal ecosystem that many researchers have worked upon. Green et al. (1998) efficiently mapped the corals and mangroves of the Turks and Caicos Islands, using LANDSAT TM, SPOT XS and CASI data. They adopted five techniques to map features – visual interpretation, unsupervised classification, supervised classification, PCA based classification and NDVI based image classification. Out of these, PCA based classification yielded maximum accuracy (92%) and visual interpretation method yielded the least with 42% accuracy.

IRS data has been previously employed for mapping mangroves, change detection, species identification, biomass estimation etc. (Ramachandran, 2000). Nayak and Bahuguna (2001) performed mangrove mapping for the entire Indian mangroves using IRS LISS III data and acquired an accuracy of approximately 94% in the state of Gujarat. They followed density wise classification i.e. classification of the mangroves on the basis of the density of the mangrove crown. It has been established by them, that LISS IV data with higher spatial accuracy (not available then) would be more capable of identifying dominant plant community with an area of about 0.04 ha promising greater ability to map very small mangrove patches.

Chatterjee, Porwal and Hussin (2008) implemented LISS IV data for mapping mangroves for the Gulf of Mannar to assess the changes occurred in lieu of the Indian Ocean tsunami of 2004 which caused severe impact on the coastal landforms of the East Indian coast. They performed Gaussian Maximum Likelihood classifier to obtain pre and post tsunami mangrove cover to quantify the damage caused by tsunami. The Pichavaram mangrove ecosystem was studied over a period of 15 years by Srinivasa et al. (2012) using LANDSAT TM and LISS IV data to divide the study area under hot spots (areas needing immediate restoration) and well managed areas. Such temporal studied prove to be extremely beneficial in identifying the anthropogenic effects on these fragile ecosystems as also for delineating the conservation measures suited to the particular region.

#### **4. Study area**

The study area extends from 69° 37' 00" E to 69° 45' 00" E and 22° 24' 00" N to 22° 30' 00" N along the southern shore of the GoK in the Jamnagar District of Gujarat state, India (Figure 3). The total area included in the study extends up to 90.31 km<sup>2</sup> with reference to only the Wetland area and Inter tidal zone. The area occupied by the sea water has not been included in this measure. Due to the availability of sea/ground truth information about the intertidal coral reefs and mangrove swamps for Narara Island and Kalubhar Island, this region was recognized as the study area, subsetted from the IRS LISS III and LISS IV (MX) images dated 04 Feb 1999, 27 May 2005 and 16 Jan 2010.



**Fig 3** Map showing study area

## 5. Materials and methods

Three temporal images were employed in this study. The specifications of the datasets are stated in table 1. Also, for geo-referencing the satellite image, National Hydrographic Office (NHO) Chart (2068) was used for the GoK with a scale of 1:75000, published in the year 2002.

**Table 1** Specifications of datasets used

Scene No.	Sensor	Date of acquisition	Spatial resolution (m)	Spectral bands ( $\mu\text{m}$ )	Swath
1	IRS 1D LISS III	04 Feb 1999	23.5	0.52 – 0.59 (G) 0.62 – 0.68 (R) 0.77 – 0.86 (NIR) 1.55 – 1.70 (SWIR)	141
2	IRS P6 LISS IV (MX)	27 May 2005	5.8	0.52 – 0.59 (G) 0.62 – 0.68 (R) 0.77 – 0.86 (NIR)	23.9
3	IRS P6 LISS IV (MX)	16 Jan 2010	5.8	0.52 – 0.59 (G) 0.62 – 0.68 (R) 0.77 – 0.86 (NIR)	23.9

## 5.1 Pre-processing

After the acquisition of satellite images, in order to remove the effects of atmospheric attenuation and geometric distortions, processing was performed. This pre-processing step is a combination of two – geometric correction and radiometric correction.

- Geometric correction is performed by establishing a relationship between the ground coordinate system and the image coordinate system. Using the NHO chart, positional values of a few Ground Control Points (GCPs) were acquired and the image was geometrically corrected using Polynomial transformation with RMS error of < 1 pixel.
- Radiometric calibration was performed using the following formula.

$$L_{rad} = \frac{(L_{max} - L_{min})}{Q_{cal\ max}} \times Q_{cal} + L_{min} \quad (1)$$

Where,  $L_{rad}$  is the spectral radiance at the sensor in units of  $W/(m^2 \cdot str \cdot \mu m)$ ;  $L_{max}$  and  $L_{min}$  are the Gain and Bias values respectively given in units of  $mw/cm^2/str/\mu m$ ;  $Q_{cal\ max}$  is the maximum possible DN value (255 for LISS III and LISS IV products) and  $Q_{cal}$  is the Calibrated Digital Number. This step is necessary because the pixel values are scaled according to the quantization level (in bits) as per the sensor, and hence they do not represent absolute radiance (Chander, Markham and Barsi, 2007). Using the above Equation 1, the DN values are converted to absolute radiance values.

In order to create a subset of the study area from the images, the NHO chart also had to be geo-referenced so as to make them perfectly overlay upon one another. Once the study area was delineated, a subset was deduced from the images completing the pre-processing phase. Post this step, the subset image was fit for further processing.

For the demarcation of coral reefs and mangrove swamps from the Inter Tidal Zone (ITZ), two different methodologies were developed. Because corals and mangroves reflect differently within the same wavelength, a similar algorithm for identification of the two features could not be adopted. These methods have been explained in the further sections.

## 5.2 Methodology for extracting Coral reefs

During the field surveys undertaken by NIO in the Narara Island and Kalubhar Island, various samples were collected of coral formations along with their geographical positions. These were advantageous as they helped in identifying the locations on the images where the corals actually existed (on field). These locations were superimposed on the three images and their corresponding radiance values were noted. It was observed that, only green band and red band were useful for coral identification due to their higher water penetrating capability (Whitepaper on World View 2, 2010), as opposed to NIR and SWIR bands.

Once the values were noted, the range was used to pick out the pixels falling in the same range from the images. But after a few attempts it was observed that, the pixel behaviour of the sample points were not normally distributed. It was then considered better to use the modal value to define the range of the corals pixels. This way  $\pm 1$  of the mode was used to select the coral pixels from the image. Total 33 sample points were assessed out of which 16 points fell within  $\pm 1$  from the mode.

In most studies, GCPs are collected from field in order to assess the accuracy of classified maps. However, in this study a reverse methodology has been adopted where the reflectance of the coral points is used to identify the other pixel members belonging to the same class.



Habitats of spectral confusion i.e. classes with similar spectral behaviour belonging to variable environments are often misclassified. Such cases lead to poor classification accuracy producing misleading results. According to Mumby et al. (1998), contextual editing substantially improves the accuracy of coral reef habitat maps. This is because coral reefs often exhibit predictable geomorphological and ecological zonation with gradients of depth and wave exposure (Huston, 1994). In the present study, similar situation was faced because few coral pixels were wrongly categorized over the land area, which were removed by contextual editing. Also, it has been found by previously conducted studies (by the NIO) in the Narara Island that corals were absent beyond 250 m from the Low Tide Line (LTL) i.e. the sea-ward edge of the ITZ. This is the reason for selecting only the ITZ for mapping corals. Hence, pixels identified as corals beyond the 250 m line were also contextually removed, thereby giving an accurately classified coral reef zone map. Quantification of the area has been done which is presented in the results section.

### 5.3 Methodology for extracting Mangroves

Mangroves have been identified in the Narara Island and Kalubhar Island during previous visits by the NIO. Various species were seen to exist there, most abundant being *A. marina*.

PCA is a technique from statistics used for simplifying a data set by reducing the dimensionality of multivariate data whilst preserving as much of the relevant information as possible (Jolliffe, 2002). One of the major advantages of applying PCA is that it increases the spectral separability between classes aiding in the process of classification (Clevers, 2010). It has also been ascertained that it is more advantageous to use the first few principal components for classification, as the computational time of performing supervised/unsupervised classification increases rapidly with the number of bands. Particularly for the purpose of change detection, PCA is regarded as the most accurate technique (Jensen, 1986). It is also held that complete reliability on classification accuracy derived from pixel based classification techniques is not always the best way. This re-emphasizes the usefulness of multi-temporal PCA images for pin-pointing change (Sader et al., 1991).

In the present study, PCA was applied on the images and 3 principal components were created per scene. On visually interpreting them, it was clear that the individual components were able to highlight the spectral variability within the mangrove regions with profound prominence. It was therefore considered better to perform classification on the principal components instead of the image directly.

Supervised classification technique was applied on the PC images using Maximum Likelihood parametric rule. It is necessary to classify PCA images in order to ascertain the temporal change occurring with respect to land cover class. According to Munyati (2004), knowledge of the land cover characteristics of the study area is vital for PCA to be used as a change detection technique. Training sets were fed into the system from the mangrove regions in order to derive the other mangrove swamps. The classification resulted in two categories of mangroves – dense mangroves and sparse mangroves. Quantification of the area has been done which is presented in the results section.

### 5.4 Quantification of Area

The areas for the respective classes in  $\text{km}^2$  were calculated using the following formula:

$$\text{Area}_{(i)} = \text{Pixel count}_{(i)} \times \text{SR}^2 \times 10^{-6} \text{ km}^2 \quad (2)$$

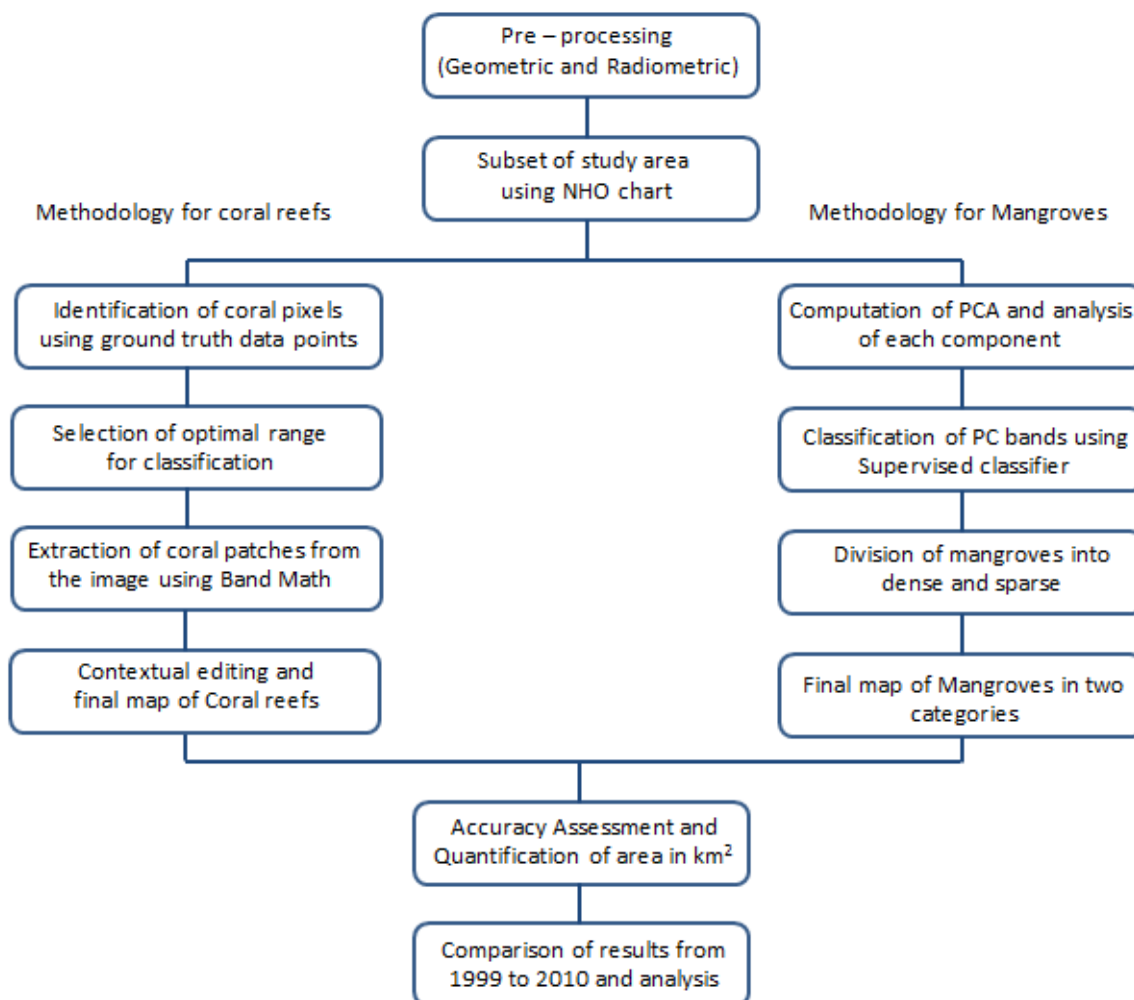
where,  $\text{Area}_{(i)}$  is the area in  $\text{km}^2$  for class 'i';  $\text{Pixel count}_{(i)}$  is the total number of pixels in class 'i';  $\text{SR}$  is the spatial resolution (m) multiplied by  $10^{-6}$  to show the values in  $\text{km}^2$ .

## 5.5 Accuracy Assessment

The accuracy of the coral zone maps and the mangrove classified maps were checked using GCPs of the respective features. The locations of the features identified on ground were superimposed on the classified maps and the frequency of matching positions was calculated. If the identified feature GCP was found to be within the class of interest i.e. corals/mangroves, then the point was considered to be accurately classified and if a GCP was falling out of the class, it was taken as inaccurately classified. In this manner, the accuracy of the dataset was estimated. Accuracy values have been discussed in-depth in section 6.2.

## 5.6 Comparison of extent from 1999 to 2010

Using the aforementioned methodology, the extent of coral reefs and mangroves in the study area for three time periods – 1999, 2005 and 2010 were known. These results were then compared with one another and variations were noted. These comparisons were purely based on the total pixel count and corresponding area covered. The analysis of this has been explained in the results section. A flow diagram of the complete methodology can be seen in Figure 4.



**Fig 4** Methodology of the study

## 6. Results and Discussion

### 6.1 Quantification of Area

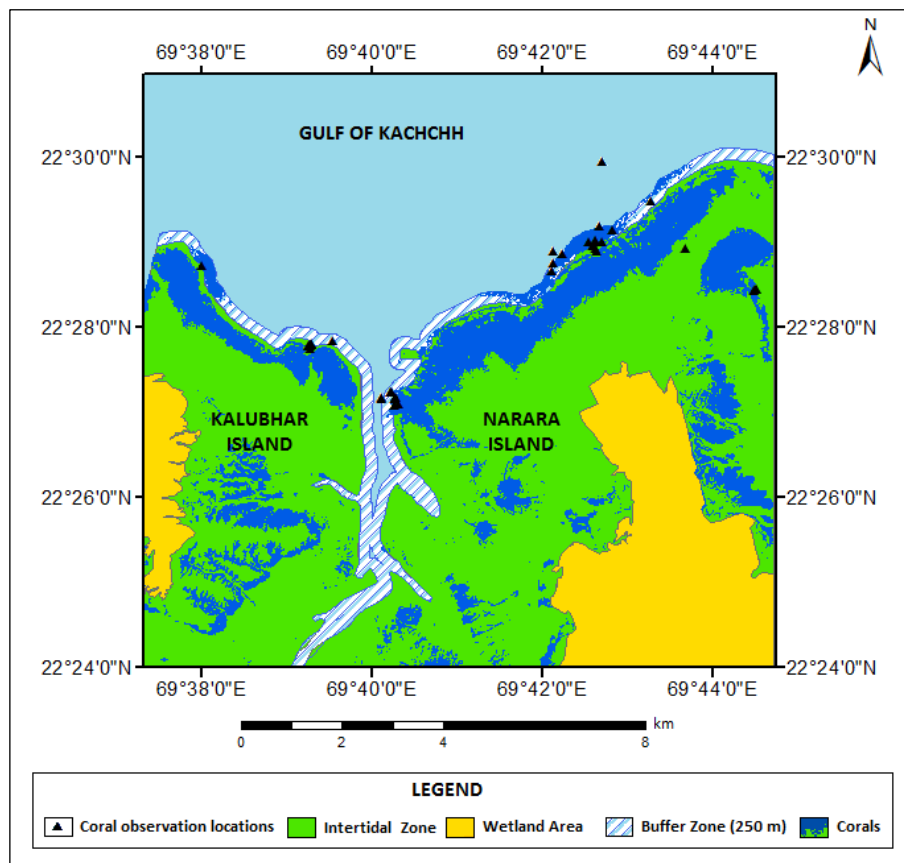
The area covered by corals and mangroves were calculated using Equation 2. The area covered by coral species have been given as it is, but the mangrove area has been divided into two classes – dense and sparse. These have been described in depth in the following paragraphs.

#### 6.1.1 Coral reefs

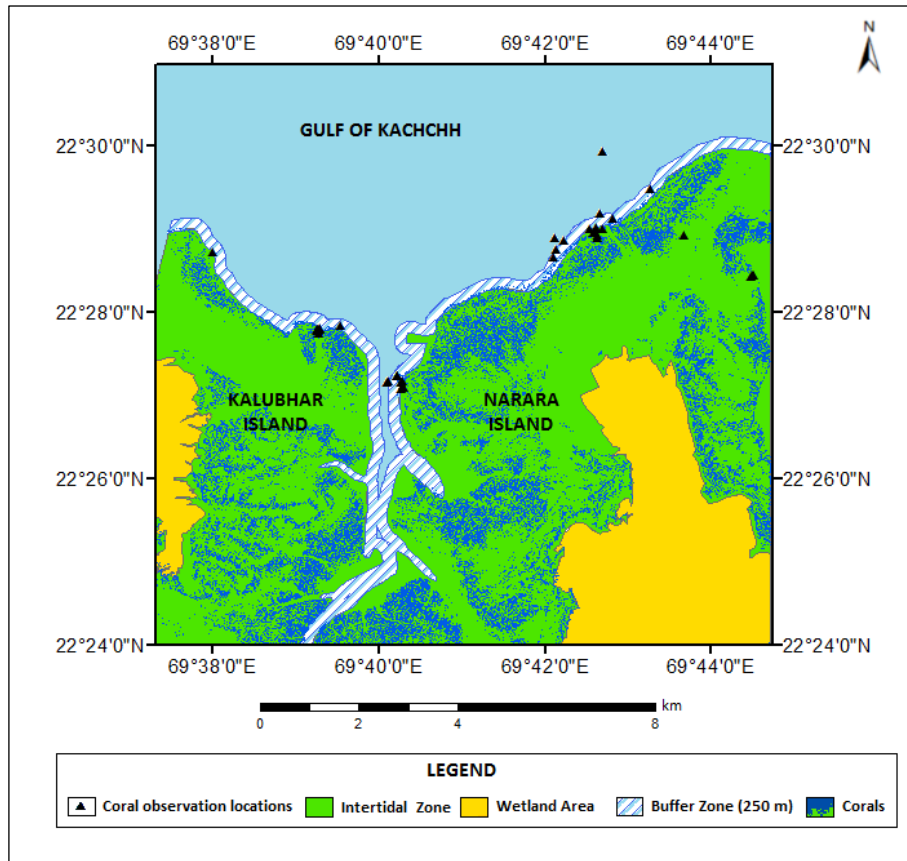
The total area studied for corals and mangroves was different. An additional area 7.17 km<sup>2</sup> extending from the LTL to 250 m seaward was taken for studying corals because it was noted by previous observations (by the NIO) that corals existed only up to 250 m from the LTL. Hence, ITZ + 250 m buffer seaward was considered for corals while area up till the ITZ was studied for mangrove estimation.

In 1999, out of 90.31 km<sup>2</sup> considered for studying corals, 22.06% area had coral deposits identified on them. This value was significantly lowered to 15.28% in 2005 and further to 10.08% by 2010 (table 2). The following Figure 5 (a), (b) and (c) given below, represents the coral cover during the period of study.

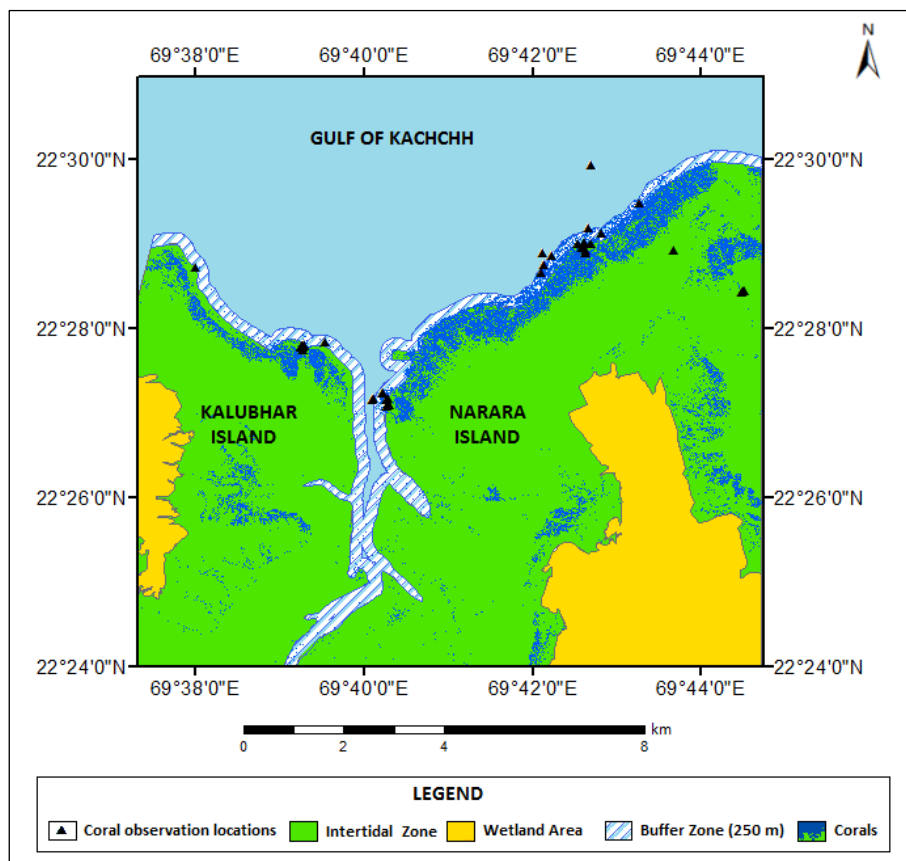
(a)



(b)



(c)



**Fig 5** (a) Extent of corals in 1999 (b) 2005 and (c) 2010

As can be clearly seen from the figures above, the coral patches represented in blue colour have significantly reduced since 1999. These effects are accruable to the constant growth of industrialization along the coastal belts in the GoK. Passage of pollutants in sea water, oil spillage, manual displacement of corals for laying underwater pipelines etc. are just a few causes for reduction in the coral reef development. The study area lies extremely close to major industrial centers which have, over the years, shown their impact on the surroundings. Such studies provide key insights to the effects of land-based pollution on the growth of the ecosystem. Since coral reef structures are extremely sensitive, constant monitoring and careful handling becomes a prerogative. The effect of pollutants and related synergistic effects can cause disease and mortality in sensitive species, disrupt critical ecological functions, cause trophic structure and dynamic changes, and impede growth, reproduction and larval settlement (NOAA, 2010).

### 6.1.2 *Mangroves*

The scenario of mangroves since 1999 to 2010 has been remarkably different from that of corals. There have been several initiatives in the GoK over the past years aiming at the rejuvenation and protection of mangroves. It was seen that Gujarat witnessed severe mangrove destruction from 1960s to 1980s (Muraleedharan et al., 2009). This was primarily due to an increase in land acquisition for agriculture, industrial development, mining, etc.

However, since the early 1990s, the positive effects of protection efforts could be noticed profoundly in the MNP regions. Although mangrove growth was seen all through Gujarat, it was analyzed that Jamnagar and Kachchh districts contributed to 90% of the overall expansion (Biswas 2009).

The total mangrove cover identified in 1999 was 30.69 km<sup>2</sup> out of the 83.14 km<sup>2</sup> stretch chosen for the study. This constituted to 36.91% which grew to 46.68% mangrove cover by 2010. As has been shown in table 2, mangroves have steadily grown in the area. Hence, the study proves the fact that mangroves are, on a whole, growing in the GoK. Figure 6 (a), (b) and (c) depict the patterns of growth of mangroves in 1999, 2005 and 2010 respectively.

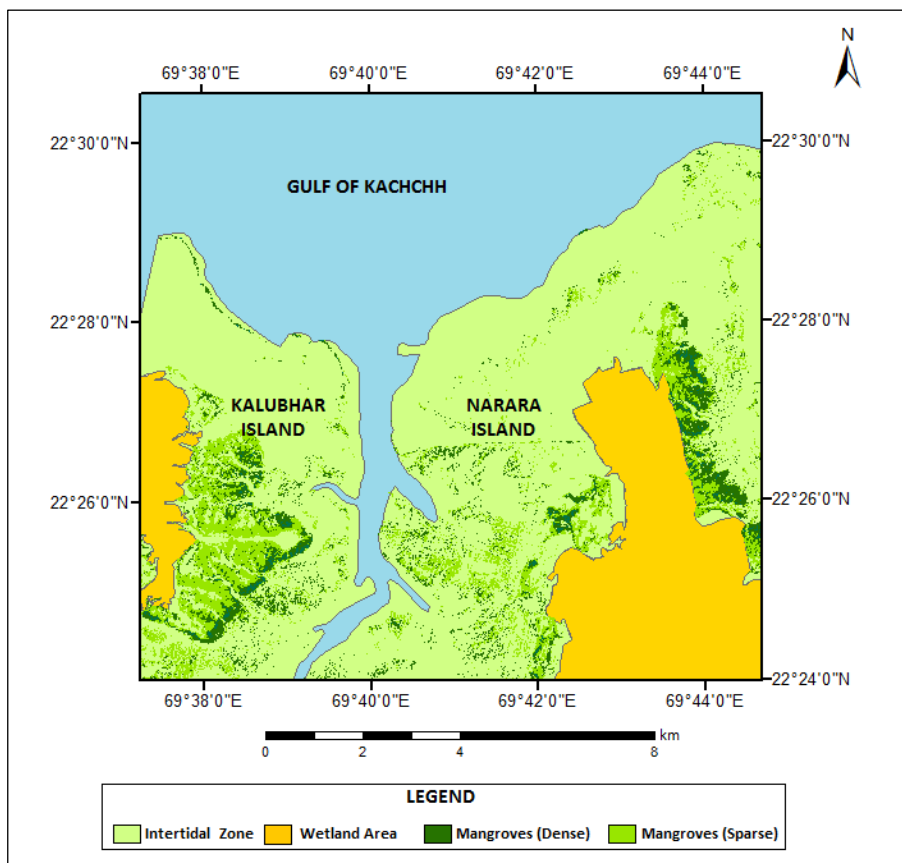
Variations in signature were noted within the mangrove swamps in all the images, hence two sub classes – dense and sparse mangroves were identified. This variation in the reflectance behaviour of the two classes was observed which can be attributed to the density of the mangroves present on field.

Within the ITZ, the densest mangroves were identified along small channels/creeks that extended into the mangrove swamps. These channels bring saline waters from the sea that act as feeders to the mangroves. Hence, the dense mangrove patches were mostly identified on the banks of the channels extending landward from the sea. On the other hand, very scanty and stunted mangrove growth was detected on the seaward edges of the ITZ, where very low elevation and greater wave action could have possibly resulted in the lack of mangrove germination.

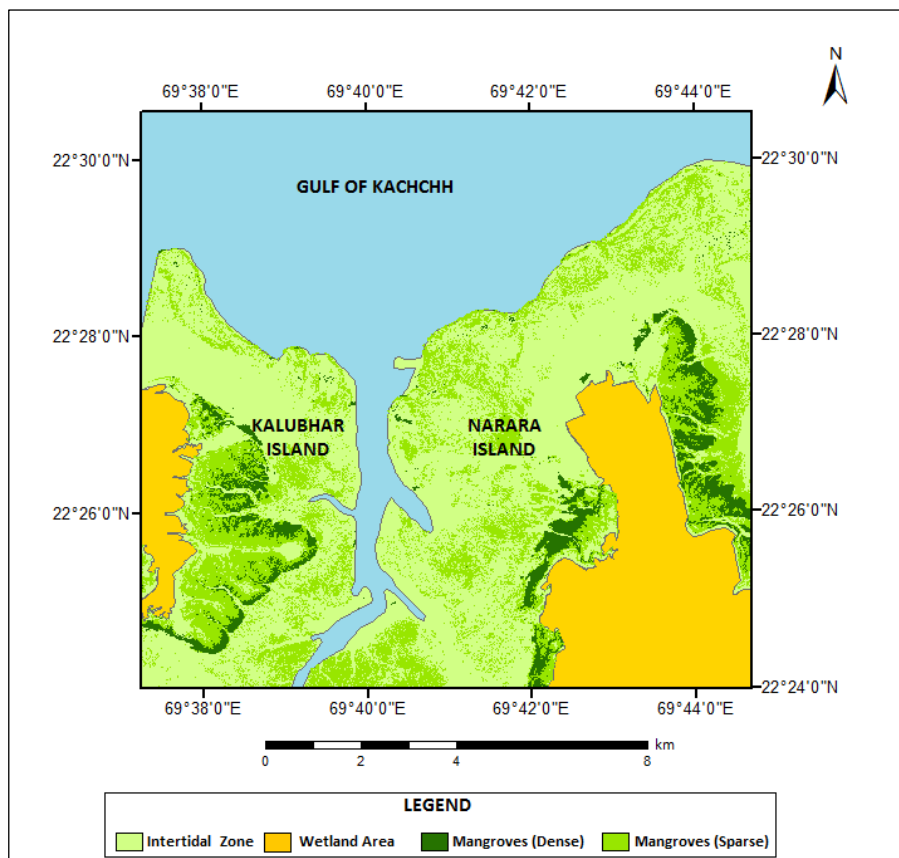
**Table 2** Extent of coral reefs and mangroves from 1999 to 2010

Year	Coral reefs (km <sup>2</sup> )	Mangroves (km <sup>2</sup> )		
		Dense	Sparse	Total
1999	19.93	5.96	24.73	30.69
2005	13.80	5.88	28.37	34.25
2010	9.11	7.47	31.34	38.81

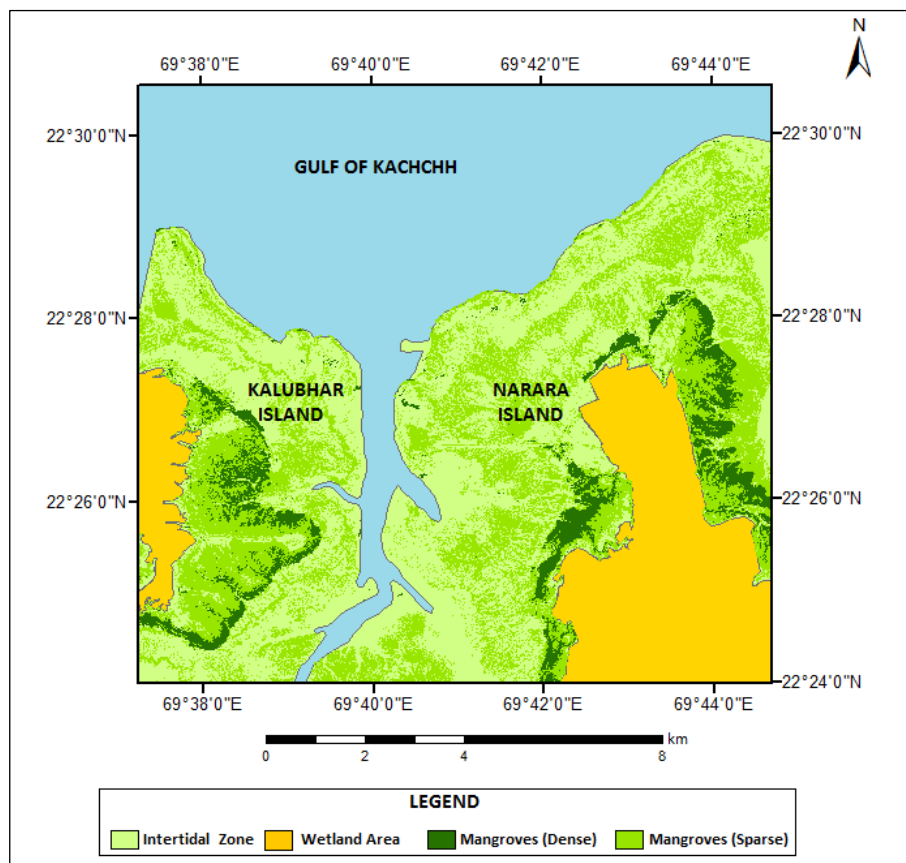
(a)



(b)



(c)



**Fig 6** (a) Extent of mangroves in 1999 (b) 2005 and (c) 2010

## 6.2 Accuracy Assessment

For accuracy assessment of the classified maps, GCPs for the coral reef zone and mangroves were compared with the identified feature locations. In the case of corals, an additional 20 points (other than the ones used for identifying corals in the classification stage) were superimposed on the classified map of corals, out of which 15 points were in congruence with the corals identified in the study. This way an average accuracy of 75% was attained for the coral reef mapping process. Inaccuracy of the remaining 25% of coral locations were found to be submerged under seawater at the time of image acquisition, thereby not matching with the true reflectance of corals.

In the case of mangroves, 41 ground locations were available, which on comparing with the classified mangroves, resulted in 33 matching points giving an accuracy of 78%. Due to the temporal variation between the time of field visit and data collection, slight reduction in accuracy could be expected. It is hence opined that more accurately timed field survey along with a greater number of sample points could perhaps increase the accuracy of classified maps.

## 6.3 Conclusion

The significance of this work is that the Kalubhar and Narara islands both belong to the Marine Sanctuary, which is an ecologically fragile zone needing continuous observation and conservation. In the case of corals, although a good growth rate of 10 cm per year is recorded, bleaching has been frequently noticed at numerous sites. Parikh and Datye (2003) also stated that dredging of corals, felling of mangroves etc. cause choking of the coral reefs thereby seriously hampering their growth. For mangrove conservation, efforts made by authorities are appreciable

but the growth of abundant industrial activities in these sensitive locations counteracts the conservational initiatives.

All these facts highlight that such ecosystems demand constant vigilance which is possible by remote sensing methods due to their cost effectiveness and reasonably high precision. With the advent of better sensors with finer resolutions over time, it would be possible to continually develop more and more techniques for monitoring different features that can be applied over space. Very few studies are performed at such micro scales as has been performed in the current study. These give a better and more accurate picture than meso or macro level studies, because in order to make monitoring techniques successful, it is essential that they be developed with respect to the specific area than to the whole universe.

### List of abbreviations

DN – Digital Number	MSS – Multispectral Scanner System
ETM – Enhanced Thematic Mapper	NDVI – Normalized Difference Vegetation Index
GCP – Ground Control Points	NHO – National Hydrographic Office
GoK – Gulf of Kachchh	NIO – National Institute of Oceanography
ITZ – Inter-tidal Zone	NIR – Near Infra-red
IRS – Indian Remote Sensing	PCA – Principal Component Analysis
LISS – Linear Imaging Self Scanner	SWIR – Short wave Infra-red
LTL – Low Tide Line	TM – Thematic Mapper
MNP – Marine National Park	

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## Figure Captions

- Fig 1:** (a) Corals (*Porites lutea*) found in the middle part of Narara island at 22.475° N 69.706° E (b) Corals (*Porites compressa*) found in the middle part of Narara island (c) Healthy growth of *Montipora* sp in tidal pools at Kalubhar Island located at 22.462° N 69.654° E
- Fig 2:** (a) *Avicennia marina* located at 22.481° N 69.227° E along the EOL pipeline corridor in the Narara Island (b) Dense mangroves *Ceriops tagal* located at 22.443° N 69.639° E found in the Kalubhar Island
- Fig 3:** Map of Study area
- Fig 4:** Methodology of the study
- Fig 5:** (a) Extent of corals in 1999 (b) 2005 and (c) 2010
- Fig 6:** (a) Extent of mangroves in 1999 (b) 2005 and (c) 2010

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