Geospatial analysis of the effects of tsunami on coral and mangrove ecosystems of Mayabunder in Andaman Islands, India

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ABSTRACT

Mangroves and coral reefs are among the major ecosystems of tropical and subtropical coastlines. The Andaman group of islands, situated at the juncture of Bay of Bengal and Indian Ocean, are one of the richest coastal ecosystems of India in terms of biodiversity. Since the tsunami waves of 2004 affected this region severely, the outer fringes as well as inland areas of these islands faced extensive ecological degradation. Mayabunder is one such place of this region, where corals and mangroves had experienced both natural and anthropogenic threat. Considering the notable vulnerability of this coastal environment, the present study aimed to assess the transformations of the coral and mangrove ecosystems at Mayabunder both in pre-tsunami and post-tsunami periods till the present year using multi-temporal satellite imageries and geospatial techniques. Results showed that the areal coverage of healthy living coral reefs was reduced by 466.56 ha (10.42 %) from 1990 to 2000. Afterwards, the coupled ecosystem had experienced serious degradation again during the 2000–2010 phase. The areal coverage of dense mangroves decreased by 47.37%, whereas the area of dead coral covers showed a significant rise of 55.52%. However, partial restoration of both mangroves as well as healthy corals had also been observed here in recent years. It was raised from the extensive field visits and feedbacks from local inhabitants that this restoration initiative could become more effective if a participatory mode of management is adopted.

Descriptors: Coral reef, Human induced stress, Mangrove, Remote sensing, Tsunami.

INTRODUCTION

Coastal ecosystems are functionally associated with various types of coastal features, ranging from physical to anthropogenic (Bulleri and Chapman, 2010). Tropical and subtropical coastal areas are mostly covered by mangrove forests and many of these are also associated with coral reefs and seagrass beds (Cannicci et al., 2009). Mangroves maintain carbon storage above and below the ground, develop land building capacity and protect the shorelines (Lee et al., 2014). Apart from numerous ecological services, mangroves help to generate income by enriching tourism, intertidal fisheries and crab farming, and forestry based products (Brander et al., 2012). However, actual services of mangroves are always underrated (Alongi, 2011). Similarly, corals also find suitable ambience to develop their communities in tropical and equatorial waters. In spite of covering only 0.2% of the seabed, corals support almost 25% of marine life (CEEC, 2003). However, corals and mangroves are facing threats of extinction throughout the world (Moberg and Folke, 1999). In general, deforestation, land use conversions, marine pollution, and changes in global climatic patterns are the major factors that threaten the very existence of these communities (Gilman et al., 2008). Approximately 35% of mangroves losses were recorded worldwide in the 1980-2000 period (Giri et al., 2011; Barbier et al., 2011) and 30% of coral reef losses was recorded globally (Barbier et al., 2011). Rising of sea surface temperature coupled with El-Nino events lead to loss of coral reefs (Baird et al., 2009; Goreau et al., 2000). It has also been facing other anthropogenic threats in the form of snorkeling, SCUBA diving, boating, and other harmful tourism activities way beyond their carrying capacities.

Submitted on: 12/March/2019
Approved on: 7/October/2019
http://dx.doi.org/10.1590/S1679-87592019025806715
Editor: Rubens M. Lopes

World mangroves can be found, ranging from mean sea level to high tide level, even in intertidal areas, or in zones where moderate salinity, average temperature and high rainfall is experienced (Alongi, 2002). Worldwide mangroves are developed in six bio geographical regions like, Western America and Eastern Pacific; Eastern Americas and Caribbean; Western Africa; Eastern Africa; Indo-Malaysia, Asia and Australasia and Western Pacific (Duke et al., 1998). On the other hand, corals also grow in an average sea temperature of 23º-25ºC with salinity between 32-35 g/kg. Sedimentation limits the growth of corals, thus the presence of mangroves helps to develop good coral cover as mangroves trap sediments. Wild distribution of coral reefs was found in tropical region. Often referred to as warm water coral reefs, they are distributed in Pacific, Indian and Atlantic Ocean (Hoegh-Guldberg et al., 2017). Indian Ocean in South Asian part has four major coral reefs location Lakshadweep, Maldives, Chagos archipelago, and Andaman and Nicobar Islands. Extensive range of fringing and barrier reefs is found in Andaman and Nicobar, while, the others happen to be atolls.

In India, mangroves cover almost 4369 sq. km of coastal stretches whereas corals occupy 5790 sq. km, distributed over three major zones in India (Kathiresan, 2010). Among these, Andaman and Nicobar Islands are the major hotspots of coral reefs in India (Mondal, 2011). Approximately 34 true mangrove species associated with 15 genera, 10 orders and 12 families are found here (Dam Roy et al., 2009). Regarding coral reefs, these islands are also well enriched with the presence of fringing reefs along the east coast and barrier reefs along the west coast (Raghuraman et al., 2013). These corals show maximum diversity among the four major coral locations in India (Brown, 2005). The total areal coverage of corals of these islands is approximately 2000 sq.km and it shares 6% of the continental shelf of these islands (Saxena et al., 2008). However, these figures of areal coverage are nothing but a partial remnant of the erstwhile extensive mangrove-coral reef complexes prevailing in these islands even half a century ago. In the islands of India, it is observed that mangroves are developed in the creek, especially near those creeks which are enriched with coral reefs. Thus, the corals and mangroves form a co-existing relationship, thereby acting as the breeding ground of fishes. Also, the juvenile coral reef fishes often inhabit the mangroves. In addition to this, biomass is significantly increased in adult coral reef habitats that are connected to the mangroves (Mumby, 2004). Since these communities are changing rapidly and thereby affecting the regional environmental balance in a considerable manner, comprehensive assessment and mapping of the areal transformations of these communities over the last few decades become imperative towards formulating necessary management guidelines. In addition, on 26th December 2004, an earthquake of 9.3 magnitudes with epicenter near Sumatra-Java, wreaked havoc in several regions and triggered a massive Tsunami in parts of Southeast Asia including the entire Andaman archipelago (Narayana, 2011). This tsunami affected poorly in Indonesia, as well as in eastern and western part of Andaman Sea. In Myanmar, almost 50% of the coral cover was severely damaged, while northern coastline of Thailand faced more than 50% severe damages of coral reefs (Brown, 2005; Satapoomin et al., 2006). Some parts of the Andaman Islands were uplifted while some were submerged due to crustal movement during this earthquake (Rajendran et al., 2007). Among the severely affected locations Mayabunder of North Andaman was the one site which experienced wide spread upliftment of seafloor causing an almost total destruction of the coral reef ecosystem (Malik, 2005).

Accordingly, this study attempted to analyze the gradual change of corals and mangroves during the last thirty years along with assessment of the long term effect of tsunami in and around the Mayabunder locality of North Andaman Island, as a case study using geospatial technologies.

STUDY AREA

Andaman and Nicobar archipelago is located at the juncture of Bay of Bengal and Andaman Sea. The areal extension is 6^{0}-14^{0} N latitude and 92^{0}-94^{0} E longitude. It is the largest archipelago system and a biodiversity hotspot in Bay of Bengal which contains 556 islands, out of which 37 are inhabited. According to Andaman and Nicobar Administrative Authority, these 37 inhabited islands are divided into three zones. South Andaman consists of 11 islands, North and Middle Andaman consists of 13 islands and Nicobar which has 13 islands. The islands are of volcanic origin and they are an extension of Arakan Yoma Mountain, Burma. It has a 1962 km long coastline (Ramesh and Vel, 2011). The geographical extension of Mayabunder is from 92°40'E to 93°40'E and 11°00'N to 12° 30'N. The interior of the island possesses evergreen, semi-evergreen and deciduous groups of trees and the coastal region is enriched with a large number of mangroves. Coral reefs have been found all over the eastern and western stretch of these islands. Coral reefs were found to be dispersed in the Middle part of Andaman, specifically around the small islands adjacent to the main island. Few parts of the eastern coast, especially the Mayabunder area, and the western coast also showed an extensive concentration of coral reefs. Here, sites like Aves Island, Interview Island and Baludera beach near Mayabunder are enriched with number of stony coral reefs and seaweeds. Based on this uniqueness, Mayabunder was considered as the preferred area of study to understand the coral ecosystem dynamics after a major catastrophe (Figure 1).

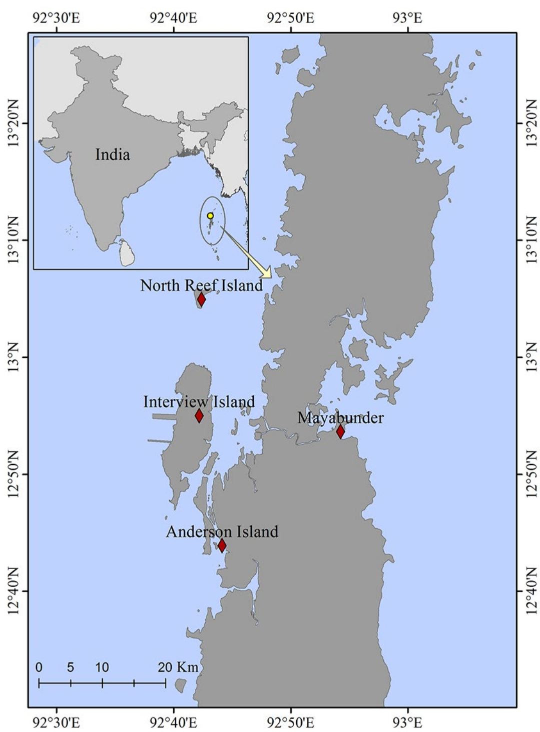

Figure 1. Location of the study area.

MATERIALS AND METHODS

Data used

Multispectral LANDSAT satellite data were used in the present research work. The post-monsoon season *i.e.* January to March was chosen as the suitable time for data selection because of the relatively cloud free conditions. Data was collected with a time interval of 10 years starting from 1990 up to 2018 for the change detection (Table 1). Here, 1990-2000 represent the pre-tsunami and 2010-2018 represent the post-tsunami conditions respectively. Field visits were conducted in the same season in 2018 for collecting Ground Control Points (GCP's) and comparing it to the image classification to find out the accuracy of images and fields in the pre and post-classification stages respectively. Apart from remote sensing techniques, focus group discussion was also conducted during field survey among fisherman groups.

Table 1. Details of the satellite imagery used in the study.

Date of Pass	Satellite	Sensor	Scene ID	Pixel Size(m)
03-23-1990	Landsat 5	TM	134/51	30
02-07-2000	Landsat 5	TM	134/51	30
02-24-2010	Landsat 5	TM	134/51	30
01-31-2018	Landsat 8	OLI-TIRS	134/51	30

Data pre-processing

After acquisition of the satellite images of four different years, these were radiometrically corrected by FLAASH model in ENVI 5.2 platform. Corrections like top of atmosphere (TOA) at level I and bottom of atmosphere (BOA) at level II were conducted to generate different reflectance and it was performed for removing the atmospheric effects from the images (Yuan and Niu, 2008). These reflectance images were further used for geometric corrections with respect to GCPs. The GCP's were collected during field survey in February 2016 and 2018 using Garmin eTrex 20 GPS device. Enhancement techniques like edge enhancement and density slicing were applied to enhance the overall quality of the product outputs.

Classification of inland land use/ land cover and coral reefs

Supervised classification using maximum likelihood technique was adopted for land use/land cover (LULC) classification. (Conese, 1992; Heumann, 2011). To obtain the results, different band combinations have been tried to find out the best resemblance with the outcome of field survey. In the LULC classification, mangroves were classified in two categories, namely, dense mangroves and newly settled/degraded mangroves. As it is difficult to denote newly settled/degraded mangroves from images, extensive field validation was conducted to solve this problem. 300 stratified random point locations were collected during field observations and using these points, accuracy assessment was performed on the classified images for coral reef mapping using Erdas Imagine 2014 software. Similarly, 200 stratified random points were used for classification of other LULC categories specifically in the island areas. Here, coral reefs were clustered into two subcategories of 'reef flat' and 'reef flat with debris' respectively. Reef flat denoted healthy living corals, while the reef flat with debris indicated the coral cover which is mixed with dead coral cover. This categorization was based on the coral reef classification scheme after Bahuguna et al. (2008). However, through LANDSAT imagery it is not possible to identify the coral zone accurately, as it has a limitation in penetrating water. To overcome this, potential coral reef zones were first identified from images, then extensive field surveys were performed by boat for later confirmation of image data. Ground truthing and field verification was integrated to the classification result. This validation was also done for mangrove classification.

Altogether, the LULC classes were identified as water body, sand exposure, built up, newly settled/degraded mangrove, dense mangrove and other forest cover. Furthermore, areal changes of all these land use classes were calculated in hectare as well as in percentage and then compared over a span of 30 years (1990, 2000, 2010 and 2018) to understand the LULC transformations.

Accuracy assessment

Accuracy assessment is performed in remote sensing to help judging the fitness of data in classification image with the field data, and it is often called thematic accuracy (Lucas et al., 1994).

Here accuracy assessment has been performed in Erdas 2014 using kappa co-efficient. Kappa statistics is formulated as:

Sensitivity = $\frac{a}{a+b}$ (equivalent to Producer's Accuracy)

Specificity = $\frac{d}{b+d}$

Commission error = 1 Specificity

Omission error = 1 - Sensitivity

Positive predictive power = $\frac{a}{a+b}$ (equivalent to user's accuracy)

Negative predictive power = $\frac{d}{c+d}$

Where,

a= number of times a classification agreed with the observed value

b= number of times a point was classified as X when it was observed to not be X

c= number of times a point was not classified as X when it was observed to be X

d= number of times a point was not classified as X when it was not observed to be X.

Total points = N = (a + b + c + d) (Rwanga and Ndambuki, 2017).

Focus group discussions

During field validation, a focus group discussion was conducted among fishermen groups. In Mayabunder, there is a separate fisherman settlement with thirty households. Among them nine fishermen participated in focus group discussion, others were busy in fishing. They had settled there in the late 90's. All of their ancestors came from main land in India. From this focus group discussion, it was revealed that after the tsunami, high tide line had decreased. They observed the loss of mangrove forests and coral covers in immediate effect of tsunami, and the beach area got uplifted. They stated that the clarity of water remained almost similar for the last few years, because no such big industry developed there. Although, they stated that in the last three to four years, the area is reconciling towards its previous condition.

RESULTS

The areal coverage of corals remained almost the same during the last three decades except in cases of direct exposure under sunlight and submergence of erstwhile shallow reefs. Although the total areal coverage remained the same, the live or healthy coral cover decreased from 1990 to 2018. Similarly, mangrove cover was also found in decreasing order from 1990-2010, although some improvements were observed in 2018. Due to Andaman's unique location near the convergent boundaries between the Australian, Indian, and Southeast Asian plates, the area had experienced periodical seismic events (Curray, 2005). Most recently, the Sumatra-Andaman earthquake of 2004 emerged as one of the major influencing factors in the changes of coral reef as well as mangroves including other inland features of the islands to its extent and vitality (Malik et al., 2006).

Changing patterns of LULC

One of the prime aims of the LULC classification was to detect the changes in mangrove covers around the islands. Here, mangrove covers were classified into two subcategories, viz. dense mangroves and newly settled or degraded mangroves. As it is difficult to distinguish different vegetation type from LANDSAT, ground truth data and different band combinations helped to solve this problem. In case of mangrove cover identification, the ratio of short wave infrared (SWIR) and near infrared (NIR) band combination was used, as SWIR reflection is very high in case of mangrove cover. Newly settled or degraded mangroves were found to be difficult to distinguish from one another since they bear almost same spectral signatures. However, the areal coverage of these subcategories could be delineated separately in few places based on the field surveys. For the present purpose, these two subcategories had been considered as a single as well as distinct LULC category to expedite the classification procedure (Figure 2). Regarding areal changes, highest amount of dense mangrove cover was found in 2000 (13351.3 ha/ 8.53%). That meant an increase of 2261.30 ha (20.39%) of mangrove cover from the 1990's amount of 11090 ha (7.09%). On the contrary, area under coral reef (including reef flat and reef flat with debris) recorded a reduction from 7429.33 ha (4.75%) in 1990 and 6246.63 (3.99%) ha in 2000 (Table 2).

Changes of LULC in the post-tsunami period were studied for 2010 and 2018. Here, dense mangrove cover recorded a considerable loss of 7026.66 (4.49%) ha in 2010 possibly due to the expansion of built ups and tsunami carnages. However, some of the mangroves were restored in the next few years thereby increasing the areal amount to 11896 ha (7.60%) in 2018. Similarly, the newly established or degraded mangroves notably decreased in 2010 (581.04 ha) from its coverage in the pre-tsunami period. Here also, a slight recovery of land (1545 ha) was observed in 2018.

Changing patterns of coral reefs

Between the two subclasses of coral reefs, reef flat areas with debris were found to be increasing from 1990 (2981.88 ha / 0.89%) to 2010 (5668.02ha / 1.70%). In contrast, there was minimum change in the areal extent of 'reef flats' subcategory in between 1990 and 2010 (Figure 3). In 2018, the area covered by reef flat was found to be 6092.37 ha. In reality, there was an episode of marine inundation between 1990 and 2018 submerging considerable amount of land in the effect

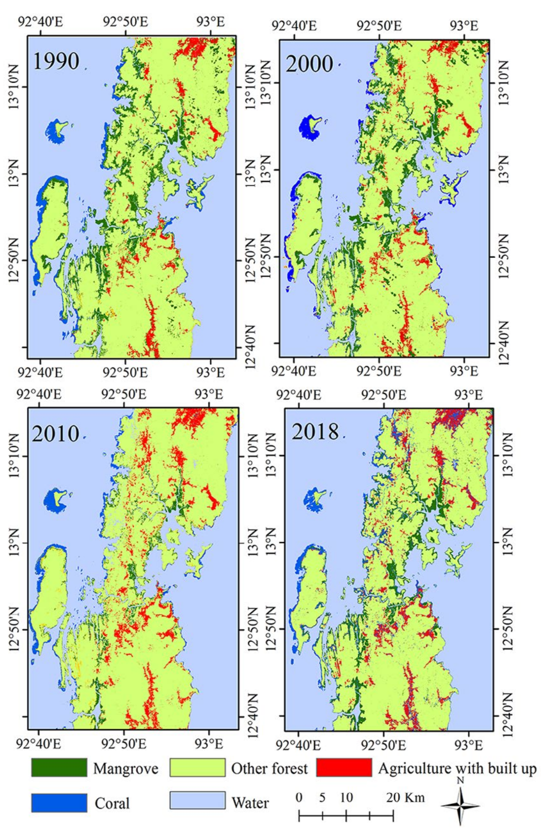

Figure 2. LULC maps of the study area for 1990; 2000; 2010; 2018.

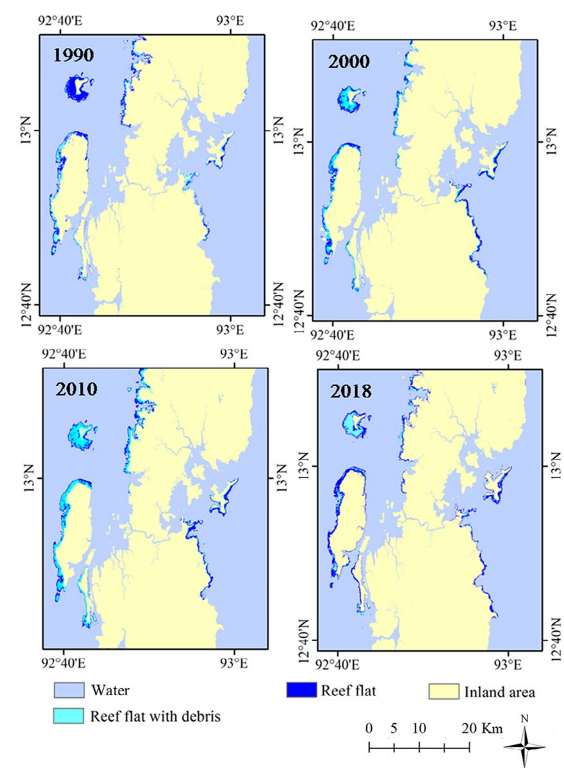

Figure 3. Distribution of the coral reefs of the study area 1990; 2000; 2010; 2018.

Table 2. Different classes for corals and other land use land cover showing changes from 1990 to 2018.

Class name		Year								Change		Change		Change	
		1990		2000		2010		2018		(1990-2000)		(1990-2010)		(1990-2018)	
		Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Dense mangrove		11090.00	7.09	13351.30	8.53	7026.66	4.49	11896.00	7.60	2261.30	20.39	-4063.34	-36.64	806.00	7.26
New/degraded mangrove		2132.36	1.36	4414.41	2.82	581.04	0.37	1545.00	0.99	2282.05	107.02	-1551.32	-72.51	-587.36	-27.54
Other forest		125728.40	80.33	119635.24	76.43	127101.98	81.20	82933.11	52.98	6093.16	-67.77	1373.58	1.09	-42795.29	-34.04
Agriculture with built up		8281.71	5.29	11003.00	7.03	13093.70	8.37	15209.10	9.72	2721.29	32.86	4811.99	58.10	6927.39	83.64
Coral reef	Reef flat with debris	2981.88	0.89	3644.46	1.09	5668.02	1.70	6092.37	1.83	662.58	22.22	2686.14	90.08	3110.49	104.31
	Reef flat	4475.79	1.34	4009.23	1.20	3995.81	1.20	3372.13	1.01	-466.56	-10.42	-479.98	-10.72	-1103.66	-24.65
Water		1861.00	1.19	1872.22	1.20	1743.79	1.11	1796.79	1.15	11.22	0.60	-117.21	-6.29	-64.21	-3.45

on tsunami. However, the area occupied by the emerged corals remained almost unchanged except in 2010 when it recorded a decrease of 4574.99 ha (Table 2).

The reef flat area decreased gradually while reef flats with debris were continuously increasing from 1990 to 2010. However, it was found in 2018 that the reef flat area was reconciling again with the pre-earthquake scenario.

Assessed accuracy of classified images

Overall classification accuracies of the different LULC classes of the maps of four assessment years had been estimated as 83.00%, 78.50%, 87.50% and 87.50% respectively from 1990 to 2018. In this context, the values of Kappa coefficients for the classified images were computed as 0.748, 0.670, 0.805, and 0.809 respectively (SI - 1a, 1b, 1c, 1d). Similarly, the classification accuracy regarding the map of coral reefs was found as 88.67%, 86.90%, 86.67% and 87.67% respectively whereas the values of Kappa coefficients were obtained as 0.789, 0.804, 0.753 and 0.774 respectively from 1990 to 2018 (SI - 2a, 2b, 2c, 2d). Kappa statistics denote the observed accuracy and random accuracy (Vilet et al., 2011).

Thus, a minimum level of 80% accuracy was maintained throughout the classification procedure which could be taken as an acceptable standard (Foody, 2002; Rahman and Saha, 2008; Liu and Zhou, 2004).

DISCUSSION

The results obtained from the study and feedbacks of the local people showed that mangroves and the coral reef ecosystems function as a co-existing natural system in most of these sites. Mangroves protect sedimentation occurring from direct run off from the inland area, and prevent the turbidity in the ocean, while high tidal effect is prevented by coral reefs (Green et al., 1998). This is how mangroves and corals, together form a co-existing ecosystem, and help to prevent coastal erosion. This association was also found to be more ecologically resilient in almost all the assessment years. Findings of different authors working in similar environments worldwide also pointed towards the same trend (Mumby et al., 2004).

A remarkable feature of the coral reef distributions for both 2000 and 2010 was that the LULC class representing 'reef flats' without any mixing of other suspended particles and flocculating materials occupied minimum areas throughout the coastline. Although, reef flat with debris spread consistently over the last thirty years (Figure 4).

Figure 4. Dead and healthy coral cover in the study area - (a) dead coral cover near Mayabunder; (b) dead coral at Baludera beach; (c) submerged healthy coral reef flat near Aves island, Mayabunder; (d) healthy coral reef flat near Curlew island, Mayabunder.

These indicated considerably poor health of coral reef population in these years when compared to those of 1990's. The prime factor behind this gradual deterioration of reef health could be identified as the severe earthquake and consequent tsunami of 26th December, 2004 causing notable vertical land movements. These were amplified by the inundation of inland areas due to towering tsunami waves engulfing huge tracts of mangroves. Similarly, the erstwhile shallow water corals became exposed above the sea level during this uplift thereby resulting into immediate death of reef organisms (Saxena et al., 2008). It was reported that Mayabunder faced 1.2 m of vertical land upliftment on average during this period (Malik et al., 2006). Although, inspite of earthquake some other factors like several instances of coral bleaching were also recorded in few areas where corals were not directly exposed above the low tide line (LTL) but uplifted almost near to it (Searle, 2006). However, upliftment could not be attributed as the sole cause of it since few cases of bleaching were also observed in sites where uplifts were minimal. This was also in lieu with the observations of global scientific community, specifically for the year 1997-1998, regarding the increase of sea surface temperature (SST) and salinity in tropics (Marimuthu et al., 2013). Apart from the tectonic and climatic factors, anthropogenic activities were also found to be detrimental in degrading the corals. Among these, indiscriminate coastal fishing, passage of large fishing trawlers and anchoring of tourist boats were the prominent ones in endangering the corals. An alarming revelation made from the focus group discussions with the local coastal communities in this regard was their overwhelming lack of awareness on the importance of corals as a living component of the ecosystem.

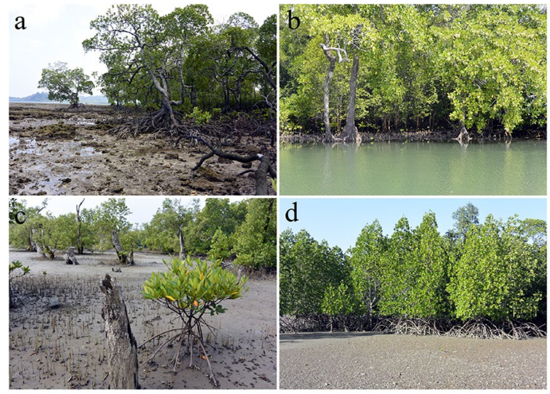

Figure 5. Notable mangrove features of the study area - (a) a mixed patch of coral debris and degraded *Bruguiera gymnorrhiza*; (b) Healthy stand of*Avicennia* marina near Austin bridge, Mayabunder; (c) An area near Baludera beach suffering from degeneration of mangrove trees; (d) A healthy stand of *Bruguiera gymnorrhiza* still excising near M.K. Gandhi College, Mayabunder.

The trend of mangrove transformation in the study area from 1990 to 2018 was quite different from that of the corals (Figure 5). In between 1990 and 2000, a noteworthy increase in dense mangrove cover (20.39%) was recorded whereas the amount of degraded mangroves or new plantations decreased sharply (-24.44%) (Figure 6); (Figure 7). This apparent anomaly could be attributed to the fact that mangroves within the jurisdiction of Reserve Forest increased in area due to stringent surveillance and protection provided by the staff of Forest Department. Although the total forest cover increased from 1990 to 2018, the forest structure and composition has been altered and mono plantation was found in some places. It is observed in field that open mangroves near village fringes and river mouths remained almost unprotected and thereby may experience gradual degradation due to the continual exploitation by the local settlers in near future.

Since 2004, substantial portions of these mangroves as well as tropical mixed and evergreen forests were lost owing to the drastic changes in the environmental conditions (Prasad et al., 2009). However, the trends of change were not uniform through the area as different micro-zones of specific forest-terrain characteristics responded differently to the post-tsunami effects and anthropogenic stresses. In few sites like the Baludera beach recorded a slight increase of mangrove cover from 2010 to 2018 (Figure 5). However, most of the other sites exhibited a trend of gradual removal of mangroves and consequent shrinkage in the areal extents of coastal forests. The major factors responsible for this transformation

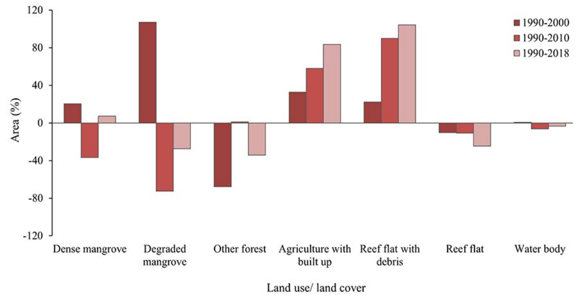

Figure 6. Areal change in percentage of different classes from the base year 1990.

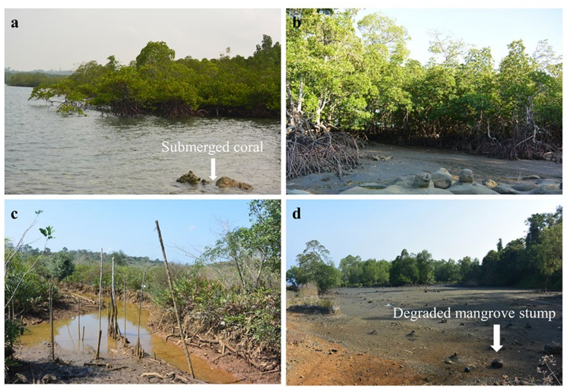

Figure 7. Co-existence of mangrove and coral concentration in the study area – (a) co-existence of mangrove and coral due to high tide; (b) mangrove and coral concentration near Baludera beach; (c) mangrove concentration where coral reefs are absent near Mayabunder; (d) degraded mangrove stock in Mayabunder where coral reefs are absent.

were identified as instability of coastal landmass, gradual rise of mean sea level, and indiscriminate exploitation of mangrove resources by the marginal farmers and fishermen of the area. As per LULC statistics of 2018, a net increase of approximately 5833.30 ha of mangroves has been estimated since 2010. This could be taken as a satisfactory initiative towards mitigating the uncertain effects of climate changes as well as other anthropogenic stresses. The worldwide loss of mangroves can be attributed to climate change and anthropogenic impacts as can be noticed in Malaysia which lost 17% mangrove forests over the last three decades and also in China which experienced 50% of mangrove loss from 1980 (Romañach et al., 2018).

CONCLUSIONS

The study highlighted that the severely destructive impacts of the tsunami and consequent land uplift were still evident in many parts of North Andaman. The trend of transformation for both the mangroves and corals was of a declining pattern although a marginal areal increase of mangrove cover had been noticed in recent years. It is so because post tsunami, some part of the inland area was inundated thereby leading to increase in salinity, which is suitable for new mangrove generation. Specifically, the health of coral ecosystem had degraded over the years in most of the sites if had not totally destructed yet.

The natural regeneration of mangroves and restoration of coral is a time consuming process. In spite of that, certain necessary management strategies can be helpful to maintain healthy mangroves and coral balance. Conservation of the older healthy mangrove areas along with the regeneration of degraded mangroves was found to be imperative for maintaining environmental sustainability. It can also be mentioned that the Ministry of Environment and Forest, Government of India, has created extensive artificial mangrove plantations in Mayabunder after the tsunami event. However, the actual status of their maintenance remains unsatisfactory until date. In case of coral reefs, apart from the earthquake and other ill effects of climate humans are also responsible. Nevertheless the corals were facing comparatively lesser damage from direct anthropogenic stresses in recent years. As the Andaman region faced several earthquake as well as tsunami events in recent past, it impacted badly on the coral reefs. This degradation took time for reconciling naturally. Apart from that, some appropriate mitigation strategies like regulating near shore fishing and enhancing general awareness on the importance of coral reefs among the local communities and tourists will certainly help to maintain a healthy reef cover. There is some limitation of the study as it was conducted using moderate resolution satellite images as well as field verifications primarily in the accessible parts of the coastline. Moreover, the perception dependent feedbacks of the local residents could not be taken as incontestable since many of them were recent settlers and hence did not possess sufficient knowledge on the coastal ecosystem processes. Thus, more nuanced methods of geospatial analysis, application of finer resolution images, higher access to remote coastal lands, and coherent opinions of local key informants may prove to be more beneficial in exploiting the complexities of this coupled ecosystem in detail in the coming years.

ACKNOWLEDGEMENTS

The authors are grateful to the Department of Science and Technology, Government of India for providing financial assistance through the WOS-A Fellowship to the first author (Reference No. SR/WOS-A/EA-1014/2015). We are also thankful to Mr. Simachalam, the ADFO of Rangat, and Mr. Nanigopal Das, Forest Development

Corporation Ltd., Andaman and Nicobar Islands for their continuous support during this study.

REFERENCES

ALONGI, D.M. 2002, Present state and future of the world's mangrove forests. *Environmental Conservation*, 29, 331-349

ALONGI, D. M. 2011. Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental Science & Policy,* 14, 462-470.

BAHUGUNA, A., NAYAK, S. & ROY, D. 2008. Impact of the Tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data. *International Journal of Applied Earth Observation and Geoinformation,* 10, 229-237.

BAIRD, A. H., BHAGOOLI, R., RALPH, P. J. & TAKAHASHI, S. 2009. Coral bleaching: the role of the host. *Trends in Ecology & Evolution,* 24, 16-20.

BRANDER, L. M., WAGTENDONK, A. J., HUSSAIN, S. S., MCVITTIE, A., VERBURG, P. H., DE GROOT, R. S. & VAN DER PLOEG, S. 2012. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. *Ecosystem Services,* 1, 62-69.

BROWN, B. E. 2005. The fate of coral reefs in the Andaman Sea, eastern Indian Ocean following the Sumatran earthquake and tsunami, 26 December 2004. The *Geographical Journal*, 171, 372-374.

BULLERI, F. & CHAPMAN, M. G. 2010. The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, 47, 26-35.

CANNICCI, S., BARTOLINI, F., DAHDOUH-GUEBAS, F., FRATINI, S., LITULO, C., MACIA, A., MRABU, E. J., PENHA-LOPES, G. & PAULA, J. 2009. Effects of urban wastewater on crab and mollusc assemblages in equatorial and subtropical mangroves of East Africa. *Estuarine, Coastal and Shelf Science*, 84, 305-317.

CARI (Central Agricultural Research Institute). 2009. *Mangroves of Andaman and Nicobar Islands*, Port Blair, Central Agricultural Research Institute.

CARRICART-GANIVET, J. P. 2004. Sea surface temperature and the growth of the West Atlantic reef-building coral *Montastraea annularis*. Journal of Experimental Marine Biology and Ecology, 302, 249-260.

CEEC (Cesar Environmental Economics Consulting). 2003. *The Economics of Worldwide Coral Reef Degradation*, Netherland, Cesar Environmental Economics Consulting.

CONESE, C. & MASELLI, F. 1992. Use of error matrices to improve area estimates with maximum likelihood classification procedures. *Remote Sensing of Environment*, 40, 113-124.

CURRAY, J. R. 2005. Tectonics and history of the Andaman Sea region. *Journal of Asian Earth Sciences*, 25, 187-232.

DAM ROY, S., P. KRISHNAN, GRINSON-GEORGE, M. Kaliyamoorthy and M.P. Goutham-Bharathi. 2009. Mangroves of Andaman and Nicobar Islands. *Central Agricultural Research Institute*, Port Blair. p. 65

DUKE, N. C., BALL, M., & ELLISON, J. (1998). Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecology & Biogeography Letters*, 7, 27-47.

FOODY, G. M. 2002. Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80, 185-201.

GILMAN, E. L., ELLISON, J., DUKE, N. C. & FIELD, C. 2008. Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany*, 89, 237-250.

GIRI, C., OCHIENG, E., TIESZEN, L. L., ZHU, Z., SINGH, A., LOVELAND, T. & DUKE, N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20, 154-159.

GOREAU, T., MCCLANAHAN, T., HAYES, R. & STRONG, A. L. 2000. Conservation of coral reefs after the 1998 global bleaching event. *Conservation Biology*, 14, 5-15.

GREEN, E. P., CLARK, C. D., MUMBY, P. J., EDWARDS, A. J. & ELLIS, A. C. 1998. Remote sensing techniques for mangrove mapping. *International Journal of Remote Sensing*, 19, 935-956.

HEUMANN, B. W. 2011. Satellite remote sensing of mangrove forests: Recent advances and future opportunities. *Progress in Physical Geography*, 35, 87-108.

HOEGH-GULDBERG, O., POLOCZANSKA, E. S., SKIRVING, W. & DOVE, S. 2017. Coral reef ecosystems under climate change and ocean acidification. *Frontiers in Marine Science,* 4, 158.

KATHIRESAN, K. 2010. Importance of mangrove forests of India. *Journal of Coastal Environment,* 1, 11-26.

LIU, H. & ZHOU, Q. 2004. Accuracy analysis of remote sensing change detection by rule-based rationality evaluation with post-classification comparison. *International Journal of Remote Sensing,* 25, 1037-1050.

LUCAS, I. F. J. & VAN DER WEL, F. J. 1994. Accuracy assessment of satellite derived landcover data: a review. *Photogrammetric Engineering & Remote Sensing,* 60, 479-426.

MALIK, J. N. (2005). Landscape changes in Andaman and Nicobar Islands (India) due to Mw 9.3 tsunamigenic Sumatra earthquake of 26 December 2004. *Current Science*, 88, 1384-1386

MALIK, J. N., MURTY, C. V. R. & RAI, D. C. 2006. Landscape changes in the Andaman and Nicobar Islands (India) after the December 2004 great Sumatra earthquake and Indian Ocean Tsunami. *Earthquake Spectra,* 22, 43-66.

MARIMUTHU, N., WILSON, J. J., VINITHKUMAR, N. V. & KIRUBAGARAN, R. 2013. Coral reef recovery status in South Andaman Islands after the bleaching event 2010. *Journal of Ocean University of China,* 12, 91-96.

MOBERG, F. & FOLKE, C. 1999. Ecological goods and services of coral reef ecosystems. *Ecological Economics,* 29, 215-233.

MONDAL, T. & RAGHUNATHAN, C. 2011. New record of two Scleractinian corals from Neil Island, Ritchie's Archipelago. *International Journal of Plant, Animal and Environmental Sciences,* 1, 76-79.

MUMBY, P. J., EDWARDS, A. J., ARIAS-GONZÁLEZ, J. E., LINDEMAN, K. C., BLACKWELL, P. G., GALL, A., GORCZYNSKA, M. I., HARBORNE, A. R., PESCOD, C. L., RENKEN, H., WABNITZ, C. C. & LLEWELLYN, G. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature,* 427, 533-536.

NARAYANA, A. C. 2011. Tectonic geomorphology, tsunamis and environmental hazards: reference to Andaman-Nicobar Islands. *Natural Hazards,* 57, 65-82.

PRASAD, P. R. C., REDDY, C. S., RAJAN, K. S., RAZA, S. H. & DUTT, C. B. S. 2009. Assessment of tsunami and anthropogenic impacts on the forest of the North Andaman Islands, India. *International Journal of Remote Sensing,* 30, 1235-1249.

PRASAD, P. R. C., RAJAN, K. S., DUTT, C. B. S. & ROY, P. S. 2010. A conceptual framework to analyze the land-use/land-cover changes and its impact on phytodiversity: a case study of North Andaman Islands, India. *Biodiversity and Conservation,* 19, 3073-3087.

RAGHURAMAN, R., RAGHUNATHAN, C. & VENKATARAMAN, K. Present status of coral reefs in India. *In*: VENKATARAMAN, K. (Ed.). *Ecology and Conservation of Tropical Marine Faunal Communities*. Berlin: Springer.

RAHMAN, M. R. & SAHA, S. K. 2008. Multi-resolution segmentation for object-based classification and accuracy assessment of land use/land cover classification using remotely sensed data. *Journal of the Indian Society of Remote Sensing, 36*, 189-201.

RAJENDRAN, C. P., RAJENDRAN, K., ANU, R., EARNEST, A., MACHADO, T., MOHAN, P. M. & FREYMUELLER, J. 2007. Crustal deformation and seismic history associated with the 2004 Indian Ocean earthquake: a perspective from the Andaman–Nicobar Islands. *Bulletin of the Seismological Society of America,* 97, 174-191.

ROMAÑACH, S. S., DEANGELIS, D. L., KOH, H. L., LI, Y., TEH, S. Y., BARIZAN, R. S. R. & ZHAI, L. 2018. Conservation and restoration of mangroves: global status, perspectives, and prognosis. *Ocean & Coastal Management,* 154, 72-82.

RWANGA, S. S. & NDAMBUKI, J. M. 2017. Accuracy assessment of land use/land cover classification using remote sensing and GIS. *International Journal of Geosciences,* 8, 611-622.

SATAPOOMIN, U., PHONGSUWAN, N. & BROWN, B. E. 2006. A preliminary synopsis of the effects of the Indian Ocean tsunami on the coral reefs of western Thailand. *Phuket Marine Biological Center Research Bulletin, 67*, 77-80.

SAXENA, A., RAJAN, R. & CHOUDHURY, S. S. 2008. Status of coral reefs in post-tsunami period in Andaman and Nicobar Islands. Proceedings of the 11*th* *International Coral Reef Symposium,* 854-858.

SEARLE, M. 2006. Co-seismic uplift of coral reefs along the western Andaman Islands during the December 26th2004 earthquake. *Coral Reefs,* 25, 2.

VAN VLIET, J., BREGT, A. K., & HAGEN-ZANKER, A. (2011). Revisiting Kappa to account for change in the accuracy assessment of land-use change models. *Ecological modelling*, 222, 1367-1375.

YUAN, J. & NIU, Z. 2008. Evaluation of atmospheric correction using FLAASH, *Proccedings of the International Workshop on Earth Observation and Remote Sensing Applications,* 1-6.