Beach Morphology Near the Inlet of Chilika Lagoon

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Abstract The sandy beach, which represents a transitional zone between terrestrial and oceanic environment, is always in motion and frequently changes its landform due to the exposure to wind, ocean waves, tide, and river discharge. In the present study, an attempt has been made to understand the complex dynamics of shorefront of Chilika and its spatiotemporal variability for effective management of its inlet system. To carry out beach morphology study, several observations were made which include seasonal beach profile and shoreline using RTK-GPS during December 2008–November 2013. Besides, the seasonal wave characteristics near the inlet are collected from ECMWF for understanding wave impact over the inlet system and the associated sandbars. Beach Morphology Analysis Package (BMAP) developed by Coastal Engineering Design Analysis System (CEDAS), Veritech Inc. is used to compute beach width and volume. Results of the above observation indicate that the spatiotemporal variability of beach morphology is mostly attributed to complex hydrodynamic conditions persistent near the inlet as well as to the occurrence of cyclonic events in the Bay of Bengal. Hence, understanding beach morphology and associated physical processes and their variability in spatiotemporal scales are very important for effective inlet management and conservation of the lagoon ecosystem.

Keywords Beach morphology · Chilika Lagoon · Inlet · Cyclonic storm

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1 Introduction

Coastal environments which represent the most dynamic and defensive system in terrestrial systems undergo several transformations due to frequent exposure with winds, waves, tides, relative sea level, and high freshwater river discharge. The wave transformation and its asymmetry caused by interaction with bottom sediment in the nearshore zone determines the degrees of beach morphology and also acts as one of the important factors for inlet migration [1, 2]. The sediment bypassing through the tidal inlet and alongshore sediment transport near coastal lagoon make the adjacent beach more complex [3, 4]. Besides, a periodic extreme phenomenon also plays a major role in the significant change in beach morphology. So far as coastal morphology is concerned, coastal erosion and accretion are two opposite physical processes in the annual morphological development of beach environment. The changes in beach morphology are generally considered as either addition or withdrawal of sediment resources or redistribution of sediment resources due to the activity caused by wind, wave, and tide. Along the world coastline, several studies have been registered, among which a few studies [5–9] are quite relevant to our study. Continuous and long-term observation of beach profile would be of immense help in evaluating the erosion and accretion status and longshore sediment transport along the coast, which, in turn, would be helpful for successful implementation of the coastal management plan. The present study is undertaken to understand beach morphological changes near Chilika Inlet during 2008–2013 and the associated factors.

2 Site Description

Chilika, along the east coast of India, is a semi-enclosed tropical coastal lagoon bounded by latitudes 19° 28′ N to 19° 54′ N and longitudes 85° 5′ E to 85° 38′ E (Fig. 1). It is one of the biggest wetlands of international importance and was designated as a Ramsar site in 1981 for its rich biodiversity and beautiful ecosystem services. The lagoon is connected with the Bay of Bengal through multiple tidal inlet(s), which vary in number and position in due course of time. The opening of the lagoon to sea is largely controlled by sediment supply from the river systems as well as alongshore sediment transport. The coastal stretch of the lagoon is about 65 km in length extending from north of Rushikulya estuary to extreme north of the lagoon. The orientation of the shoreline is about 45°. The inlet channel of the lagoon is very irregular and divergent type towards its upstream region. The lagoon is connected with the sea with multiple inlet systems, which shows its ephemeral nature. These inlet systems, in due course of their operation, have merged and separated from each other with an island system. The lagoon was connected with one inlet during 2005 , while it was connected by two inlets during 2008 due to the opening of a new

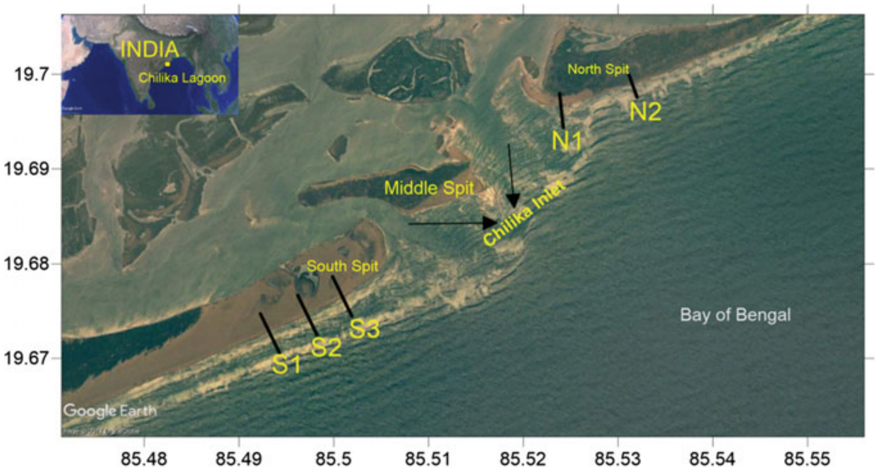

Fig. 1 Study area showing inlet(s), spit(s) and the beach profile stations (S1–S3) on the south spit and north spit (N1 and N2) (Google Earth Image—June 1, 2009)

inlet near Gabakuda inlet as a result of the severe wave-tide interaction. Thereafter, these two inlets are operated for a couple of years and merged into one called as Gabakuda inlet. Until 2008, the inlet system of Chilika is classified as bar-passing by nature [10] due to excess alongshore sediment transport and less tidal prism. Beach near shorefront of Chilika is macro-tidal by nature and composed of sediments with median grain size diameter equivalent to fine sand [11].

3 Data and Methods

Observations include seasonal beach profiles and shoreline using RTK-GPS over the sand spits (south, north, and middle spits) adjacent to the inlets of Chilika Lagoon during 2008–2013. Leica SR 1200 Real Time Kinematic (RTK) Global Positioning System (GPS) was used for beach profile and shoreline survey, which has the position accuracy of ± 1 cm and elevation accuracy of ± 2 cm. A base reference station was established at the southern end of the south spit. A total of five transects; three on the south spit (S1, S2, and S3) and two on the north spit (N1 and N2) were monitored. The distance between two consecutive transects was maintained at 500 m while observation across the profile was taken at 10 m interval in predefined transects inshore normal direction to the lowest low water mark (Fig. 1). The Beach Morphology Analysis Package (BMAP) version 2.0 of Coastal Engineering Design Analysis System (CEDAS), Veritech Inc. was used to compute beach width and volume. The ERA-Interim reanalysis wave parameters of Chilika coast were downloaded for the period

2008–2013 from European Centre for medium-range Weather Forecast (ECMWF) and the point series data were extracted for analysis.

4 Results and Discussion

4.1 Wave Characteristics

The wave properties at the nearshore environment of Chilika lagoon (from December 2008 to December 2013) were obtained from ECMWF data center and analyzed for three seasons such as Pre-monsoon—PRM (February–May), Southwest monsoon—SWM (June–September), and Northeast monsoon–NEM (October–January) period. Figure 2 depicts the frequency distribution of significant wave height (Hs) and wave period (Tz). Hs varies from 0.36 to 2.85 m during PRM, 0.77 to 3.47 m during SWM and 0.42 to 4.15 m during NEM. Frequency distribution of wave parameters indicates the maximum occurrence of Hs in the range 1–2 m (81%) followed by

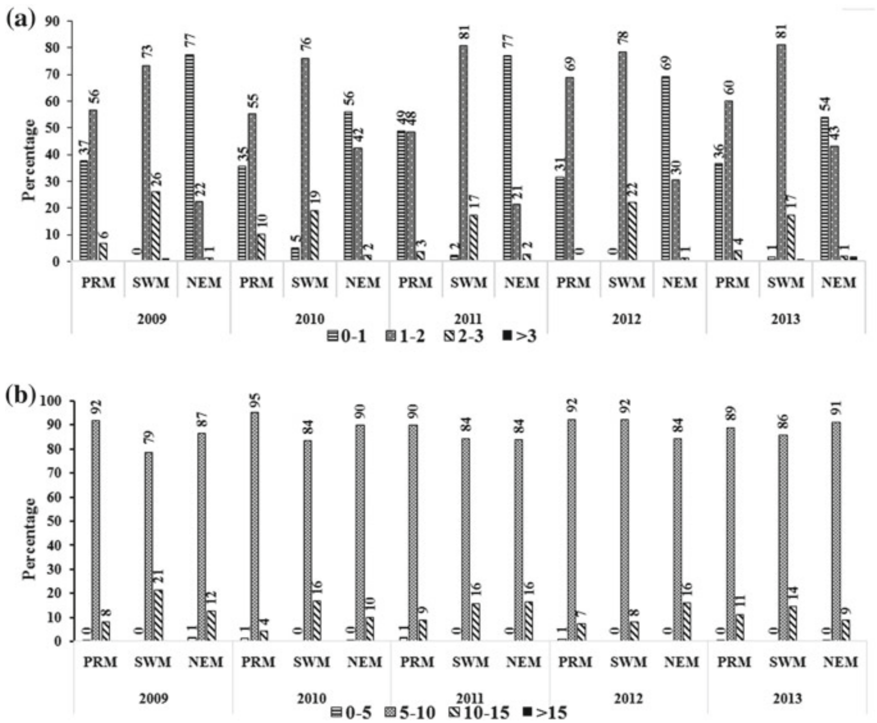

Fig. 2 Frequency distribution of wave characteristics along Chilika Coast **a** significant wave height (Hs) in meter and **b** wave period (Tz) in second

0–1 m (77%) while Hs in the range of 2–3 m is only 26%. Highest wave heights are observed during SWM. Considering the interannual variability, the highest magnitude of Hs is observed during 2013 followed by 2011, which is evident from the erosional trend of the spits (Fig. 5) in particular years. The frequency distribution of Tz indicates that maximum percentage of Tz occurs in the range 5–10 s followed by 10–15 s. Besides, Tz in the range of 5–10 s is predominant during PRM while Tz in the range 10–15 s is predominant during SWM. Interannual variability indicates that the maximum percentage of Tz in the range 5–10 s is observed during 2010 followed by 2009 and 2012. Similarly, the maximum percentage of Tz in the range 10–15 s is observed during 2009. Figure 3 depicts wave rose diagram from 2009 to 2013, which distinctly indicates round the year wave approach from SW to SSE, with predominant wave direction as SW. Interannual variability in wave direction shows that SSW to SSE waves is predominantly high during 2009 and low during 2012. On the other hand, SW to SSW wave approach is predominantly high during 2012 followed by 2013.

4.2 Shoreline

The shoreline continually changes over time because of the littoral drift and dynamic wave climate along the coast. The shoreline of adjacent sand spits (south, middle, and north) near Chilika Inlet are monitored during 2008–2013 and the results are presented in Fig. 4. It is observed that the geomorphology of spits show significant spatiotemporal variability and the results agree with Pradhan et al. [4]. The south spit (S) gets accreted and elongated toward north direction while the middle (M) and north (N) spits get eroded (Fig. 4). To understand the exact depositional/erosional trend of the three spits, the temporal variation in the area is examined (Fig. 5). It is evident that south spit continuously shows a depositional trend with time while middle and north spit show erosional trend with time. North and middle spit existed up to November 2012 and later on split in north spit (to N1 and N2) is observed while middle spit completely vanished (Fig. 5). Spit N1 further divided into N11 and N12 due to the impact very severe cyclonic storm (VSCS) Phailin, which crossed the Odisha coast on October 12, 2013. The results of the present study agree with the observation made by Pradhan et al. [4]. Besides wave characteristics, spatial variability in longshore sediment transport, higher on the updrift side (i.e., south spit), and lower on the downdrift side(i.e., middle and north spit) is attributed as one of the important factors by Pradhan et al. [4] for the depositional (erosional) trend of the south(middle and north) spit.

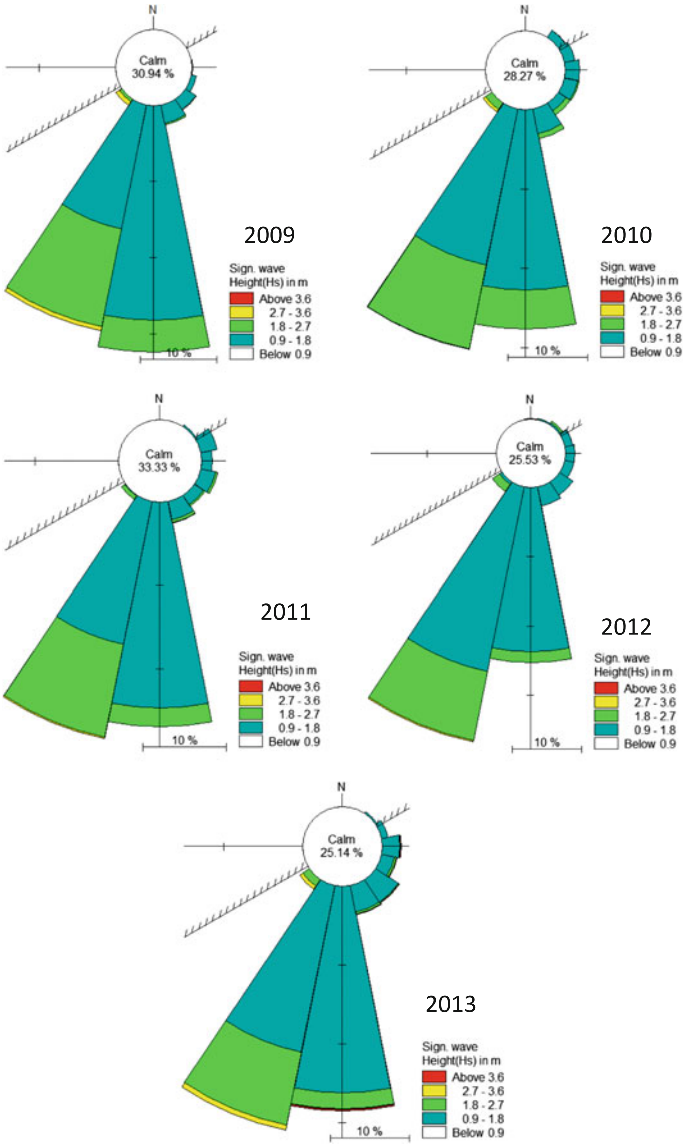

Fig. 3 Wave rose diagram at the nearshore environment of Chilika Lagoon (2009–2013)

4.3 Beach Profile

The morphodynamic variability of south and north spits near Chilika Inlet is monitored and the results are presented in Fig. 6. Three profiles (S1, S2, S3) on the south spit and two on the north (N1, N2) spits are presented for three seasons (PRM, SWM,

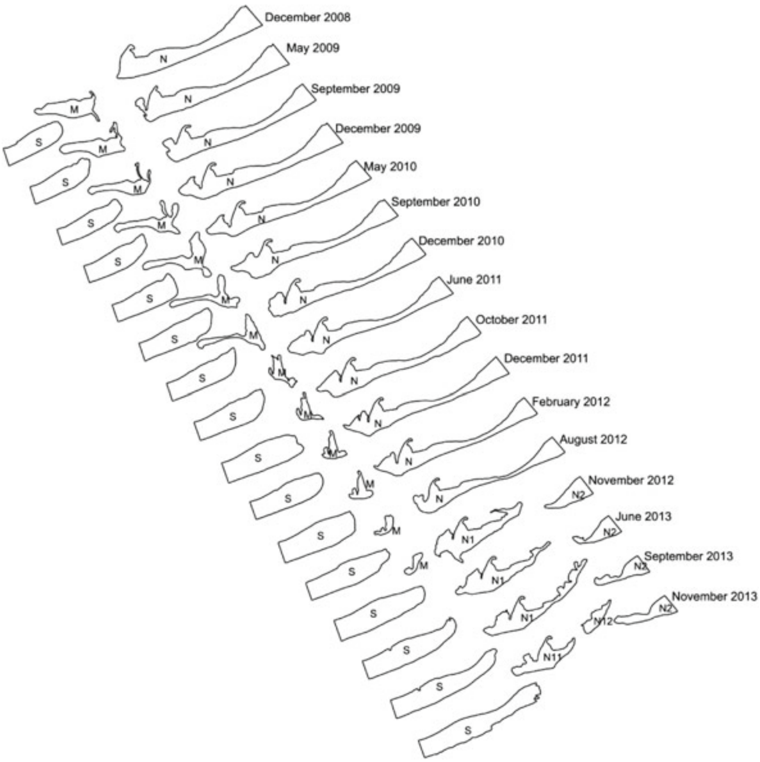

Fig. 4 Shoreline positions of adjacent sand spits near Chilika Inlet [South Spit-S, Middle Spit-M, North Spit-N, North Spit divided-N1 and N2, N1 Spit divided-N11 and N12 (not to scale)]

NEM) from December 2008 to November 2013. Measurements for all profiles are made at a constant benchmark to the limit of lowest low water mark. The largest variance in the profile occurs around the bermline and swash zone. The beach profile at S1, located extreme south of south spit, follows a definite pattern maintaining a width of 153–197 m with the continued depositional trend, while at S2 and S3, advancement of bermline toward seaside with variable width is observed due to accretion during the interaction of ocean waves with beach environment (Fig. 6). Further, it is noticed that the beach profile during December 2008 is very gentle compared to June 2013. The gradual depositional process at south spit maintains the stability of the spit and acts as a defensive system against the cyclonic disturbances. On the contrary, beach profiles on the north spit (N1 and N2) show a declining trend in elevation even at the constant benchmark. The berm width at N1 drastically reduced from 60 to 30 m from 2008 to 2013 while the height reduced from 4 m during 2008 to 1.05 m by the end of September 2013. The profile was completely washed away due to the impact of

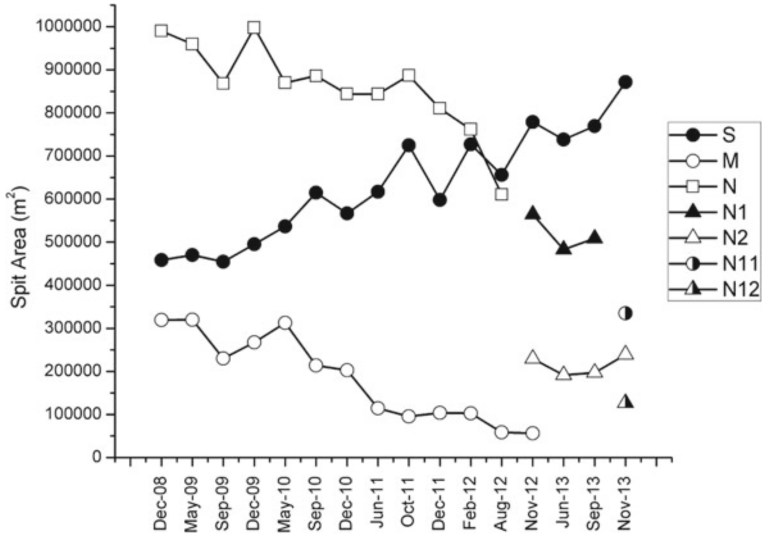

Fig. 5 Variation in the area of adjacent sand spits near Chilika Inlet (South Spit-S, Middle Spit-M, North Spit-N, North Spit divided-N1 and N2, N1 Spit divided-N11 and N12)

VSCS Phailin during October 2013. Profile N2 existed till May 2009 and thereafter the benchmark was washed out and the shoreline position shifted towards lakeside. To understand the spatiotemporal variability, beach width and volume are computed and the change in width and volume with reference to December 2008 are presented in Table 1. It is noticed that change in beach width shows increasing pattern with time for S1, S2, and S3, albeit higher magnitude in S3. On the other hand, the width of N1 and N2 reduced (negative change as in Table 1) with time. Concomitant with beach width, beach volume of south spits show a significant increase from September 2010 to September 2013. The magnitude of beach width and volume changes are highest at S3 followed by S2 and S1. Change in volume of N1and N2 is distinctly negative with time indicating erosion.

4.4 Impact of Cyclonic Disturbances

Figure 7 depicts three case studies showing the impact of the cyclonic disturbances on beach morphology. Case-I: It refers to the impact of cyclone Bijli and Aila as detailed in Table 2. Profiles of north spit (N1) during pre- and post-cyclonic events are compared, which distinctly indicate the significant impact of the cyclone Bijli and Aila with erosion predominantly in the midshore and foreshore region during post-cyclone period. Case-II: It refers to the impact of depression during September 2011 (Table 2). The pre- and post-depression profiles are compared at both south

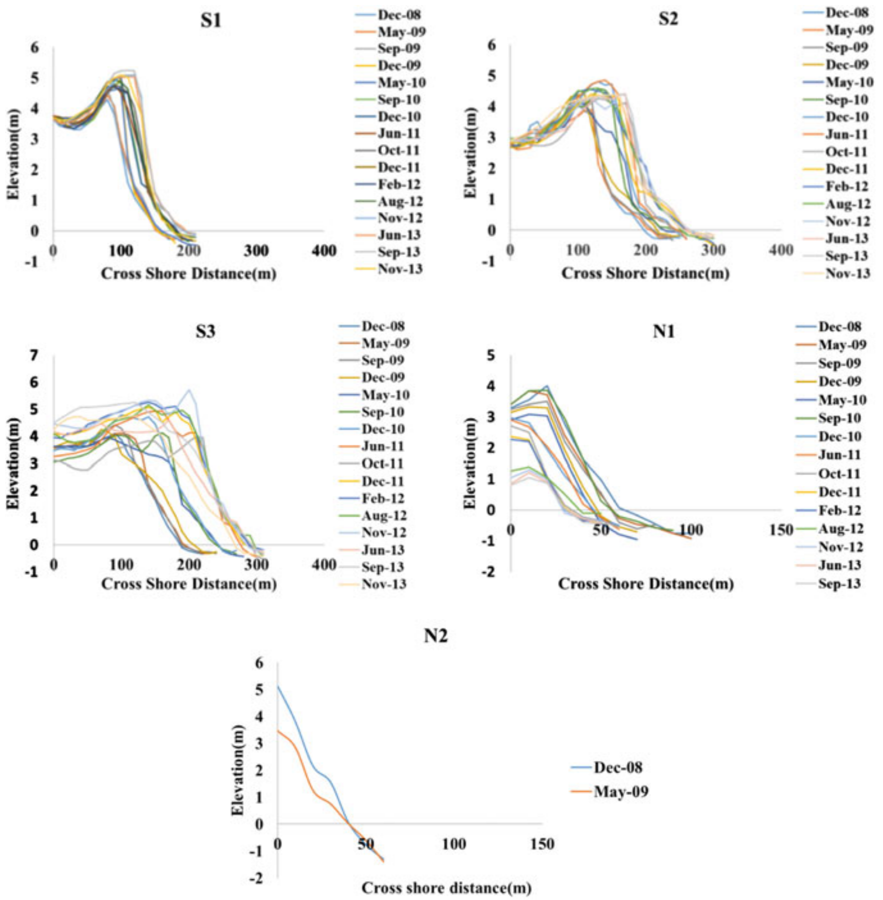

Fig. 6 Seasonal changes in beach profiles at adjacent sand spits of Chilika inlet [S1, S2, and S3 are at South Spit and N1 and N2 are at North Spit]

(S2) and north (N1) spits. On the north spit, the profiles show steep slope and severe erosion after depression while on the south spit, the profiles show distinct ridge in the midshore, stiff cut in the foreshore, erosion in the backshore and midshore, and deposition in the foreshore. Case-III: It refers to the impact of the VSCS Phailin (Table 2) on the south spit (S2). The pre- and post-cyclone profiles show ridge in the midshore, deposition in the backshore and severe erosion on the foreshore.

Table 1 Seasonal variation in beach volume (cu.m/m) and beach width (m) (*reference month)

	S1	S2	S3	N1	N2
Beach width (m)					
December 2008	157.7*	197.5*	187.0*	63.2*	40.9*
May 2009	−4.6	9.6	5.9	−6.7	−0.5
September 2009	−1.3	13.1	2.2	−7.4	
December 2009	−2.4	19.1	19.8	−15.1	
May 2010	2.3	29.4	56.1	−17.8	
September 2010	18.2	52.5	52.6	−7.2	
December 2010	19.6	44.7	56.2	−17	
June 2011	24.5	49.8	89	−18.5	
October 2011	22.3	42.5	104.6	−29	
December 2011	21.8	61.3	98.7	−31.1	
February 2012	25.9	61.6	102.1	−32.9	
August 2012	21.9	55.1	109.3	−25	
November 2012	35.2	58.4	98	−34.1	
June 2013	38.8	64.3	106.2	−32	
September 2013	37.8	69.8	105.8	−32.3	
November 2013	19.2	59.8	80.6	−63.2	
Beach volume (cu.m/m)					
December 2008	415.7*	507.2*	540.0*	146.5*	101.4*
May 2009	25.5	−22.2	39.2	−11	−35.3
September 2009	39.4	22.6	33.2	−21.6	
December 2009	56.3	35.1	49.1	−38.4	
May 2010	51.2	73.6	162.2	−50.1	
September 2010	109.6	108.6	172.7	−3.7	
December 2010	131.2	180	259	−69.2	
June 2011	129.5	219.6	448.1	−70.5	
October 2011	143.8	168.8	298.7	−96	
December 2011	130.8	191.4	529.6	−102	
February 2012	133	238.6	575.8	−102.6	
August 2012	165.2	233.6	535	−111.1	
November 2012	207.7	237.7	616.1	−119	
June 2013	211.9	223.8	430	−120.8	
September 2013	228.8	273.9	577.9	−123.1	
November 2013	190.3	245.1	404.1	−146.5	

5 Conclusion

The nearshore environment of Chilika inlet(s) is studied. The study includes long-term observation (2008–2013) on wave characteristics derived from ECMWF reanalysis, shoreline of the three spits(south, middle, and north) near the inlet(s), beach profiles of south and north spits and impact analysis of some specific cyclonic disturbances on beach morphology near Chilika inlet. The study reveals that frequency

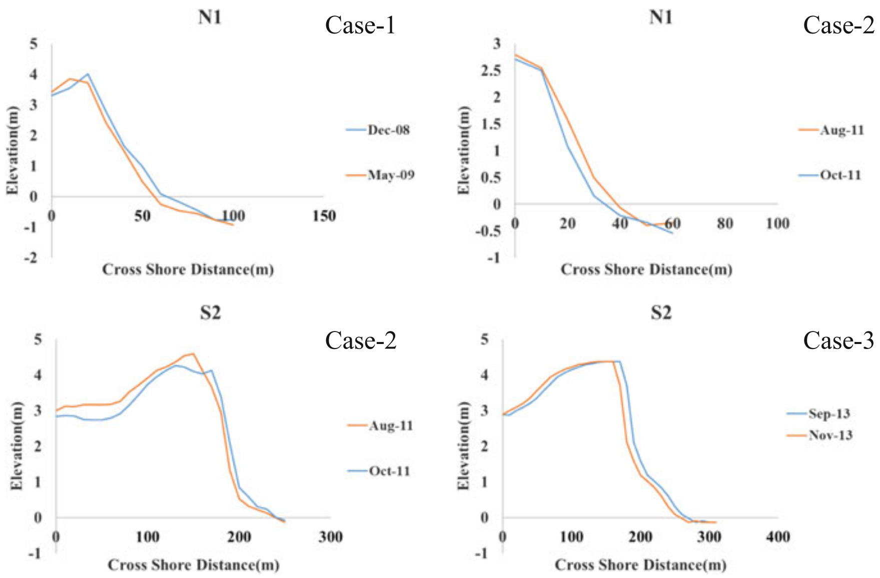

Fig. 7 Impact of cyclonic disturbances (Table 2) on beach morphology (Case-1: Impact of Cyclone Bijli and Aila during April and May 2009, Case-2: Impact of depression during September 2011 and Case-3: Impact of Phailin during October 2013)

Table 2 Cyclonic disturbances along northwest Bay of Bengal during 2009–2013

Year	Period	Type of disturbances	Location
2009	April 14–17	Cyclone **(Bijli)**	Formed in the southeast Bay of Bengal and Andaman sea and moved parallel to Odisha coast in northwesterly direction and landfall at Bangladesh coast
	May 23–26	Severe cyclonic storm **(Aila)**	Formed in the east-central of Bay of Bengal and move northerly direction and crossed West Bengal
2011	June 16–23	Deep depression	A low-pressure area formed over the northwest Bay of Bengal and crossed West Bengal–Bangladesh coasts
	September 22–23	Depression	A well-marked low-pressure area over the northwest Bay of Bengal and adjoining West Bengal–Orissa coasts resulted in heavy rains and caused floods in Orissa and Bihar
2013	October 8–14	VSCS **(Phailin)**	Crossed Odisha and north Andhra Pradesh coast close to Gopalpur on October 12, 2013
	October 20–26	Low pressure	Caused heavy rainfall over coastal Andhra Pradesh and Odisha

of Hs with range 1–2 m is highest (81%) followed by Hs in the range 0–1 m (77%). Highest waves are experienced near inlet during south-west monsoon compared to pre- and northeast monsoon. Wave periods of 5–10 s have a maximum frequency followed by wave period of 10–15 s. The direction of wave approach near inlet is from SW to SSE with predominant direction from SW round the year. Shoreline change near the inlet of Chilika depicts significant spatiotemporal variability. The north and middle spits show an erosional cycle while the south spit undergoes a continuous depositional process. As a result, the beach near south spit is stable while the beach near north spit undergoes very first geomorphological changes leading to opening/closing of inlet(s) mostly in the northward direction. The beach profile analysis (beach width and volume changes) further confirms depositional and stable environment at south spit and erosional and unstable environment at north spit. Shoreline information also reveals that it is progressive towards the seaside near south spit while retreating towards inner shelf of the lagoon near north spit. Impact of extreme weather events on beach morphology indicates that northern spit(s) is highly responsive compared to southern spit. The magnitude of erosion due to these episodic events is quite high compared to seasonal or interannual variability in beach morphology. The investigation warrants urgent attention on conservation/stability of north spits for maintaining inlet stability, which, in turn, would be helpful for sustainable management of Chilika lagoon.

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