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# †Sedimentation pattern in Pirotan reef, Gulf of Kachchh, India

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**Abstract**

Reef building corals flourish in tropical and subtropical clear waters within a narrow range of bio-physical environmental parameters. Among the parameters, sedimentation affects corals through tissue damage. Multi-temporal, high spatial resolution, multi-spectral satellite images can be integrated on a GIS platform to identify the micro reef-zones vulnerable to future sedimentation. This study attempts to identify micro-level regions of Pirotan reef, part of Jamnagar Marine National Park, Gujarat, India. RESOURCESAT (IRS P6) LISS IV MX images were used to study the reef-scale sedimentation pattern for a period of four years (2004-2007). Digitally classified images were used as base reference to create vector inputs for identifying the micro-level, reef–scale changes in sedimentation pattern. Close observations on the sedimentation pattern in Pirotan reveal an ongoing process of sand filling in the central tidal pool, extension of a juvenile beach within the core region of the reef, a NE-SW trendline demarcating a clear distinction between the relatively sediment-free seaward face of the reef and the contrasting eastern and south-eastern areas showing high sediment loading.

**Keywords:** Coral reef, remote sensing, morphodynamics, benthic community-sediment relationship

## Introduction

Reef building corals thrive within a narrow range of bio-physical environmental parameters. They are increasingly being threatened with the persistent problem of sedimentation (Rogers, 1990; Spalding *et al*., 2001). Sedimentation *per se* is a natural process, commonly associated with high turbidity. However, it can also be due to anthropogenic activities. Long-term or episodic sediment influx in reef environment has deleterious effect on coral communities, as it blocks the sunlight penetration to the photic depths, thus hindering photosynthesis of zooxanthellae (Fabricius and Wolanski, 2000), resulting in a low supply of nutrients to the host coral polyp. Remote sensing techniques have been proved to efficiently monitor the problem of sediment loading in a reef environment over time as it can provide repetitive, synoptic, reef scale coverages over the field methods (Andréfouët and Riegl, 2004; Calhoun and Field, 2008).

Pirotan reef (22º34′41" - 22º37′06" N lat.; 69º55′54"- 69º58′57" E long.), identified as a part of Jamnagar Marine National Park (Jamnagar district, Gujarat, India), is situated in the Jamnagar-Okha coastal segment of the Saurashtra Peninsula, in the interior of southern part of Gulf of Kachchh. Pirotan is a fringing type of reef with an island (Pirotan Island) in its core and lies to the north of Jindra bet (island) and to the NW of Munde-Ka-Bet reef (Fig. 1).

Satellite imagery-based early records of Pirotan reef (habitat level maps prepared at Space Applications Centre: Source: Coastal Habitat of Selected Marine Protected Areas: Atlas of India, Bahuguna *et al.*, 2007) show a narrow, east-west

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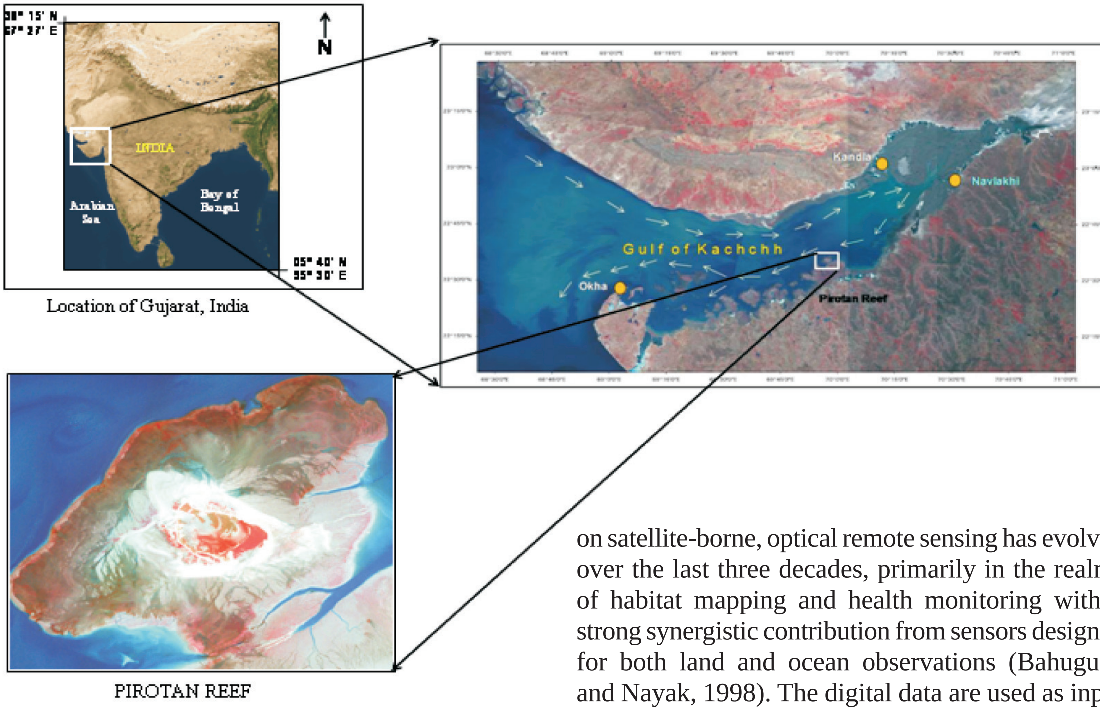


Fig. 1. Location of study area: Pirotan reef with flow of sediments in Gulf of Kachchh

transverse belt (adjacent to the central island) of mud deposition over the reef in 1975. Within a span of fifteen years, there was considerable extension of mud deposition in the eastern part of the reef. Over a short period of three years from 1982 to 1985, mud deposition over the reef transpired a particular pattern: a gradual, NE-SW orientation of the mud-spread along the eastern margin of the reef. The scenarios over the period 1990-2007 depict that the gross pattern of sedimentation remains the same. However, a careful observation reveals a gradual obscurity of the eastern margin of the reef under a column of mud with time. Interestingly, the relative spatial occupancy of sand and mud, over time demonstrates a high dynamicity.

This study aims to identify micro-level regions vulnerable to future sediment loading of Pirotan Reef, Jamnagar Marine National Park, Gujarat. Conventional field based methods of data collection fail to provide a comprehensive reef-scale picture. An alternative approach can be adopted using a multi-temporal sequel of high resolution (spatial), multi-spectral satellite images. Reef research based on satellite-borne, optical remote sensing has evolved over the last three decades, primarily in the realms of habitat mapping and health monitoring with a strong synergistic contribution from sensors designed for both land and ocean observations (Bahuguna and Nayak, 1998). The digital data are used as input to identify litho/sediment-substrate characteristics and map reef-scale morphodynamics. Reef scale morphodynamics is considered as a key for understanding the changing hydrodynamic conditions of the reef and to infer the sedimentation patterns and processes operating on the reefs.

## Material and Methods

Indian Remote Sensing satellite RESOURCESAT (IRS P6), Linear Imaging Self Scanner (LISS IV) sensor multi-spectral images of Pirotan reef of low tide conditions have been used to study the reef-scale sedimentation pattern during 2004-2007. Using the standard formula, the pixel level Digital Numbers (DN) were converted into radiance values. Ten pixels were selected randomly as dominant ecological and lithological substrate and radiance values were plotted against spectral channels to generate spectral signature. These help to understand the response of different substrates in the 3 broad spectral channels present in the LISS IV sensor. Vector polygons representing different geomorphic zones and ecological units were created for the core area for all four years to carry out change detection in the core area of the reef overlaying vector maps of the current year on the

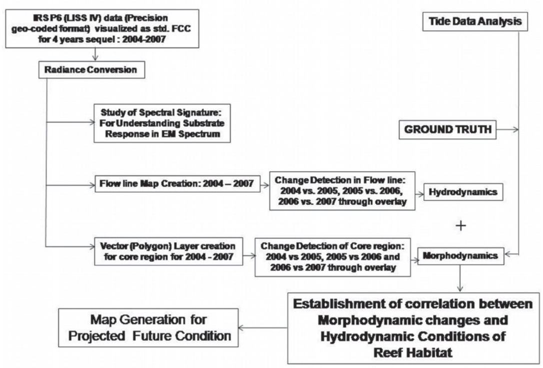


Fig. 2. Flow chart indicating methodology

preceding year. Thus, change detection maps of the core region were prepared to analyze the trends of morphodynamics. For correlating the trends of morphodynamics with hydrodynamic conditions prevailing in the Pirotan reef, flow lines (water channels present over reef through which water moves on reef at the time of tidal inundation; Glossary of Geology, AGI) were traced for all four years to carry out similar change detection through overlay technique. For correlating the inferred hydrodynamic condition with the prevailing tidal conditions at the time of image acquisition, S.O.I Tide Tables for the corresponding dates were referred and tide graphs were generated for three tidal stations of Gulf of Kachchh: Okha, Kandla and Navlakhi. The methodology followed has been indicated in Fig. 2. The sedimentation pattern and processes operating on Pirotan reef are discussed in the light of reef-scale morphodynamics and hydrodynamic conditions of the reef. On this basis of understanding, a map depicting the vulnerable areas of Pirotan reef has been generated and accordingly reef-scale microhabitat level changes have also been predicted.

## Results and Discussion

***Change detection of core region from 2004 to 2007:*** The morphodynamics of the core region shows micro-level changes in the eco geomorphic system

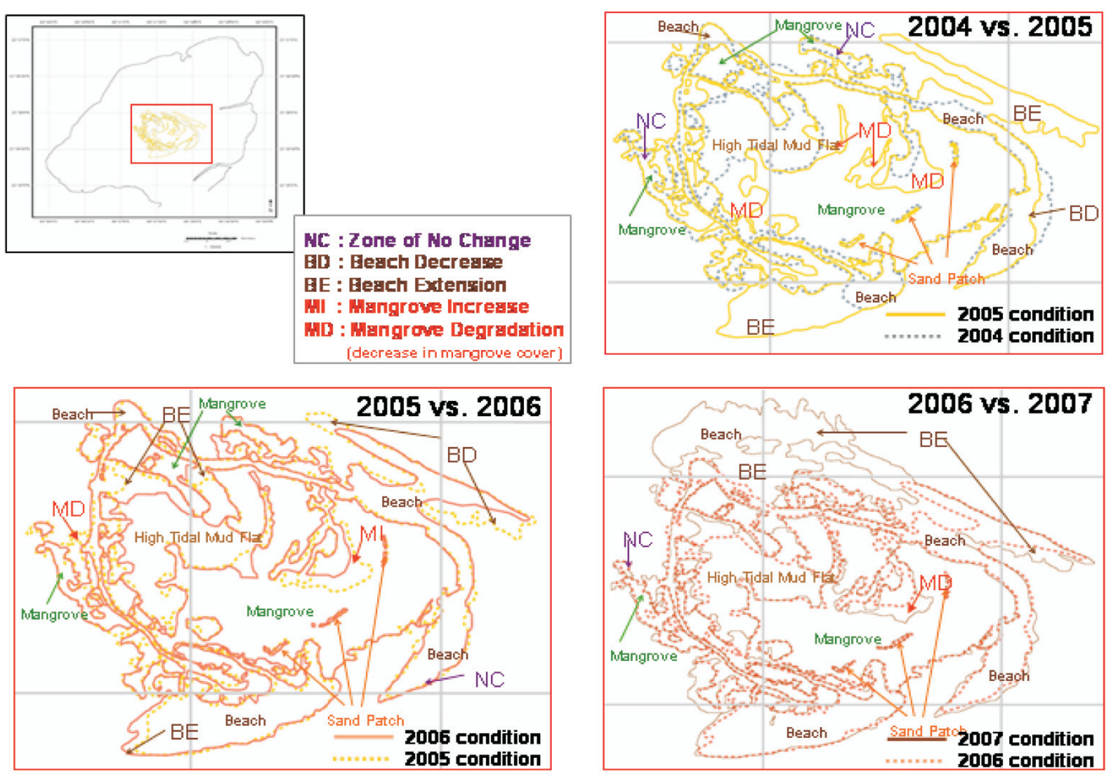


Fig. 3. Change detection: Core Region

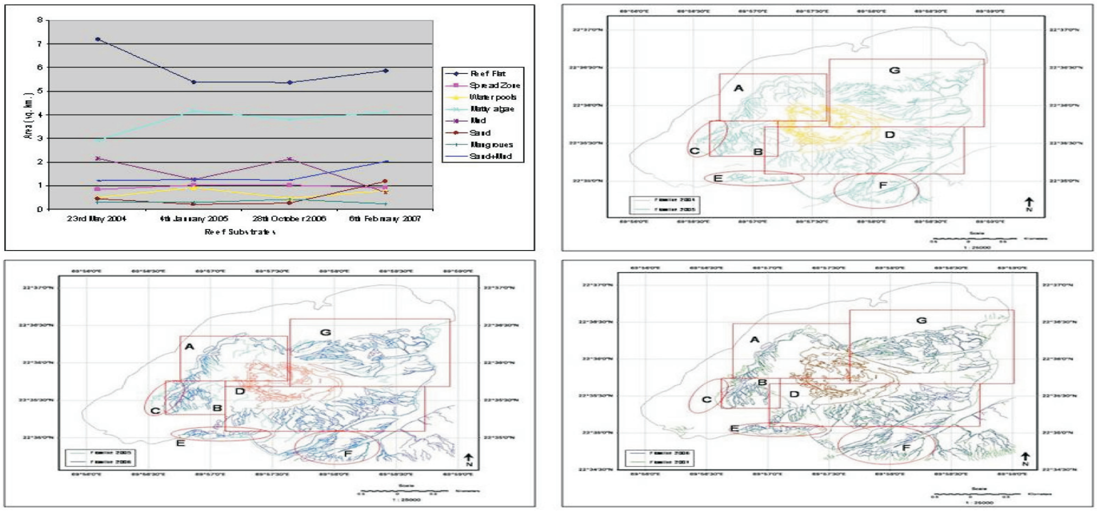


Fig. 4. Area occupied by different reef substrates on Pirotan reef and change detection of flow lines

Table 1. Summary of change detection of flowlines during 2004-2007

| | | Statistics | | | Comparison | | | |
|---|---|---|---|---|---|---|---|---|
| Segment | Year | Principal flow lines | Flow lines segments | Interfluves | Complete overlap | Partial overlap | Landward extension | Substrate |
| A | 2004 | 7 | 16 | 14 | | | | Sand |
| | 2005 | 15 | 10 | 22 | 8 | 4 | 2 | Sand |
| | 2006 | 13 | 17 | 17 | 10 | 6 | 0 | Sand |
| | 2007 | 12 | 12 | 23 | 9 | 10 | 0 | Sand |
| B | 2004 | 10 | 11 | 11 | | | | Sand |
| | 2005 | 5 | 23 | 26 | 3 | 7 | 0 | Sand |
| | 2006 | 9 | 37 | 30 | 12 | 7 | 0 | Sand |
| | 2007 | 10 | 39 | 26 | 9 | 11 | 0 | Sand |
| D | 2004 | 13 | 14 | 15 | | | | Silt |
| | 2005 | 26 | 45 | 60 | 3 | 12 | 0 | Silt |
| | 2006 | 28 | 128 | 106 | 9 | 19 | 0 | Silt |
| | 2007 | 25 | 142 | 115 | 7 | 30 | 2 | Silt |
| E | 2004 | 4 | 9 | 10 | | | | Silt |
| | 2005 | 10 | 20 | 21 | 3 | 2 | 0 | Silt |
| | 2006 | 12 | 31 | 21 | 15 | 5 | 0 | Silt |
| | 2007 | 11 | 29 | 26 | 10 | 13 | 0 | Silt |
| F | 2004 | 7 | 6 | 6 | | | | Silt |
| | 2005 | 12 | 47 | 29 | 2 | 4 | 4 | Silt |
| | 2006 | 15 | 49 | 42 | 7 | 7 | 6 | Silt |
| | 2007 | 12 | 46 | 47 | 16 | 8 | 13 | Silt |
| G | 2004 | 15 | 16 | 13 | | | | Silt |
| | 2005 | 35 | 53 | 74 | 3 | 7 | 0 | Silt |
| | 2006 | 35 | 60 | 67 | 5 | 19 | 2 | Silt |
| | 2007 | 38 | 65 | 100 | 5 | 27 | 1 | Silt |

(Fig. 3). The mangrove cover decreased in the core region indicating shortage of availability of tidal water in terms of frequency and volume as well as residence time of water of the tidal inundation. The areas losing out the mangrove cover were subsequently getting turned into high tidal mudflats (HTM). The HTM fragmented over time and during 2006-2007, the HTM showed evidence of salt encrustation. The core region was in the process of isolation with an increased level of beach deposition during 2004-2005, which is a contrast in terms of sand influx. The period between 2005 and 2007 shows different direction of sand movement and its relocation. There was new deposition of sand in the eastern part which can be considered as a juvenile beach.

***Change detection of flow lines: hydrodynamics from 2004 to 2007:*** To detect flow line change, the entire area was divided into 7 sectors on the basis of local slope and flow line direction. The results are summarized in Table 1 and Fig. 4.

***Sector A*:** In this sector the slope as well as the principal flow direction are from beach to the pool. The main flowlines have almost doubled and the number of segments has decreased. The overlapped length of permanent flowlines and segment indicates seasonal flow in the channel. Partial overlap of segments indicates subtle depression in their length of flow. Interfluves (area between adjacent streams flowing in the same direction; Glossary of Geology, AGI), which were initially 14, increased to 22 indicating increase in number of flows dissecting the earlier interfluves. The most surprising observation was the absence of any stream/flow line in the northern part of the region which continued from 2006 to 2007. It was observed that sand filling of the pool has completely erased the gradient and converted the pool into an extremely smooth, flat surface. Towards the southeast part of sector A, a network of parallel flowlines aligned southeast to northwest direction exists. These flowlines and interfluves show complete or partial overlaps over the period 2006-2007. The overlap over the length of the flowline continues with different seasons. In 2006 to 2007 the overlap shows a cut off mostly in their headward direction whereas the poolside segments show consistency in water retention. Thus, volume of water seems to be important in maintaining the flow lines. The changing slope factor also shows a control in distribution, length and number of flowlines.

***Sector B*:** The B sector shows dynamicity in terms of depositional features observed over time in different seasons. In 2004, the number of principal streams was 10 with 11 interfluves, which increased to 26 interfluves with 5 principal and 23 segments in 2005. In 2006, the interfluves increased to 30 indicating that with more volume of water the number of channels and small depositions increase over time and merge with each other and extend in size. Notable in this sector was the disappearance of the streams in between the mangrove arm and the pool suggesting smoothening of the slope.

***Sector C* (*Pool morphodynamics*)**: Adjacent to the central core there is a shallow tidal pool. This pool shows sediment filling during 2004-2007. It shows an “s” shaped juvenile beach in the process of making. There is a series of linear NNW-ESE sand ridges and gullies. In the southern part of the pool it shows fragmented sand patches criss-crossed by gullies. In 2006-2007, the central concavity of juvenile beach shows a cover of matty algae indicating relative stability of the deposits. Numerous small sand cays are observed on the seaward side of the pool on the inner reef flat in 2005-2006, which merged together in 2007. These sand patches act as interfluves areas cut off by tidal gullies on either side. The process of beach extension complements the pool-filling process and strengthening the s-shaped juvenile beach of the pool in terms of continuous supply in the sediment volume. It can be inferred that the beach surrounding the entire core region is acting as the source of sediments for this tidal pool.

***Sector D*:** This is a mud draped area with approximate 1-2 meter thick mud column (Bahuguna *et al*., 2007). The number of principal streams and interfluves shows a positive correlation with seasonal influx in water volume. The overlapped length increases with the retention of volume of water, whereas the partial overlaps, especially on fragmented flowlines, indicate the proper areas of the channels. It can be inferred that the rate of siltation is consistently high in this area.

***Sector E*:** Sector E appears to be a relatively new area of sediment deposition. Proximity to the open face of sea makes this region a little more unstable with less change compared to any other region after 2005.

***Sector F*:** The sector F is basically a miniature of creek network connecting the southern part of Pirotan Reef with the adjacent island of Jindra Bet to its south. The flowlines are basically creeks of different dimensions and an overall stability in their existence was observed. The numerous small segmented flowlines may be a result of an ebbing tide in 2005, 2006 and 2007. Some of the major flowlines are long enough to sustain a flow with a fair width dimension showing a potential to become future creeks. However, differences in their bathymetry due to siltation control the development of these future creeks.

***Sector G*:** This sector located in the eastern part of Pirotan reef shows a mixed influence of sand deposition and siltation governed by hydrodynamics and slope. The part of the sector which lies close to the extending beach towards the NE shows more influence of sandy deposition and flowlines originating almost from the foot of the beach. Two major creeks protrude inside the reef. An extensive mud deposition is detectable from this flow pattern. The following two distinct slope zones can be observed: a) just beneath the beach, dominated with parallel WE aligned flowlines and interfluves; and b) towards a reef edge a zone of extensive mud deposition cut across by different WE running flowlines. These two zones are separated by a mix zone of sandy deposition draped with mud as a zone of confluence. The number of flowlines and interfluves shows a steady increase with time, showing changes in the hydrodynamics. However, the interfluves decrease in number indicating their gradual merging with each other.

***Tidal condition:*** Since hydrodynamics and sedimentation processes can never be understood in isolation without the information of tidal condition, the observations drawn from the maps prepared using the satellite images were analyzed considering the tidal conditions at the time of the satellite pass. Tidal conditions of three major ports, Okha (22º28′N lat., 69º05′E long.), Kandla (23º01′N lat., 70º13′E long.) and Navlakhi (22º88′N lat., 70º27′E long.) were taken into consideration for understanding the satellite imagery based observations for Pirotan. The tidal conditions at Okha, Kandla and Navlakhi during RESOURCESAT (IRS P6) LISS IV MX Pass indicate that the images of 2004, 2005 and 2006 have been captured at the mid of an ebbing condition, while in 2007 the image acquisition synchronizes with the start of a flooding condition. In addition, the data confirmed that the funnel shape of the Gulf of Kachchh results in differing tidal amplitudes at different locations (Wagle, 1979). For example, the tidal range at Okha, situated almost at the mouth of the Gulf of Kachchh is 4 m, whereas the tidal range at Kandla and Navlakhi, situated at the head of the Gulf is comparatively higher at 7-8 meters. The relative location of these three tidal stations also results in a phase lag of 2 to 2 hrs. 45 min (Deshmukh *et al.*, 2005) in tidal propagation. Studies on Gulf of Kachchh sediment dynamics have supported the concept that the sediment movement within the Gulf is southeast to eastward. Movement of the sediments of the Indus delta along the northern and southern coasts is derived from the southern shelf region and the Saurashtra peninsula (Hashimi *et al*., 1978). With tidal propagation in the flooding phase, the sediments move inwards towards the head of the Gulf and while in the ebbing, there is a trial to flush these sediments outside along the southern margin of the Gulf (Merh, 1995).

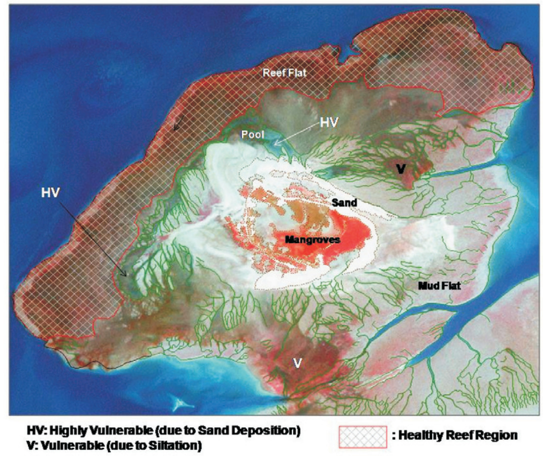


Fig. 5. Vulnerable areas and future scenario of Pirotan reef

The sedimentation process occurring at Pirotan reef is similar to the regional sediment movement pattern of Gulf of Kachchh. The imprint of a NE-SW trendline demarcates a clear distinction between the relatively sediment-free seaward face of the reef and the contrasting eastern and SE areas showing high sediment loading (mud deposition). Thus morphodynamics of the Pirotan reef during 2004-2007 has helped in understanding the establishment of substrates and the sedimentation pattern and distribution.

***Future Projection of Pirotan Reef:*** If the sedimentation on Pirotan reef continues in a similar fashion, it will result in reduction in the reef flat area (Fig. 5). The central shallow tidal pool (which is in the process of sand filling) will eventually become a sand-filled area. The trend line separating the sand-mud will, however, be sustained by the regional hydrodynamics and sediment dynamics of the Gulf of Kachchh. The changing hydrodynamic features in the core zone of Pirotan reef and the decreasing and degrading mangroves suggest that this core zone will become a high tidal mudflat area lined by beaches on all sides. This in turn will alter the ecosystem at the micro-level.

In conclusion this study shows the effectiveness of space borne remote sensing techniques to investigate the sedimentation pattern on Pirotan reef in the Gulf of Kachchh. It is clear that morphodynamic and hydrodynamic changes can be more rigorously quantified moving from mapping to measurement. Future scenarios can be projected and with the established knowledge of animal-sediment relationship, ecological changes can also be predicted. This information modeled on a GIS platform, may facilitate the substantial community of reef researchers especially biologists and ecologists to pre-plan sample sites for field data collection. These data can also be used by planners and managers for management of these sensitive ecosystems and critical habitats of coastal zone.

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