

IDENTIFICATION OF MANGROVES AND CORAL REEFS IN THE SOUTHERN GULF OF KACHCHH USING PRINCIPAL COMPONENT ANALYSIS AND GEO-SPATIAL TECHNIQUES: A CASE STUDY

R. Prerna ¹, V.S. Naidu ², S. Soniya ³

¹Project Assistant II, National Institute of Oceanography, Regional Center

²Senior Scientist, National Institute of Oceanography, Regional Center

³Senior Scientist, National Institute of Oceanography, Regional Center
Four Bungalows, Lokhandwala Road, Andheri (W), Mumbai – 400 053

Abstract:

The major objectives of this study were to extract the coral reef zones and mangroves using IRS P6 LISS IV data by employing the most appropriate technique, suited for the particular feature. Firstly, a few sample locations of corals were superimposed on the imagery to note the behaviour of the coral pixels was observed, the range of the reflectance values was noted in all bands. Since these values were not normally distributed, it was considered best to use the modal value of the dataset to truly represent the reflectance of coral pixels instead of using the entire range. The final range was taken as ± 1 from the mode, which was used for the extraction of coral pixels by band mathematics in ENVI 5.0. The findings suggested that corals covered 14.01 km² of the study area.

For extracting the mangroves, the technique of Principal Component Analysis (PCA) was applied. This technique was found to give better results by not only identifying the mangrove swamps but also to differentiate between the dense and sparse mangroves. The greatest variance in the dataset could be identified by this method, thereby making it easier to outline the variations existing within the mangroves. Further classification (by supervised method) of the principal components was required to identify Dense and Sparse mangroves. The final findings highlighted that out of the 89.69 km² of the study area, mangroves covered 38.35 km² (42.76%). Further classification of the mangroves quantified to 7.47 km² of dense mangroves and 30.88 km² of sparse mangroves showing a reasonably high prominence of mangroves in the area. The area quantifications were executed using ArcGIS software.

In this manner, different techniques adopted for extracting different features proved the worth of remote sensing for mapping marine ecosystems and also highlighted the heterogeneity inherent in the spectral responses of the features which need to be duly understood for executing meaningful classification.

About the Author:



Ms R. Prerna, M.Sc. Geoinformatics

Educational Qualification:

M.Sc. Geoinformatics, B.A. (Honours) Geography

Work Experience:

Currently employed as Project Assistant (Level II) at National Institute of Oceanography. Major tasks performed at NIO include studies on coastal ecosystems to highlight the application of remote sensing and geo-spatial techniques, and implementation of different techniques as per the requirement of the organization.

In the past, have performed many other studies on the application of remote sensing and GIS in heterogeneous domains like, coastal vulnerability, land-use / land-cover changes, rural electrification and distribution network, automated building footprint extraction using LiDAR and a variety of other spatio-temporal analyses.

E mail ID: prerna.geoinfo@gmail.com,

Contact No: +91 – 09930836886

1. INTRODUCTION

The Gulf of Kachchh runs in an east-west orientation flanked by the state of Gujarat on both of its edges. It is about 170 km long, 75 km wide at its mouth covering an area of 7300 km² [1]. There is a marked variation in the northern and southern shores of the gulf mostly due to tidal variations causing differential sedimentation [2]. The southern border of the gulf is, thus, 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; and the reasons for this are continuous wave action and littoral sediment transport [1].

1.1 Ecosystem in the Gulf of Kachchh:

(i) Coral Reefs:

The entire southern shore of the Gulf of Kachchh is speckled by coral reef deposits making this belt a major tourist attraction over the past few decades. 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 as per growing conditions like salinity, temperature, wave actions etc.

As per recent studies performed by NIO Mumbai, both Narara bet and Kalubhar bet have corals existing around them in the intertidal and sub-tidal zones (Figure 1). Some of the common species are *Montipora*, *Favia*, *Favites*, *Porites*, *Goniastrea*, *Goniopora*, *Cyphastrea*, *Platygyra*, *Symphyllia* and *Turbinaria* [3].

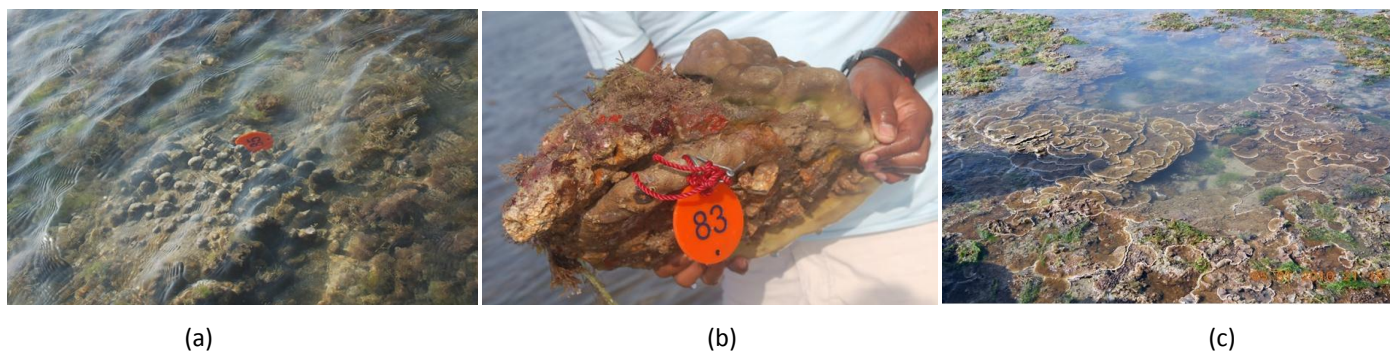


Figure 1 (a) *Porites compressa* and (b) *Porites lutea* located at 22.475° N 69.706° E in the middle part of Narara bet; (c) Healthy growth of *Montipora* sp in tidal pools at Kalubhar Island located at 22.462° N 69.654° E [4]

(ii) Mangroves:

Mangrove vegetation is found in the tropical and subtropical coasts, consisting of a number of species of trees and shrubs that adapt to survival in the intertidal zone [5]. The best locations are where abundant silt is brought down by rivers or on the backshore of accreting sandy beaches. Their physiological adaptation to salinity stress helps them to absorb fresh water from saline/brackish water and they can also withstand logged anaerobic mud. Observations conducted by NIO in the Narara region

revealed that *A. marina* had a better average density (20-130 plants/100 m²) as compared to other species like *C. tagal*, *Rhizophora mucronata* etc. The heights of these mangroves ranged between 0.5 to 4 m and thus were mostly of the bushy and dwarf type ^[4].

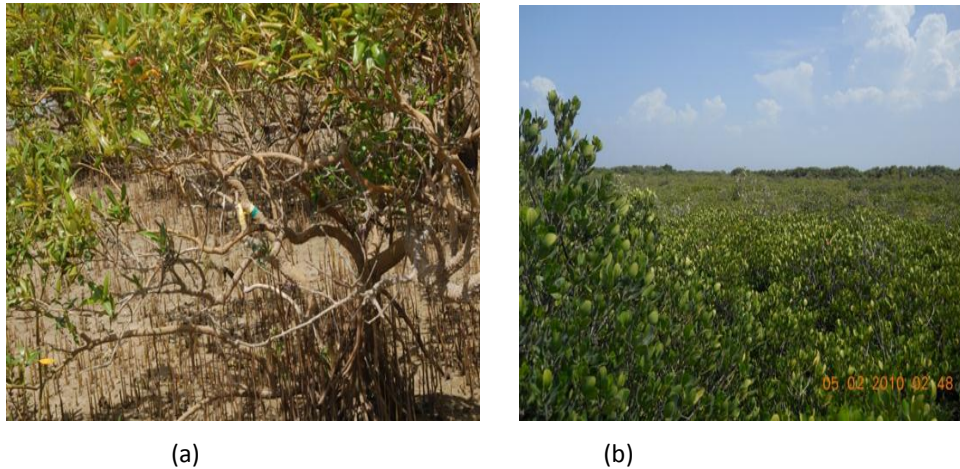


Figure 2 (a) *Avicennia marina* located at 22.481° N 69.227° E along the EOL pipeline corridor in the Narara Island and **(b)** Dense mangroves *Ceriops tagal* located at 22.443° N 69.639° E found in the Kalubhar Island ^[4]

1.2 Previous Work:

Indian Remote Sensing (IRS) Satellite with Linear Imaging Self Scanner (LISS) sensor has been asserted as a popular choice in many coral studies. IRS LISS II and LISS III data have also been employed 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 ^[6]. 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 using PCA. In one such study, mapping of the corals and mangroves of the Turks and Caicos Islands, using LANDSAT TM, SPOT XS and CASI data was done ^[7] using five techniques and PCA based classification yielded maximum accuracy (92%). The concept of “contextual editing” ^[8] (post classification the misclassified pixels are re-assigned to classes to which they truly belong) is also a popular technique for improving accuracy. This process normally needs to be applied to the pixels of similar spectral habitats, existing in different physical environments. In another study also, it was found that contextual editing to improve map accuracy in their study on corals of Pacific Panama ^[9].

The Pichavaram mangrove ecosystem was studied over a period of 15 years using LANDSAT TM and LISS IV data to divide the study area under hot spots (areas needing immediate restoration) and well managed areas ^[10]. From the aforementioned citations, it can be affirmed that satellite remote sensing data is an extremely beneficial tool for mapping costal features, while promising accurate results; and also shows the capability of IRS LISS data to effectively identify the features in question.

2. 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 Gulf of Kachchh in the Jamnagar District of Gujarat state (Figure 3). The total area included in the study extends up to 90.31 km² with reference to only the Wetland area and Intertidal zone, excluding the area occupied by the seawater. Due to the availability of ground truth information about the intertidal coral reefs and mangroves for Narara bet and Kalubhar bet, this region was recognized as the study area, subsetted from the IRS LISS IV (MX) image dated 16 Jan 2010.

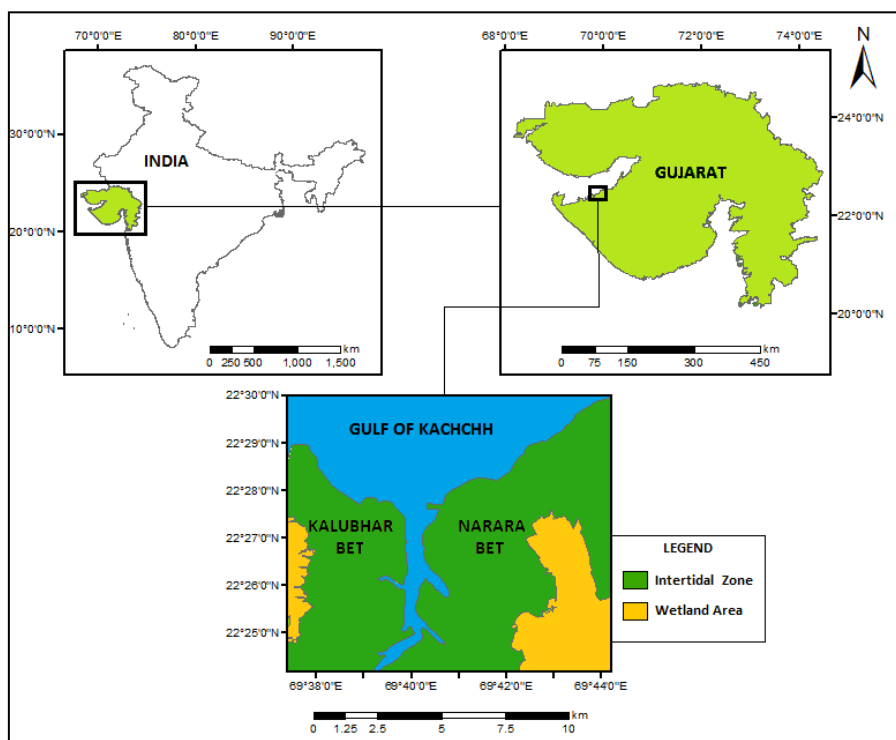


Figure 3: Map of Study Area

3. MATERIAL AND METHODS

3.1 Material used:

IRS LISS IV (MX) data with spatial resolution of 5.8 m; having spectral range of 0.52µm-0.59µm (Green), 0.62µm-0.68µm (Red) and 0.77µm-0.86µm (NIR) was used for the study. Also, for geo-referencing the satellite image, Naval Hydrographic Office (NHO) Chart (2068) was used for the Gulf of Kachchh with a scale of 1:75000, published in the year 2002.

3.2 Methodology:

3.2.1 Pre-processing:

After the acquisition of IRS LISS IV (MX mode) image, processing of the image in order to remove the effects of atmospheric attenuation and geometric distortions were performed. This pre-processing step is a combination of two processes:

- 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 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^[11]. Using the above formula (1), the pixels can be converted to the absolute radiance values (executed with *ENVI's band mathematics* tool). A subset of the study area from the image was created, using the NHO chart.

3.2.2 Methodology for extracting Coral reefs:

By previous field surveys undertaken by the NIO in the area, various samples were collected of coral deposits along with their geographical positions. These were advantageous in identifying the locations in the image where the corals actually existed (on field). These locations were superimposed on the image and the radiance values were noted for all locations. It was observed that, out of the three bands of the LISS IV data, only green band and red band were useful for coral identification due to their high water penetrating capability^[12], as opposed to NIR band.

Once the values were noted, the range was used to pick out the pixels falling in the same range from the image, but it was observed, that the pixel behaviour of the sample points was not normally distributed. It was then considered better to use the modal value to define the range of the corals pixels. This way ± 1 of the mode was used to select the coral pixels from the image. From what has been seen by previous studies, once the classification (irrespective of the type) is performed, field data is used to check the accuracy of the classification. However, the methodology adopted here follows a reverse technique wherein 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. Contextual editing has been seen to substantially improve the accuracy of coral reef habitat maps^[13]. This is because coral reefs often exhibit predictable geomorphological and ecological zonation with gradients of depth and wave exposure^[14]. 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 NIO), that corals were absent beyond 250 m from the Low Tide Line (LTL) i.e. the sea-ward edge of the intertidal zone. This is the reason for selecting only the intertidal zone 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 (Figure 4). All these processes were performed using ENVI 5.0 and ArcGIS software.

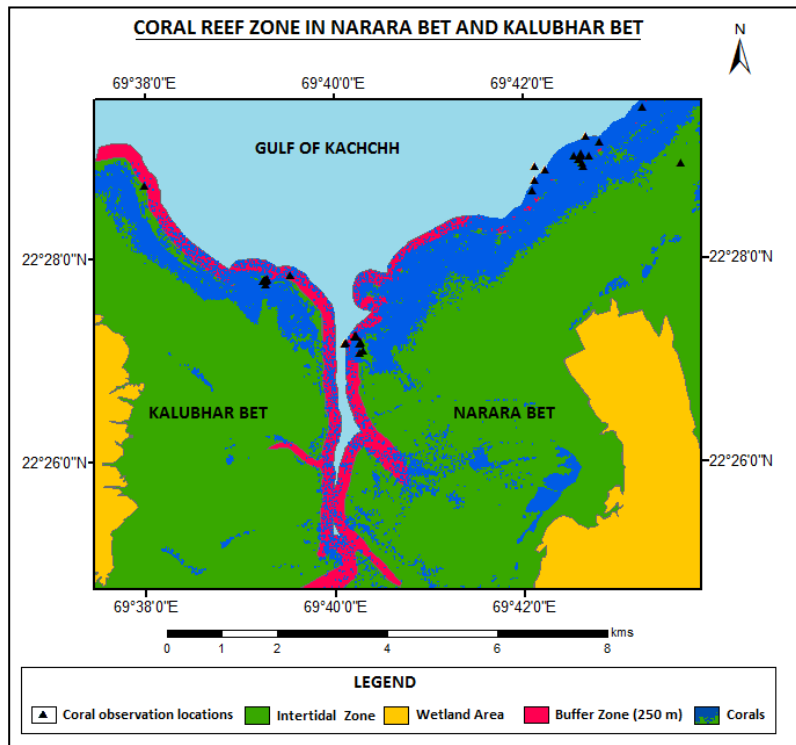


Figure 4: Map showing coral reef zone

3.2.3 Methodology for extracting Mangroves:

Principal Component Analysis (PCA) is a technique used for simplifying a data set by reducing the dimensionality of multivariate data whilst preserving as much of the relevant information as possible ^[15]. One of the major advantages of applying PCA is that it increases the spectral separability between classes aiding in the process of classification ^[16]. It is considered 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 ^[17].

In the present study, PCA was applied on the image and 3 principal components were created. On visually interpreting the three components, 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. Training sets were fed into the system from the mangrove regions in order to derive the other mangroves. The classification resulted in two categories of mangroves – dense mangroves and sparse mangroves. Figure 5 shows the mangrove classes derived by the aforementioned technique. Quantification of the area has been done using ArcGIS software which is presented in the results section.

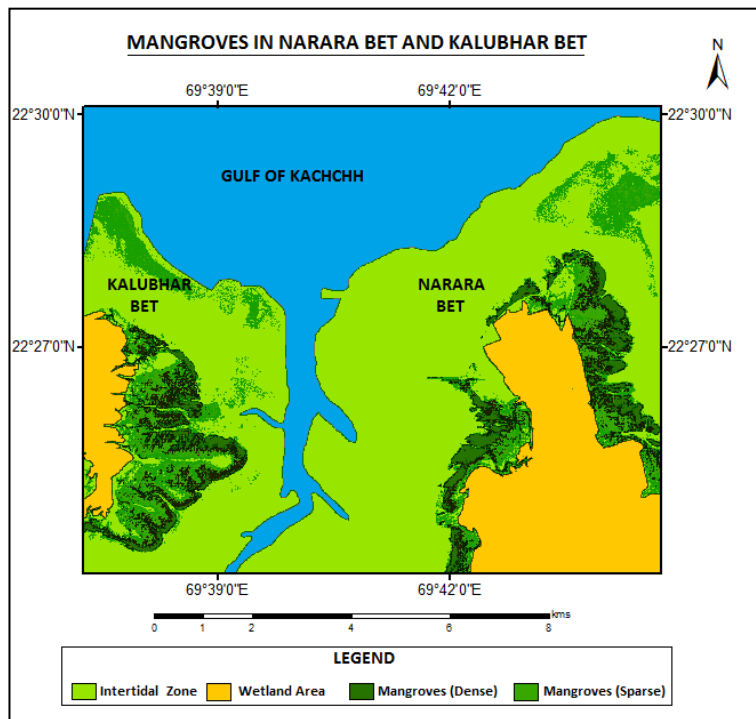


Figure 5: Map representing Dense and Sparse Mangroves

3.2.4 Quantification of Area and Accuracy Assessment:

The areas for the respective classes in km² were calculated in ArcGIS and the accuracy of the coral zone maps and the mangrove classified maps were checked using ground truth points of the respective features in ENVI. The locations of the features identified on ground were superimposed on the classified maps and the frequency of matching positions was calculated.

4. RESULTS

4.1 Quantification of Area:

The findings of the study suggested that the afore-stated methodologies were able to provide good results for mapping the features under study.

Table 1: Area (km²) calculated for Coral reefs and Mangroves

Coral Reefs	Total Area considered	Mangroves		Total Area considered
		Dense	Sparse	
14.01	90.31	7.47	30.88	82.84

The total area under study considered for corals and mangroves was different. An additional area of 8.07 km² extending from the LTL to 250 m seaward was taken because it was noted by previous observations (by NIO) that corals existed only up till 250 m from the LTL. Hence, intertidal zone + 250 m buffer seaward (for corals) and only intertidal area (for mangroves) was considered. Out of



90.31 km² area considered for studying corals, 15.51% of the area was identified as coral zone. This value helped in concluding that a significant coral population existed in the study area, previously asserted by ground survey and, validated by satellite image analysis.

The total mangrove cover identified was 38.35 km² out of the 82.24 km² stretch chosen for the study. This came to about 46.63%. Since variations were noted within the mangrove swamps, two sub classes – dense and sparse mangroves were identified. A variation in the reflectance behaviour of these two classes was observed which can be attributed to the density of the mangrove swamps present on field. 8.73% and 37.27% of the total area were occupied by dense and sparse mangroves respectively. Alternatively, it can also be stated that only 19.5% of the mangroves were dense while the remaining 80.5% were sparsely grown.

Within the intertidal zone, the densest mangroves were identified along small channels/creeks that extended into the mangroves. 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 intertidal zone, where very low elevation and greater wave action could have possibly resulted in the lack of mangrove germination.

4.2 Accuracy Assessment:

For accuracy assessment of the two maps, ground survey points for the two features were tallied with the identified feature locations. Firstly, in the case of corals, an additional 20 points (other than the ones used for identifying corals initially) 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 accuracy of 75% was attained for the coral reef mapping process. A justification for this lacking accuracy can be attributed to the fact that the points not matching with the map were in the region submerged under seawater at the time of image acquisition, thereby not providing the true reflectance of the 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 variations in such comparison techniques could arise. More accurately timed field survey along with a greater number of sample points could perhaps increase the accuracy of such outputs.

5. CONCLUSION

The significance of this work was that the Kalubhar and Narara islands both belong to the Marine Sanctuary which is an ecologically fragile zone needing continuous observation and conservation. Data is available about the extent of corals and mangroves for the Gulf of Kachchh, but most are rough estimates and are not available at micro level. Careful monitoring cannot be initiated without an updated and accurate inventory of the existing resources for which, such studies prove to be beneficial.

The corals selected for monitoring in the studies performed by NIO at Narara and Kalubhar showed most corals to be surviving in healthy conditions with high tolerance to adverse conditions like sedimentation and algal competition. The growth rate was also seen to be good at about 10 cm per year due to factors like higher temperature, less submergence in shallow pools, adequate light and heavy skeletal structure which activated the growth rate. However, bleaching was noticed in different degrees

at different sites, mainly associated with sedimentation and predation. In general bleaching was seen in *P.lutea* and *C.serailia*. The decline in the health of the corals has also been seconded by others ^[18] who have stated that dredging of corals, felling of mangroves etc cause choking of the coral reefs thereby seriously hampering their growth.

In the case of mangroves, there can be no debate on the degree of ecological contribution of these ecosystems in maintaining the fragile ecosystem existing within and around them. According to a study conducted in the Gulf of Kachchh, mangroves are being depleted at extremely fast rates for various industrial activities that are coming up in these sensitive locations ^[19].

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 only.

Apart from a few limitations like time lag between the image acquisition and ground data collection; and small number of sample points available for the coral/mangrove locations, the methodology discussed in this work can be considered fit for applying in other regions over space and time, without much requirement of other ancillary data sources. Also, more enhanced radiometric calibration techniques based on radiative transfer models can be applied if time and data constraints do not exist, so as to determine the true surface reflectance of the features in question.

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