ASSESSMENT OF ENVIRONMENTAL VARIABLES AND THEIR IMPACTS ON CORAL REEFS USING REMOTE SENSING AND GIS

SYNOPSIS

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DOCTOR OF PHYLOSOPHY

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Jalpa Karanubha Jadeja

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Research Supervisor

Dr. P. C. Mankodi

Professor of Zoology

DEPARTMENT OF ENVIRONMENTAL STUDIES, FACULTY OF SCIENCE,

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA,

VADODARA, 390002, GUJARAT

INTRODUCTION

Coral reefs are one of the important ecosystems on the earth, with high biological production and complicated environmental conditions. They can be found along the shore and off shores of islands and continents in shallow tropical waters. The majority of coral reefs are made up of stony corals, which are made up of polyps that cluster in groups. This type of corals is known as Hermatypic corals and also as Scleractinia corals, which are held together by calcium carbonate structures produced by corals (Sreekumaron and Gogate, 1972). Hermatypic corals has the zooxanthellae algae which lives in with a symbiotic relationship. In the process of symbiotic relationship, coral provides shelter to the zooxanthellae algae and in return algae provides food and nutrients to the coral by the process of photosynthesis. As this process requires the sunlight, this type of corals can survive in shallow water and in the depth up to euphotic zone. Ahermatypic corals are referred as a non-reef building corals and they are independent from the zooxanthellae. As they do not need sunlight for their survival, they can be found at higher depths of the ocean.

The Scleractinia corals are formed around 245 million years ago in Mesozoic Era (Stanley, 2003). Thus, Coral reefs are one of the world's most significant, diversified, and ancient habitats, providing a home for a variety of marine animals (Moberg and Folke, 1999). Many species dwell on the reef in a symbiotic and prey-predator interaction (Dave and Mankodi, 2009). The protection provided by corals helps in formation of associated ecosystems, which facilitates integrated food web of marine ecosystem (Moberg and Folke, 1999). Coral reefs also act as a coastal protector by protecting coastal area from storm damage, floods, tsunamis, hurricanes, coastal erosion through controlling power of waves (Parasharya, 2012). Coral reefs support local communities by generating revenue from tourism, building materials, fishing, etc. (Carte, 1996; Spalding et al., 2001; Bhattji, 2011). Thus, in comparison to other marine habitats, coral reefs are a very dynamic environment (Spalding et al., 2001).

As coral reefs are extremely sensitive to the environmental conditions, they are often used as important indicators of climate change (Chaudhury et al., 2014). In recent decades, various stressors have affected reef health negatively and as a result, coral reefs have been quickly decreasing across the world. They are primarily threatened by rising anthropogenic activity and the global climate change problem (Joshi, 2016). Assessments to late 2000 stated that 27% of the world’s reefs have been effectively lost (Almada-Villela et al., 2002) because of the massive climate-related coral bleaching event. Global warming's effects, such as an increase in the frequency and intensity of hurricanes and drastic changes in ocean temperature, have resulted in significant damage, such as coral bleaching and colony decline (Ameris et al., 2012). Temperature alone does not account for the bleaching patterns. The sources of this variation are also including environmental parameters like light, turbulence, solar radiation, water flow, and salinity. The use of these environmental variables is suitable to achieve the goal of determining the general pattern of meso-scale bleaching event, and to associate this event broadly with both long term inherent oceanographic conditions and conditions when they occur (Joseph, 2007).

Remote sensing is more practical way to monitor the change in health and coverage of the reef ecosystem covering larger area. Corals usually found in relatively shallow waters are exposed to direct sunlight with an optimum temperature of 23ºC-25ºC. However, the water column on coral reefs strongly absorbs longer wavelengths, thus the use of electromagnetic radiations is limited to visible regions (450-650nm). Also, corals have symbiotic association with zooxanthellae, discrimination of corals from algae merely based on the spectral signatures is difficult especially with data sets of broad spectral resolution (Nadoka et al., 2004). Thus, Space borne multispectral imagery demonstrates great spatial potential to accurately map coral reef habitats (Collin et al., 2016), health and resilience.

Landsat Thematic Mapper (TM) and Sentinel-2 Multispectral (MS) images offer some potential for classification of different classes of Coral reef ecosystem. Mumby et al., (1998) had tested a retrieval algorithm using the Landsat Thematic Mapper (TM), comparing the satellite-based estimates of coral reef extent against similar 1-m-resolution retrievals from an airborne imaging spectrometer; the satellite-based method yielded an overall accuracy of 75%. In one study by Prerna, et. al., (2015) on temporal change in the extent of coral reefs and mangroves patches along the Narara and Kalubhar islands using multi-temporal data of IRS LISS-III and LISS-IV from 1999 to 2010 it has been stated that only green band and red band were useful for coral identification due to their higher water penetrating capability, as opposed to NIR and SWIR bands.

Development of Spectral signature library of reef eco-system increases the understanding of controlling factors of reflection and absorption of light in reef environment. Though it is difficult to definitively determine the difference between spectral reflectance signatures of corals with algae and corals without algae in its associated reef environment, there are two documented pigments that occur only in zooxanthellae of Corals which are Peridinin and

Dinoxanthin. Peridinin shows maximum absorption at 475 and 570 nm (Myers et al., 1999), whereas Dinoxanthin shows maximum absorption at 418, 442 and 470 nm (Hedley and Mumby, 2002). As per Hochberg et al., (2003), brown Corals have shown a reflectance peak near 570 nm, whereas blue corals strongly absorb in the 580 nm region. According to Joyce et al., (2013) second derivative of reflectance at 564 nm was one of the wavelength regions most sensitive to variations in live coral cover and least sensitive to variations in water depth and quality. Chaudhury, (2012) studied on the In-Situ hyperspectral signatures of eight coral targets using Analytical Spectral Devices, Field-Spec spectroradiometer at Paga and Laku Point reefs of Gulf of Kachchh to effectively understand the spectral behaviour of corals. In the visible range over 400 to 600 nm range, the live and the bleached corals are differentiated. Spectral band ratios derived from image data have been used previously in reef environments to map bottom cover (Mumby, 2000). However, when based on Landsat TM/ETM+ image data, they are restricted to clear, shallow waters, especially when utilizing the red channel (Dustan et al., 2001). Earlier Hochberg, (2003) had separated Corals, Algae and Sand by spectral band ratio based on linear discriminate function analysis using field spectrometer data, and applied them to airborne hyper spectral images, with promising results.

Using the spectral signatures, remotely sensed indices can provide a more widely applicable method for mapping and monitoring environmental parameters. Spectral indices like Normalized Difference Vegetative Index (NDVI) are among the most common data transformations for mapping vegetation's structural or physiological attributes. They are simple and relatively easy to implement from multispectral and hyper spectral datasets (Joyce et al., 2013). This type of spectral indices relies on measured absorption and scattering processes, which are strongly negatively and positively correlated to the chemical and structural properties of the object. In reef ecosystem, impact of environmental conditions may differ for different benthic features. An effective spectral index will exhibit a direct response to relatively small changes in coral cover, across a range from low to high cover levels (Joyce et al., 2013). Also, as the generation of spectral indices is not much complex process and can be applied with entry level image processing software, widely they are being used for reef environment.

Amongst the various spatial interpolation techniques, Inverse Distance Weighted (IDW) method is relatively simple and easy to calculate and also more convenient to interpret the outcomes than other techniques (Lu & Wong, 2008). In one of the studies Kumari et al., (2017) adopted the IDW interpolation method to know the spatial distribution pattern of zoanthids along the Saurashtra coast of Gujarat. Using IDW technique they found that *Palythoa mutuki* is the most common and abundant species across the Saurashtra coast and reported the highest amount of live coverage of *P. mutuki* with 60% at Dhamlej and Charra.

Coral Reefs are rich in diversity and fine-scale monitoring of these ecosystem is needed for their management and spatial planning. Remote sensing is more practical way to monitor the change in health and coverage of the reef ecosystem covering larger area. Mapping and monitoring of such large and remote ecosystem can be easily done by remote sensing and Geographic information systems (GIS) techniques. Space borne multispectral imagery demonstrates great spatial potential to accurately map coral reef habitats (Collin et al., 2016), health and resilience. Thus, coral reef mapping usually relies on remote sensing for cost effectively identifying their structural complexity, benthic composition, and regime surrogates over large areas (Goodman et al., 2013; Hedley et al., 2016).

AIM AND OBJECTIVE

Aim:

To assess environmental variables and its impacts on coral reefs of Gujarat using Remote Sensing and GIS data

Objectives:

1. To assess the impacts of environmental variables on coral reefs.
2. To determine stress and impact severity of environmental variables.
3. To generate the maps using remote sensing and GIS data for environmental stresses.

MATERIALS AND METHODS

Study area

According to Spalding et al., (2001), India contains around 2% of the world's coral reefs, with Gujarat having one of the country's four major coral reefs, mostly in the Gulf of Kachchh. The Gulf of Kachchh's coral formation is mostly limited along southern shore of Gulf. The existence of coral reef has been recorded on 42 of the 45 islands in the Gulf of Kachchh (Joshi, 2016). The majority of the islands in the Gulf of Kachchh have fringing reefs, while some of the islands in the Gulf of Kachchh have platform and patchy reefs (Dave, 2011). It covers a total area of 352.5 square kilometers with reefs (Jayaprakas and Radhakrishnan, 2014).

As it is not convenient and feasible to cover all the islands of the gulf for the study, reef areas of Dwarka and Okha for pioneer work and two islands of the Gulf of Kachchh named Narara and Poshitra have been selected to achieve the objective set for the study. Both the Narara and Poshitra comes under the protection of Marine National Park & Sanctuary (MNP & S). Many natures education camps have been conducted by MNP & S at Narara, one of the tourist destinations, to raise awareness of the importance of marine ecosystem in our lives. As there is no distinct demarcation of the mainland, Narara island has become a part of the mainland as a result of human invasion. In Narara, one can see living corals with a moderate distribution over the reef. According to Pandey et al., (2010), here the live coral cover is around 4.93 percent, and the density of recruits of various genera found on the island is 21 recruits/100 m^2. Poshitra is also known as the 'Crown of the Gulf of Kachchh' (Parasharya, 2008). Eulittoral fringing reefs are mostly found in the vicinity of Poshitra near Laku Point, on the edge of the embayment, in a 100m wide region.

In-Situ Data

The reefs were studied by random quadrant method for habitat characterization and sea water sample collection to assess prevailing physio-chemical environment. Each field visit was planned following the daytime low tides to study the seasonal variations in reef ecosystem.

As corals falls into the category of schedule-1 of Indian Wildlife Act 1972, required permission were taken to conduct the field survey. The reef area of Dwarka and Okha were surveyed during January 2019 to study the bleaching conditions. Reef of Narara and Poshitra islands were visited over the period of 03 months from December 2019 to March 2020 and also in June 2021 to study the seasonal variations. Collection of in-situ data for all the sites has been done by random quadrate sampling method as it is generally used for biodiversity and ecological research. Random sampling was done using 1m^2 PVC frame. Field observations were performed to document coral bleaching and mortality by taxon using the Coral Health Chart. Therefore, during the field visit number of live corals, bleached corals and dead corals were recorded.

Satellite and GIS data

The data collected from secondary sources like satellite images were compiled and analysed systematically by keeping in view of the objectives of the study. GIS and Remote Sensing techniques were used for the visual analysis and interpretation of the images. Satellite images of Landset-5 TM and Sentinel-2 MSI of different years were downloaded from website https://earthexplorer.usgs.gov/. The detailed information of satellite data used for the study is given in Table 1.

Table 1: Details of Satellite Data Used

Study Area	Satellite	Sensor	Resolution	Date
Narara	Sentinel-2	MSI	10 m	24 April, 2019
	Landsat-5	TM	30 m	14 April, 1998
Poshitra	Sentinel-2	MSI	10 m	24 April, 2019
	Landsat-5	TM	30 m	13 Feb, 1997

The GPS coordinates of the coral colonies were recorded and photographs of all the coral colonies have been taken to generate the spectral signatures with intent to compare with secondary satellite data. Data collected from the field with the use of GPS were transferred into the excel file. With the use of Geo tagging technique coordinates of each coral colony were converted into shapefile and geo tagged on satellite image along with field photographs.

Computation of Bleaching Response Index (BRI)

The coral health of different species was assessed using Coral Health Chart. The Lightest and darkest data of each species were recorded to generate the graphs based on the color distribution and frequency of all the species observed in the study area. These graphs show the frequency of occurrence a particular coral species in a particular color code category. From these graphs bleaching percentage of each species were calculated for further statistical analysis. Further, bleaching data were defined in four different categories of bleaching severity. Each of these categories then denoted with the vector value ($\mathbf{C_i}$) to define the beaching category limits (Floros et al. 2004).

$$C_i, \text{ where } i = 1, \ldots\ldots, M + 1$$

Table 2: Bleaching Categories and their Weightages

Categories ($\mathbf{C_i}$)	Bleaching Severity	Bleaching Percent	Percentage Weightage **(w)**
1	No Bleaching	0	0
2	Partial Bleaching	0 – 30	0.3
3	Medium Bleaching	31 – 70	0.7
4	Severe Bleaching	71 – 100	1.0

Based on the Table 2, values of category vector (C) are taken as, C = (0, 0.3, 0.7, 1) which are the weightage given to each category. Depending on the bleaching percentage at species level, each species was given the vector value based on the bleaching severity categories.

Furthermore, vector (b) of mean of the bleaching categories was also calculated (Swain et al. 2016).

$$\text{Where,} \qquad b_i = (c_i + c_{i+1})/2$$

finally, to calculate the bleaching response index, ratio of number of coral colonies within each category (Swain et al., 2016) of a particular species and total number of colonies of all the species in particular category were calculated. Thus, using this data, BRI was calculated using following formula:

$$\text{Bleaching Response Index (BRI)} = \frac{N_i b_i}{\sum_{i=1}^{M} N_i} \times 100$$

Where, b = Vector of the mean of Bleaching Categories

N = Number of Coral species within each Bleaching Categories

But, in order to calculate the BRI in percentage, ratio of total number of bleached coral colonies in particular genus and total number of bleached coral colonies of all the genus is multiplied by 100 and also with the vector (b) of mean of the bleaching categories to find out the response of particular genus of coral in overall bleaching event. The percentage of BRI shows the resistibility of particular coral species or genus towards the bleaching conditions. Different level of resistibility for the BRI generated here, are divided into three categories which are shown in table 3.

Table 3: Bleaching response categories of different Coral Species in percentage

Bleaching Response	Bleaching Percentage
Resistible	0 - 30 %
Moderately Susceptible	31 – 70 %
Highly Susceptible	71 – 100 %

Coastal land use mapping from satellite image

With the use of free version Software of QGIS 3.10, on screen digitization of different land-use classes including coral reef and other coastal features was carried out to generate the Land-use Land-Cover maps of study area. These maps were generated using the images of satellite Landsat-5 TM and Sentinel-2 MSI of the year 1998 and 2019 to study and compare the change in the study sites in past two decades.

Generation of Inverse Distance Weighting (IDW) Index

Li & Heap (2008) stated that the IDW method is a simpler non-geo statistical methodology which calculates the attribute values of unsampled points using a linear combination of values of sampled points weighted by the inverse distance function from the point of interest to the sampled points with the help of formula:

$$\lambda_i = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

Where, d_i is the distance between two points x_0 and x_i, p = Power parameter, and the number of sampled points used for the estimation represented as n. Thus, creating distance between two sampled points demolish the weight where nearby sampling helps to get possible accurate results.

Here, ArcMap application was used to generate the maps of IDW index. In-Situ data like latitude, longitude and total number of coral species in each randomly sampled quadrate were used to generate the IDW maps.

Generation of Spectral Signatures

Multi-band spectral signatures of Corals and Coastal Land use classes were generated using satellite images with the help of image processing software. For this process corals and other Land use classes (mudflats, mangroves, algae on sandy reef, sea water) were identified on Satellite images using geo-locations and polygons were created. Then, Histogram of spectral signatures in four different bands of areas covering polygons was generated. Different statistics like Mean, Standard Deviation, Minimum and Maximum values were also generated in each spectral band. Then mean spectral value of each land-use class plotted for studying the spectral separability of different land-use classes in the area.

Generation of Coral Indices

Remotely sensed spectral indices are used in a range of environments for estimating properties of vegetation, soil, atmospheric, and water features (Joyce and Phinn, 2013). The Index generated here is intended to distinguish between Corals and Algae. For these, A simple band ratio (Band X ∕ Band Y), and normalized difference Index [(Band X − Band Y) ∕ (Band X + Band Y)] was applied, with use in determining the ratio band combination that are most sensitive to distinguish between Corals and Algae.

Based on the study and literature surveys, the bands are selected which shows some difference to separate Corals with Algae and Corals without Algae. The spectral band ratios sensitive to corals namely Green / NIR, Red / NIR, NIR / Red, Blue / Red and NIR / Green were generated for Sentinel and Landsat data sets. Apart from these ratios, NDVI index also has been calculated. Based on the concept of NDVI, new normalized difference Index named Coral Index also has been generated to monitoring the coral health over different seasons.

$$\text{NDVI} = [(\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})] \quad (1)$$

$$\text{Coral Index (CI)} = [(\text{NIR} - \text{Green}) / (\text{NIR} + \text{Green})] \quad (2)$$

RESULT AND DISCUSSION

Species Diversity Distribution

Narara:

Total 12 species of corals were found in Narara. As reef area covering coral cover is larger in Narara in compare to Poshitra, Here in Narara reef area has been divided into two parts.

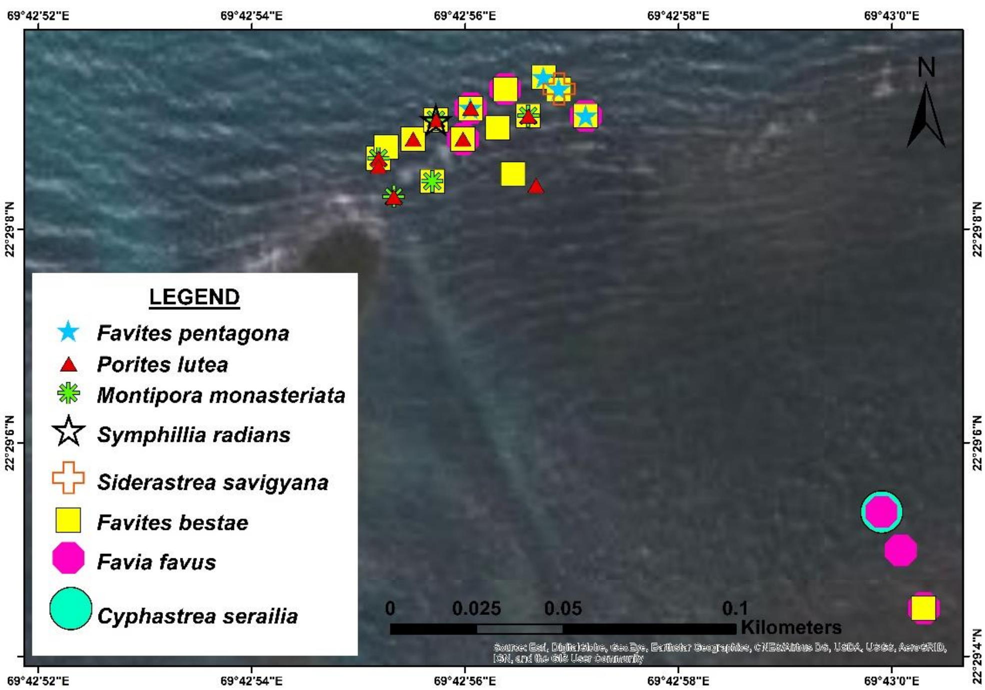

Figure 1: Species diversity distribution at Narara (Site 1)

As per the maps generated, site 1 in Narara shows that coral diversity is rich in here. 8 different species of coral were found in this particular site. From the map, it is also concluded that *Favites bestae, Porites lutea*, *Favia favus* and *Montipora monasteriata* are the most abundant species here. *Favites pentagona, Symphillia radians, Siderastrea savigyana* and *Cyphastrea serailia* are the least found species at site 1, Narara. It is also shown that *Favia, favites* and *Porites* species shares the same habitat with a healthy growth. Thus, it can be said that, this are the non-competitive species with each other.

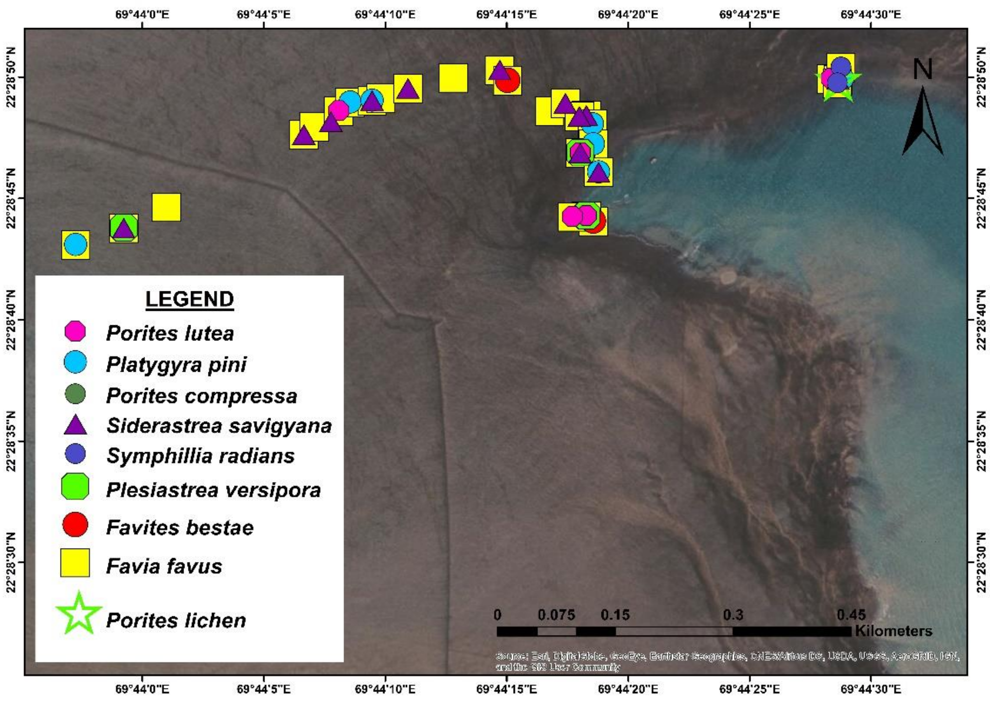

Figure 2: Species diversity distribution at Narara (Site 2)

Same as site 1, random quadrant sampling method was used to know the distribution pattern of coral diversity at site 2 also. Species diversity is also rich in here as there are many species found in a single quadrate. Most commonly found species at this site are *Favia favus, Platygyra pini, Symphillia radians* and *Siderastrea savigyana. Porites lutea, Porites compressa, Plesiastrea versipora, Favites bestae* and *Porites lichen* were the least found coral species at site 2, Narara. Also, *Favia favus* and *Siderastrea savigyana* mostly found together. Only one colony of *Porites lichen* was recorded at this site.

Poshitra:

As Poshitra is protected area of Marine National Park of Gujarat, coral species diversity is very rich here. Here coral species are found in tide pools at sea shore which are specially monitored to protect corals by maintaining the water currents and water temperature. Because of suitable environment and habitat, corals here are very healthy and total 20 different species were found at Laku point in Poshitra during this study.

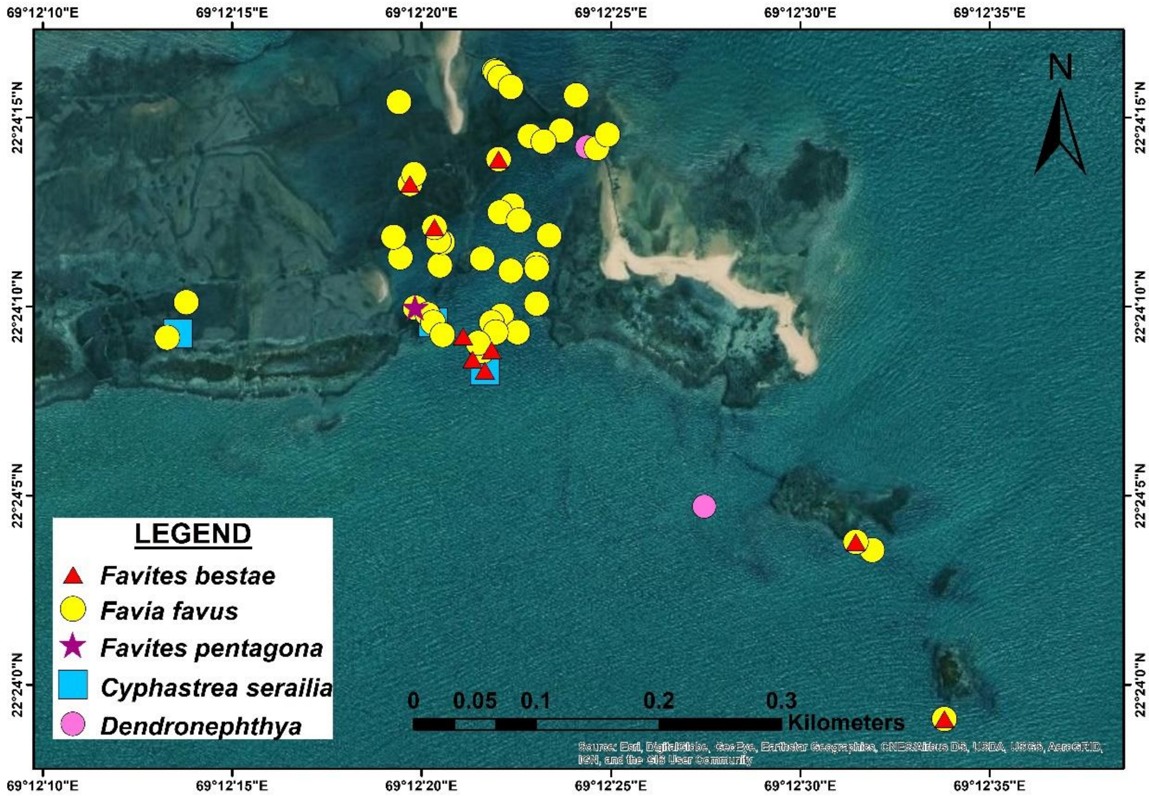

Figure 3: Species diversity distribution at Poshitra

Amongst them *Favia favus* is most commonly found species ~~in~~ here and *Goniopora* and *Porites* are also more commonly found species. *Acanthastrea hillae, Cyphastrea serailia, Dendronephthya*, *Favites pentagona*, *Montipora explanata*, *Montipora monasteriata*, *Mycedium elephantotus*, *Platygyra pini*, *Plesiastrea versipora* and *Siderastrea savignyana* are least found species. Study site at Poshitra is more protected and diverse than Narara. According to the study, *Acanthastrea hillae, Dendronephthya, Goniopora minor, Montipora explanata, Mycedium elephantotus, Platygyra sinensis, Turbinaria mesenterina* and *Turbinaria peltata* has not been found at selected study site in Narara.

The results of species diversity distribution mapping indicates that more anthropogenic and tourist activities at Narara reef has been damaging reef diversity as compared to Poshitra. The Camping and tourist activities at Narara also affects the health and growth of corals. Where as in Poshitra, these types of activities are highly restricted and the area is more protected than Narara. Thus, corals at Poshitra are much healthier and corals are found in bigger boulders. The number of species are also more at Poshitra as compared to Narara reef.

Computation of Bleaching Response Index (BRI)

Based on the field survey and with the use of Coral Health Chart, corals were listed into two categories named bleached corals and healthy corals. Total numbers of bleached coral species observed in each genus are given in Table 4.

Table 4: In-Situ data of bleached Corals

Colour Scores	1 - 3	4 - 6	Total
Bleaching Condition	partial to sever bleaching	No Bleaching	
Genus			
Porites s*p.*	8	5	13
Goniopora s*p.*	8	16	24
Goniastrea s*p.*	1	3	4
Favia s*p.*	0	5	5
Favites s*p.*	1	4	5

From the data of bleached corals, bleaching percentage of different corals species in each genus was calculated. Based on the frequency distribution, the individual coral species were classified in different categories and C_i and b_i values were calculated as shown in Table 5.

Table 5: Frequency of bleached corals in each genus

Genus	Bleaching (%)	Category (C_i)	b_i
Porites	23.03	2	0.5
Goniopora	33.33	3	0.85
Goniastrea	25.0	2	0.5
Favia	0.0	1	0.15
Favites	20.0	2	0.5

The final Bleaching Response Index of different coral species has been calculated which indicates that highest BRI is observed for *Goniopora sp.* followed by Porites and lowest for Goniastrea and Favia species. Based on the BRI of each species, they have been further classified into Resistible and Susceptible categories as given in Table 6.

Table 6 Bleaching Response of different coral species

Genus	Bleaching Response Index (%)	Bleaching Response
Porites sp.	22.20%	Resistible
Goniopora sp.	37.70%	Moderately Susceptible
Goniastrea sp.	2.75%	Resistible
Favites sp.	2.75%	Resistible

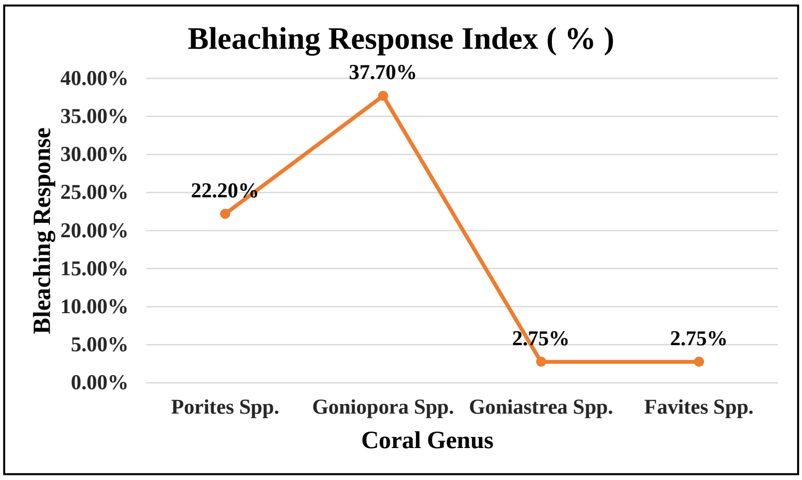

Figure 4: Final Percentage of Bleaching Response Index (BRI) of each genus

The results of these study bring out the fact that, response of corals towards the local stress conditions varies a lot at genus level. Amongst all the genus considered in the calculation, *Goniopora sp.* has the highest impact of stress conditions present at the time of data collection followed by the *Porites sp.* as compared to *Goniastrea sp.*, *Favites sp.* and *Favia sp.*

Coastal land use mapping from satellite image

Mapping of different coastal land use classes from satellite data covering study area was carried out identifying different coastal classes like corals on rock boulders, sparse corals, seaweeds, mangroves and algae on sand or mud bottom etc. From the land use-land cover maps, total area of various coastal classes was calculated to find out the area of coral reef in Narara. In the year 2019, area calculated from Land use map of coastal features of Narara is 7,984.6 ha. Amongst them, coral covers only 5% of the total reef ecosystem in Narara which is very less as compared to other reef ecosystem classes like algae, sea-weeds and mangroves.

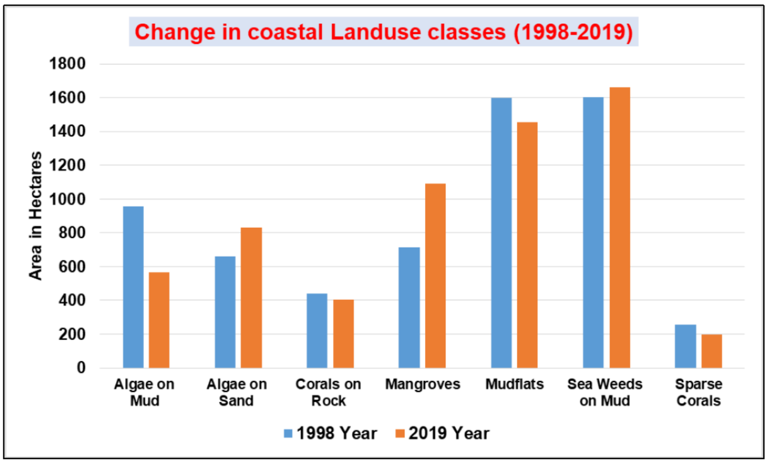

Figure 5: Change in area of coastal landcover classes (Narara reef)

The results indicate that area under classes has reduced during 2019 as compared to 1999. The area of corals on rock boulders has reduced by around 32.63 hectares and corals on rock boulders, area of sparse corals has also reduced by 57.44 hectares. Whereas areas of classes like algae on sand, mangroves and seaweeds on mud have increased as compared to the year 1998. On an average, most of the area of the reef ecosystem of Narara has been covered by mud flats followed by mangroves. In past 20 years total cover of area of algae on mud flats and mangroves has shown the most increment compared to other coastal features in Narara Island.

The area estimated from the Land use map of Poshitra island in the year 2019 is around 1,525.3 ha. In Poshitra island also area covered by corals has decreased by 3% during last 20 years. Major decrease in past two decades has been noticed in mudflats of reef ecosystem amongst all coastal features. Whereas sandy area in the reef of Poshitra has increased by 3 hectares and same in the case of mangroves also, total area coverage of their diversity has been increased by approximately 5 hectares.

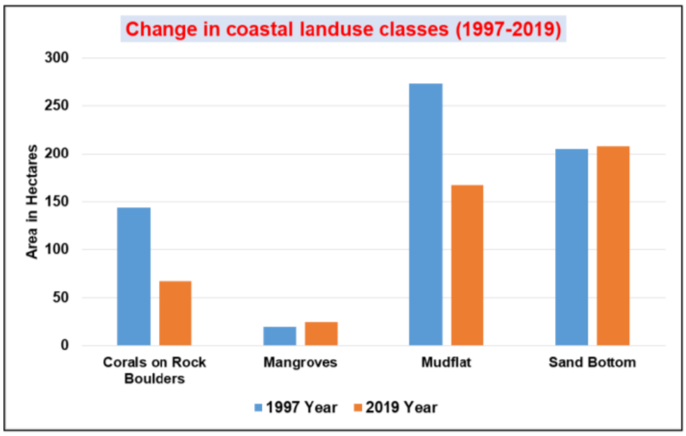

Figure 6: Change in area of coastal landcover classes (Poshitra Island)

All though Poshitra is much protected area, the results of Land Use-Land cover mapping indicate the decrease in overall cover of corals in both the study sites of Gulf of Kachchh since past 20 years. This may show the impact of various anthropogenic activities and natural phenomena like temperature rise due to global warming, Ocean acidification, sea level rise, El Niño and La Niña etc.

Generation of Inverse Distance Weighting (IDW) Index

Spatial diversity distribution of coral species has been studied using the IDW technique. The purpose of the IDW is to show continues species distribution of the coral species even in the area from where In-Situ data has not been collected.

Narara:

Reef area in Narara is mainly rocky and is little bit covered under the water even in low tide timings. Northern part of this reef (site 1) is facing towards the sea with the sudden steppe as go towards the southern site the area is becoming flat and less rocky.

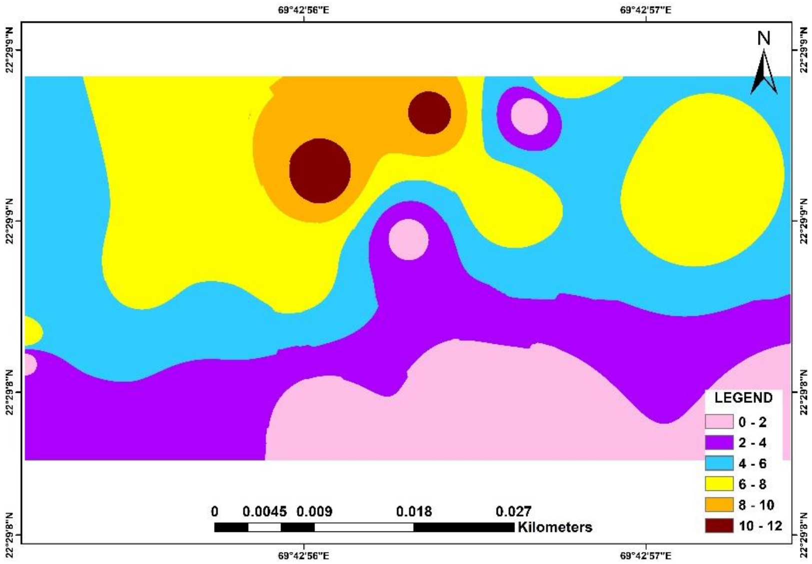

Figure 7: IDW maps with legend denoting number of species of Narara (Site 1)

With the help of generated IDW it is clearly shown that, diversity of coral species in site 1 was more uniformly distributed in the northern part of the site which is mainly rocky and under water most of the time. Thus, it can be said that this kind of geo morphology is more suitable for corals to grow and survive.

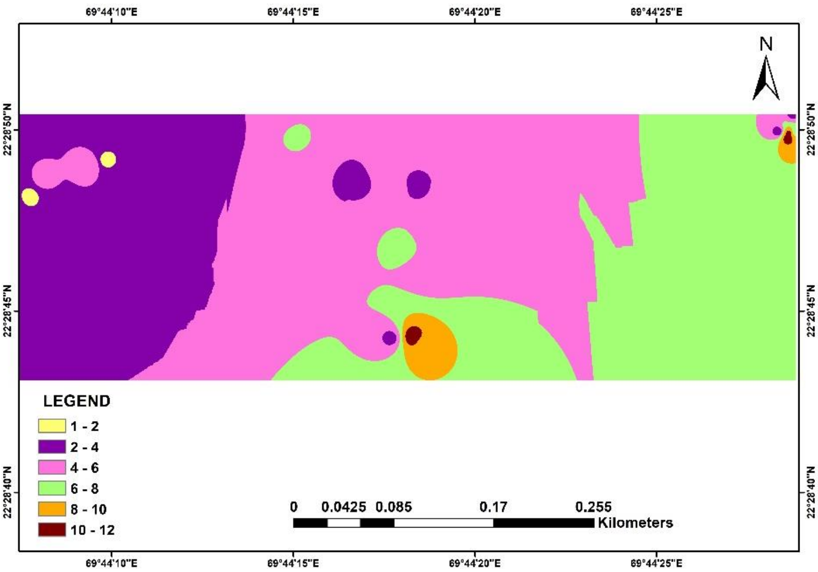

Figure 8: IDW maps with legend denoting number of species of Narara (Site 2)

Second site at Narara was in the shape of horseshoe with little bit higher elevation which creates kind of small waterfall like structure in that area. Right hand side of the IDW map shows the area near the edges of the waterfall. As we go towards the left-hand side, the elevation of area is much flatter and away from the waterfall. Thus, the generated IDW shows that coral species are more diverse and more homogeneously distributed near the area of waterfall.

Poshitra:

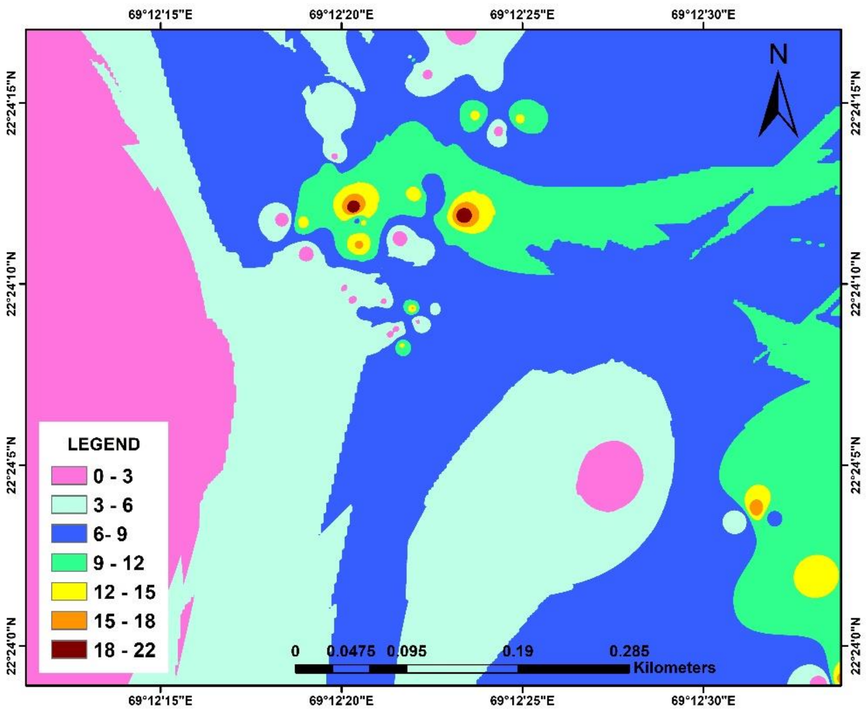

Figure 9: IDW maps with legend denoting number of species of Poshitra

At Poshitra, Laku point was selected as a study area which is highly protected reef in Marine National Park and Sanctuary (MNP&S). Here, different tide pools maintain the temperature which is suitable to the corals. It also helps to maintain a minimum water level during low tide timing, so that there are lesser chances of corals to be fully exposed to the atmosphere. Thus, corals at Laku point are more diverse and distributed evenly throughout the site. It can be concluded that reef at Poshitra is more suitable habitat for corals to survive and multiply with much better health. So, if the favourable environmental conditions can be maintained by the local authorities, coral diversity can be protected and also can be increased in terms of species richness and abundance.

Generation of Spectral Signatures

Spectral signatures of different coastal classes were generated in all the four bands namely red, green, blue and NIR to differentiate each class by their spectral value.

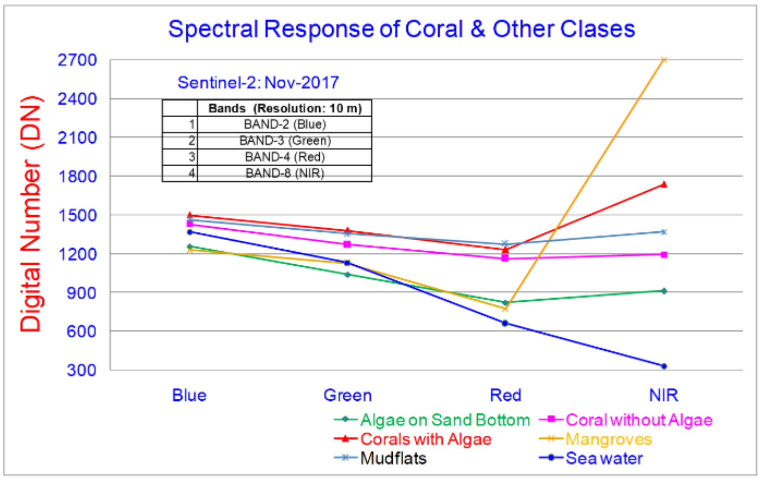

Figure 10: Spectral response of Land-Use classes in Sentinel-2 satellite image

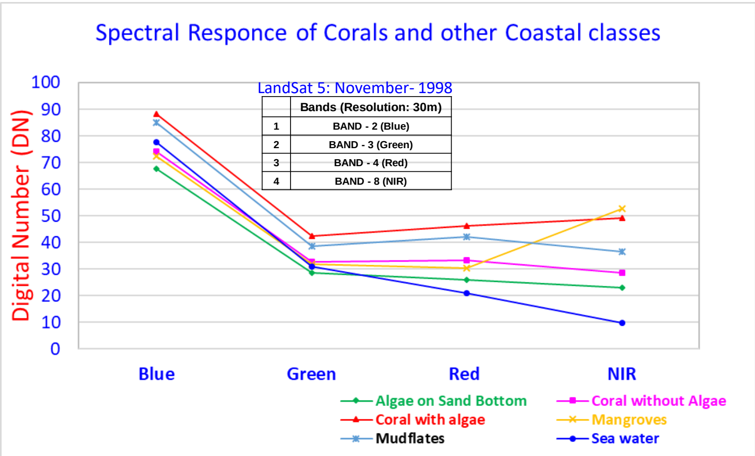

Figure 11: Spectral response of Land-Use classes in LandSat-5 satellite image

Because of the resolution and pixel variation in Landsat and Sentinel-2 image, there is a huge difference in DN values in both the images. But, the behavioral pattern of different coastal classes is same in all bands of different satellite images. Based on the graphs (Fig. 10 & 11) of different classes, it can be clearly concluded that polygons generated on image for particular coastal class were correct according to In-Situ data and measurements and all the coastal classes can be identify separately on Landsat and Sentinel-2 images by their spectral signature values in different bands.

Generation of Coral Indices

Different band ratios for both the Landsat-5 and Sentinel-2 images have been generated to find out band ratios which are sensitive to Corals and Algae. According to study, ratios which differentiate Corals with its associated Algae are ratios with NIR band. Which shows that there is difference between absorption and reflection values in NIR band for different images is different because of the resolution but pattern is almost same.

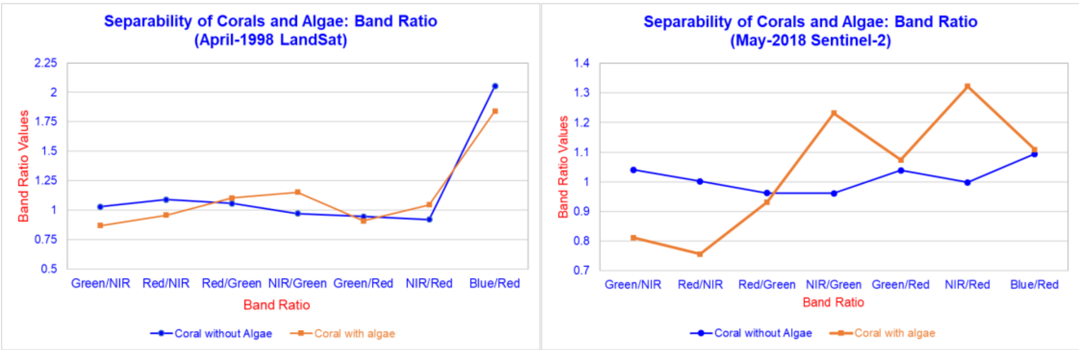

Figure 12: Spectral response of corals and algae in different Band Ratio

Red/Green and Green/Red ratios can also be used for separability of corals with its associated algae as red band absorbing band and green band will be reflected for the vegetation. Same as green band, NIR band also shows reflection for vegetation but with the greater magnitude. As there is less water column it is not showing absorption in the NIR band. Thus, the band ratios with NIR band in this study are more useful to differentiate corals with its associated algae than the band ratios with the combination of green bands.

Based on the spectral band ratio, spectral normalized difference indices are also generated for different Coastal classes. As the purpose of the study is to identify the indices sensitive to differentiate Corals and Algae, focus was to generate graphs showing comparison between Coral with Algae and Corals without Algae for different spectral indices.

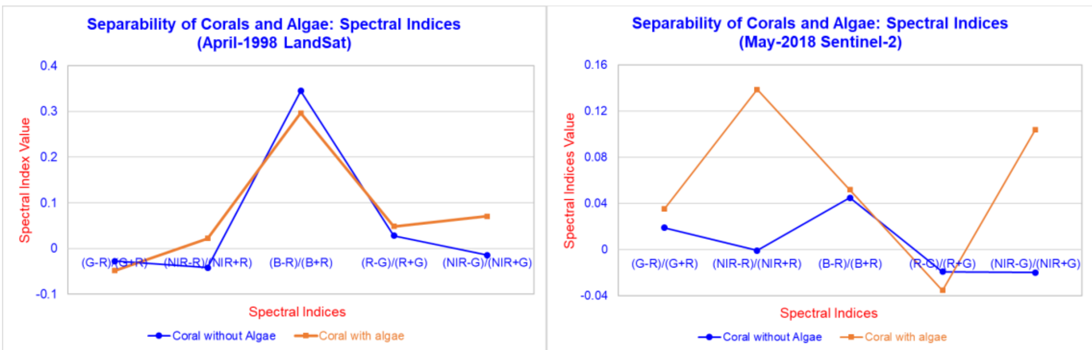

Figure 13: Spectral response of corals and algae in different Coral Indices

Same as band ratios, spectral indices with NIR band shows more accuracy to differentiate both the classes.

Remotely sensed spectral indices have been used in a range of environments for estimating properties coastal features. Thus, development of spectral reflectance library of common reef benthic features is useful concept to identify different benthic features from the satellite images only.

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