Coastal morphodynamics of Tupilipalem Coast, Andhra Pradesh, southeast coast of India

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Coastal zones are dynamic interfaces of land and water of high ecological diversity and critical economic importance. The boundaries, shape and size of this coast change constantly under the influence of both natural and anthropogenic factors. The study area, Tupilipalem is one of the proposal sites for constructing a major port, to be named Dugarajapatnam Port, along the east coast of Andhra Pradesh, India. We have used multitemporal satellite images of IRS P6 LISS-III and Landsat 8 OLI/TIRS data from 2011 to 2015 to delineate changes in Tupilipalem coast. The subsequent short-term lagoon mouth closure and the long-term coastal erosion and accretion rates have been calculated for the periods between 2011 and 2015. Low river inflow, wind, tides, the movement of the waves and littoral currents play a key role in the closure of the lagoon mouth and also for the dynamic activities of erosion and accretion. Moreover, the impact on socio-economy and ecology of the study area during the lagoon mouth closure period has been studied.

Keywords: Coastal zone, east coast of India, morphodynamics, remote sensing and GIS, sediment dynamics.

COASTLINE is the boundary between land and sea which keeps changing its shape and position continuously due to water dynamics. The change on shore line is mainly associated with waves, tides, winds, periodic storms, sea-level change, geomorphological processes such as erosion and accretion and human activity[1,2]. However, the shoreline morphology has a direct bearing on coastal processes[3]. Studies on morphology and structure of Indian coast have revealed that erosion of beaches and damage to coastal properties are governed by seasonal waves[4,5]. Especially in estuaries, the river mouth was periodically closed (separated from the marine environment by a sand bar) during low river flow conditions combined with the wave-driven onshore movement of marine sediments[6]. These environments provide critical habitat to the marine biota[7]. Moreover, the river/lagoon mouth closure has also affected socio-economically the human activities such as navigation, agriculture, fisheries, aquaculture, transportation and communication[8]. Shoreline change detection and measurement is an important task in environmental monitoring and coastal zone management[9].

Periodic and precise observation of earth's surface features for change detection is extremely important for understanding interaction and relationships between human and natural phenomena to promote better decision making[10]. Several methods have been employed to monitor and map changes in shoreline location using different techniques of data collection[11]. Fletcher *et al.*[12] and Kerh *et al.*[13] have used Topomap to demarcate shoreline positions and to assess the impact of anthropogenic and hydrological factors on coastal morphology of the beaches of Hawaii and Taiwan respectively. Aerial photographs were used to study the shoreline changes due to erosion and/or sedimentation[14–16]. Multi-dated satellite images can be used to monitor shoreline changes by measuring sedimentation, erosion and accretion[17–21]. Moreover, Li *et al.*[22] used the integration of LiDAR data with high resolution of ortho images to improve the accuracy of shoreline mapping and a new method for coastal bluffline extraction has been developed[23].

Remote sensing (RS) satellite data having the ability to provide comprehensive, synoptic view of fairly large area at regular interval with quick turnaround time integrated with Geographical Information System (GIS) makes it appropriate and ideal for monitoring and studying river erosion and its bank line shifting[24–27]. Many authors have used these RS and GIS techniques to demarcate the changes for some major rivers[28,29]. RS technology provides a satellite image with synaptic coverage on a large area with high spatial resolution to identify shoreline changes and delineating various factors at national, regional and local level[30]. Computer-based image processing or signal processing enhances the image or picture quality. However, the algorithm correlated with the GIS represents the earth's landform features from the image. This may help in planning better management of human sophisticated life in future[31].

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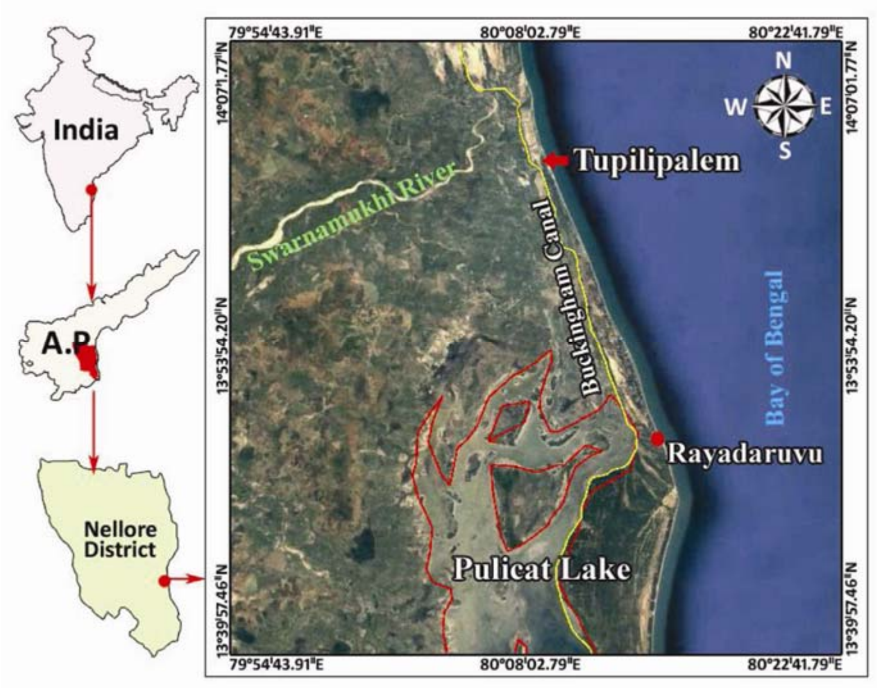

Figure 1. Location map of the study area.

In this study, Indian Remote Sensing (IRS) P6 Linear Imaging Self Scanner-III (LISS-III) and Landsat 8 Operation Land Imager (OLI)/Thermal Infrared Scanner (TIRS) multispectral data were used to delineate the changes of Tupilipalem coast. Periodic lagoon mouth closure and other shoreline changes in spatial and temporal aspect were analysed using RS[32] and GIS. Further, the impact of wave energy and meteorological factors on the erosion and accretion process were also evaluated. Moreover, impact of lagoon mouth closure on ecosystems and socio-economic conditions of the study area were also studied.

Study area

Tupilipalem is 20 km away from Dugarajapatnam, Nellore district of Andhra Pradesh, India (southeast coast of India) and more than 120 km away from Pulicat Lake and the satellite launching centre at Sriharikota. Tupilipalem is the proposal site for constructing a major port to be named Dugarajapatnam Port. The study area is geographically located in the southeastern part of Nellore district, lying between 14°0′10″–14°02′30″N and 80°08′20″–80°19′00″E and it is connected to Pulicat Lake. The Buckingham Canal (navigation channel) is part of the lagoon on its western side. It is connected to the sea through Rayadaruvu and Pulilcat Lake from north to south. This lagoon (mouth) connects the open Bay which forms the study area. The subtropical climate prevails over the study area with an average annual rainfall of 1041 mm. The average minimum and maximum temperatures are 20°C and 39.6°C respectively. However, the currents are also affected by the tidal cycles, by the action of waves, the shoreline geography and by the presence of different water masses, assuming predominantly a SW–NE direction (Figure 1).

Methodology

The baseline map was prepared using the Survey of India (SOI) toposheet map nos 66B4, 66C1 and 66C5 on 1 : 50,000 scale. The multi-temporal IRS-P6 LISS-III and Landsat 8 OLI/TIRS images acquired for the period between 2011 and 2015 were used as primary data source for shoreline extraction. The images used for analyses were of different satellite types with different sensors and spatial resolutions (Table 1). The cropped images were geometrically corrected using the auto-sync tool in ERDAS Imagine 9.1 software by applying the Universal Transverse Mercator (UTM)–The World Geodetic System (WGS) 84 projection and coordinate system[33]. After geometric corrections, all the images were processed digitally using the Water Index Method[34,35]. This method provides a sharp edge between water and land. Shoreline positions were digitized manually with ArcGIS for several dates, i.e. 2 October 2011, 18 March 2012, 1 May 2013, 9 November 2013, 20 May 2014, 9 September 2014, 14 December 2014 and 7 May 2015. This shoreline position was exported to ArcGIS with attribute fields that included object identity (ID), name, date, area and feature characteristics. These multidated shape files of shorelines

Table 1. Salient characteristics of satellite data used

Satellite	Date of acquisition	Sensor	Path	Row	Resolution (m)	No. of bands
IRS-P6 (Resourcesat-1)	2 October 2011	LISS-III	102	063	23.5	4
IRS-P6 (Resourcesat-1)	18 March 2012	LISS-III	102	063	23.5	4
Landsat 8	1 May 2013	OLI/TIRS	142	050	30	11
Landsat 8	9 November 2013	OLI/TIRS	142	050	30	11
Landsat 8	20 May 2014	OLI/TIRS	142	050	30	11
Landsat 8	9 September 2014	OLI/TIRS	142	050	30	11
Landsat 8	14 December 2014	OLI/TIRS	142	050	30	11
Landsat 8	7 May 2015	OLI/TIRS	142	050	30	11

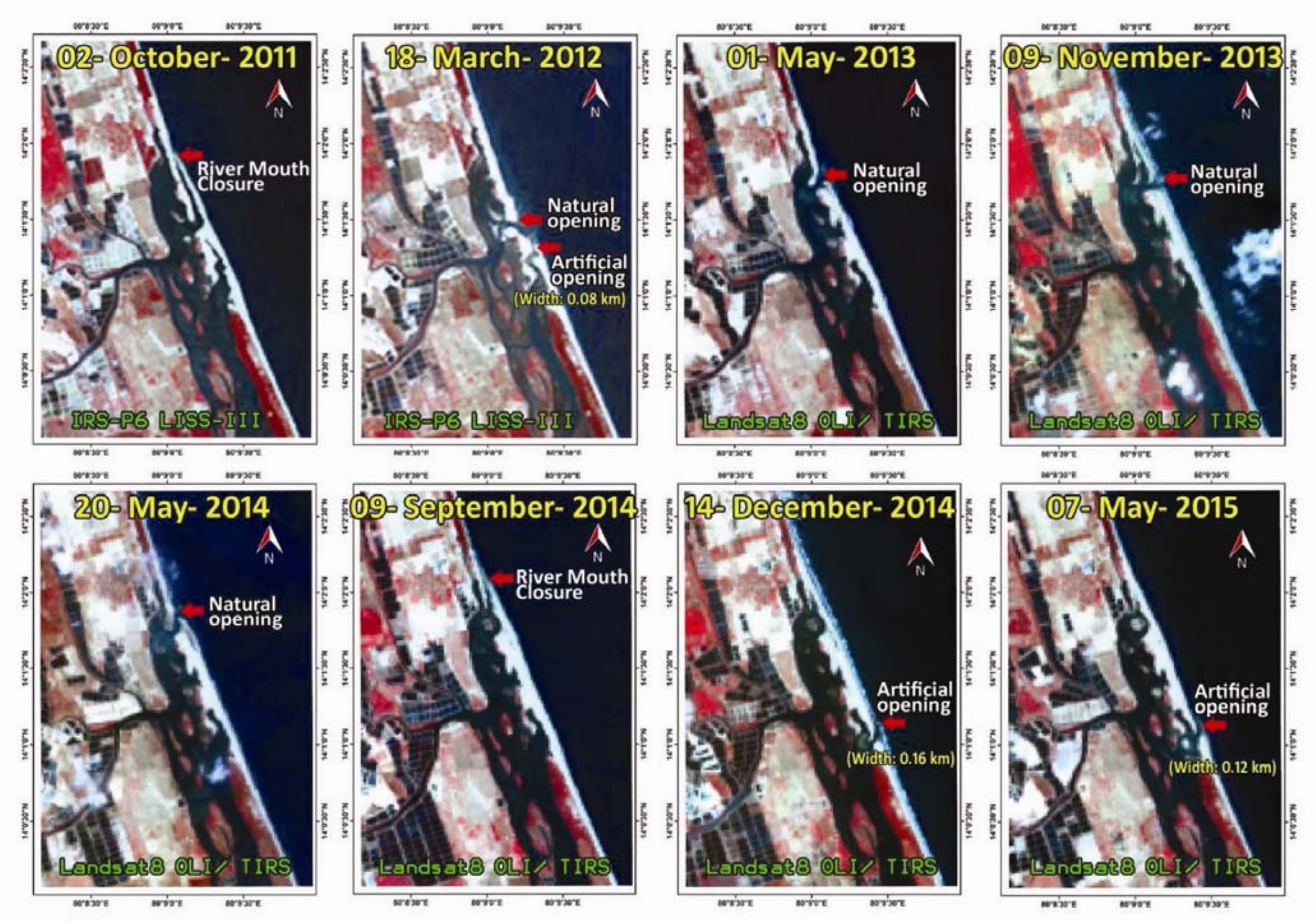

Figure 2. Satellite images showing the open and closed mouth of lagoon.

were overlaid together for the identification of shoreline changes (shift towards either offshore or onshore). Then, the intersection of shoreline geometry was converted into polygon geometry using the feature to polygon conversion tool in ArcGIS 9.3 for the estimation of erosion and accretion[36].

Results and discussions

Shoreline changes were quantified from two aspects: periodic lagoon mouth closure and erosion and accretion of Tupilipalem coast for a period of five years from 2011 to 2015 using RS and GIS.

Periodic lagoon mouth closure

Remotely sensed multi-date image analysis revealed that sandbar across the lagoon mouth is highly dynamic. Lagoon mouth closure was observed on 2 October 2011, 9 September 2014, 14 December 2014 and 07 May 2015 (Figure 2). In this zone, the mild accretion is due to the angle of the wave approach and littoral current which transports the suspended sediments from the adjacent area to deposit in the lagoon mouth and thereby closed it. The images on 14 December 2014 and 7 May 2015 have a small opening at the southern part of the lagoon, which is artificially opened by the villagers (0.16 km and 0.12 km width respectively) for their fishing boats.

The lagoon mouth opening (naturally) was observed on 18 March 2012, 1 May 2013, 9 November 2013 and 20 May 2014. This process reflects that the coast is facing continuous erosion, and the coastal landforms include sea cliffs, sand dune and beach ridges have been affected by a series of erosional process. Two openings are observed in the image captured on 18 March 2012. Of these, one is a natural opening (northern side) and the other is an artificial opening (with the width of 0.08 km on the southern side). It is seen from the image dated 2 October 2011 that the lagoon mouth was completely closed by the sand bar and the villagers around the reservoir opened it. After this, the lagoon mouth was naturally opened, and hence image shows two openings.

We have also observed the displacement of lagoon mouth opening (Figure 3). The image dated 2 October 2011 shows that the lagoon mouth was completely closed by the sand bar. On 18 March 2012, the lagoon mouth was opened and the opening point lies between 14°1′27.426″N, 80°9′11.9232″E respectively. During 18 March 2012 to 1 May 2013 it is observed that the lagoon mouth has shifted significantly around 0.654 km towards NNW and during 1 May 2013 to 9 November 2013, it has shifted slightly around 0.139 km towards SE direction. Again, it moved 0.244 km towards the NNW direction from 9 November 2013 to 20 May 2014. Field observations revealed that these deposits across the lagoon mouth are silt, clay and mud flats with fine sand. Instability of the sandbar motion under the action of water waves is the main factor for this lagoon mouth dynamics. The prevailing northern wind causes an oblique wave approach to the shoreline and it also causes shifting the position of the lagoon mouth.

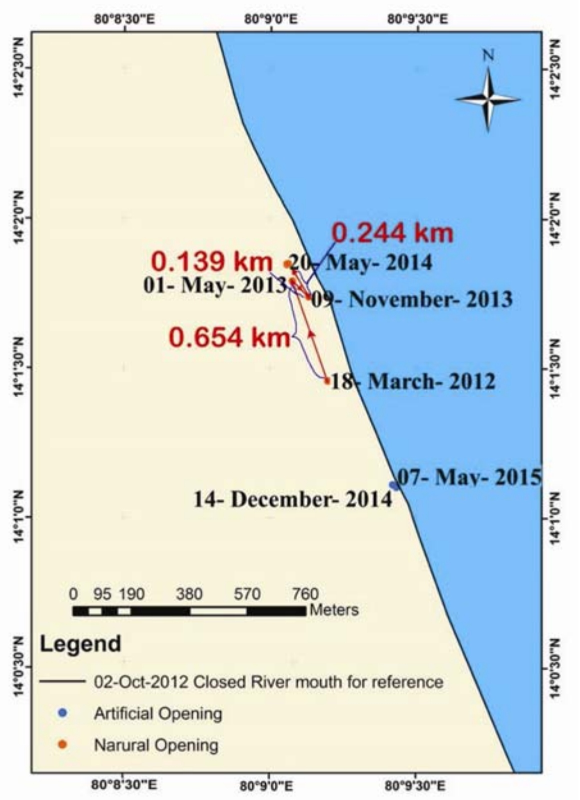

Figure 3. Displacement of lagoon mouth opening.

Erosion and accretion

On an average, about 40% of Indian coastline is facing varying degree of erosion. From the last 25 years data (1990–2014), it is observed that about 25–33% of Andhra Pradesh shoreline is experiencing erosion of various magnitudes. According to the Naval Hydrographic Office, 9.2 km out of 973.7 km of coastline of Andhra Pradesh was affected by erosion. Erosion and accretion rates estimated along the Tupilipalem coast using RS and GIS techniques are given in Table 2.

In Figure 4 *a*, blue colour shows the erosion from 2 October 2011 to 18 March 2012 and violet, green and red colours show the erosion from 1 May 2013 to 9 November 2013, 20 May 2014 to 9 September 2014 and 14 December 2014 to 7 May 2015 respectively. Considering the changes, the highest erosion occurred at lagoon mouth of Tupilipalem coast. The total net rate of erosion was estimated at 0.316 km^2. The sand bars and beach ridges along this coastal zone have been washed away due to wave action. Further, the short-term analysis was carried out to estimate the rate of erosion separately from 2011 to 2015. Between 14 December 2014 and 7 May 2015, heavy erosion was noticed with an average of 0.157 km^2 and also during 20 May 2014 to 9 September 2014, 1 May 2013 to 9 November 2013 and 2 October 2011 to 18 March 2012, the erosion was reported to be 0.063 km^2, 0.049 km^2 and 0.047 km^2 respectively. The erosion rate from 2011 to 2015 was slightly increased from 0.047 to 0.157 km^2.

In Figure 4 *b*, blue colour shows the accretion from 2 October 2011 to 18 March 2012 and violet, green and red

Table 2. Coastal erosion and accretion rates during 2011–2015

Duration	Erosion in km^2 (E)	Accretion in km^2 (A)
2 October 2011 to 18 March 2012	0.047	0.147
1 May 2013 to 9 November 2013	0.049	0.244
20 May 2014 to 9 September 2014	0.063	0.134
14 December 2014 to 7 May 2015	0.157	0.046
Total net change	0.316	0.571

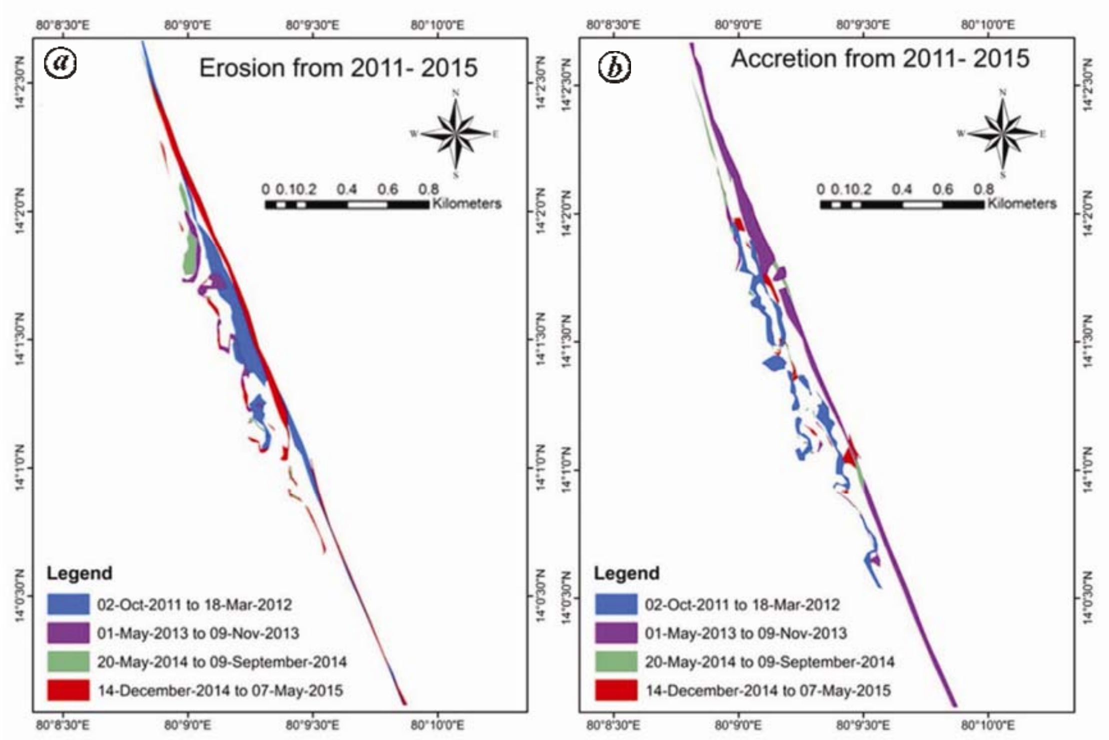

Figure 4. Coastal erosion and accretion during 2011–2015.

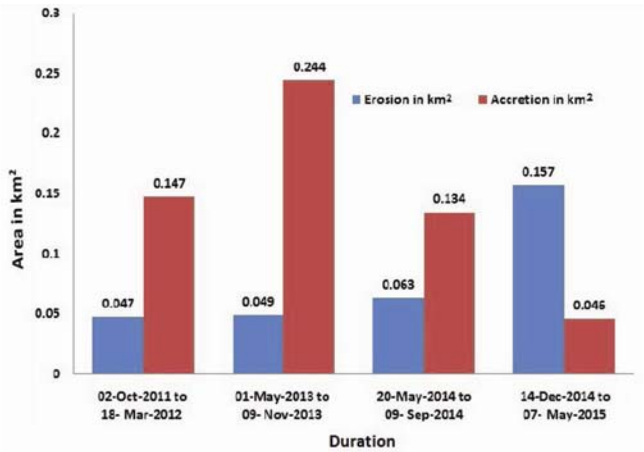

Figure 5. Graphical representation of coastal erosion and accretion during 2011–2015.

Figure 6. Opening the lagoon mouth mechanically.

colours show the accretion from 1 May 2013 to 9 November 2013, 20 May 2014 to 9 September 2014 and 14 December 2014 to 7 May 2015 respectively. Between, 1 May 2013 and 9 November 2013, heavy accretion was noticed with an average of 0.244 km^2 and also during 2 October 2011 to 18 March 2012, 20 May 2014 to 9 September 2014 and 14 December 2014 to 7 May 2015, the accretion was reported to be 0.147 km^2, 0.134 km^2 and 0.046 km^2 respectively. Accretion with sand deposition was caused by the wind, tides, movement of the waves and long shore current. Wind direction, wind speed and wave action play a significant role in the sand deposition along the coast in the study area.

The study shows that during the last five years (2011–2015) comparatively accretion is more than the erosion (Figure 5). Lagoon mouth having highly fluctuating erosion and accretion characteristics reflects the periodic mouth closure in the short-term scale.

Ecological impact

Periodic lagoon mouth closure is a natural phenomenon. Several small rivers along the Andhra coast have apparently suffered with mouth closure owing to sand deposition at their outlets. This may pose a threat to the lake biodiversity, particularly aquatic (fishes and shrimps) and rare migrant bird species diversity[37]. Studies on the ecological impact of periodic lagoon mouth closure at Tupilipalem coast have been carried out earlier. The gradual closure of lagoon mouth caused the loss of biodiversity in migratory avifauna species and aquatic fauna which include fishes, shrimps and zooplanktons[38–40]. Basha *et al.*[41] reported that lagoon mouth closure at Tupilipalem leads to fluctuation of salinity and water levels of the lake. It has maximum effect on the biotic components of the ecosystem. This mouth closure is a major determining factor for the hydrology, biodiversity and fisheries in the study area.

Socio-economical impact

Tupilipalem is one of the appealing beaches in Nellore district and it has a world class diversity. It is a small village in Dugarajapatnam Panchayat and the entire panchayat depends on this beach for their economy. A total of 1041 families are residing with the population of 3393 in Dugarajapatnam Panchayat as per the population census 2011. These villages have lower literacy rate (57%). About 90.05% of the people are engaged in fishing which is fundamental for the whole economy. In fact, our field inquiries revealed two fishing harbours that have been found in the study area namely Kondurupalem and Tupilipalem. Approximately 134 and 87 fishing boats were stopped at Kondurupalem and Tupilipalem fishing harbours respectively, during the lagoon mouth closing period.

In that period the fishing boats cannot enter the sea, thus directly affecting the development of the fishing profession and its economy. Two thirds of the population are economically poor and prone to occupational crisis owing to lagoon mouth closure. Villagers open the lagoon mouth mechanically for their livelihood to reduce its impact on their economy and the ecosystem (Figure 6).

Conclusions

Study of Tupilipalem coast using RS and GIS provides a viable source of data for monitoring and assessing the coastal changes. This study revealed that the rate of erosion and accretion reflects coastal dynamics and the loss or gain of sediments causes the formation of young beaches, berms, sand dunes and seacliffs depending on wave energy and littoral currents. During the last five years (2011–2015), accretion is more than erosion which deposits the sediments in the lagoon mouth, thereby causing the closure of it. It is observed that the prevailing northern wind causes an oblique wave approach to the shoreline and it causes shifting the position of the lagoon mouth. Migratory avifauna species and aquatic fauna that includes shrimps, fishes and zooplanktons have been affected due to periodic lagoon mouth closure. As the study area comprises high level of agricultural and aquacultural activity, it needs to be protected. Moreover, an artificial structure needs to be constructed to prevent this periodic lagoon mouth closure for the survival of aquatic fauna and lives of fishermen. This study may help in making a conceptual model of this dynamic activity in future for betterment of biodiversity, ecosystem and fishing community.

The proposed construction of new major port in the study area has both advantages and disadvantages. Opening of the lagoon mouth and construction of a new port will always pave the way for the betterment of socio-economic conditions of the society. The port development may harm the marine biodiversity of Pulicat lake including National Pelican Bird Sanctuary situated in the vicinity.

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