CHAPTER 2: REVIEW OF LITERATURE

For many years, coral reefs have helped keep the coasts and many marine species protected. But it's becoming clear that coral reefs are seriously threatened by global warming. As a result, stressed corals expel their symbiotic algae, which raises the potential for further coral ailments and mortality. This has led to coral bleaching. Over the world, both the frequency and the severity of this tendency have been rising. Over the past few decades, various researchers have used field observation data or reef environmental variables retrieved from satellite data to record regional or global coral bleaching trends and implications (Barkley *et al.,* 2018; Hughes *et al.,* 2018a). This research underscores the need of comprehending how coral bleaching is related to environmental variables. There is an urgent need for more accurate coral bleaching mapping that is both time and money efficient.

Remote sensing technologies have been demonstrated to be effective tools for coral reef monitoring so far (Mumby *et al.,* 1999; Hedley *et al.,* 2016). Remote sensing has made it possible to study the oceans in greater depth with global coverage, which has sparked a significant deal of interest in the topic of ocean remote sensing (Guerra *et al.,* 2016). In the field of ocean remote sensing, many researchers nowadays use Ocean Colour (OC) to study the effects of different environmental variables on coral reefs. Since OC satellite instruments offer estimates of the light that exits a water mass and defines its colour, OC is frequently referred to as spectral water-leaving radiances (Werdell *et al.,* 2018). These sensors typically measure the spectral radiation coming from the top of the atmosphere ($Lt(\lambda)$; $\mu W cm^{-2} nm^{-1} sr^{-1}$) using wavelengths at the distinct visible and near-infrared (400-1000 nm) ranges (Werdell *et al.,* 2018). Ocean Colour Remote Sensing (OCRS) sensors have the potential to continuously measure physical, environmental, biological, and biogeochemical variables that are important for managing fisheries and aquaculture, managing coastal areas, assessing ecosystem health, and contextualizing behavioral changes in the context of climate change (Le Traon, 2011; Payne *et al.,* 2021).

2.1 ENVIRONMENTAL VARIABLES THAT AFFECT CORAL COMMUNITY

It is significant that historical environmental variables did influence the coral communities and how they react to different stressors. Finding specific areas with environmental variables that increase the coral community's resilience-such as resistance to heat stress, survival during bleaching, and reef regrowth following bleaching-related mortality is still a problem for researchers and managing authorities of coral reefs (Obura, 2005). The ecosystem conditions, biological diversity and local environmental conditions are the main pillars to investigate the susceptibility of coral to different stressors.

Table 1: Capability for evaluation of environmental factors by remote sensing (Source: Hedley *et al.*, 2016)

Objective/Proxy	**Association**	**Sensor / Technology**	**Considerations**
Photic depth			
Estimation of water attenuation (K_d)	High	Ocean colour and multispectral moderate and high-resolution satellites	Newer methods improve on the limitations of standard ocean colour algorithms in shallow coastal waters
Sedimentation			
Turbidity	Medium	Ocean colour and multispectral moderate and high-resolution satellites	Seafloor reflectance in shallow waters limit the quantification of in-water constituents
Pollution			
Turbidity	Low	Ocean colour and multispectral	Direct quantification of pollutants is not feasible using remote

		moderate and high-resolution satellites	sensing. Turbidity monitoring offers a proxy for the assessment of pollutant pathways
Algal blooms	Low	Ocean colour satellites	Algal blooms, often triggered by pollution enrichment, can help pinpoint polluted areas
Coastal development			
Changes in land use	High	Multispectral high and moderate resolution satellites, airborne sensors	Changes in land use resulting in the loss of habitats and the modification of coastlines is a good proxy for the quantification of coastal development
Thermal stress			
Sea surface temperature	High	Spatially low-resolution radiometers	The only stress variable that can be directly measured using remote sensing. Proven to be useful in the forecasting of bleaching events and hindcasting of bleaching severity
Ocean acidification			
Sea surface temperature	Low	Spatially low-resolution radiometers	Together with in situ datasets can be used to model the effects of

	increased CO_2 concentrations in water chemistry

Estimates of species richness, coral abundance, and the management status of a reef system can be used to reflect the biological and ecological circumstances of the reefs in the context of resilience modeling (Roberts, C. M., 2006; Cowen *et al.,* 2000; Dawson *et al.,* 2006; Cowen *et al.,* 2006). But, when it comes to environmental variables, in their review of West and Salm (2003) they identified environmental variables that correlated with coral bleaching resistance and resilience. These variables included the presence of clouds, fluctuating temperatures, turbidity, salinity, suspended particulates (Blondeau-Patissier *et al.,* 2014; Garaba & Zielinski, 2015; Dev *et al.,* 2022), wind, strong waves, upwelling, and proximity to deep water. As an indirect indication of bleaching tolerance, they included corals' history of surviving bleaching events, species ranges, and sizes in general. Given continuous changes in coastal environmental conditions (Panseriya *et al.,* 2021) and spatial-seasonal trends, analysis of these variables is a challenging task to complete (Magyar *et al.,* 2013). To extract key environmental variables of the reef ecosystem, constant monitoring is indeed necessary (Sargaonkar and Deshpande, 2003; Simeonov *et al.,* 2003; Magyar *et al.,* 2013). Some of these environmental variables which have been included in this study have been explained below.

(i) Sea Surface Temperature (SST)

Seasonal temperature ranges that corals and their symbionts experience determine their tolerance levels and, consequently, how they react to temperature extremes (Berkelmans, 2002; Donner *et al.,* 2005; Hoegh-Guldberg, 1999). When corals are exposed to extended temperatures above normal, they experience thermal stress. In the 1990s (Glynn and D'Croz, 1990), for the first time the positive correlation between rising temperatures and widespread coral bleaching was confirmed and the severity of the stress relies on the absolute temperature, the rate of change, and the duration of the exposure (Baker *et al.,* 2008). The worst events to date have been the 1982–1983 event in the eastern tropical Pacific, Caribbean, and possibly other places around the world (Coffroth *et al.,* 1990; Glynn, 1988); the 1997–1998 global bleaching event (Berkelmans and Oliver, 1999; Wilkinson, 1998); the 2005 event in the Caribbean (Eakin *et al.,* 2010; Wilkinson and Souter, 2008); the global bleaching event in 2010 (Thomas and Heron, 2011; Moore *et al.,* 2012; Alemu and Clement, 2014; Heron *et al.,* 2014) and another global bleaching event in 2015-16 (Joshi, 2016). Temperature, in the form of Sea Surface Temperature (SST), is the stressor that can be monitored most directly by remote sensing that affects coral reef ecosystems. The U.S. National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High-Resolution Radiometers (AVHRR) offer near real-time observations of SST all over the world due to its sensors on polar- and geostationary-orbit satellites. A variety of different coral reef thermal stress incidence indices have been created using SST data (Hedley *et al.,* 2016). These indices link bleaching frequency and severity to: (1) absolute sea surface temperature values; (2) overall averages related to thresholds derived from the summer maximum or warmest monthly average temperature; (3) magnitude of temperature anomalies; (4) the duration of temperature anomalies and (5) the sum of temperature anomalies over time. So, the implicit assumption of all these studies is that the surface temperature metrics provide useful environmental information with respect to corals who typically live meters to tens of meters below the surface. Since the 1990s, NOAA's Coral Reef Watch programme (CRW) has been developing the only global and most developed set of SST products for coral reef management. The "legacy" Decision Support System (DSS) was also created based on earlier assessments of satellite and in situ SST data that were published in various papers from 1994 to 2000 (Montgomery and Strong, 1994; Gleeson and Strong, 1995; Strong *et al.,* 1997; Goreau *et al.,* 2000). The "heritage" Decision Support System (DSS) is made up of near real-time products (Liu *et al.,* 2013). At 0.5° spatial resolution (about 50 km), heritage products are created and updated twice a week. Among the spatial products are SSTs at night, their anomalies (HotSpots), accumulated anomalies (Degree Heating Weeks), and a bleaching alert region product. They are supplemented with information and images for particular reef areas around the globe that are offered as time series and connected to an automatic email warning system that notifies users when coral reefs nearby are in danger of bleaching. The CRW platform includes two programmes specifically designed to determine temperature conditions connected to coral bleaching. The positive anomaly of temperatures above the maximum monthly mean (MMM) from SST climatology for each pixel, known as the Coral Bleaching HotSpots product, indicates areas that are currently experiencing thermal stress (Strong *et al.,* 1997). The technique was developed using analysis by Atwood *et al.,* (1992) and experiments by Glynn and D'Croz, (1990), and it is based on the "ocean hot spots" idea proposed by Goreau and Hayes, (1994). The Degree Heating Weeks (DHW) product, which accumulates the HotSpot values equal to or greater than 1° C in each pixel over a 12-week period (Skirving *et al.,* 2006; Strong *et al.,* 2006), records the response of corals to the cumulative thermal stress to which they are exposed. The threshold of 1° C above the MMM was established by Glynn and D'Croz, (1990) and Atwood *et al.,* (1992).

After reefs start to experience DHW values of 4 C-weeks or above, significant coral bleaching is anticipated to happen one to three weeks later. Reefs that undergo DHW values more than 8 C-weeks are predicted to experience mass bleaching and the beginning of coral mortality. The CRW HotSpots and DHW metrics are computed twice a week using SST data from POES AVHRR and NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). Examples include the examination of recent global and regional trends in SST anomalies (Chollett *et al.,* 2012; Good *et al.,* 2007) and thermal stress (Peñaflor *et al.,* 2009; Selig *et al.,* 2010) made possible by the NOAA Pathfinder dataset (Casey *et al.,* 2010) (http://www.nodc.noaa.gov/sog/pathfinder4km). It is feasible to incorporate forecasting into the near real-time monitoring algorithms by using global sea surface temperature (SST) forecast models. Based on the statistical Linear Inversion Model system, the first NOAA CRW Outlook system was published in 2008 (Liu *et al.,* 2008), but there have been problems noted in some particular reef areas. Hence, even though certain satellite data offer direct SST data and retrieval algorithms, researchers are working on methods to further estimate SST data and provide more precise forecasts.

(ii) Sea Surface Salinity (SSS)

One of the most important climate variables is Sea Surface Salinity (SSS) because it plays a crucial role in understanding ocean currents, climatic variations, and the hydrologic cycle (Santos, 2022). Salt concentration in the top centimeter of the ocean surface is known as Sea Surface Salinity (SSS) and is measured in Practical Salinity Units (PSU) or Parts Per Thousand (PPT) (Xiong *et al.,* 2013). By evaporation, precipitation, and river runoff, SSS is connected to the global water cycle as well as to the mass and heat balances between the atmosphere and the ocean (Santos *et al.,* 2022; Sommer *et al.,* 2015; Yu *et al.,* 2020). Precipitation, runoff, and ice melt all result in a decrease in salinity because they increase the amount of freshwater in the environment and subsequently dilute the salt of the surface water. On the other hand, evaporation and sea ice formation end up leaving behind salt, which raises the salinity of the saltwater (Talley *et al.,* 2002; Trujillo & Thurman, 2011; Yu *et al.,* 2020). Since these variations can have an effect on biological and physical processes in the ocean, which can have dangerous long-term repercussions on ocean circulation and the water cycle, changing regional climates and marine life, it is crucial to continuously map SSS in order to understand climate changes and how they affect our hydrologic cycle (Klemas, 2011). Understanding SSS variability is essential for preserving coastal marine life since it determines seawater concentrations and circulation in coastal oceans (Geiger *et al.,* 2013).

For centuries, SSS in situ measurements have been recorded, however, these data reveal some spatial and temporal coverage gaps, with portions of the world's oceans that were never sampled (Marghany & Hashim, 2011; Qing *et al.,* 2013). Along with these local data, the use of remote sensing for SSS monitoring has increased the precision of SSS observations and enabled the construction of ocean global maps with a greater temporal resolution.

Since the launch of the Soil Moisture and Ocean Salinity (SMOS) mission in 2009, SSS has been directly measured from space. The Aquarius and Soil Moisture Active-Passive (SMAP) missions joined in 2011 and 2015, respectively. The missions measure the Earth's surface emission using an onboard L-band microwave radiometer (Reul *et al.,* 2020). However, these missions offer a limited geographical resolution; SMOS, for example, offers a spatial resolution of approximately 35-50 km. The complexity of coastal and estuary waters is constrained by the low spatial resolution of these missions, and another fact is that they perform effectively in the open ocean (Fu *et al.,* 2021; Qing *et al.,* 2013).

Yet, SSS mapping from space had already been accomplished before SMOS was even launched. These studies can generally be divided into two categories. The first group of studies was able to extract SSS from Coloured Dissolved Organic Matter (CDOM), which can be derived from OC satellite products and is inversely related to salinity (Ahn *et al.,* 2008; Bai *et al.,* 2013; Khorram, 1982; Palacios *et al.,* 2009). The second set of studies showed that it is possible to estimate SSS from optical sensors like MODIS, Landsat [Operational Land Imager (OLI) and Thematic Mapper (TM)] and Sentinel-2 MSI (Multi Spectral Instrument) by using simple regression methods (Chen & Hu, 2017; Daqamseh *et al.,* 2019; Santos, 2022; Marghany *et al.,* 2010; Marghany & Hashim, 2011; Qing *et al.,* 2013; Sun *et al.,* 2019; Wouthuyzen *et al.,* 2020; Zhao *et al.,* 2017). Multilinear Regression models and spectral signature data from optical sensors (Wouthuyzen *et al.,* 2020) were used to make this achievable. The earliest study can even be dated back to 1982 (Khorram, 1982), where he observed the correlations between Landsat TM colour bands and SSS in an estuarine ecosystem.

(iii) Turbidity and Sedimentation

The term "turbidity" refers to the degree of transparency of water and is impacted by suspended particles from several sources, including phytoplankton, zooplankton, soil, silt, and clay particles. Historical changes to the watersheds of tropical islands frequently cause a rise in land-based pollution, including silt, fertilizers, and other pollutants that pose a threat to numerous coral reefs around the world. Through erosion and storm runoff, terrestrial sediment is transported to the nearshore environment. While a background level of natural sediment is expected in a healthy ecosystem, excessive levels can result in the destruction of reefs. Understanding how benthic organisms react to light availability, particularly in shallow coral reef environments, depends on the ability to detect changes in the transparency of the water column (Fabricius *et al.,* 2013; De'ath and Fabricius, 2010). Because photosynthetic species construct coral reefs, these ecosystems are extremely sensitive to changes in the water column that impact light attenuation. As a result, in coral reef systems, water transparency is regarded as a crucial indicator of water quality.

Today, mesoscale trends within a reef area can be investigated using data from remotely detected ocean colour. In order to complement in situ characterizations of water quality, low-resolution ocean colour data have been utilized to describe stress events such as algal blooms (Hu *et al.,* 2003; Tomlinson *et al.,* 2004), sedimentation and turbidity (Udy *et al.,* 2005). Ocean colour information has also been used to assess regular connectivity patterns within reef regions (Paris and Chérubin, 2008; Sheng *et al.,* 2007; Soto *et al.,* 2009) or unexpected connectivity patterns following a stressed event (Andréfouet *et al.,* 2002) as well as to distinguish the relative causes (resuspension or runoff) of high sedimentation rates in a reef area (Segal *et al.,* 2008). Also, using moderate-resolution satellite pictures, detailed sedimentation patterns have been evaluated (Segal *et al.,* 2008). Recently, the development of quasi-analytical techniques for calculating the photic depth ($Z_{\%}$) from observed satellite radiances has contributed to advancements in remote sensing applications (Lee *et al.,* 2007). $Z_{\%}$ is a unit of measurement for water attenuation; for instance, $Z_{1\%}$ is the depth at which only 1% of the PAR (photosynthetically active radiation) from the surface is still present. The Secchi depth (Z_{SD}), which is the depth at which a white disc stops being visible to an observer above the surface, is the most commonly used indicator of water transparency in the field. Despite not being an exact assessment of transparency (Secchi depth might vary by up to 20% owing to sun angle), Millions of observations have been taken of Secchi depth over a long period of time, and more recent work has enhanced the theory behind it and the alignment of Secchi depth with remote sensing data (Lee *et al.,* 2015). In one specific implementation, Weeks *et al.,* (2012) improved and validated the Lee *et al.,* (2007) quasi-analytical technique for the waters of the Great Barrier Reef, Australia, using approximately 15 years of regional Z_{SD} data. Water transparency was demonstrated to change greatly in both space and time using the recently created photic depth product over a decadal satellite time series, principally driven by river discharge and oceanic invasions. The multispectral diffuse attenuation coefficient (Kd), which can be derived from satellite data, has also been the subject of subsequent studies to look at the geographical and temporal variability of water clarity in coral reef ecosystems (Barnes *et al.,* 2013; Zhao *et al.,* 2013; Petus *et al.,* 2014). According to the comprehensive perspective, due to the robust, frequent, and synoptic coverage, satellite data from moderate resolution sensors like MODIS, and more recently VIIRS (Wang *et al.,* 2012; 2013) provide significantly better estimates of turbidity conditions in coral reefs (Wang *et al.,* 2014).

2.2 REMOTE SENSING OF CORAL REEFS USING SPECTRAL CHARACTERISTICS

Remote sensing technologies have so far proved to be significant methods for collecting information on coral reefs (Mumby *et al.,* 1999; Hedley *et al.,* 2016). Benthic habitats are easier to map in great depth and with greater accuracy using remote sensing data with high spatial and spectral resolution (Hochberg and Atkinson, 2003; Kutser *et al.,* 2020). Any given sensor's individual spectral bands are designed to cover a specific range of wavelengths. For instance, the multispectral system uses spectral bands that are 100 nm wide to cover the blue, green, red, and near-infrared regions of the electromagnetic spectrum. The hyperspectral system, in comparison, uses hundreds of spectral bands that are each 10 nm broad to cover the same wavelength range. To map coral reef benthic features at a coarse scale, multispectral methods offer widely applicable spectral reflectance characteristics. Holden *et al.,* (2001) and LeDrew *et al.,* (2004) contend that spatial statistics can be used to extract a measure of reef health from moderate spatial resolution multispectral satellite image data (such as SPOT). Landsat and SPOT are suitable for mapping geomorphological zones with low to intermediate complexity, according to prior research on benthic classification (Lyzenga, 1981; Leon and Woodroffe, 2011; Phinn *et al.,* 2012; Roelfsema *et al.,* 2013; Xu *et al.,* 2016). However, due to the variety of coral phenomena such as bleaching occurring at sizes of a few meters or less, the Copernicus Sentinel-2 mission with a special resolution of 10 m, is becoming very useful to improve coral reef remote sensing. It combines a number of excellent features for monitoring coral reefs. It contains a blue band similar to Landsat 8, but with a finer spatial resolution of 10 m and atmospheric correction, it permits the mapping of corals in shallow waters. However, due to the fact that bleached corals' reflectance resembles the sand on the reef island. Similarly, healthy corals' spectral signatures match up with the corals covered in algae due to the mixed pixels effect and the reason is, normally corals have a symbiotic association with zooxanthellae (Chaudhury *et al.,* 2019), making discrimination of corals from algae merely based on the spectral signatures very difficult, especially with data sets of broad spectral resolution. Though, as it has been determined which wavelength ranges are absorbed by particular chemicals and processes in water bodies and coral photosystems, algorithms can be used to estimate or map these features for each pixel using reflectance signatures resolving these features.

For mapping, the structural or physiological characteristics of reefs, one of the most popular data transformations are to use spectral indices, such as the Normalized Difference Vegetative Index (NDVI). There are a variety of spatial interpolation methods that can be used to determine the pattern of diversity distribution. One of which is the Inverse Distance Weighted (IDW) interpolation approach, which was used by Kumari *et al.,* (2017) to determine the spatial distribution pattern of zoanthids along the coast of Saurashtra in Gujarat. Benthic structures on a coral reef vary from one area of the reef to another based on a variety of environmental factors, such as hydrodynamics, light quality, predation, and human influences. Hence, an effective spectral index will show a direct reaction to environmental variables with very slight variations in coral cover. Prior to now, reef ecosystems have used spectral band ratios generated from satellite imagery data to map bottom cover (Mumby, 2000; Dustan *et al.,* 2001). However, they are limited to clear, shallow waters. In their early study, Hochberg and Atkinson (2000) explored the separation of coral, algae, and sand using field spectrometry data and a linear discriminant function analysis. They then applied this to airborne hyperspectral images and saw encouraging results. Thus, when considering atmospheric attenuation, varied water depths, transparency, and circumstances at the air-sea interface, a usable coral index can be generated by spectral signatures.

2.3 USE OF CoralWatch CORAL HEALTH CHART

The frequency of high thermal stress episodes and rising sea surface temperatures (SSTs) brought on by climate change have led to widespread coral bleaching (Ainsworth *et al.,* 2016; Eakin *et al.,* 2009; Hughes *et al.,* 2018b; Kwiatkowski *et al.,* 2015; Skirving *et al.,* 2019). A straightforward approach of assessing coral health is essential to obtain a widespread understanding of coral bleaching and recovery given that SSTs are expected to rise in the upcoming years (Pachauri *et al.,* 2014). The Coral Health Chart, created by the Coral Watch system, can record coral condition in more detail than the conventional division of living hermatypic corals into bleached and nonbleached groupings by taking into account the human visual system and the colour change corals experience during bleaching (Hochberg *et al.,* 2003; Holden and LeDrew, 1997). CoralWatch (CW), a global citizen science initiative founded in 2002 as a scientific research project, currently combines education and global reef monitoring to look at coral bleaching (Marshall *et al.,* 2012). The CW citizen science monitoring programme offers a low-cost proxy for assessing and documenting natural coral colour variability and health by allowing non-specialists to evaluate coral health using a colour chart as a health diagnostic tool with the potential to expand global coral bleaching and health datasets (Marshall *et al.,* 2012). CoralWatch Health Score (CWHS) can be used as a diagnostic to track coral health over time and coral sensitivity to local thermal stress, according to Siebeck *et al.,* (2006). Darker CWHS values (near to 6) imply larger densities of Symbiodinium and, thus, healthier or recovering corals, while lighter CWHS values (closer to 1) represent decreasing densities of Symbiodinium linked to stress and bleaching. Many research articles have been published using CW colour health charts to validate remote sensing techniques for monitoring hazards from coral bleaching and temperature stress (Fabricius *et al.,* 2011; Leiper *et al.,* 2009). As corals bleach, Siebeck *et al.,* (2006) demonstrated a correlation between a decrease in symbiont and chlorophyll-a content and an increase in brightness and a decrease in coral colour saturation (hue remains relatively constant). The Coral Health Chart was then utilized by Leiper *et al.,* (2009) in their work to give an objective standard technique to correlate the spectral response of bleached corals. They used the bleaching data produced from the CoralWatch health chart and the spectral reflectance of corals in their study to demonstrate that coral spectral reflectance characteristics can be given a colour score to identify the health of a corals.

2.4 STUDIES CONDUCTED ON THE REEFS OF THE GULF OF KACHCHH (GoK)

Many studies on corals, coral reefs, and reef associates as well as reef geomorphology have been conducted in Gujarat. The first comprehensive publication for taxonomists on the distribution of different coral species in the Gulf of Kachchh (GoK) was given by Pillai and Patel in 1988 where they described the prevalence of 37 species of Scleractinians on several islands of GoK. Whereas Dave, (2011) conducted an ecological assessment of Narara Reef with an emphasis on the coral community. In 2012, Parasharya researched the opisthobranch fauna and coral populations of the GoK. Coral migration and growth patterns in the GoK were examined by Pandey *et al.,* (2010) whereas Bhattaji, (2011) investigated the principal abiotic and biotic issues affecting the GoK coral reefs.

The physiochemical characteristics of water can be a useful tool to identify the ideal conditions for the growth of corals and coral reefs. Since the coral species of GoK are acclimated to a wide range of temperature fluctuation at the intertidal zones, much research has been done to record the bleaching phenomena in this region. Arthur, (1995) recorded 1.2-1.4% percent coral bleaching in the Gulf of Kachchh during the summer months of Gujarat and concluded it was a normal summer response of corals towards the summer temperature rise. However, in the summer of 1998, an average of 11% coral bleaching in the Gulf of Kachchh was recorded (Arthur, 1995) as a result of the El Nino Southern Oscillation which was anticipated as more coral bleaching than would normally occur during the summer. Vivekanandan *et al.,* (2009) investigated the temperature-related susceptibility of India's corals and coral reefs. They made predictions about the future and the course of the Indian Reef in their study. They hypothesized that the increase in sea surface temperature could lead to an increase in the frequency of disastrous bleaching events across all locations. Between May and June 2010, Joshi *et al.,* (2014) observed coral beaching and discovered coral whitening colonies along the reef of the Narara and Poshitra region in the Gulf of Kachchh. In September 2014, Adhavan *et al.,* discovered bleaching in seven scleractinian species on Pirotan Island and stated that coral bleaching at Pirotan Island might be caused by the SST and sedimentation. They further stated that the Island's high SST may be the result of the southwest monsoon's delayed arrival, which would have prolonged the summer season (Adhavan, *et al.,* 2014). Arora *et al.,* (2019) conducted research on coral bleaching brought on by elevated SST in the Gulf of Kachchh in 2016. The coral reef experienced thermal stress that lasted for 28 days and had a maximum positive anomaly of 1.31°C in June 2016. Researchers from different fields have also documented similar trends in the temperature of GoK's surface water (Saravanakumar *et al.,* 2008; Devi *et al.,* 2014; Kumar *et al.,* 2016; Panseriya *et al.,* 2021).

There have been reports of both natural and man-made pollutants such as sedimentation, turbidity, Dissolved Oxygen (DO), nutrients, and many other contaminating the coastal water of the reefs of GoK. Several researchers have noted these contaminants and their impact on water quality in various coastal regions during the past ten years (Zingde, 1999; Kunte *et al.,* 2005; Vethamony *et al.,* 2007; Gosai *et al.,* 2018a, 2018b, 2018c; Panseriya *et al.,* 2020). Seasonal impact and anthropogenic pressure both had an impact on the changes in turbidity and salinity of the coastal regions of GoK. Panseriya *et al.,* (2021) reported the seasonal variation in turbidity from 9.2 ± 6.9 NTU to 60.4 ± 47.9 NTU. Whereas Bignesh *et al.,* (2014) and Patel *et al.,* (2018) concluded that turbidity of seawater with 50-100 NTU has a negative effect on coral growth at GoK. The range of the average salinity in the surface water was found to be between 36.5 ± 0.5 ppm to 52.0 ± 6.0 ppm in GoK (Panseriya *et al.,* (2021). Due to the influx of fresh monsoon water from the catchment area into the GoK and subsequent dilution, lower salinity has been recorded during the post-monsoon season (Unnikrishnan and Luick, 2003; Devi *et al.,* 2014; Rathoure, 2018). On the other hand, Dixit *et al.,* (2010) and Devi *et al.,* (2014) reported greater water salinity as a result of a high rate of evaporation during summer seasons. Many works of literature further suggest that the vulnerability of water pollution is caused by the geographic locations of sites, various industrial activities, mining activities, and strong agricultural and domestic activities around the vicinity of GoK

(Saravanakumar *et al.,* 2008; Bhadja and Kundu, 2012; Chakraborty *et al.,* 2014; Devi *et al.,* 2014; Kumar *et al.,* 2015).

Bleaching is a physiological, cellular adaptation to environmental challenges, and spectroscopy helps in characterizing coral health in terms of reflectance spectra or reflected light as a function of wavelength. On the basis of the spectral properties, Sharma *et al.,* (2008) performed supervised classification using the Maximum Likelihood classifier to map the different reef features of GoK. Similarly, Prerna *et al.,* (2015) also used geospatial techniques to detect the change in the coral reefs of GoK. Choudhury *et al.,* (2019) used a field hyperspectral spectrometer to identify the bleaching in one of the coral species. they observed in this study, that live and bleached corals get distinguished in the visible region over 500–600nm. In one of their study, Arora *et al.,* 2019 studied Coral bleaching using the indices like Bleaching Threshold (BT), Positive SST Anomaly (PA), and Degree Heating Weeks (DHW) to analyze the thermal stress on the coral reefs.

2.5 LACUNA

Research on reefs has been accorded higher importance worldwide; but, on a regional scale, less work has been done on the reef in the Gulf of Kachchh (GoK) compared to other Indian reefs. In spite of the fact that the reefs of GoK are protected by the National Marine Park and Sanctuary (MNP-S), the reefs of GoK have suffered significant destruction as a result of natural and anthropogenic activities in the past. The geological, and biological components of reef ecosystems have been the primary focus of earlier studies. The work that has been done on the coral reef ecology in the Gulf of Kachchh based on the concepts of Remote Sensing and GIS has been restricted. The tools of remote sensing and Geographic information systems (GIS) make it possible to map and monitor an environment that is both diverse and geographically favorable for the growth of corals and coral reefs.

In light of the findings of previous research on the Gulf of Kachchh, it is necessary to conduct research on corals using remote sensing techniques. This will assist in the identification of the reef area and the ecosystem that is contained within it, as well as the diversity distribution and the predominant regional threats to corals and other reef associates. However, much less research has been done to identify the bleaching phenomenon in coral reefs GoK using spectral analysis and spectral indices.

With said that this work is framed to correlate the impacts of various environmental parameters with the present scenario and condition of the corals in GoK reefs. The use of statistics, remote sensing, and GIS technology is the main aspect of this study in identifying the effects on corals. In correspondence with the in-situ data, secondary satellite data of different parameters have been analyzed to conclude the aim of the study.

2.6 AIM AND OBJECTIVES

Aim:

Nowadays, the ecosystem of the reef is under stress from climate change and global warming. Corals are at significant risk of extinction because they depend on a small set of environmental factors, including sea water temperature, salt, turbidity, and photosynthetically active radiation (PAR), for development and sustenance. The reefs of Poshitra and Narara are also facing major threats from various environmental parameters. The most commonly observed effect on corals has been seen as coral bleaching. Thus, the ultimate aim is to identify the conditions that are most and less vulnerable to stress using environmental variables.

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.