# CHAPTER 4: RESULT & DISCUSSION

This chapter describes all the processes done to achieve the successful outcome of described objectives. This chapter introduces models and many other methods obtained as well as their performance with site comparison and also with using a review of similar studies as the basis of discussion. Starting from the coastal land-use classification, overall work done, discussion on the results, found limitations, and proposed future work are provided in this chapter.

### 4.1 Coastal Land-Use Classification

Mapping of different coastal land use classes from satellite data covering study area was done to map the change during the last decade. Mapping was done using open source QGIS image processing software. Process in detail has been explained in methodology section (3.4). Maps of coastal land use mapping of both the sites for the year 2010 to 2022 are given bellow.

From the FCC image, different coastal classes like corals on rock boulders, sparse corals, seaweeds, mangroves and algae on sand or mud bottom etc. were identified and on-screen digitization was carried out to generate the land use map of various coastal features. Landsat-5 satellite image of the year 2010 was also used to generate coastal land use map of the same year and also for the comparison with year 2022 to detect the change in reef cover area.

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 2022, 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.

The results indicate that area of sparse coral and corals on rock has reduced during 2022 as compared to 2010. 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 2010. On an average, most of the area of the reef ecosystem of Narara has been covered by mud flats followed by mangroves. In past 12 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.

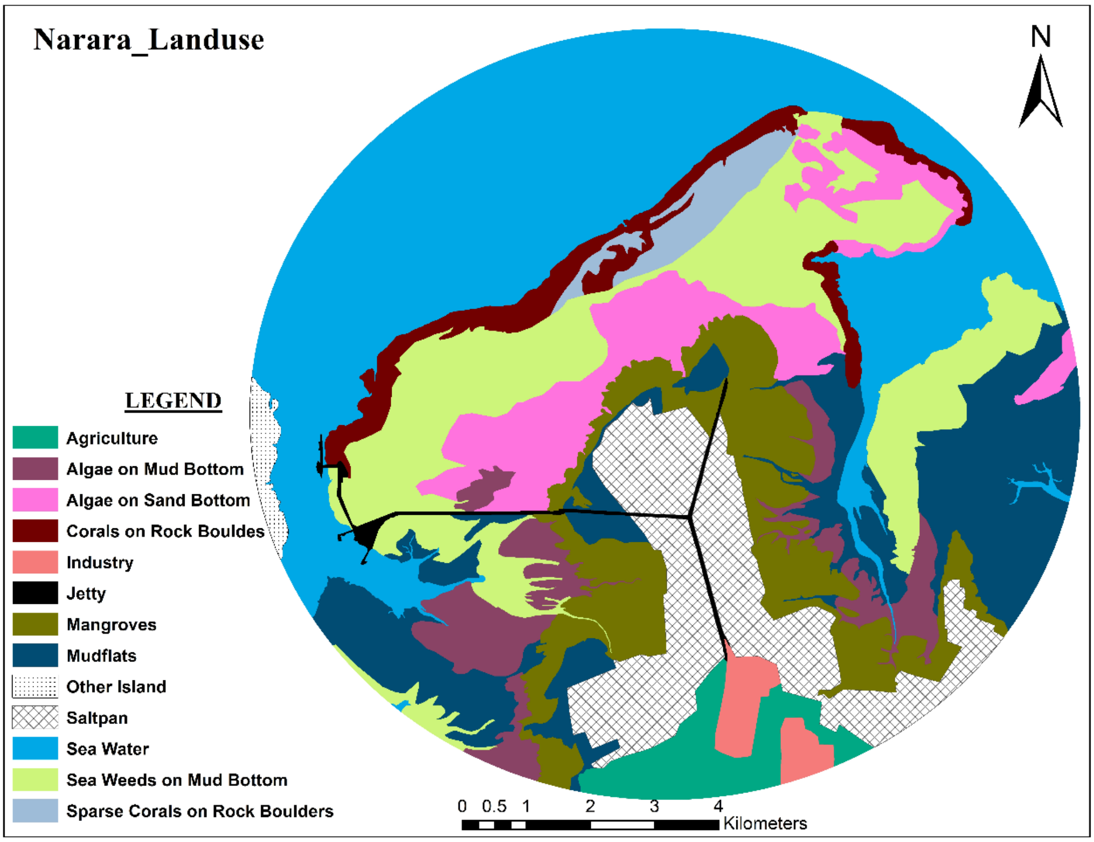



**Figure 23:** Land-Use classification of Narara

Total area under various coastal classes was calculated to find out the total area covered by coral reef in Poshitra, from the coastal land use maps. The area estimated from the Land use map of Poshitra in the year 2022 is around 1,525.3 ha. In Poshitra Island also area covered by corals has decreased by 3% during last 12 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. All though Poshitra is much protected area when it comes to anthropogenic activities, decrease in the reef diversity shows environmental impacts of climate change and increase in temperature in past 12 years in Poshitra.

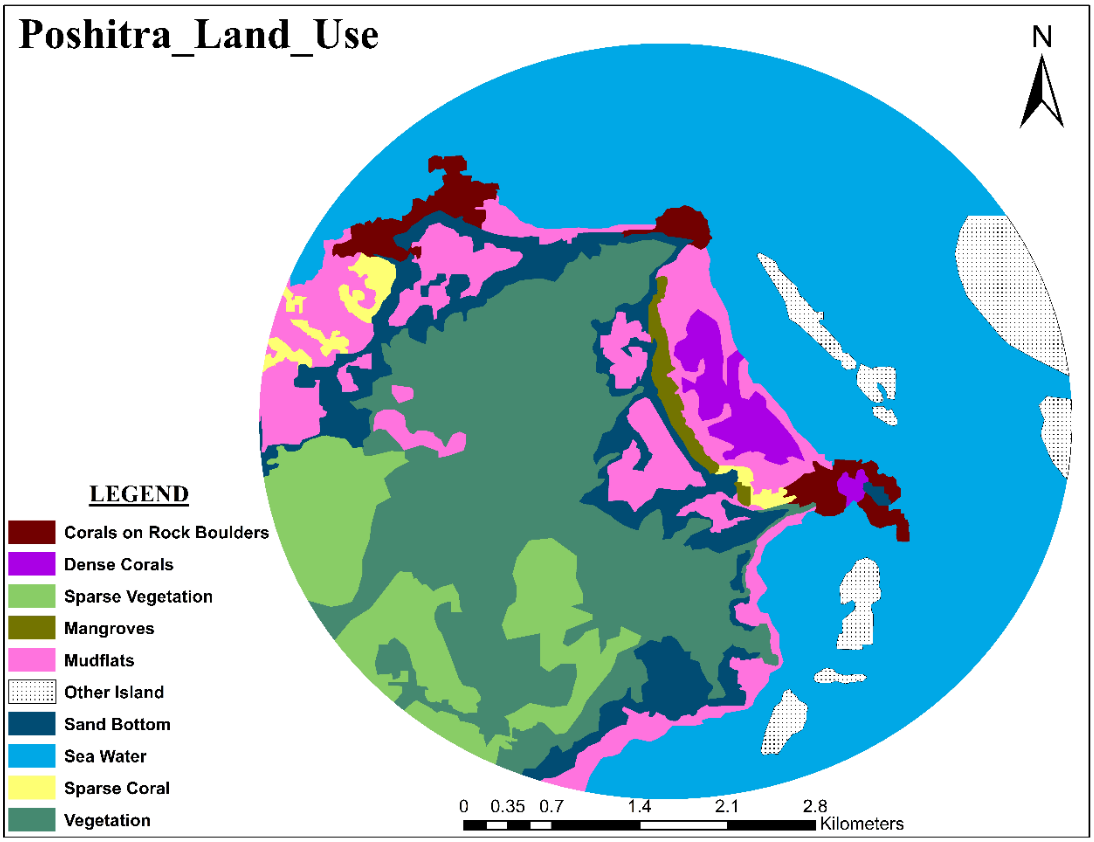



**Figure 24:** Land-Use classification of Poshitra

### 4.1.1. Species Diversity Distribution

During the field visit, coral species from 22 deferent genera were observed from both the Narara and Poshitra. In Narara, coral colonies of total 14 different genera were recorded while in Poshitra total 18 genera of coral species were recorded. The genus wise diversity distribution maps of both the Narara and Poshitra has been attached in appendix (1).

The results of species diversity distribution mapping indicates that more anthropogenic and tourist activities at Narara reef have 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 found at Poshitra are in much bigger boulders. The number of species are also more at Poshitra as compared to Narara reef.

## 4.2 Description of coral species

Corals are marine invertebrates within the class Anthozoa of the phylum Cnidaria. They typically form compact colonies of many identical individual polyps. Coral species include the important reef builders that inhabit tropical oceans and secrete calcium carbonate to form a hard skeleton. In present study, several species of coral were identified and described using reference of "Hand book on hard corals of Gulf of Kachchh" (Satyanarayana and Ramakrishna, 2009) and their scientific name were opted from the World Register of Marine Species (WoRMS).

***1.) Poritidae Gray,* 1840**

***Bernardpora* Kitano & Fukami, 2014**

***(a) Bernardpora stutchburyi* (Wells, 1955)**

**Characters:** Colonies are submissive to encrusting. Calices are small and shallow with crowded septa giving colonies a smooth surface. Polyps have short tapered tentacles which are often extended during the day.

**Colour:** Usually pale brown or cream, sometimes with pale blue mouths.

***2.) Porites Link,* 1807**

***(a) Porites compressa* Dana, 1846**

Characters: Colonies may form large patches of reefs. Branches are cylindrical and commonly fuse. Growth-forms and corallite characters are extremely variable so much so that single reef patches are composites of distinct races.

Colour: Mostly dull greys and browns.

*Porites harrisoni* Veron, 2000

**Characters:** Colonies are usually less than one metre across. They have a wide range of sub-massive, nodular, columnar and branching growth-forms on a broad encrusting base.

**Colour:** Commonly dark brown, also pink or blue.

***(b) Porites hawaiiensis* Vaughan, 1907**

**Characters:** Colonies are small (<100 mm diameter), encrusting. Corallites are small (<0.7 mm diameter), not moderately space, and have the same septal configuration as P. rus. The consteum is covered with distinctive spinules.

**Colour:** Mottled yellow and green-brown.

***(c) Porites lichen* (Dana, 1846)**

**Characters: Colonies are flat laminae or plates, or fused nodules and columns. Corallites are commonly aligned in irregular rows separated by slight ridges. Septal structures are variable and irregular.**

**Colour:** Usually bright yellowish-green, sometimes brown.

***(d) Porites lutea* Milne Edwards & Haime, 1851**

**Characters:** Colonies are hemispherical or helmet-shaped and may be over 4 metres across. They usually form 'micro-atolls' in intertidal habitats. The surface is usually smooth.

**Colour:** Usually cream or yellow but may be bright colours in shallow water.

***(e) Porites solida* (Forskål, 1775)**

**Characters:** Colonies are massive, usually hemispherical, and may be several metres across. The surface is smooth to undulating. Corallites are conspicuously large.

**Colour:** Brown or greenish yellow.

***3.) Goniopora* de Blainville, 1830**

***(a) Goniopora columna* Dana, 1846**

**Characters:** Colonies are short columns, oval in transverse section. Corallites near the tops of columns have fine irregular septa and diffuse columellae. Those on the sides of columns have broad compact columellae and short septa. Colonies have large polyps with large oral cones.

**Colour:** Brown, green or yellow, usually with white oral cones. Contracted polyps usually have distinctly different colours.

***(b) Goniopora djiboutiensis* Vaughan, 1907**

**Characters:** Colonies are submassive or are short thick columns. Columellae are prominent, dome-shaped, and commonly divided into six parts, each part having a deltaic pattern of four septa. Polyps have large oral cones.

**Colour:** Pale or dark brown or green. Oral cones are usually white or blue (which may photograph pink).

***(c) Goniopora lobata* Milne Edwards, 1860**

**Characters:** Colonies are hemispherical or, more usually, form short thick columns. Columellae and oral cones are small. Polyps are elongate when fully extended.

**Colour:** Usually brown, yellow or green, often with contrasting oral cones and tentacle tips.

***(d) Goniopora pendulus* Veron, 1985**

**Characters:** Colonies are hemispherical. Columellae are large. Polyps are large, with drooping tentacles.

**Colour:** Brown or greenish-brown.

***(e) Goniopora pedunculata* Quoy & Gaimard, 1833**

Characters: Encrusting or domed, calices 3-5mm in diameter, extended tentacles (2) short, brown or dark green, small oral cones and tentacle tips white or pink. Indo-Pacific excluding Hawaii.

Colour: Brown or dark green coloured

***(f) Goniopora planulata* (Ehrenberg, 1834)**

**Characters:** Colonies are submassive with small compacted columns or mounds. Corallites have thin walls. Septa are thin and irregular and do not form deltas except in colonies in very shallow water. Paliform lobes form a diffuse crown. Polyps are short with tentacles of uniform length.

**Colour:** Dark grey-brown, usually with white mouths.

***4.) Merulinidae* Milne Edwards & Haime, 1857**

***Coelastrea* Verrill, 1866**

#### *(a) Coelastrea aspera* (Verrill, 1866)

**Characters:** Colonies are massive to encrusting. Corallites are angular in shape and have thick walls. Long and short septa generally alternate. Paliform lobes are well developed in colonies from turbid water but may be absent in colonies from exposed habitats.

**Colour:** Usually pale brown. Corallite centres are often cream.

### *5.) Goniastrea* Milne Edwards & Haime, 1848

#### *(a) Goniastrea pectinata* (Ehrenberg, 1834)

**Characters:** Colonies are submassive or encrusting. Corallites are cerioid to submeandroid. The latter usually have less than four centres. Walls are thick, paliform lobes are well developed.

**Colour:** Usually pale brown or pink but may be dark brown in deep or turbid water.

#### (b) *Goniastrea thecata* Veron, DeVantier & Turak, 2000

**Characters:** Colonies are massive and more than one metre across. Corallites are irregular in shape, with 1-3 centres. Walls are thick. Septa are evenly spaced and strongly alternate with short septa developed only near the corallite rim. Paliform lobes are poorly developed or absent. Columellae form distinct centres. Fleshy polyp tissue forms a distinctive rim above the theca giving a subplocoid appearance.

**Colour:** Steel grey.

### *6.) Hydnophora* Fischer von Waldheim, 1807

#### *(a) Hydnophora exesa* (Pallas, 1766)

**Characters:** Colonies are submassive, encrusting, or sub arborescent. Much of this variation may occur in the same colony but some colonies are composed only of encrusting plates. Hydnophores are 5-8 millimetres diameter. Tentacles are often extended day and night; they are long and shaggy and of uniform length.

**Colour:** Cream or dull green.

### *7.) Platygyra* Ehrenberg, 1834

***(a) Platygyra pini* Chevalier, 1975**

**Characters:** Colonies are generally massive. Corallites are monocentric or form short valleys. Walls are thick, with rounded edges. Septa are thin and evenly spaced. There may be some development of columella centres and/or paliform lobes.

**Colour:** Usually grey- or yellow-brown with green or cream valley floors.

**(b) *Platygyra sinensis* (Milne Edwards & Haime, 1849)**

**Characters:** Colonies are massive or flat and usually fully meandroid, with thin walls. Septa are thin and slightly exsert. Columellae are weakly developed and there are no columella centres.

**Colour:** Variable dull or bright colours.

***8.) Cyphastrea* Milne Edwards & Haime, 1848**

***(a) Cyphastrea serailia* (Forskål, 1775)**

**Characters:** Colonies are massive or encrusting to columnar, with a smooth or hillocky surface. Corallites are rounded and equal in size. Costae do not alternate strongly. There are 12 primary septa.

**Colour:** Usually uniform or mottled grey, brown or cream.

***9.) Favites* Link, 1807**

***(a) Favites chinensis* (Verrill, 1866)**

**Characters:** Colonies are massive and rounded. Corallites are shallow, angular to subplocoid, with thin walls. Septa are straight and even. Those of adjacent corallites are aligned across the wall. There are no paliform lobes.

**Colour:** Usually yellow or greenish-brown.

***(b) Favites complanata* (Ehrenberg, 1834)**

**Characters:** Colonies are massive with slightly angular corallites. Corallites have thick, rounded walls. Paliform lobes are weakly developed. Columellae are large. Septal spines may be prominent. Costae commonly form a three-pointed star where three corallites adjoin.

**Colour:** Usually brown, sometimes with green or grey oral discs.

***(c) Favites flexuosa* (Dana, 1846)**

**Characters:** Colonies are hemispherical or submassive. Corallites are angular and deep. Septa are prominent, with large conspicuous teeth. Paliform lobes are weakly developed.

**Colour:** A wide range, usually with contrasting walls and oral discs.

***(d) Favites halicora* (Ehrenberg, 1834)**

**Characters:** Colonies are massive, either rounded or hillocky. Corallites have very thick walls and tend to become subplocoid. Paliform lobes may be developed.

**Colour:** Usually uniform pale yellowish- or greenish-brown.

***(e) Favites melicerum* (Ehrenberg, 1834)**

**Characters:** Colonies are submassive to encrusting. Corallites are thick walled and rounded, becoming subplocoid. Septa are few in number, uniform in height and are usually in two (alternating) orders. Paliform lobes and columellae are well developed.

**Colour:** Browns and greens, usually with contrasting walls and centres.

**(f) *Favites pentagona* (Esper, 1790)**

**Characters:** Colonies are submassive to encrusting, sometimes forming irregular columns. They commonly exceed one metre across. Corallites are thin walled and angular. Septa are few. Paliform lobes are well developed, commonly forming a conspicuous crown.

**Colour:** Often brightly coloured, brown or red, commonly with green oral discs.

***10.)* *Dipsastraea* Blainville, 1830**

***(a) Dipsastraea favus* (Forskål, 1775)**

**Characters:** Colonies are massive, rounded or flat. Corallites are conical. Septa are slightly irregular and widely spaced. Paliform lobes are poorly developed.

**Colour:** A wide variety, often mottled, with pale calices.

***(b) Dipsastraea speciosa*** **(Dana, 1846)**

**Characters:** Colonies are massive. Corallites are circular and closely compacted in shallow water, more widely spaced in deeper water. Septa are fine, numerous and regular. Paliform lobes are usually poorly developed.

**Colour:** Pale grey, green or brown, usually with calices of contrasting colours.

***11.) Mycedium*** **Milne Edwards & Haime, 1851**

***(a) Mycedium elephantotus*** **(Pallas, 1766)**

**Characters:** Colonies are laminar or encrusting. Corallites are up to 15 millimetres diameter and nose-shaped, facing outward towards the colony perimeter. Septa and columellae are well developed and costae form outwardly radiating ribs on the colony surface which may become highly elaborated on corallite walls. The coenosteum is never pitted at the commencement of new septo-costae. Tentacles are usually extended only at night.

**Colour:** Usually a uniform brown, grey, green or pink but may have green, white or red oral discs. Colonies may have distinctively coloured margins.

***12.) Plesiastreidae*** **Dai & Horng, 2009**

***Plesiastrea*** **Milne Edwards & Haime, 1848**

***(a) Plesiastrea versipora*** **(Lamarck, 1816)**

**Characters:** Colonies are flat and are frequently lobed, up to 3 m across in high latitude localities, usually smaller in the tropics. Corallites are 2-4 mm diameter. Paliform lobes form a neat circle around small columellae. Tentacles are sometimes extended during the day; they are short and are of two alternating sizes.

**Colour:** Yellow, cream, green or brown, usually pale colours in the tropics and bright colours (green or brown) in high latitude areas.

***13.) Acroporidae*** **Verrill, 1901**

***Montipora*** **Blainville, 1830**

***(a) Montipora monasteriata*** **(Forskål, 1775)**

**Characters:** Colonies are massive or are unifacial or bifacial thick plates which may be tiered in large colonies. Corallites are mostly immersed. The coenosteum is covered with papillae and/or tuberculae.

**Colour:** Pale brown or blue (which may photograph pink), with blue or white margins.

***(b) Montipora explanate* Brüggemann, 1879**

Characters: Colonies are encrusting and with small gibbosites on the surface. Calices less than 1 mm in diameter. Irregular in outline and crowded. Primary septa well developed. Second cycle usually not seen. Coenchme reticulate with small spines and sometimes with round topped tubercles. It is characterised by the presence of scattered low tubercles though it is essentially a glabrous form.

***14.) Dendrophylliidae* Gray, 1847**

***Duncanopsammia* Wells, 1936**

***(a) Duncanopsammia peltata* (Esper, 1790)**

**Characters:** Colonies are flat laminae often forming overlapping tiers. They are sometimes columnar. They may be several metres across. Corallites are immersed to tubular and average 6 millimetres diameter. Polyps are large and tentacles are usually extended during the day.

**Colour:** Usually grey or brown.

***15.) Turbinaria* Oken, 1815**

***(a) Turbinaria mesenterina* (Lamarck, 1816)**

Characters: Colonies are composed of wtifacial laminae, which are highly contorted. Fronds more vertical than horizontal, amount of folding vary greatly and can form d n rna f folds and tubes, less convoluted (and corallites more tubular than conical) in deeper water or less light. Corallites, are crowded, slightly exsert, 2.5-3.5 nun, tubular or conical, calices 1.3-2.0 mm, usually protuberant and strongly inclined i.e., vertical, older corallites deeply embedded to smooth.

***(b) Turbinaria reniformis* Bernard, 1896**

**Characters:** Colonies are composed of unifacial laminae sometimes forming tiers which are mostly horizontal. Corallites are widely spaced, thick walled, immersed to conical in shape and average 2.5 millimetres diameter.

**Colour:** Usually yellow-green with distinctly coloured margins.

***16.)*** **Lobophylliidae Dai & Horng, 2009**

***Lobophyllia*** **de Blainville, 1830**

***(a) Lobophyllia hataii*** **Yabe, Sugiyama & Eguchi, 1936**

**Characters:** Colonies are flabello-meandroid at the periphery, and submeandroid at the centre. Valleys are shallow, with flat floors. Columellae are usually in two rows except at valley ends, or are distributed evenly on flat areas.

**Colour:** Usually brown or green. Valley floors and walls are usually of contrasting colours.

***(b) Lobophyllia radians*** **(Milne Edwards & Haime, 1849)**

**Characters:** Colonies are hemispherical to flat. Valleys average 20-25 millimetres wide, and are irregularly meandroid, becoming straight in flat colonies. Walls have a moderately thick fleshy appearance and usually have a groove along the top.

**Colour:** A wide range of red, grey and green, with valleys and walls usually of contrasting colours. Red Sea colonies are usually cream.

***17.)*** ***Homophyllia*** **Brüggemann, 1877**

***(a) Homophyllia bowerbanki*** **(Milne Edwards & Haime, 1857)**

**Characters:** Colonies are cerioid and usually small but sometimes over 1.5 metres across. Corallites have irregular shapes and sometimes form short valleys with several centres. Colonies have moderately fleshy tissue over the skeleton.

**Colour:** Red, cream and brown, with walls and oral discs of contrasting colours; sometimes mottled.

***18.)*** **Rhizangiidae d'Orbigny, 1851**

***Pseudosiderastrea*** **Yabe & Sugiyama, 1935**

***(a) Pseudosiderastrea tayamai*** **Yabe & Sugiyama, 1935**

**Characters:** Colonies are encrusting to slightly dome-shaped and up to 160 millimetres across. Corallites are cerioid, polygonal and 3-6 millimetres diameter. Septa are evenly spaced and usually fuse with each other in fan-like groups. They have fine, saw-like teeth. Columellae consist of one to four pinnules.

**Colour:** Pale grey with distinctive white corallite walls. Uniform brown in the western Indian Ocean.

***19.) Siderastrea*** **Blainville, 1830**

***(a) Siderastrea savignyana*** **Milne Edwards & Haime, 1849**

**Characters:** Colonies are encrusting or are low mounds up to one metre across. Corallites are polygonal, 2-4 millimetres diameter. Septa are neatly arranged: 30-35 at the wall, fusing in neat fan-like groups so that 10-15 fuse with the columella. Walls have a fine ridge along their tops.

**Colour:** Pale tan or with dark centres and white corallite walls.

***20.) Leptastreidae*** **Rowlett, 2020**

***Leptastrea*** **Milne Edwards & Haime, 1849**

***(a) Leptastrea purpurea*** **(Dana, 1846)**

**Characters:** Colonies are generally flat with angular, cerioid corallites which vary in size within the same colony. Colonies on reef flats may have several corallites in shallow valleys. Septa are tightly compact, approximately similar in size, and have margins that slope uniformly towards the corallite centre. Columellae are small and compact.

**Colour:** Usually pale yellow, greenish or cream on the upper surface and dark sides.

***21.) Nephtheidae*** **Gray, 1862**

***(a) Dendronephthya*** **Kükenthal, 1905**

***22.) Lobophytum*** **Marenzeller, 1886**

***(a) Lobophytum pauciflorum*** **(Ehrenberg, 1834)**

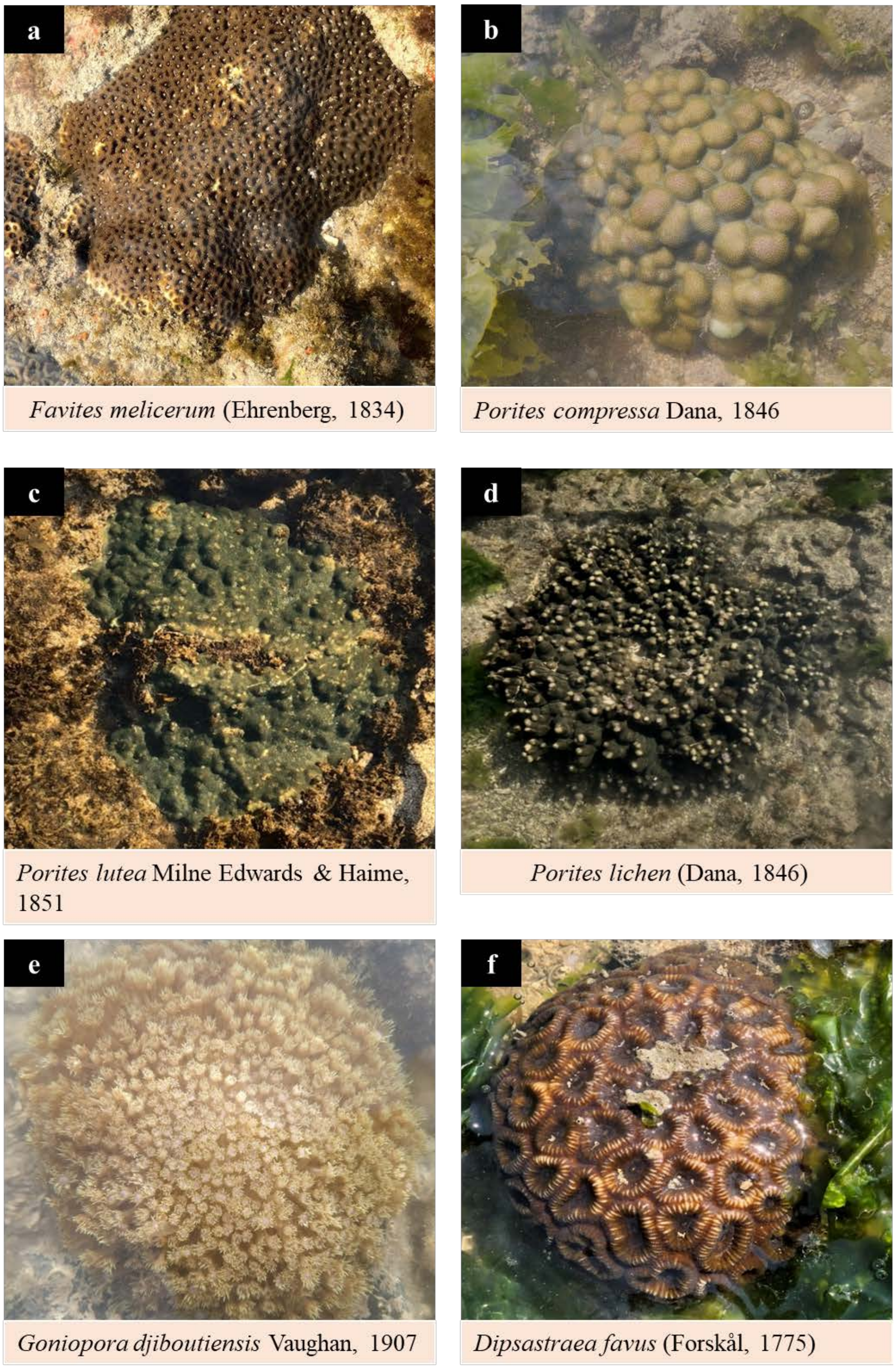
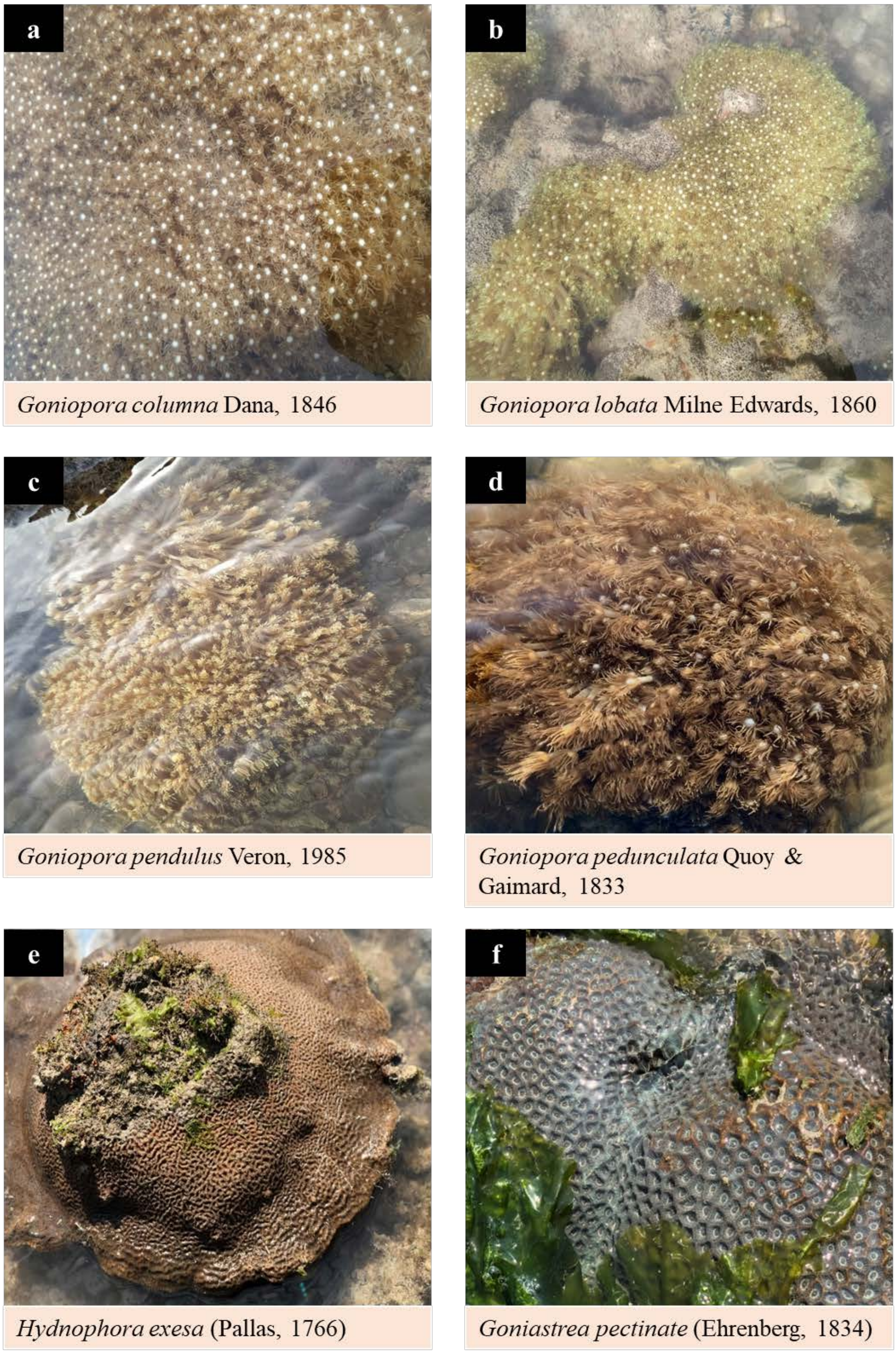
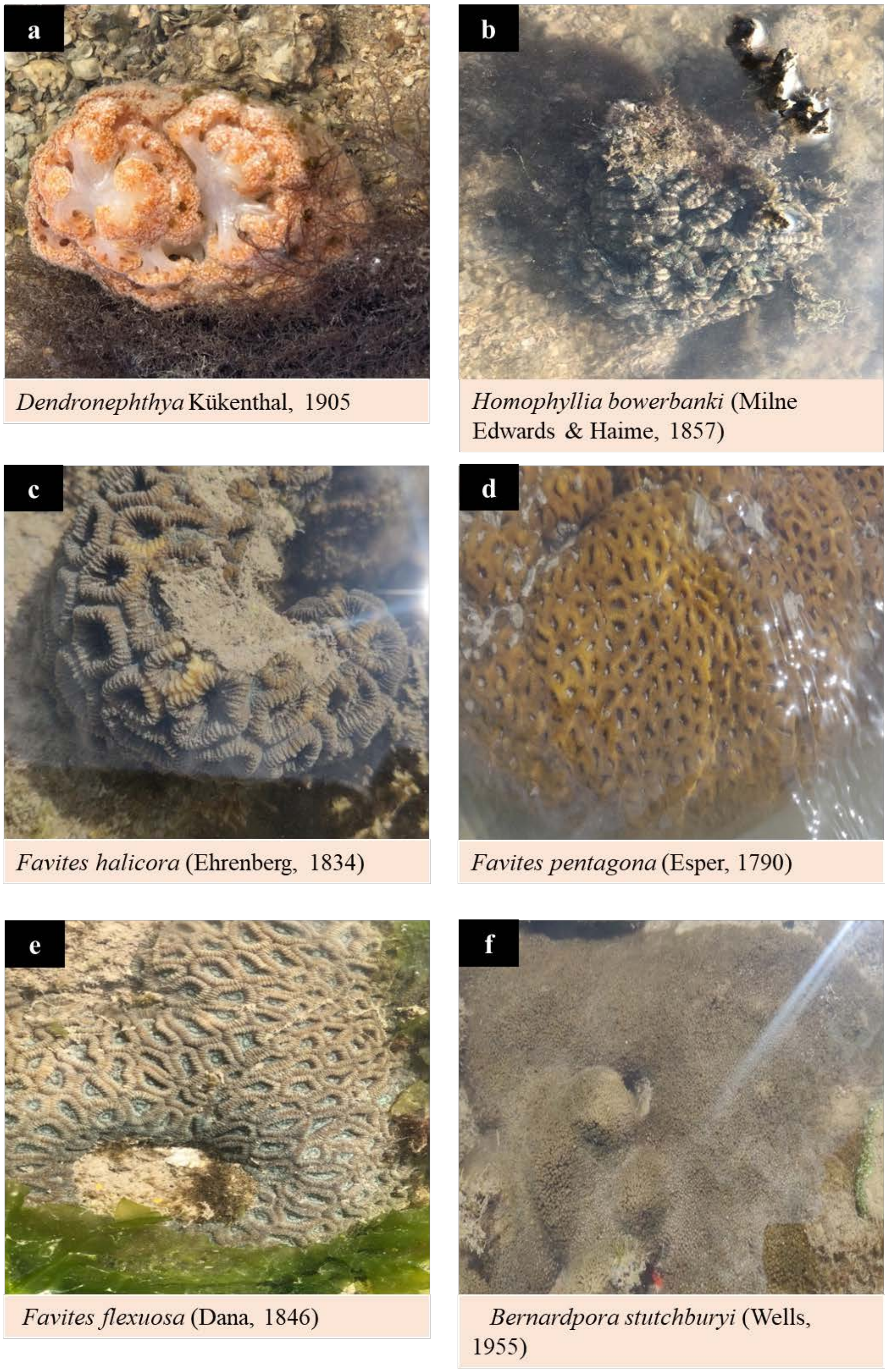



**Figure 25**: (a) *Favites melicerum* (Ehrenberg, 1834), (b) *Porites compressa* Dana, 1846, (c) *Porites lutea* Milne Edwards & Haime, 1851, (d) *Porites lichen* (Dana, 1846), (e) *Goniopora djiboutiensis* Vaughan, 1907, (f) *Dipsastraea favus* (Forskål, 1775)




(a) *Goniopora columna* Dana, 1846
(b) *Goniopora lobata* Milne Edwards, 1860
(c) *Goniopora pendulus* Veron, 1985
(d) *Goniopora pedunculata* Quoy & Gaimard, 1833
(e) *Hydnophora exesa* (Pallas, 1766)
(f) *Goniastrea pectinate* (Ehrenberg, 1834)

**Figure 26**: (a) *Goniopora columna* Dana, 1846, (b) *Goniopora lobata* Milne Edwards, 1860, (c) *Goniopora pendulus* Veron, 1985, (d) *Goniopora pedunculata* Quoy & Gaimard, 1833, (e) *Hydnophora exesa* (Pallas, 1766), (f) *Goniastrea pectinate* (Ehrenberg, 1834)




*Dendronephthya* Kükenthal, 1905

*Homophyllia bowerbanki* (Milne Edwards & Haime, 1857)

*Favites halicora* (Ehrenberg, 1834)

*Favites pentagona* (Esper, 1790)

*Favites flexuosa* (Dana, 1846)

*Bernardpora stutchburyi* (Wells, 1955)

**Figure 27**: (a) *Dendronephthya* Kükenthal, 1905, (b) *Homophyllia bowerbanki* (Milne Edwards & Haime, 1857), (c) *Favites halicora* (Ehrenberg, 1834), (d) *Favites pentagona* (Esper, 1790), (e) *Favites flexuosa* (Dana, 1846), (f) *Bernardpora stutchburyi* (Wells, 1955).

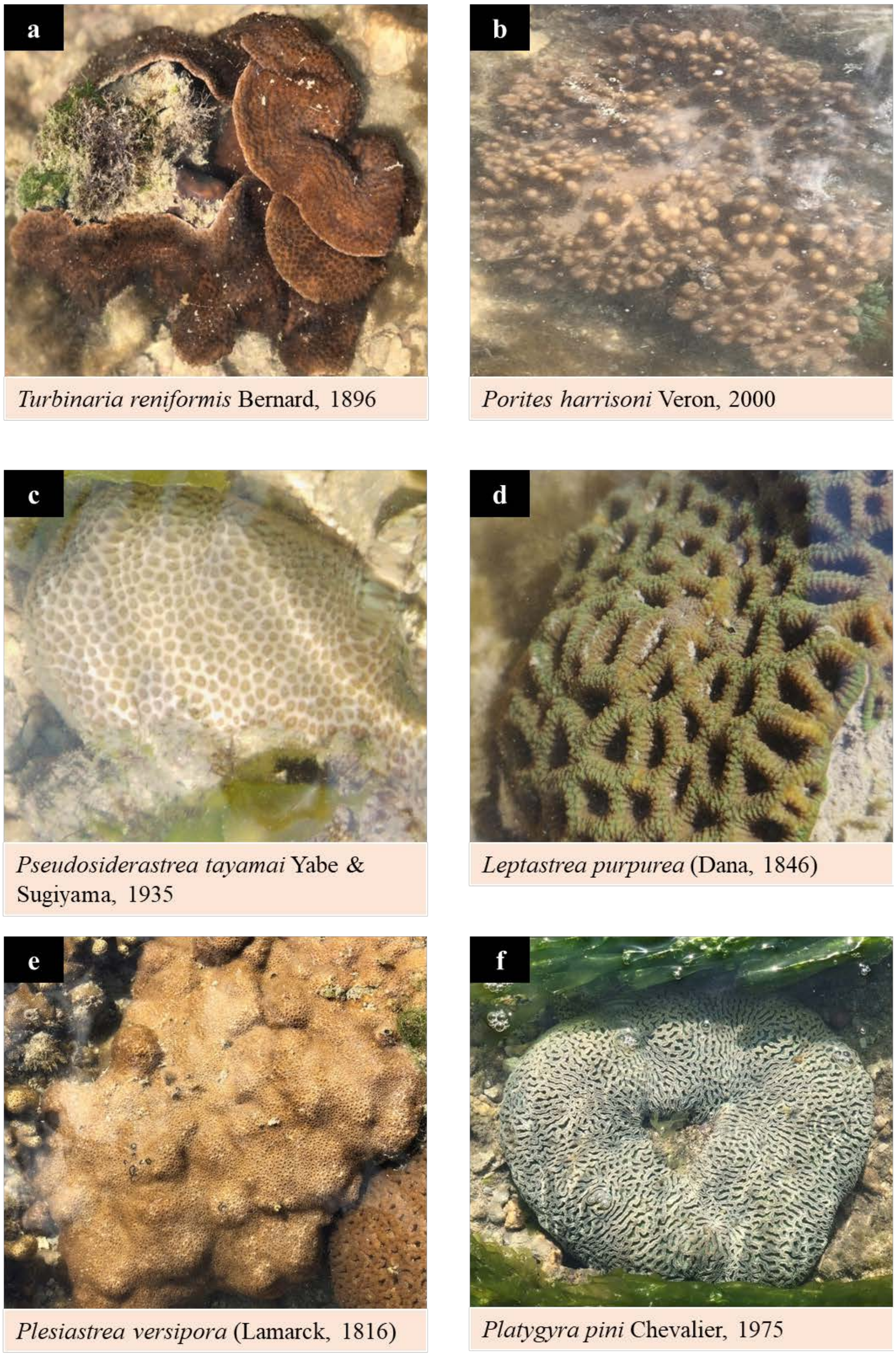



**Figure 28**: (a) *Turbinaria reniformis* Bernard, 1896, (b) *Porites harrisoni* Veron, 2000, (c) *Pseudosiderastrea tayamai* Yabe & Sugiyama, 1935, (d) *Leptastrea purpurea* (Dana, 1846), (e) *Plesiastrea versipora* (Lamarck, 1816), (f) *Platygyra pini* Chevalier, 1975.

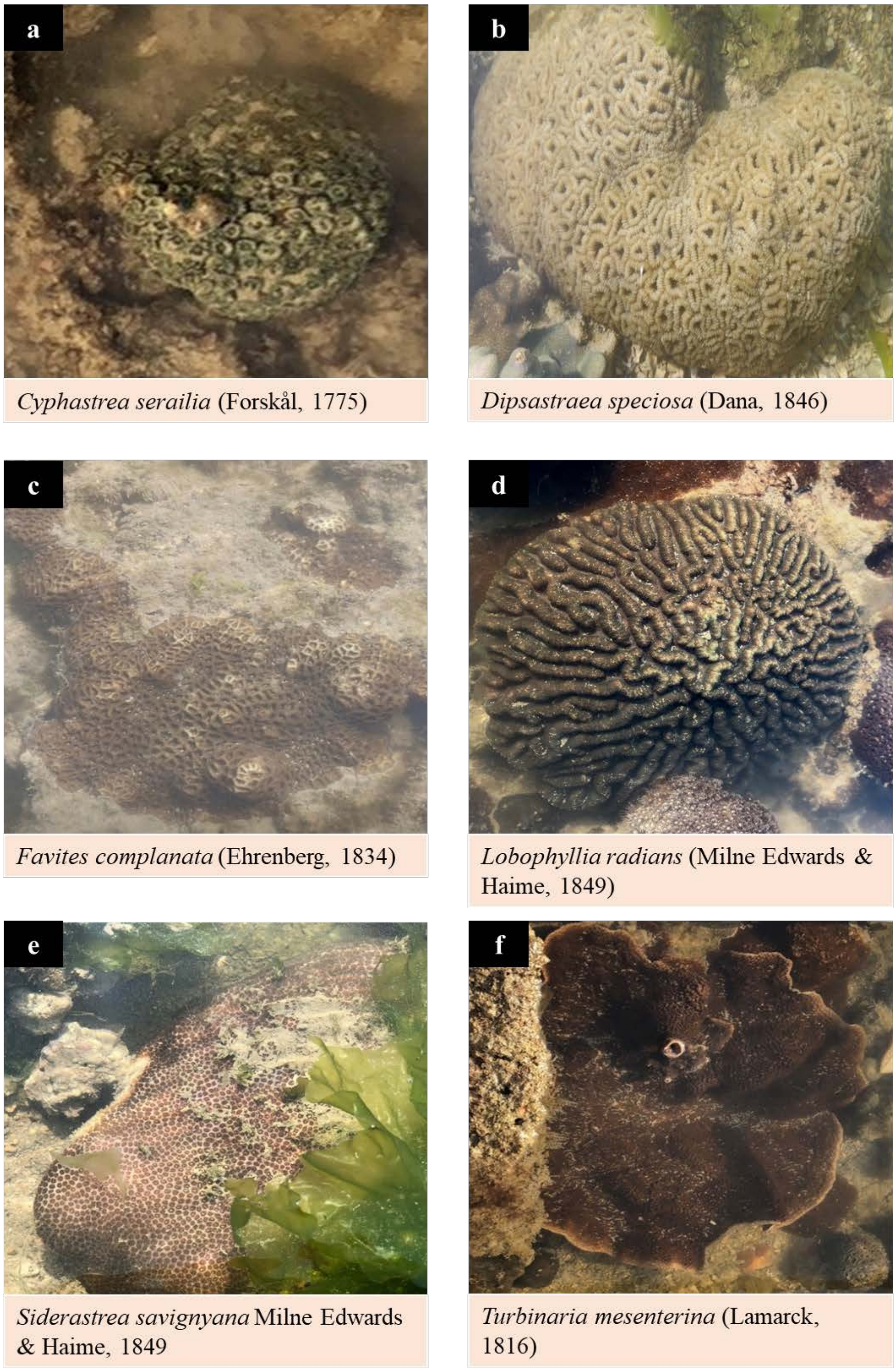



**Figure 29**: (a) *Cyphastrea serailia* (Forskål, 1775), (b) *Dipsastraea speciosa* (Dana, 1846), (c) *Favites complanata* (Ehrenberg, 1834), (d) *Lobophyllia radians* (Milne Edwards & Haime, 1849), (e) *Siderastrea savignyana* Milne Edwards & Haime, 1849, (f) *Turbinaria mesenterina* (Lamarck, 1816).

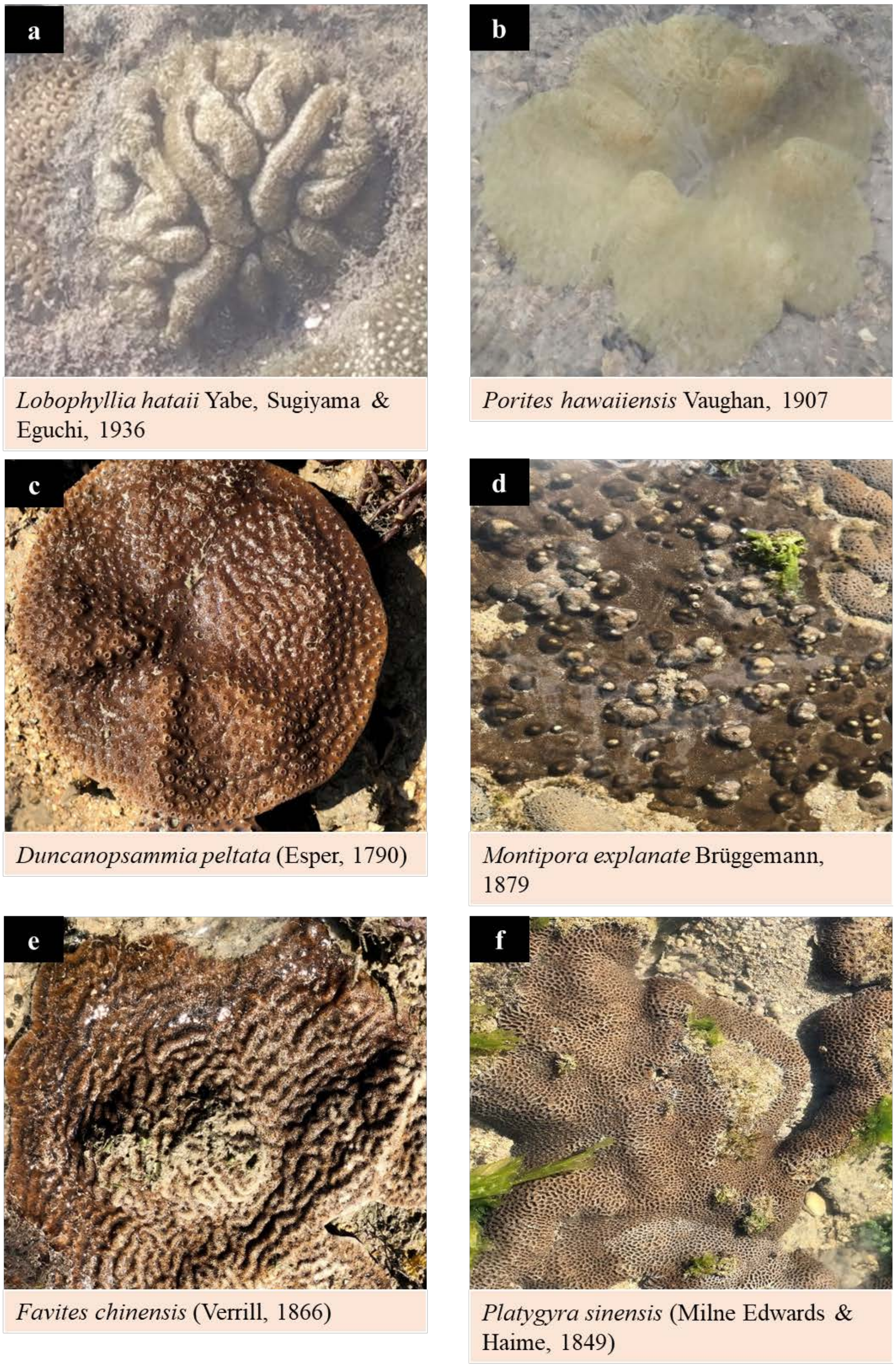
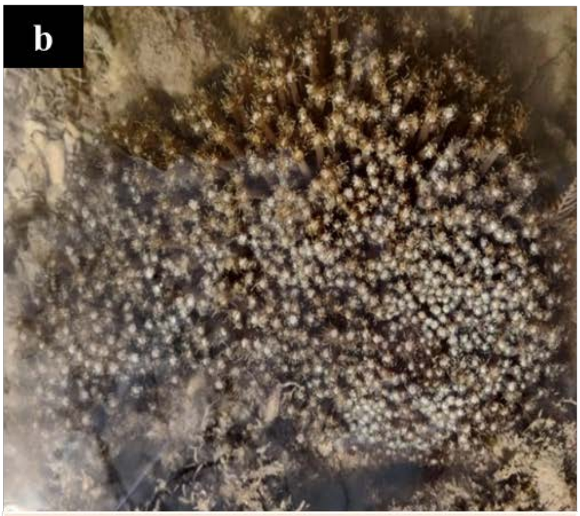



**Figure 30**: (a) *Lobophyllia hataii* Yabe, Sugiyama & Eguchi, 1936, (b) *Porites hawaiiensis* Vaughan, 1907, (c) *Duncanopsammia peltata* (Esper, 1790), (d) *Montipora explanate* Brüggemann, 1879, (e) *Favites chinensis* (Verrill, 1866), (f) *Platygyra sinensis* (Milne Edwards & Haime, 1849).


*Montipora monasteriata* (Forskål, 1775)




*Goniopora planulata* (Forskål, 1775)


*Favites flexuosa* (Dana, 1846)


*Lobophytum pauciflorum* (Ehrenberg, 1834)

**Figure 31**: (a) *Montipora monasteriata* (Forskål, 1775), (b) *Goniopora planulata* (Forskål, 1775), (c) *Favites flexuosa* (Dana, 1846), (d) *Lobophytum pauciflorum* (Ehrenberg, 1834).

## 4.3 Calculation of Bleaching Response Index (BRI)

During the visit was observed that, despite of leaving in the same environmental condition, coral colonies have a different response to different climatic conditions. Since the main focus of the study is to assess the impacts on coral reefs, the calculation of BRI at the genus level was found suitable.

In response to this concept, the health condition of coral colonies was studied using the CoralWatch coral health chart for both sites. As the reefs of Narara and Poshitra have different geographic features, site-specific calculation of BRI was found to be a better choice. Also, the presence of coral species in both sites was different, the calculation was done at the genus level. Following is the calculation of BRI for both sites for different years.

### (i) Calculation of BRI for Narara

As described in the methodology, all the surveyed colonies were divided based on the colour score with colour scores 1 and 2 being the most bleached corals and colour scores 5 and 6 being the healthy corals (Table: 2). After the segregation of colonies at the genus level for the summer season of 2019, coral colonies of a total of 278 coral colonies of 8 genus were counted for health assessment. Number of coral colonies less than 5 in one genus has not been included in BRI. The reason behind this is, it will the result bias by giving maximum percentage in one category only. As the abundance of *Favites* and *Dipsastraea* (previously known as *Favia*) is more at Narara, maximum number of colonies were found of these genera only. Out of 278, number of coral colonies with 70-100% is 38. Out of all genera, total 39 colonies are falling into the moderately bleached. Maximum BRI for Narara in the year 2019 was calculated for the colonies of *Dipsastraea,* whereas *Platygyra Sp.* Showed the minimum bleaching with 31.09 % of BRI. However overall result of BRI indicates that, in summer months of 2019 coral colonies of all the genera in Narara were falling under the moderately bleached corals.

**Table 6:** Bleaching Response Index in 2019 at Narara

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 2 | 5 | 5 | 6 | 10 | 7 | 35 | 47.99 |
| ***Dipsastraea*** | 3 | 11 | 15 | 17 | 21 | 9 | 76 | 52.29 |
| ***Favites*** | 2 | 9 | 9 | 18 | 21 | 11 | 70 | 46.34 |
| ***Platygyra*** | 1 | 0 | 1 | 8 | 13 | 4 | 27 | 31.09 |
| ***Lobophyllia*** | 2 | 3 | 3 | 11 | 12 | 10 | 41 | 39.86 |
| ***Cyphastrea*** | | | | | | 3 | | - |
| ***Montipora*** | 0 | 0 | 6 | 9 | 10 | 4 | 29 | 40.33 |
| ***Hydnophora*** | | | | | | 2 | | - |

**Table 7:** Bleaching Response Index in 2020 at Narara

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 1 | 6 | 4 | 3 | 7 | 2 | 23 | 72.5 |
| ***Dipsastraea*** | 2 | 7 | 7 | 15 | 19 | 7 | 57 | 46.21 |
| ***Favites*** | 3 | 7 | 6 | 13 | 17 | 6 | 52 | 48.16 |
| ***Platygyra*** | 0 | 0 | 0 | 5 | 9 | 3 | 17 | 25.29 |
| ***Lobophyllia*** | 0 | 0 | 1 | 8 | 10 | 8 | 27 | 27.96 |
| ***Cyphastrea*** | | | | | | 3 | | - |
| ***Montipora*** | 0 | 1 | 3 | 3 | 6 | 0 | 13 | 45.75 |
| ***Hydnophora*** | | | | | | 2 | | - |

In summer of 2020, total 189 colonies in Narara were surveyed to calculate BRI. Colonies of *Porites* showed the maximum BRI of 72.5% being highly susceptible towards bleaching. However, in comparison to 2019, colonies of *Dipsastraea* showed the less BRI with 46.21%. However, they are still under the moderate threats from stress conditions. Whereas, colonies of *Lobophyllia* were resistible to the stress conditions with BRI at 27.96%.

**Table 8:** Bleaching Response Index in 2021 at Narara

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 4 | 8 | 7 | 6 | 8 | 4 | 37 | 61.47 |
| ***Dipsastraea*** | 8 | 11 | 12 | 16 | 22 | 15 | 84 | 50.87 |
| ***Favites*** | 6 | 9 | 9 | 15 | 8 | 16 | 63 | 48.05 |
| ***Platygyra*** | 3 | 2 | 2 | 5 | 11 | 6 | 29 | 45.5 |
| ***Lobophyllia*** | 3 | 4 | 5 | 8 | 10 | 8 | 38 | 47.23 |
| ***Pseudosiderastrea*** | | | | | | 1 | | - |
| ***Cyphastrea*** | | | | | | 3 | | - |
| ***Montipora*** | 3 | 5 | 0 | 8 | 2 | 13 | 31 | 45.95 |
| ***Hydnophora*** | | | | | | 2 | | - |

Most of all the colonies of Narara in 2021 were under the moderate threat from the stress conditions with *Porites* showing the maximum bleaching of 61.47%.

### (ii) BRI calculation for Poshitra

At Poshitra, bleaching response of varies from resistible to highly susceptible amongst the coral colonies of different genera. Apart from *Pseudosiderastrea sp.* and *Goniopora sp.* most of coral colonies are moderately susceptible to coral bleaching condition at Poshitra.

**Table 9:** Bleaching Response Index in 2019 at Poshitra

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 9 | 39 | 14 | 14 | 3 | 10 | 89 | 77.3555 |
| ***Dipsastraea*** | 7 | 6 | 6 | 30 | 29 | 21 | 99 | 41 |
| ***Favites*** | 0 | 7 | 2 | 3 | 6 | 15 | 33 | 40.45 |
| ***Goniopora*** | 0 | 1 | 0 | 0 | 4 | 5 | 10 | 23.5 |
| ***Turbinaria*** | | | | | | 5 | 5 | - |
| ***Platygyra*** | 2 | 3 | 5 | 4 | 7 | 1 | 22 | 56.59 |
| ***Lobophyllia*** | | | | | | 5 | 5 | - |
| ***Plesiastrea*** | 0 | 0 | 1 | 4 | 0 | 1 | 6 | 50 |
| ***Pseudosiderastrea*** | 0 | 0 | 0 | 1 | 0 | 6 | 7 | 19.99 |
| ***Cyphastrea*** | | | | | | | 4 | - |
| ***Siderastrea*** | | | | | | | 3 | - |

**Table 10**: Bleaching Response Index in 2020 at Poshitra

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 9 | 39 | 14 | 14 | 3 | 10 | 89 | 7.35 |
| ***Dipsastraea*** | 5 | 28 | 7 | 29 | 18 | 5 | 92 | 59.95 |
| ***Favites*** | 2 | 3 | 6 | 5 | 7 | 18 | 41 | 39.86 |
| ***Goniopora*** | 0 | 3 | 2 | 2 | 1 | 6 | 14 | 48.19 |
| ***Turbinaria*** | | | | | | 4 | | - |
| ***Platygyra*** | 0 | 4 | 8 | 2 | 13 | 5 | 32 | 45.31 |
| ***Lobophyllia*** | | | | | | 4 | | - |
| ***Plesiastrea*** | 0 | 1 | 3 | 4 | 2 | 1 | 11 | 54 |
| ***Pseudosiderastrea*** | 0 | 0 | 0 | 4 | 7 | 8 | 19 | 22.36 |
| ***Cyphastrea*** | | | | | | 3 | | - |
| ***Siderastrea*** | | | | | | 5 | | - |

**Table 11**: Bleaching Response Index in 2021 at Poshitra

| Genus | Colour score | | | | | | Total | BRI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| ***Porites*** | 14 | 45 | 16 | 13 | 2 | 13 | 103 | 78.97 |
| ***Dipsastraea*** | 8 | 36 | 6 | 35 | 23 | 6 | 114 | 62.22 |
| ***Favites*** | 1 | 10 | 2 | 12 | 2 | 19 | 46 | 53.48 |
| ***Goniopora*** | 0 | 0 | 1 | 0 | 15 | 7 | 23 | 18.02 |
| ***Turbinaria*** | 0 | 1 | 0 | 0 | 0 | 3 | 4 | 36.25 |
| ***Platygyra*** | 0 | 4 | 8 | 7 | 10 | 3 | 32 | 50.77 |
| ***Lobophyllia*** | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 15 |
| ***Plesiastrea*** | 0 | 0 | 0 | 7 | 1 | 0 | 8 | 45.67 |
| ***Pseudosiderastrea*** | | | | | | 11 | | - |
| ***Cyphastrea*** | | | | | | 3 | | - |
| ***Siderastrea*** | | | | | | 2 | | - |

In contrast to 2019 and 2021, coral colonies of *Porites* showed very less effects of bleaching with only 7.35% of BRI. Results of BRI also shows that the corals at Poshitra are more effective to stress condition in compare to Narara.

Similarly, in 2010, Joshi *et al.* (2016) also reported massive bleaching effects at both the sites. As a result of the coral species in these latitudes being adapted to a wide range of temperature fluctuation at the intertidal regions, Arthur (1995) reported 1.2-1.4% of coral bleaching in the Gulf of Kachchh during the summer months of Gujarat and came to the conclusion that it was a normal summer response of corals to the summer temperature rise. However, in the summer of 1998, he saw an average of 11% coral bleaching in the Gulf of Kachchh as a result of the El Nino Southern Oscillation and thought that this was more coral bleaching than would normally occur during the summer. He continued by saying that high temperatures, even those below the bleaching threshold, can negatively impact coral health by hindering growth and reproduction (Arthur, 2000). Moreover, WTI ecologists noted coral bleaching near Mithapur in the Gulf of Kachchh in 2010.

## 4.4 Model Generation for Coral Bleaching Index (CBI)

### 4.4.1 Spectral Reflectance (R) analysis

Spectral characteristic analysis is a base for the evaluation of coral health using satellite imagery. As the main aim of the work is to assess the impact on corals using remote sensing techniques, the main focus of the work is to examine the spectral behaviour of corals at different wavelengths.

In the process of coral health assessment, geo-references of healthy, bleached and sedimented corals were also recorded. Using this data spectral reflectance of different classes was generated. With the intention to identify the difference between healthy and bleached corals, the spectral response of different colonies was analyzed using the SNAP software.

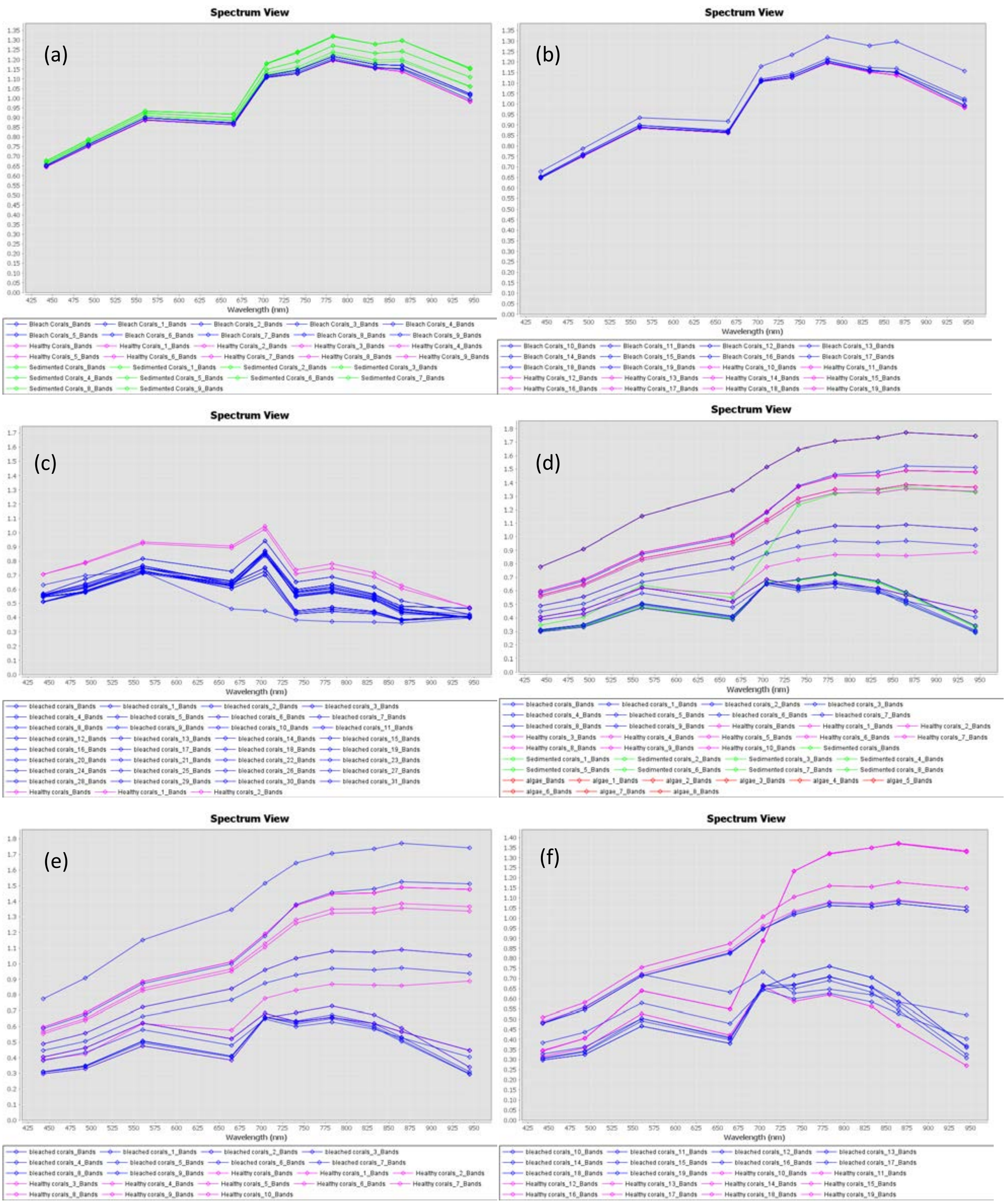



**Figure 32**: Spectral Signature of Different Coral Classes.

Figure (32) shows the reflectance pattern of healthy, bleached, and sedimented corals over the months of the summer season in Narara. While mapping the spectral reflectance, overall, it was observed that all three classes followed almost the same pattern in that particular satellite image. At Narara, sedimentation deposition was not seen over a large area during the field visit. Thus, reflectance separability between sedimentation and bleached corals was clearly visible (Figure: 32(a)) in all the bands ranging from 440 - 940 nm wavelengths. The reflectance values of sedimented corals are also high in all the bands compared to bleached corals. Whereas Figure: 32(d) shows the reflectance from the area where multiple colonies of all three classes were seen within 10 $m^2$ of the area. Here the reflectance values of bleached and sedimented corals were very similar in the visible band with a sudden peak at 705 nm of sedimented corals. In Figure 32 (a) and (b) also second reflective peak was observed at 705 nm. Since 705 nm wavelengths are useful for red edge transition, reflectance peaks at this wavelength might be the result of suspended particulate matter of seawater. In one of their study, Choudhury et al. (2019) used a field hyperspectral spectrometer to discriminate between the bleached and healthy corals of the *Turbinaria* genus and observed that bleached corals have higher reflectance value in comparison to healthy corals. The spectral response of healthy and bleached corals in Narara showed a mixing of reflectance values in most of the samples. However, some separability at some level in the reflectance was seen between 700 – 940 nm (Figure 32(d) and (e)). Spectral separability of healthy and bleached corals was good in June 2019, however healthy corals had the highest reflectance values with compare to bleached corals. The highest reflectance value of bleached coral in Narara was around 1.8 at 865 nm. Same as bleached, healthy corals also showed the highest reflectance of 1.34 at 865 nm. Though there is a difference between the highest peak of healthy and bleached corals, the spectral response of these classes in visible band is very similar.

**Figure 33**: Large scale sedimentation and Blooming effect

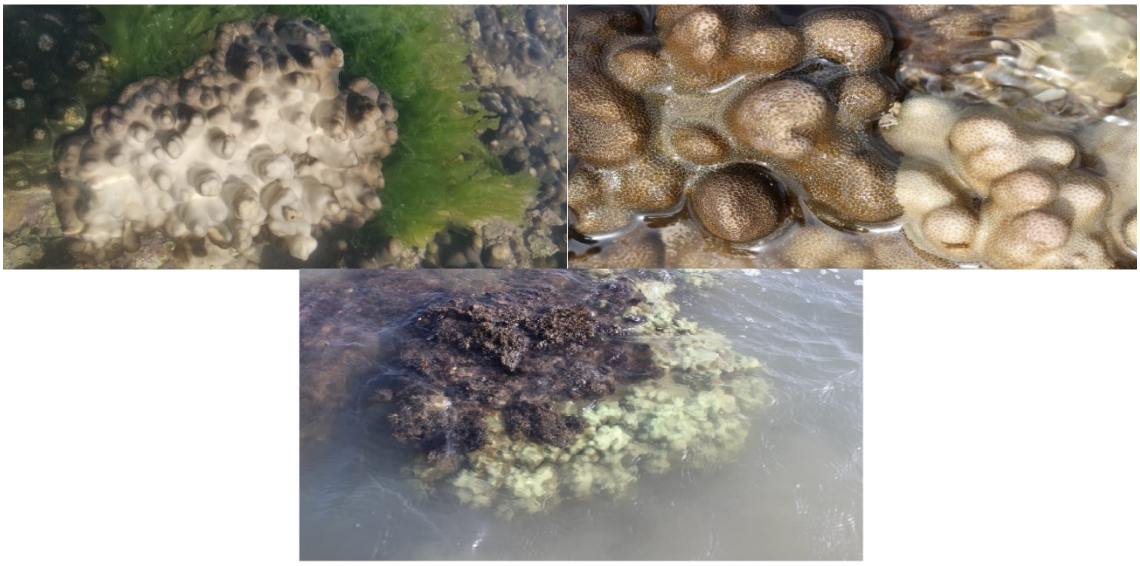


**Figure 34**: Bleaching effect

At Poshitra, corals are more densely populated and the size of coral colonies is also bigger. Thus, the reflectance separability of the selected coral classes gives good results in comparison to Narara. As discussed previously, sedimented coral again showed the highest reflectance between 665 nm – 940 nm. Thus, reflectance in these wavelengths can be useful to differentiate sedimented or dead coral colonies with bleached coral colonies. However, mixing in spectral response has been seen in the month of March (Figure 35(d) and (e)). The months of February and March are also the months of phase shift phenomenon at both the Narara and Poshitra. During this period algal bloom season is about to finish and on the other hand turbidity and sedimentation loads also increase. Because of this phenomenon, there is a mixing of the spectral response between different classes.

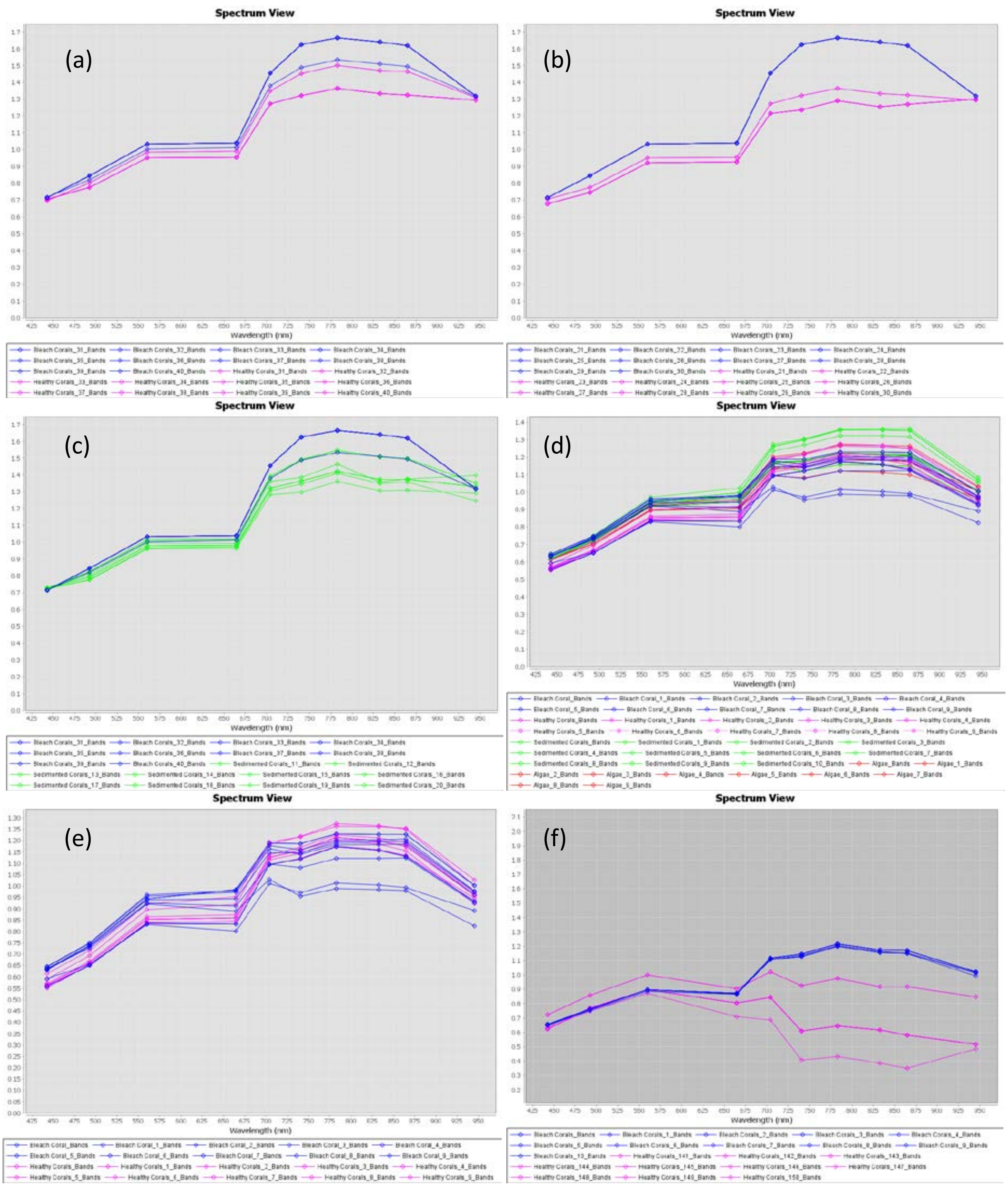



**Figure 35**: Spectral Signature of Reef Classes.

Though it is difficult to definitively determine the difference between the spectral response of bleached corals and healthy corals with medium spatial resolution, the development of the spectral signature library of reef eco-system increases the understanding of controlling factors of reflection and absorption of light in reef environment. There are two documented pigments that occur only in zooxanthellae of corals 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 and Phinn (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. In this study also, the first reflectance peak most of the coral was at 556 nm. However, most of the bleached coral colonies also had the first reflectance peak at the same wavelength. Since, the spectral response of healthy and bleached corals is visibly distinguishable in all the bands for the month of June in Poshitra, the reflectance values of bleached corals in these months were further used to generate the Coral Bleaching Index.

### 4.4.2 Selection of a suitable model

Throughout the course of three years, spectral responses of various coral classes were created for the Narara and Poshitra during the summer. Out of all these six sets of spectral analysis, three sets of analysis were considered for further study. One is from reflectance spectra of the summer months of 2019 in Narara and the other two are from the Poshitra for the summer season for both the years 2019 and 2021.

Spectral analysis of corals was the quality analysis and the next step is the quantity analysis. To check the effects of bleaching for a particular reflectance value, a number of bleached coral colonies in a 10 $m^2$ area was calculated. And geo-locations of these areas were also located. During this calculation, it was found that at Narara, each 10 $m^2$ had only one or two bleached corals with a maximum of four at some places. Thus, the spectral responses of these pixels will have less than a 1% contribution to the reflectance value of that pixel. Also, the reflectance values of healthy corals were more than the bleached coral, so it was concluded that there might be a chance of other reef features having more influence on the reflectance values apart from corals. Thus, further studies were carried out using the reflectance spectra of Poshitra.

After calculating the frequency of bleached corals for both years, the spectral reflectance of these newly calculated pixels was also generated for all the bands.

Then, using multi-linear regression, P- values and $R^2$ were calculated to find out the bands that have the best correlation with the bleaching percentage. Following are the results of the regression analysis for the year 2021.

**Table 12**: Regression analysis of bleaching and spectral reflectance for the year 2021

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.62883 |
| R Square | 0.395428 |
| Adjusted R Square | -0.15418 |
| Standard Error | 6.777334 |
| Observations | 18 |

**Table 13**: Covariance at a different wavelength for bleaching percentage in the year 2021

| | *Coefficients* | *P-value* |
|---|---|---|
| Intercept | -208.86 | 0.588427 |
| 443 nm | -88.2777 | 0.964903 |
| 492 nm | 1178.458 | 0.55254 |
| 560 nm | -857.789 | 0.602553 |
| 665 nm | -109.26 | 0.944746 |
| 704 nm | 317.7209 | 0.722645 |
| 741 nm | 381.9181 | 0.894115 |
| 783 nm | -534.591 | 0.890126 |
| 833 nm | 604.8356 | 0.396269 |
| 865 nm | -577.998 | 0.654611 |
| 945 nm | 66.91881 | 0.719604 |

Since the 10 m resolution is not the best spatial resolution when it comes to coral health identification, the inaccuracy of data was kept in mind and the analysis was carried out with a 90% confidence level. But the results in table (13) show that the P-values are beyond the confidence level in all the selected wavelengths. The $R^2$ value for the set is 0.395, which is within an acceptable range, still, 0.395

is considered as a low correlation between variables. Thus, it is concluded that, this set of reflectance values cannot be used to generate the model and also not to predict the bleaching of the unknown area.

Regression analysis for the reflectance data of the year 2019 was also performed for each wavelength. The $R^2$ value for this set of data is 0.6664, which can be considered as good and significant for any multi-linear equation. Following is the table of covariance and P-values of each wavelength with the bleaching percentage data.

**Table 14**: Regression analysis of bleaching and spectral reflectance for the year 2019

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.816345 |
| R Square | 0.666419 |
| Adjusted R Square | 0.363164 |
| Standard Error | 5.034255 |
| Observations | 22 |

**Table 15**: Covariance at a different wavelength for bleaching percentage in the year 2019

| | *Coefficients* | *P-value* |
|---|---|---|
| Intercept | 9.765846 | 0.925696 |
| 443 nm | -170.716 | 0.069969 |
| 492 nm | -303.167 | 0.753126 |
| 560 nm | 622.1904 | 0.668974 |
| 665 nm | -327.114 | 0.48351 |
| 704 nm | 51.08547 | 0.830276 |
| 741 nm | 328.505 | 0.067289 |
| 783 nm | -354.719 | 0.101506 |
| 833 nm | 7.179951 | 0.978695 |
| 865 nm | 5.822632 | 0.974966 |
| 945 nm | 31.03883 | 0.462389 |

Regression analysis of this data showed that with the 90% confidence level, bleaching severity can be calculated from the 443 nm, 741 nm, and 783 nm wavelengths with the P-values 0.0699, 0.0672, and 0.1015 respectively. Since only three variables had the P-values < 0.1, using these three variables only coefficients were again generated for accuracy in prediction (Table 16).

**Table 16**: Coefficients of the selected wavelengths

| | *Coefficients* |
|---|---|
| Intercept | 4.3081 |
| 442.7 | -18.9758 |
| 740.5 | 138.5788 |
| 782.8 | -123.728 |

Using these new coefficients, a multi-linear model was run again to calculate the bleaching percentage. These calculated values were then compared with in-situ data to see the correlation (Figure 36).

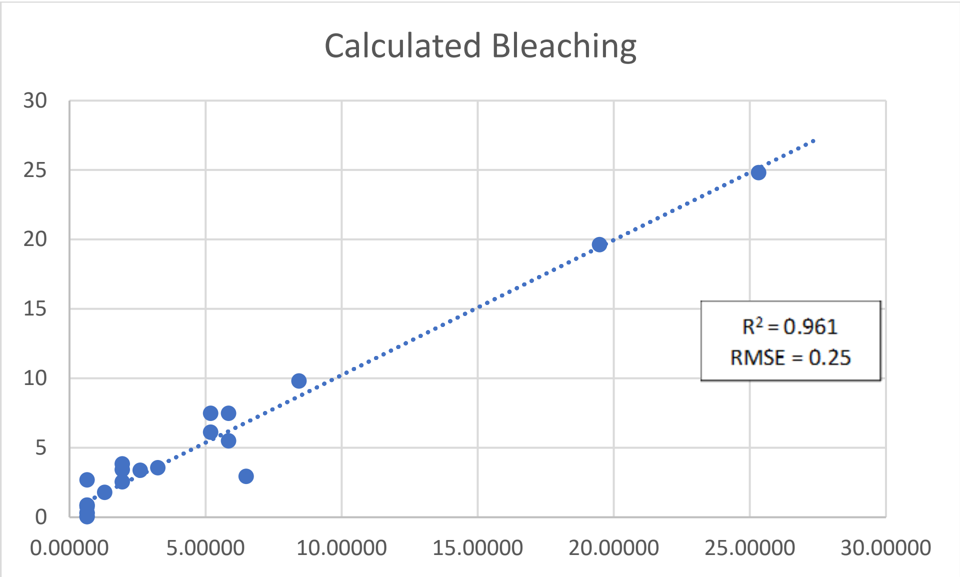



**Figure 36**: Model generated bleaching (%).

With the 0.961 $R^2$ value and 0.25 RMSE, it can be concluded that the selected band combination was useful to calculate the bleaching. And with reference of Table 3, it is concluded that the calculated bleaching in 2019 in Poshitra was 25% which falls under the resistible category of bleaching susceptibility. And observed bleaching in 2019 was also 26.14 % falling into the same category. Thus, most of the colonies in Poshitra were resistant to environmental changes.

## 4.5 Assessment of Environmental Variables

Environmental variables are the major influencing factor in coastal environments and control a variety of coastal activities (Bokuniewicz and Gordon, 1980). Many sources, including farmland, urban, rural, wastewater, and industrial discharge, reach the coastal environment and contribute nutrients that encourage phytoplankton growth. The overabundance of nutrients in coastal areas is the primary cause of events like eutrophication, hazardous algal blooms, and water quality degradation (Rabalais and Turner, 2001). Therefore, it is essential to comprehend the environmental and biogeochemical characteristics that govern the chemistry and biology of coastal ecosystems in order to evaluate complicated environmental challenges including biodiversity, climate change, pollution, and deforestation.

Sea Surface Temperature (SST), Sea Surface Salinity (SSS), turbidity, Photosynthetically Available Radiance (PAR), and diffuse attenuation Coefficient (Kd_490) are some of the environmental parameters that have been studied in this work to evaluate their effects on coral reefs.

In-situ data collection for both sites was done to analyze the real-time effects of that parameter on the status of corals' health. Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and turbidity are the three selected parameters, to assess if they have any short-term or real-time effects on corals. Satellite-derived SST is easily available from various sources to analyze further. However, satellite-derived salinity and turbidity data from the study area were not available. The calculation of Normalized Difference Turbidity Index (NDTI) is a normally used spectral index for turbidity measurements however, there is no universally accepted method or formula for the measurement of SSS, especially for coastal areas. Therefore, efforts to build the model and their results using the in-situ data have been described below.

### (1) Model generation to calculate Sea Surface Salinity (SSS)

The reflectance of satellite images has been used successfully in several research to model SSS (Choi et al., 2021; Garaba & Zielinski, 2015; Qing et al., 2013; Sun et al., 2019; Zhao et al., 2017). Based on these studies, it is found that the use of multiple bands in the model generation of SSS is more reliable than using only one band. Keeping this research as a base (Choi et al., 2021; Santos dos, 2022; Ellero, 2018; Sun et al., 2019) a multi-linear regression method has also been used in this work also to generate the SSS model.

After the selection of suitable band combinations reflectance values of each sampling location were extracted for the blue, green, and red bands of sentinel-2 (Table 17). Following here in Table (17), are the sampling locations of both site 1 and site 2.

**Table 17**: Reflectance values of in-situ salinity in different sentinel-2 bands

| Sampling Sites | Salinity (In-situ) | Band_2 (490) | Band_3 (560) | Band_4 (665) |
|---|---|---|---|---|
| Sampling Site 1 | 34.203 | 0.690100014 | 0.939100027 | 0.832300007 |
| Sampling Site 2 | 35.493 | 0.699899971 | 0.957499981 | 0.854600012 |
| Sampling Site 3 | 35.154 | 0.657299995 | 0.917500019 | 0.837499976 |
| Sampling Site 4 | 35.034 | 0.722199976 | 0.968599975 | 0.851999998 |
| Sampling Site 5 | 35.457 | 0.775900006 | 0.998099983 | 0.863799989 |
| Sampling Site 6 | 35.732 | 0.7949 | 0.981700003 | 0.838199973 |
| Sampling Site 7 | 34.436 | 0.730099976 | 0.972500026 | 0.838800013 |
| Sampling Site 8 | 34.032 | 0.731400013 | 0.968599975 | 0.850000024 |
| Sampling Site 9 | 34.452 | 0.694700003 | 0.956200004 | 0.842100024 |
| Sampling Site 10 | 34.454 | 0.722899973 | 0.975799978 | 0.84799999 |
| Sampling Site 11 | 34.894 | 0.716300011 | 0.969299972 | 0.846700013 |
| Sampling Site 12 | 34.784 | 0.690100014 | 0.944400012 | 0.830299973 |
| Sampling Site 13 | 34.988 | 0.700600028 | 0.962100029 | 0.836899996 |

| | | | | |
|---|---|---|---|---|
| Sampling Site 14 | 34.382 | 0.745800018 | 0.9745 | 0.849300027 |
| Sampling Site 15 | 34.986 | 0.78579998 | 0.99089998 | 0.854600012 |
| Sampling Site 16 | 34.568 | 0.779200017 | 0.993499994 | 0.866999984 |
| Sampling Site 17 | 35.108 | 0.832300007 | 0.996800005 | 0.846700013 |
| Sampling Site 18 | 37.547 | 1.009899974 | 1.028900027 | 0.841499984 |
| Sampling Site 19 | 35.987 | 0.978399992 | 1.020400047 | 0.845399976 |
| Sampling Site 20 | 35.654 | 0.927299976 | 1.007300019 | 0.838199973 |
| Sampling Site 21 | 36.264 | 0.88410002 | 0.996800005 | 0.836899996 |
| Sampling Site 22 | 36.834 | 0.983699977 | 1.023699999 | 0.846099973 |
| Sampling Site 23 | 35.942 | 0.909600019 | 1.008599997 | 0.840200007 |
| Sampling Site 24 | 35.433 | 0.907000005 | 1.010499954 | 0.844699979 |
| Sampling Site 25 | 35.953 | 0.959399998 | 1.029600024 | 0.85589999 |
| Sampling Site 26 | 36.395 | 0.923399985 | 1.001399994 | 0.834299982 |
| Sampling Site 27 | 36.195 | 0.971199989 | 1.026299953 | 0.84740001 |
| Sampling Site 28 | 34.007 | 0.667100012 | 0.940400004 | 0.804099977 |
| Sampling Site 29 | 36.897 | 0.947600007 | 1.009199977 | 0.832300007 |

Using these reflectance values, regression analysis with the dependent variable, in-situ salinity was calculated to generate the model.

**Table 18**: Regression analysis of in-situ salinity with different bands

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.8718528 |
| R Square | 0.7601274 |
| Adjusted R Square | 0.7313427 |
| Standard Error | 0.4728069 |
| Observations | 29 |

**Table 19**: Coefficients of multilinear regression analysis

| | *Coefficients* | *P-value* |
|---|---|---|
| Intercept | 40.130986 | 8.1097E-06 |
| Band_2 (490.0) | 12.332277 | 0.000243577 |
| Band_3 (560.0) | -23.59687 | 0.056146918 |
| Band_4 (665.0) | 10.03255 | 0.352124686 |

With a confidence level of 95%, the P-values of only Band 2 and Band 3 were within the acceptable range. However, Band 4 is sensible to identify the turbidity and sedimentation and salinity are inversely proportional to these variables, we tried to run the model keeping band 4 in the equation and the results of calculated salinity were compared with in-situ salinity data. Both the data showed a positive correlation with the $R^2$ value of 0.7556 (Figure 37).

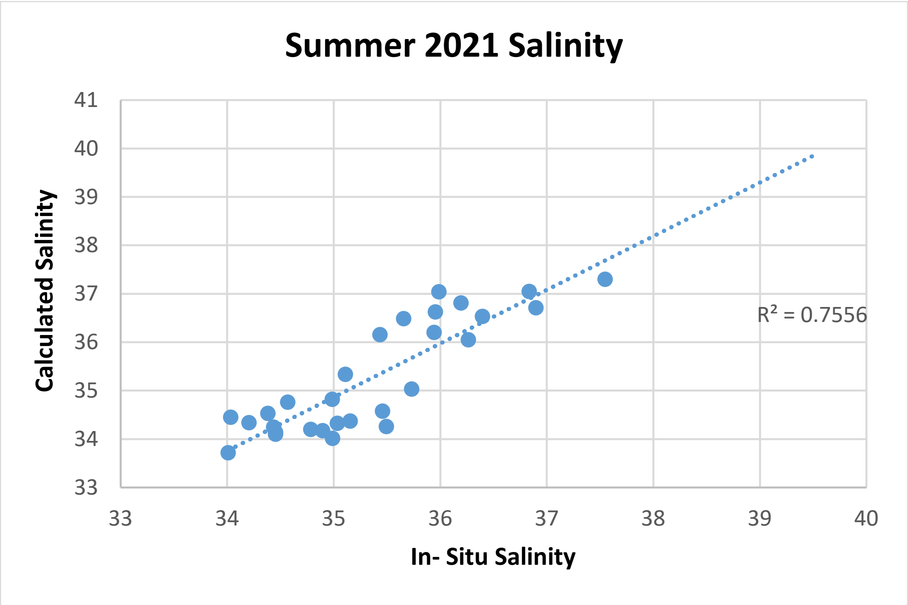



**Figure 37**: Salinity comparison of summer year 2021

As there was a good similarity between the predicted values and in-situ data, the same formula was applied to all the in-situ data given below.

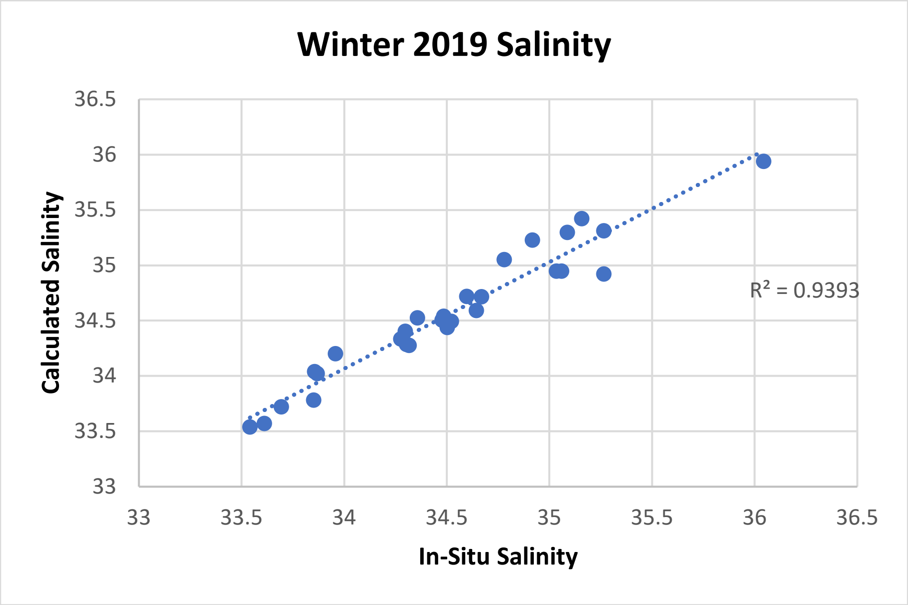



**Figure 38**: Salinity comparison of winter year 2019

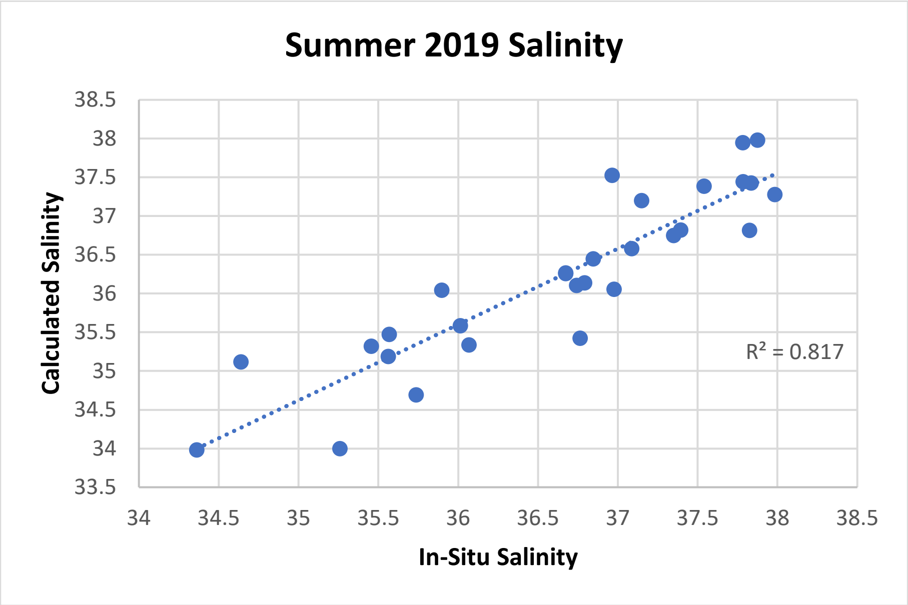



**Figure 39**: Salinity comparison of summer year 2019

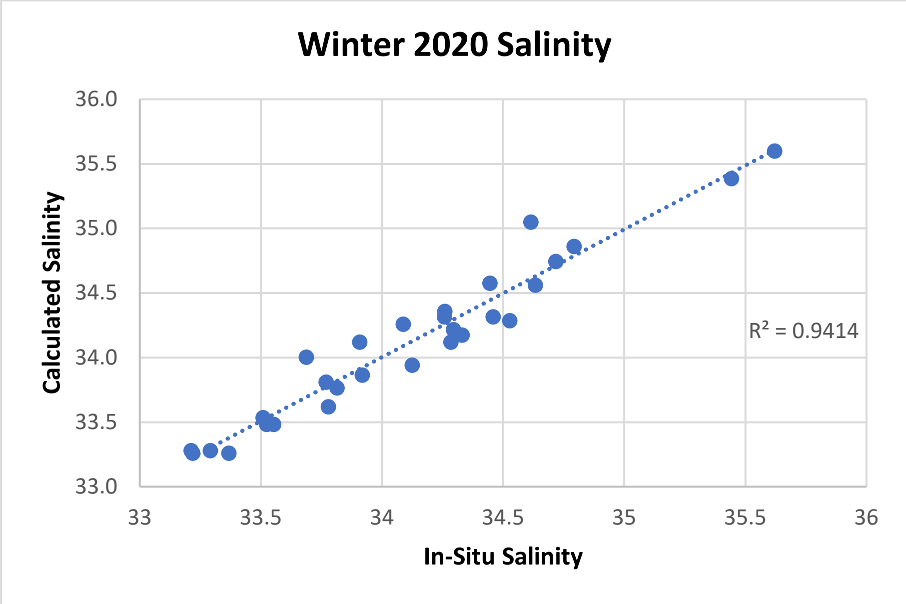



**Figure 40**: Salinity comparison of summer year 2020.

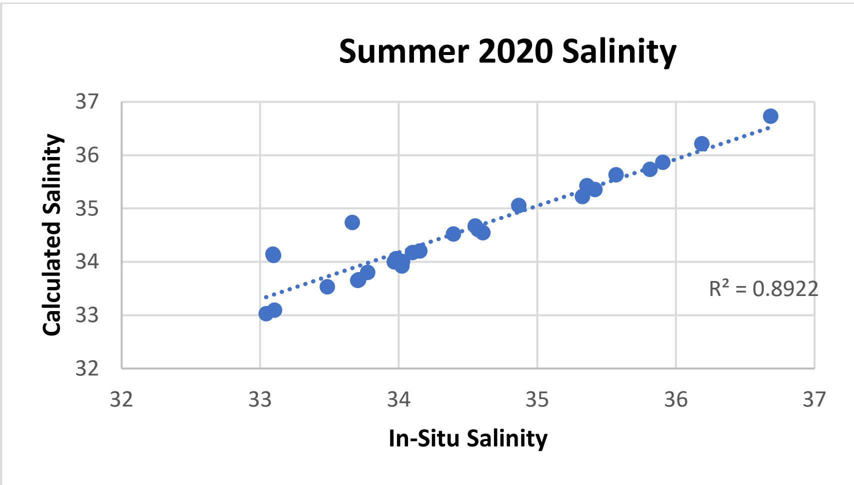



**Figure 41**: Salinity comparison of summer year 2020

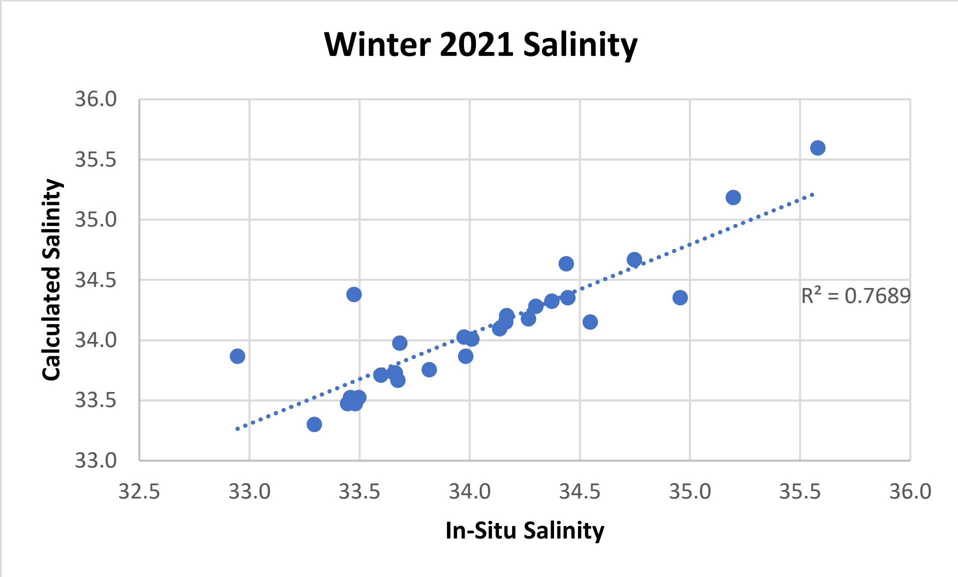



**Figure 42**: Salinity comparison of winter year 2021

The main aim of generating the SSS model is that, although there are many researches has been done on calculating the SSS from satellite images, yet when it comes to coastal areas, secondary data on SSS is not widely available. It observed that the best models all included the bands B2, B3, and B4 in their equations. Regarding the published models we used, with the exception of Garaba and Zielinski (2015) equation that only used B1 to estimate SSS, all of them included these bands. In (Urquhart et al., 2012), 488 nm was shown as favourably linked with salinity, instead of which, Band 4 with 490 nm wavelength has been used here to generate the model. The wavelengths 488, 540, 555, 625, 680, and 865 nm were suggested in preliminary research for AEROS (Santos dos, 2022) to assess salinity. This allowed us to be more confident in the choice of bands of the model and it was seen that Band 2, Band 3, and Band 4 fit the model and are of great use to calculate the salinity.

### (2) Generation of Normalized Difference Turbidity Index

NDTI images for the sites were generated using the band math tool in SNAP software. NDTI is spectral index to measure the turbidity. Since it is an index, it calculates the values of turbidity generally ranging from -10 to +10. Calculated maps generated for this study are listed below.

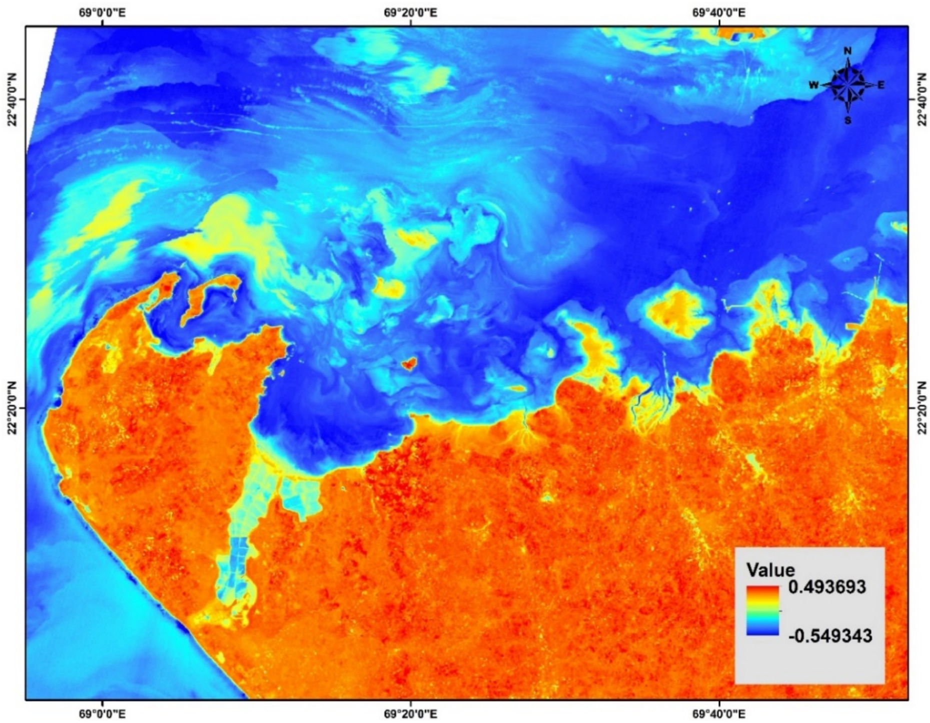



**Figure 43**: Normalized Difference Turbidity Index of Gulf of Kachchh January 2019.

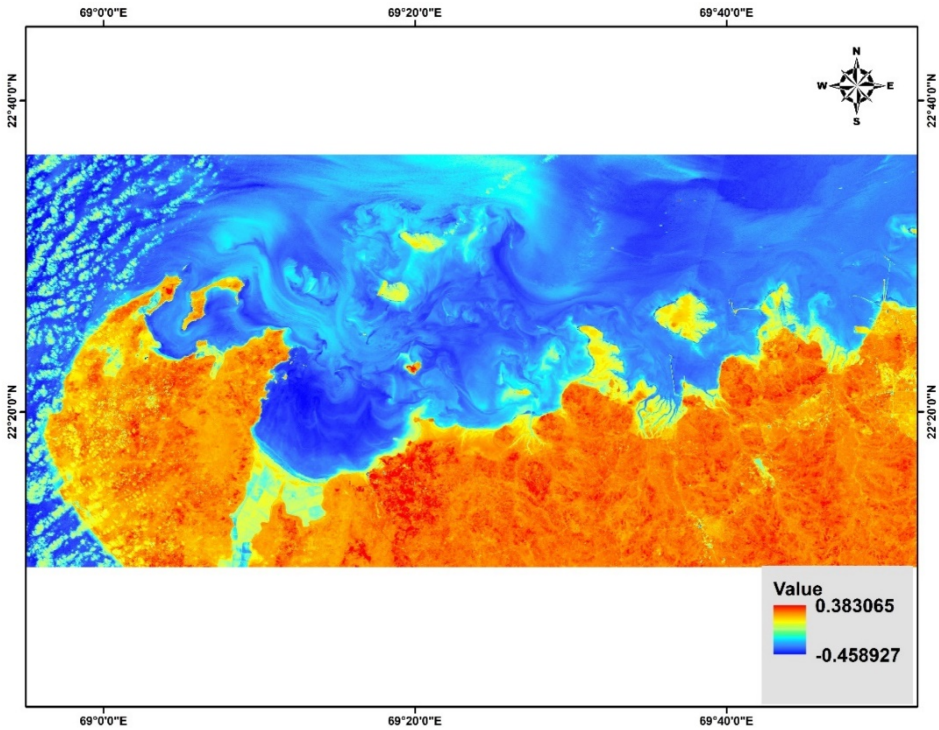



**Figure 44**: Normalized Difference Turbidity Index of Gulf of Kachchh June 2019

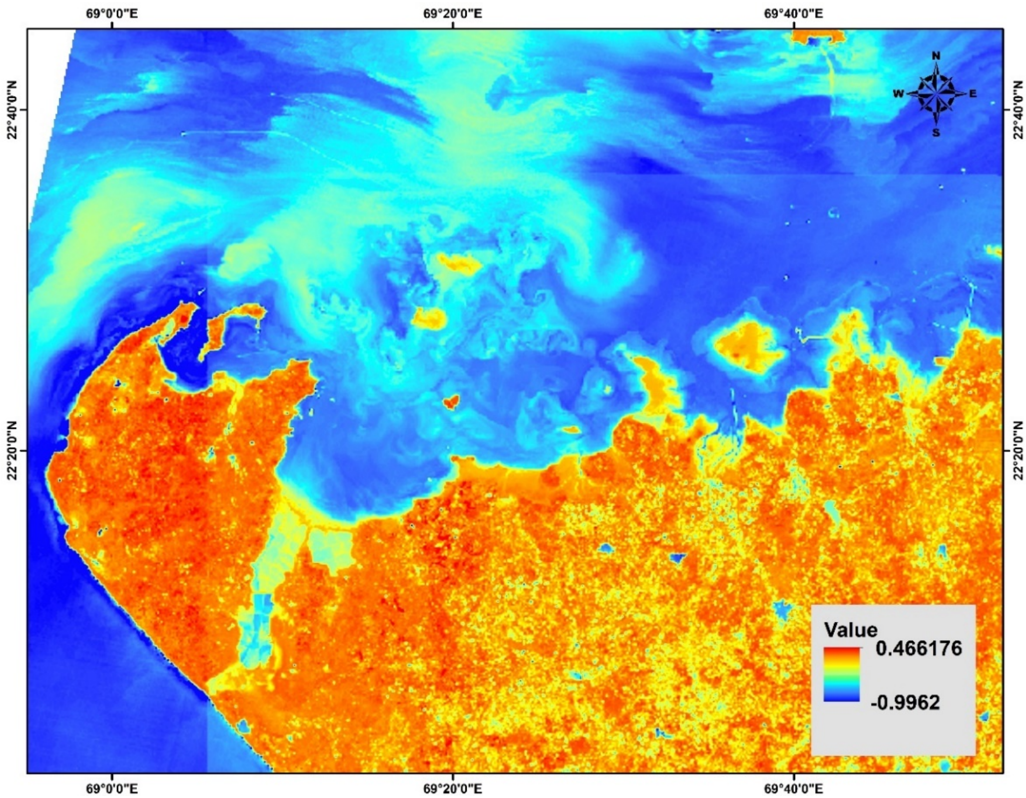



**Figure 45**: Normalized Difference Turbidity Index of Gulf of Kachchh January 2020

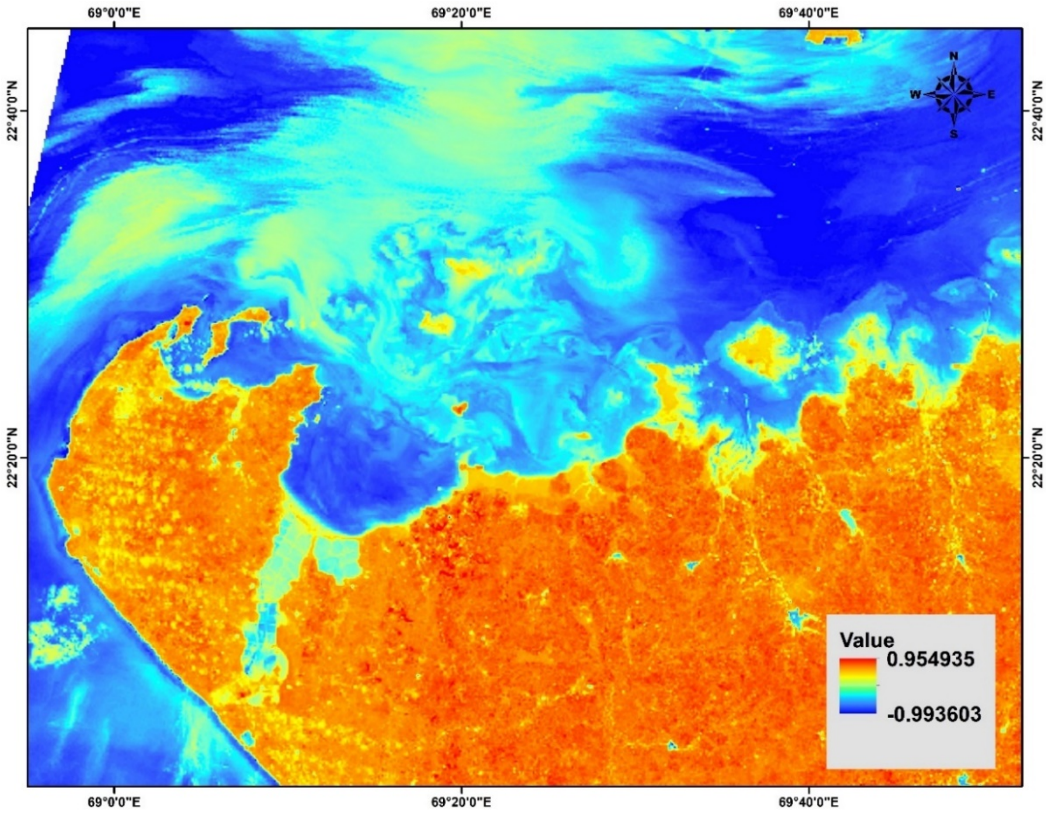



**Figure 46**: Normalized Difference Turbidity Index of Gulf of Kachchh March 2020

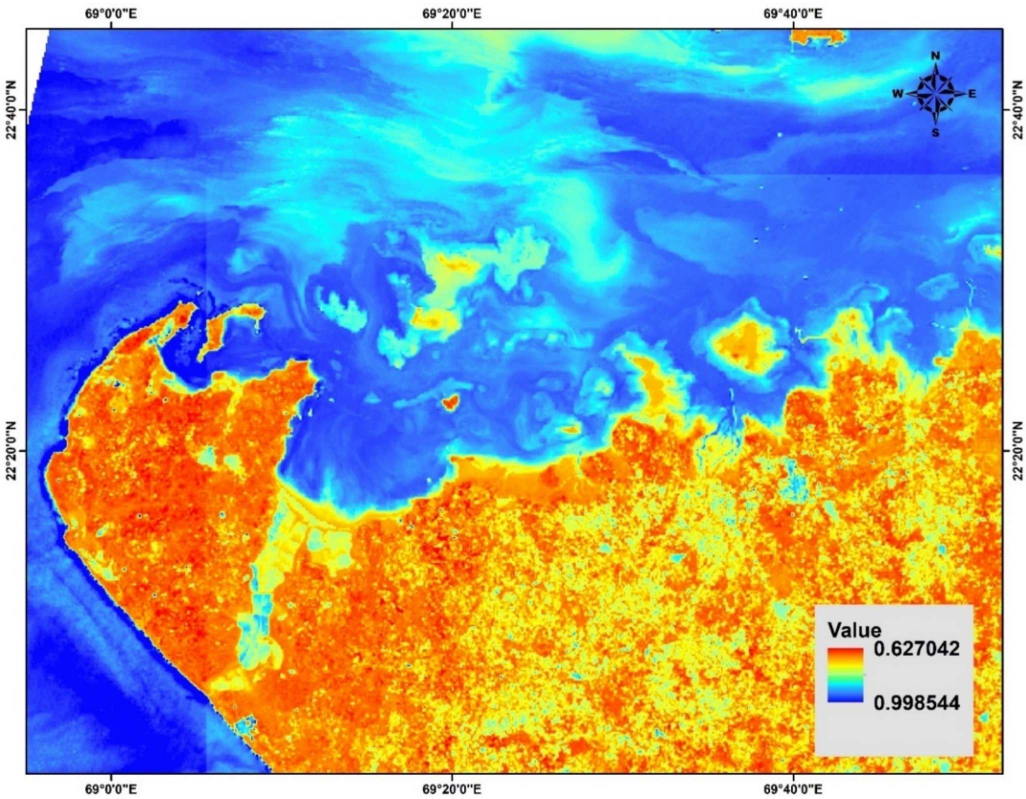



**Figure 47**: Normalized Difference Turbidity Index of Gulf of Kachchh January 2021

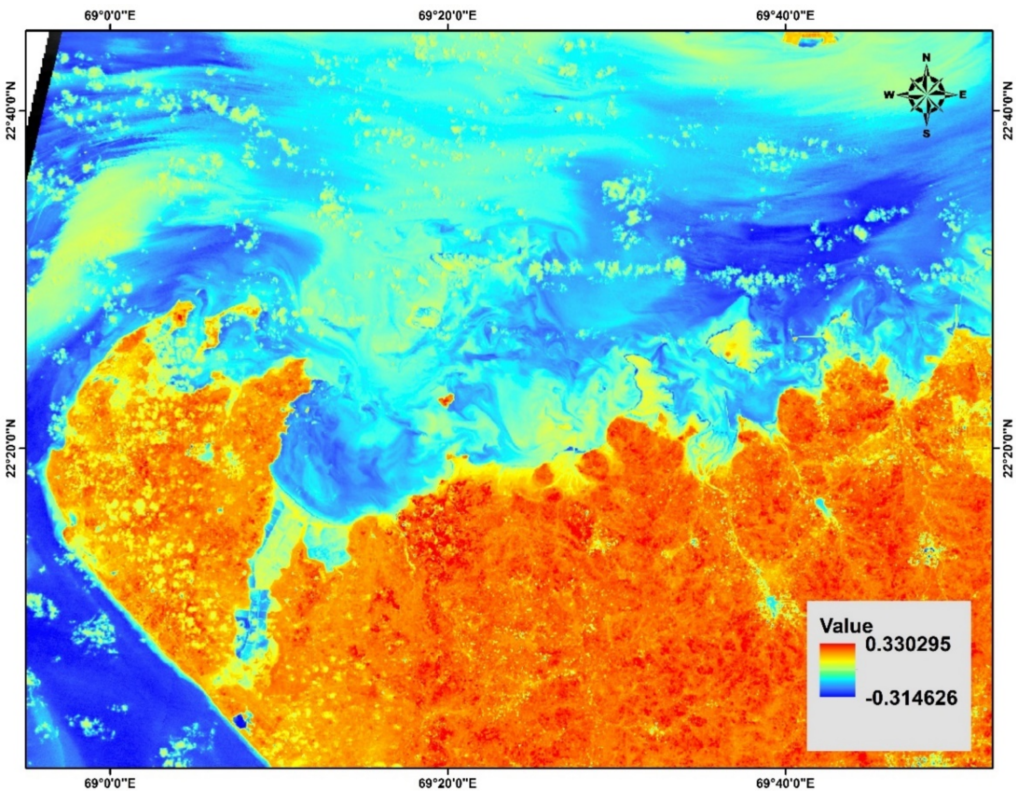



**Figure 48**: Normalized Difference Turbidity Index of Gulf of Kachchh June 2021

Same as salinity, turbidity data were also generated within the six months period of time to observe the gradual change over the period of three years. And from the maps it was observed that values of NDTI for both the sites in all three years were below 0 in minus. Thus, it can be concluded that open ocean water is not that turbid and higher concentration of turbidity near the coastal region is reason of agricultural and industrial runoff and also the geography.

Apart from Other parameters, which were not able to measure have been downloaded from open sources and were analyzed further. These parameters were used to check the long-term effects of coral bleaching. As all the parameters have different units, anomalies of all of these parameters were calculated to generalize their effects on coral bleaching. All environmental parameter included in study have been listed below with the bleaching percentage over a period of three year.

**Table 20**: Correlation of different environmental variables

| | PAR (einstein m-2 day-1) | kd490 (m-1) | SST | NDTI | TSM (mg/L) | Salinity |
|---|---|---|---|---|---|---|
| **Poshitra 2019** | 0.819996 | 1.299326 | 0.0244 | -0.14109 | 0.645435 | 37.386 |
| **Poshitra 2020** | 0.444123 | 1.624988 | 0.2585 | -0.19431 | 0.518606 | 35.737 |
| **Poshitra 2021** | 0.973097 | 1.890513 | 0.5231 | -0.02087 | 0 | 36.395 |
| **Narara2019** | 0.732278 | 0.757797 | 0.0059 | -0.14108 | -0.428708 | 34.69 |
| **Narara2020** | 0.616468 | -0.751977 | 0.3916 | -0.27704 | 0.449409 | 34.176 |
| **Narara2021** | 1.016556 | 0.565175 | 0.5433 | -0.15271 | 0 | 35.457 |

Parameters calculated in table (20) are the anomalies of that parameter apart from NDTI and salinity. Anomalies calculated here are the yearly anomalies of five years. The results of these anomalies indicates that, throughout the span of three years, SST have positive anomalies. This also have positive correlation with PAR. These means that bleaching recorded during the study, does have effects of higher than usual intensity of solar radiation. Salinity ranges from 33 PSU in winter season to 39 PSU in summer is normally seen at these sites. Thus, the coral colonies of these sites are used to this high level of salinity. Kd490 is also the variable of turbidity and TSM. Thus, positive anomalies of these variables indicated that both the reefs experience higher loadings of sedimentation and suspended particulate matters and turbidity which makes the reefs on GoK, one of the most stressed reefs in India. According to Vivekanandan et al. (2009), eight out of ten bleaching episodes between 2080 and 2089 will be catastrophic events, up from zero between 2000 and 2009 and two between 2050 and 2059 in the Gulf of Kachchh. According to studies done by Done et al. in 2010, the reef cannot withstand catastrophic catastrophes more than three times per ten years. In line with this assertion, Vivekanandan et al. (2009) predicted the vulnerability of the coral reefs of Lakshadweep, Andaman and Nicobar, and the Gulf of Mannar as well as the Gulf of Kachchh. They noted that reef building corals may begin to decline between 2020 and 2040 and that they would lose dominance between 2030 and 2040 in the Lakshadweep region and between 2050 and 2060 in the Andaman and Nicobar regions (Vivekanandan et al., 2009). They specifically attempted to project the susceptibility of the corals in the Gulf of Kachchh in their study. The corals may start to decline by 2030 to 2040, and by 2060 to 2070, the reef-building corals may lose their supremacy. Although other factors, such as rising ocean acidification, which would make it more difficult for corals to form exoskeletons, as well as UV radiation, sedimentation, nutrient load, and variations in the physico-chemical properties of the ocean water, which also contribute to the growth of corals, have not been taken into account in their study, they have made predictions by analyzing and projecting future trends of sea surface temperature. Moreover, McClanahan et al. (2007) hypothesized that SST background variation is a better predictor of coral survival than temperature rise rate. They also discovered a favorable correlation between bleaching and water flow speed. Also, studies have indicated that ocean warming is correlated with sea level rise, which causes more storms and El Nino. These events harm the reefs by making them more susceptible to coastal erosion, sedimentation, and turbidity, which would hasten their demise (Hodgson, 1999). It is challenging to predict what will happen to creatures that depend on the reef ecosystem and the nearby ecosystems that the reefs sustain in altered settings with reduced or no coral cover.

Following are the generated maps of secondary data.

(1) Sea Surface Temperature (SST)

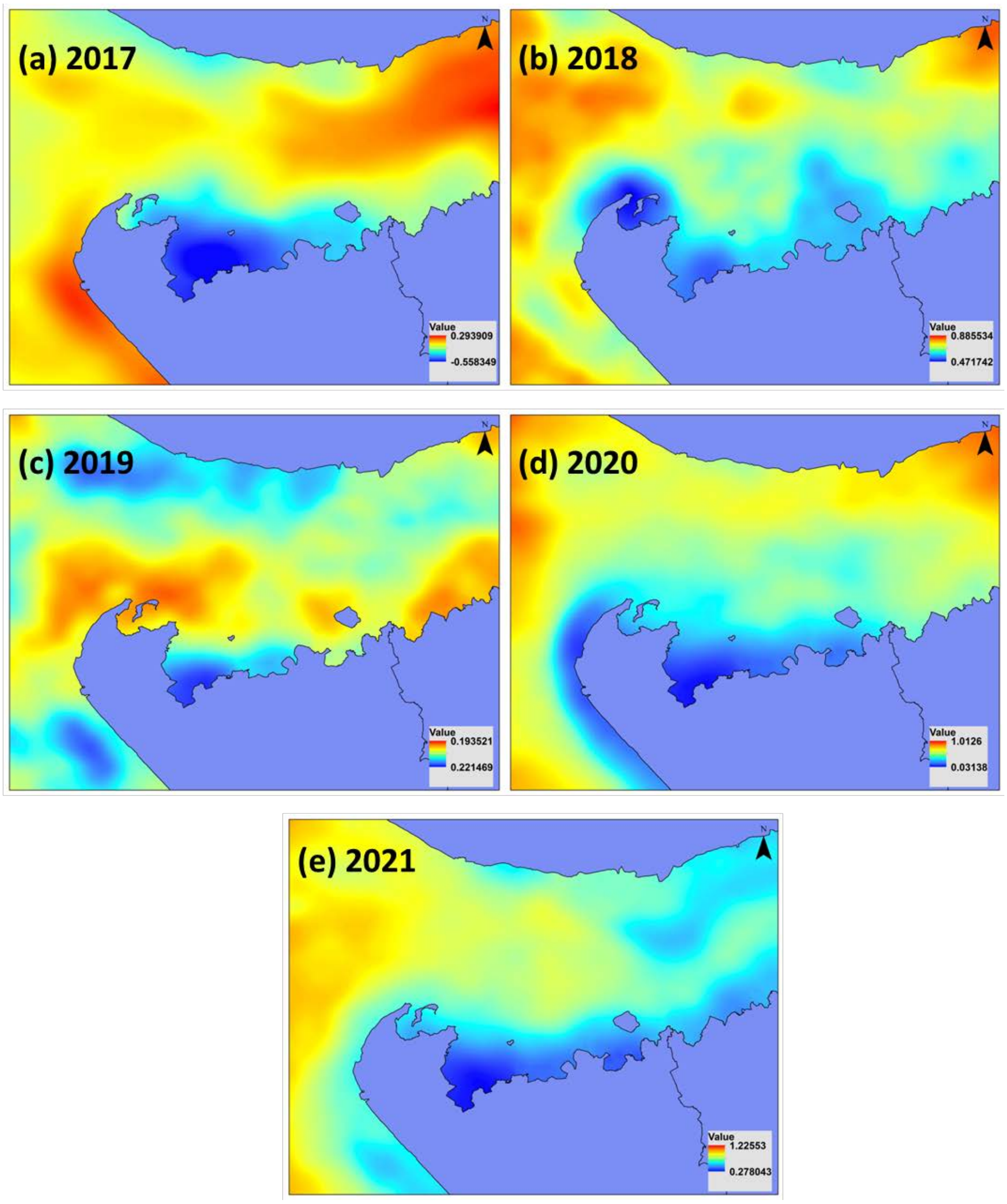



**Figure 49**: Five-year anomalies of temperature.

(2) Photosynthetically Available Radiance (PAR)

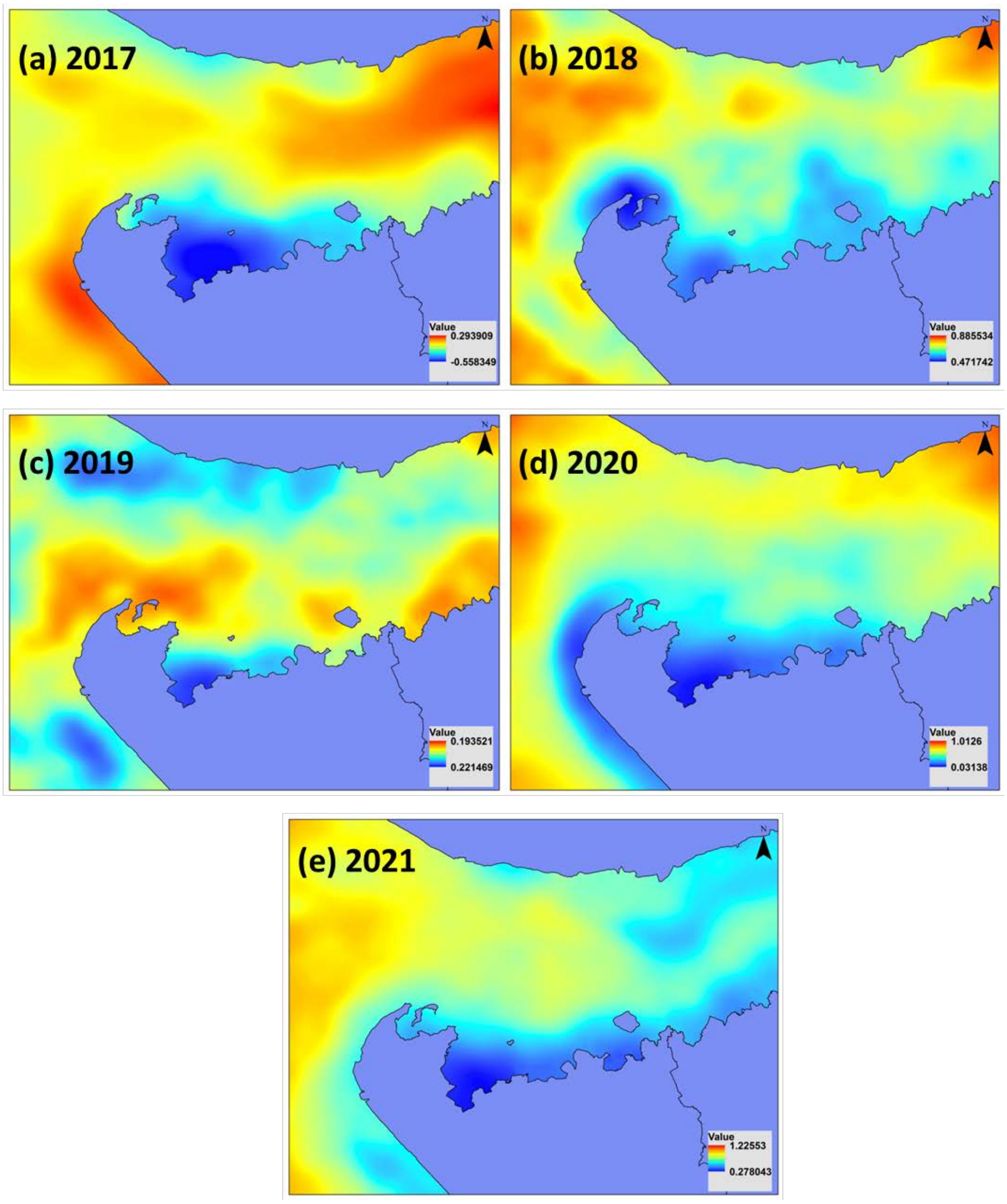



**Figure 50**: Five-year anomalies of Photosynthetically Available Radiance.

(3) Kd490 (Diffuse attenuation coefficient of K490)

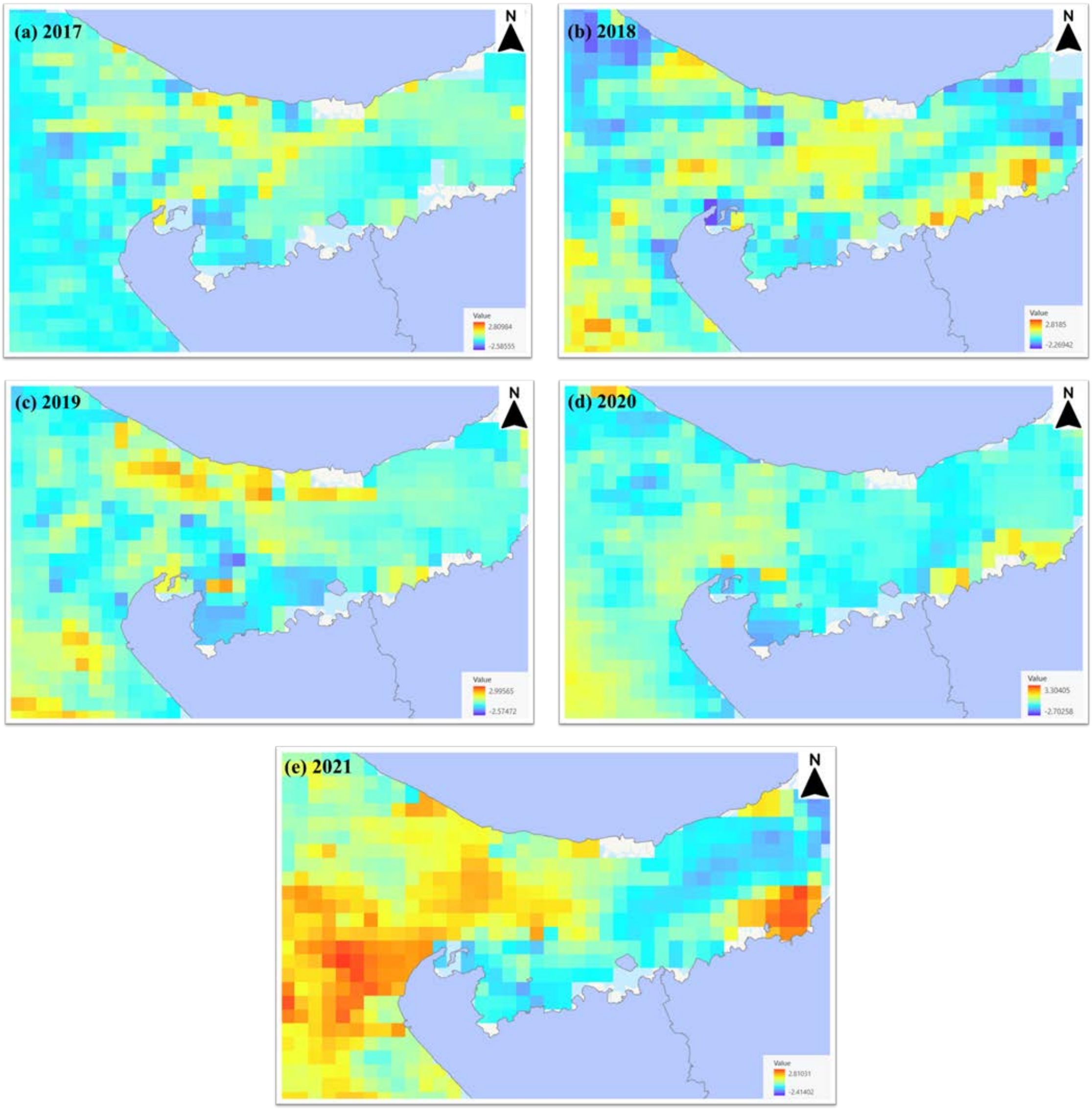



**Figure 51**: Five-year anomalies of kd490.

(4) Total Suspended Matter (TSM)

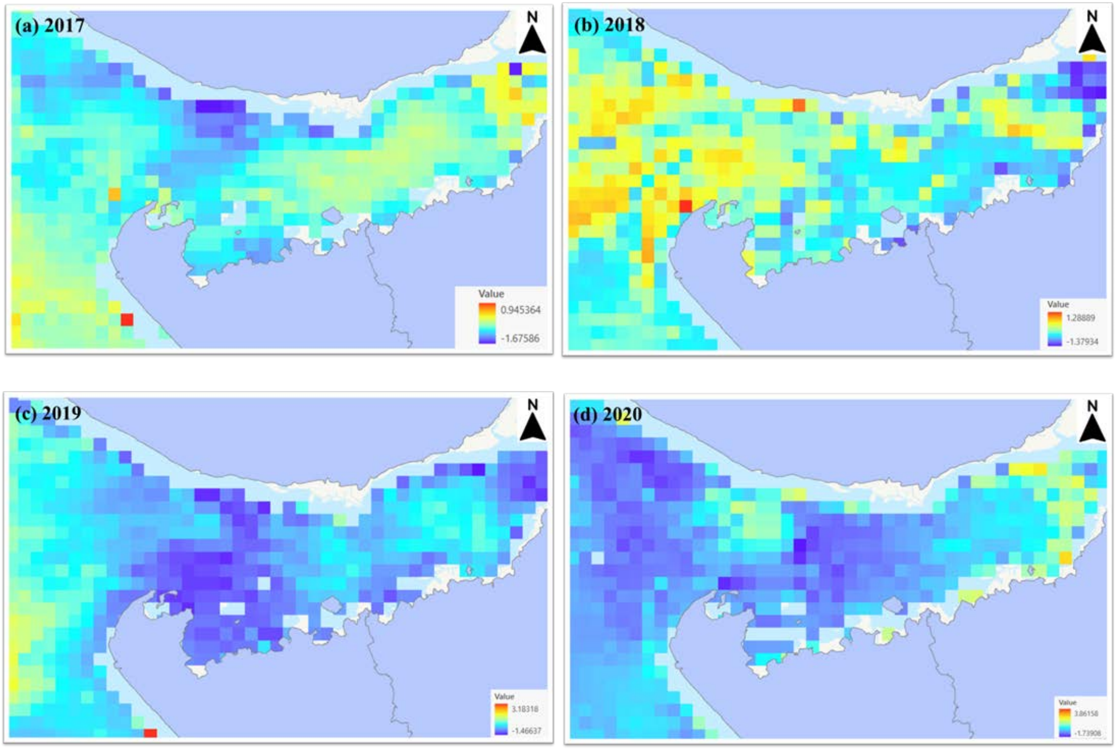



**Figure 52**: Four-year anomalies of Total Suspended Matter.