

## Sand spit and shoreline dynamics near Terekhol River mouth, Goa, India

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Evolution of shoreline and sand spit at the mouth of the Terekhol River, near Keri beach, located in the Indian state of Goa has been investigated. From the analysis of the data collected, the shoreline oscillation (accretion & erosion) is seasonal up to 2010. A sand spit of 2 m height has been stabilized in 2012 during monsoon in the southern bank of the river which obstructs the natural flow of the river and also hindrance to the ferry transport system. This leads to the unbalanced scenario between the sediment discharge from the river and the littoral transport. Around 2 km stretch of shoreline is under severe erosion in which a stretch of 500 m of sea wall is completely damaged. Sand spit present in the northern part of the shoreline plays a vital role in the shoreline oscillation. Tetrapods were placed recently to protect the eroding part of the coast. Due to the unbalanced littoral movement, the erosion is still persisting and started damaging the new tetrapod protective measure.

**[Keywords:** Shoreline, Sand spit, Beach profile, Sediment.]

### Introduction

Sand spits near river inlets are accumulation of sediment that are formed and developed by longshore sediment transport and also supply from the river. Evans<sup>1</sup> defines sand spit as a ridge or embankment of sediment attached to the land at one end and terminating in open water at the other and also younger than the land mass to which it is attached. Sand spits are structured surface-piercing amassing of sediment that can develop by transport directed from a landmass or sediment source towards a water body<sup>2</sup>.

The sand spits are dynamic in nature and changes its size, shape and position but it will be cyclic unless its regular process is undisturbed. Bernardes and Rocha<sup>3</sup> reported from their field observations that the evolution of the sand spit may be attributed to sea level fluctuations. Uda and Yamamoto<sup>4</sup> studied the beach erosion around the sand spit in Minhono-Matsubara in Japan. They emphasized on the relationship between the sea bottom topography and sand spit dynamics. The erosion is a serious problem in the shoreline which is associated with the sand spit. It becomes necessary to understand the morphological changes of the sand spit and along with the variation in the shoreline adjacent to the sand spit since such beach erosion are different from those of straight beaches. The

construction of the coastal structures such as breakwater, sea walls etc. certainly having an effect on the evolution of the sand spit<sup>5</sup>.

### Materials and Methods

#### *Study area*

Goa is internationally celebrated for its beaches which attracts the tourists from all over the world which is located on the west coast of the Indian peninsula. Keri beach (15°43'06"N and 73°41'27"E), located in the Indian state of Goa, is connected with the River Terekhol having its confluence with the Arabian Sea in the northern side of the beach. A sand spit exists near the mouth of the Terekhol River during non-monsoon period and a headland is present to the north of the river mouth. Keri beach slope varies along its length with the slope being steeper near the river mouth and comparatively flat away from the river mouth. Flat bottom ferries operate about 150 m east of the river confluence to transport people and vehicles across the Terekhol River during all seasons. The beaches along the Goa state erode during southwest monsoon months (June-September) and subsequently recover during the non-monsoon period.

A rubble mound sea wall with a concrete slab on the top was placed during 2010 to protect the eroding beach and the southern bank of river. Over the past few

years the beach was continuously eroding and a stretch of the earlier shore protection was damaged. Hence Tetrapods were placed during 2012-13 to protect the eroding part of the coast. The construction of the shore protection works seems to have increased the erosion as this region is affected by depletion of sediments from the river due to sand mining of the river bed, which is supposed to be stopped very recently in 2013. After the construction of the sea wall, the pattern of the sand spit started changing. Presently, 3 km stretch of shoreline is under severe erosion in which a stretch of 500 m of sea wall is completely damaged. During monsoon period, the sand spit at the river mouth migrates inland resulting in a wide beach along the southern bank of the river, which becomes a hindrance to the ferry transport system.

### Materials and Methods

The variation of shoreline and the sand spit was been observed through field measurements. Starting in December 2011, regular surveys were undertaken to measure the beach profiles, littoral environmental observations and sediment volumes of different regions using the Total Station. The tidal variation in this region is about 2.8 m<sup>6</sup>. So the measurements were made during the low tide conditions in order get the more information on the field data and also taken along the instantaneous water level of the sand spit edge.

In the present study, the shoreline of Keri has been divided into two parts in. One is the sand spits region, 600 m from the top boundary and the shoreline of vertical length of 1200 m. An imaginary baseline was formed from south to north which is parallel to the shoreline and approximately 100 m distance behind the shoreline in order to find the spatial and temporal variations. Fig. 1a & 1b denotes the location of the study area and the features present respectively.

### Results and Discussion

#### Shoreline variation

The variation in the position of the shoreline alters with the seasons and the morphological conditions. The maximum seasonal variation of the shoreline usually happens during the south-west monsoon season followed by the non-monsoon season. The wave activity in the south west monsoon is high which cause the loss of the sediments from the shore to the ocean. In return, the moderate wave activity during the non monsoon season results the regaining of the beach<sup>7</sup>.

The shoreline variation has been studied from the four different data sources. One is from Survey of India Toposheets, next is Satellite imageries, next is from the measurement using total station and finally from the Goggle Earth images which was geo-corrected. The satellite imageries used in the present study are from IRS-1D Image (December 2002), Resourcesat-2 Image (December 2011) and Resourcesat-2 Image (March, 2013) and the last two imageries are shown in Fig. 2. The variation of shorelines from 2002 to 2013 may was presented in Fig. 3.

The variation of rate of change of the shoreline from 1954 to 2011 was presented in Fig. 4. The initial shoreline was digitized from the Survey of India Toposheets of 1954. The shoreline is behind the present shoreline for nearly 200 m. The next shoreline was taken from the satellite imagery at 2002. During the period between 1954 and 2002, a notable accretion was noticed. It was found that the beach and vegetation along the along the beach are recently developed.

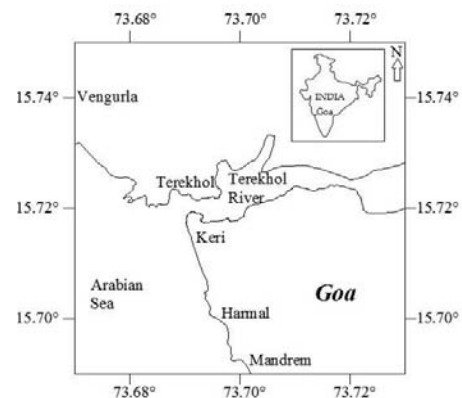


Fig. 1a—Location map of Keri, Goa, India

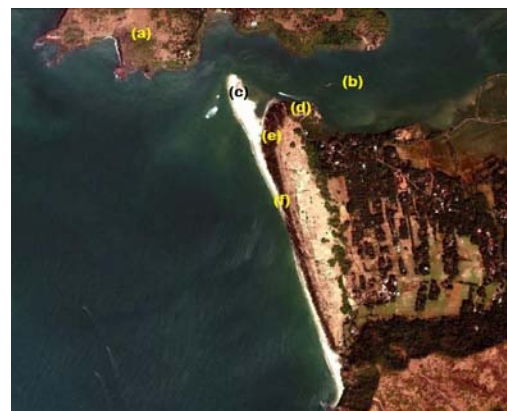


Fig. 1b—Aerial photography of Keri shoreline taken in October, 2001. (a) Headland of Terekhol Fort; (b) Terekhol River; (c) Sand spit formation; (d) Ferry deck; (e) Sea wall; (f) Keri beach. (Extracted from Google Earth)

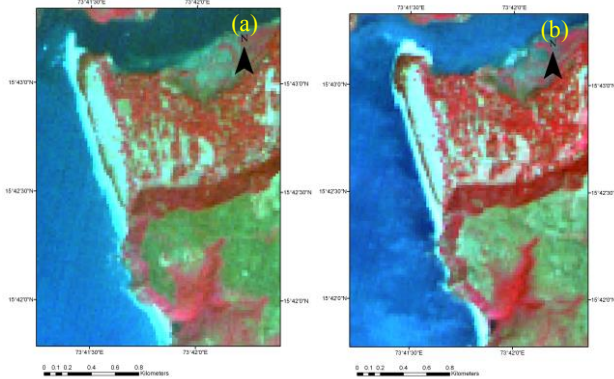


Fig. 2—(a) Resourcesat-2 Image (2011) (b) Resourcesat-2 Image (2013)

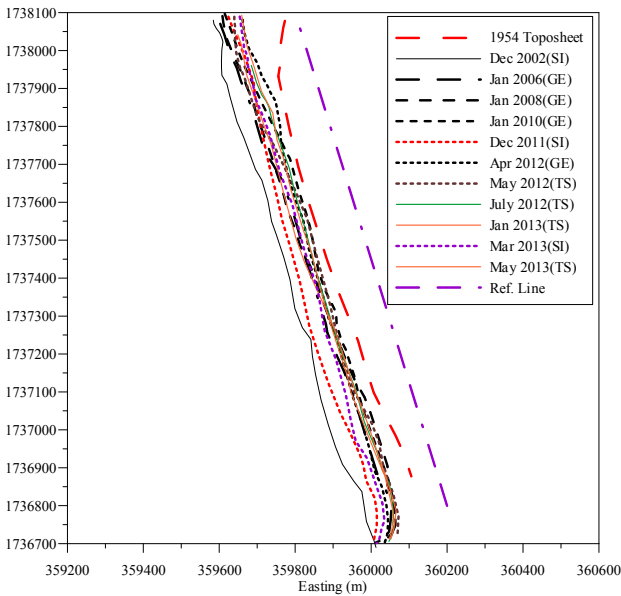


Fig. 3—Variation of the shoreline along Keri beach. (SI - Satellite Imagery; TS - Total Station; GE - Google Earth Imagery)

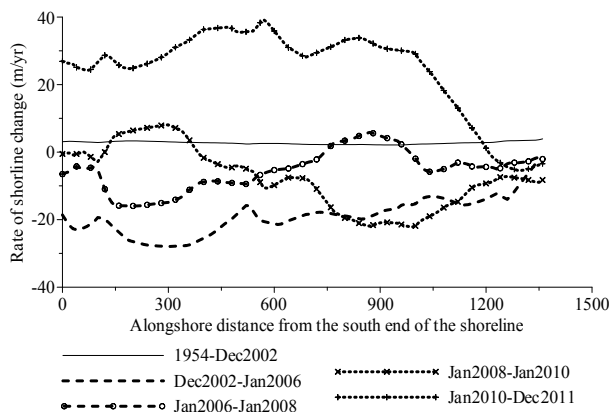


Fig. 4—Variation of rate of change of the shoreline from 1954 to 2011

The average accreting value along the stretch is about 2.7 m/yr during this period. Between 2002 and 2006, there was a heavy erosion was noticed on an average of -18.12 m/yr. The erosion rate is high in the southern end than the northern end. The same area experienced the similar scenario between 2006 and 2008, but the average erosion rate was -10 m/yr which is less than the previous years. Between 2008 and 2010, the area has experienced erosion in the northern side up to the influence of the River Terekhol. Erosion was also noticed in the mid-section of the stretch with an average rate of -8.7 m/yr. The average rate of change of the shoreline is -7 m/yr. When comparing the consecutive years (January 2010 and December 2011), a notable accretion zone developed along the shoreline except in the northern part.

The net change of the shoreline from December 2011 to May 2013 is presented in Fig. 5. Between 2011 to April 2012, heavy erosion was noticed with an average erosion of 42 m. The rate of discharge of the sediments from the river is reduced due to sand mining and reduced rainfall has aggravated the erosion in this stretch. The erosion further continued up to the starting of the southwest monsoon. But there was accretion near the mouth of the river since the discharge of the sediments might be high due to the monsoon and less sand mining. Generally, the erosion and accretion is a cyclic process unless there is change in the wave action on the coast and the supply of sediments from the river.

*Sand spit dynamics*

Considering the sand spit shape and position evolution, there are three major scenarios; (i) spit forming seaward, (ii) no spit formation and (iii) spit

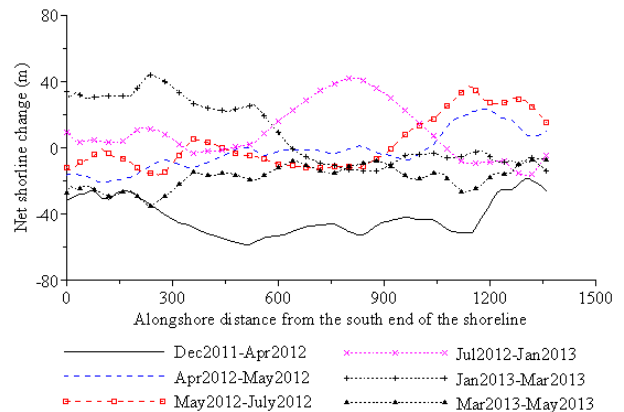


Fig. 5—Variation of net shoreline change from December 2011 to May 2013 (from south to north)

forming towards river side. The variation of the sand spit from December 2011 to May 2013 is plotted in Fig. 6. The evolution of spit can be analyzed in two parameters viz., surface area and volume respectively.

The incoming wave action towards the shore plays a major role in shaping the sand spit. During December, the discharge from the river might be at higher rate and the wave action from the sea was less which makes the sand spit to form in the seaward direction. The significant wave height during this period is of the order of 0.5 m<sup>7</sup>. It starts increasing in the month of January and the discharge from the river also reduces. It makes the shape of the sand spit to change and the spit starts depleting and fully vanishes in the month of March. The sand spit started developing in the river side before the starting of the monsoon where the incoming significant height was nearly 1 m.

Severe erosion has been noticed on the shoreline near the river mouth and sea wall was damaged for nearly 500 m. The sand spit was further developed in

the river side. During 2012, the amount of rainfall is very less when compared to normal average rainfall in that area. Hence, the sand spit deposited in the river side got stabilized. Again the cyclic process of sand spit transformation has been started slowly during the preparation of this manuscript. The resultant sand spit shape and orientation can be known only after the monsoon period.

The variation in the volume of the sand spit including the tidal corrections and corrected to the mean sea level and the volume of sand spit are presented in the form of contour maps in Fig. 7 and Fig. 8 respectively. The volume of sand in the month of May 2012 is less than the month of July 2012, because of the change of the wind wave parameters to rough condition due to the monsoon and the ban of sand mining in the River Terekhol. Since the sediment in the surfzone is not quantified, it is difficult to authentically provide accurate reason for the reduced volumes in April and May 2012.

The sand spit reached a height of 2 m above the mean sea level in the month of January 2012. But during April 2012, it has fully vanished. The sand spit developed in the river side with greater volume of sand during January 2013. The sand spit along the river side formed after July 2012 got stabilized and reached a height of 2 m and persisted for a year. The development of this river side sand spit hindered the flat bottom ferry transport across the Terekhol River.

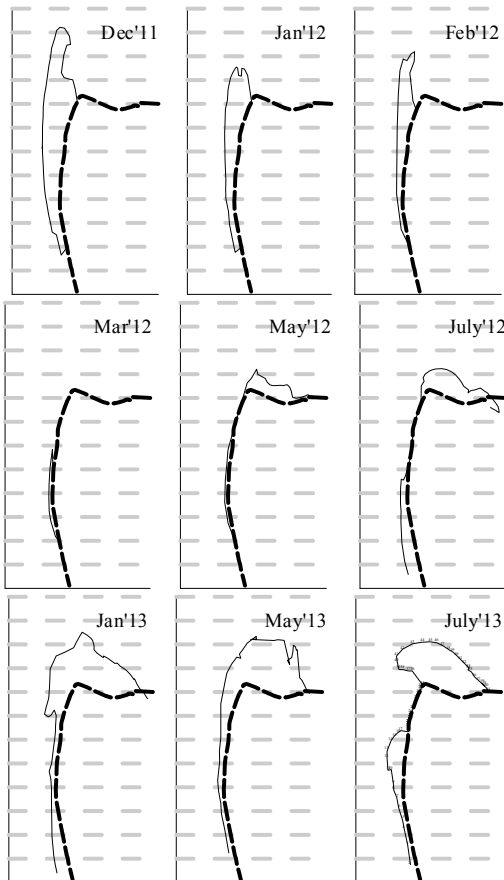


Fig. 6—Variation of the sand spit from December 2011 to July 2013. (Dotted line - Sea wall; Solid line - Sand spit)

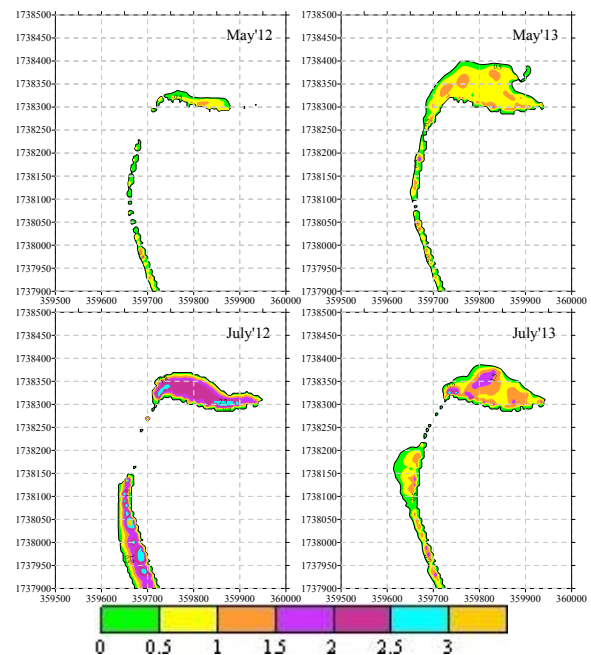


Fig. 7—Variation of the sand spit volume

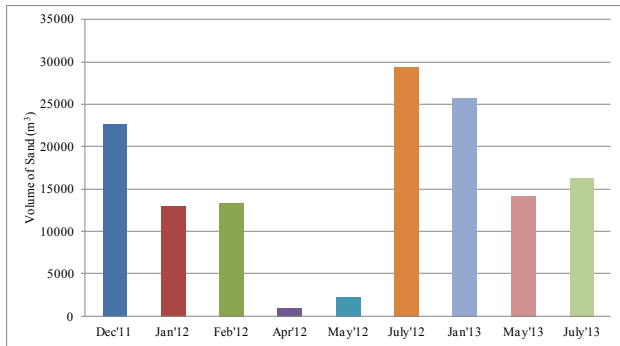


Fig. 8—Volume of sand in the sand spit measured from the Total station

Due to the presence of newly stabilized sand spit, the supply for the littoral transport has become unbalanced. Hence, the shoreline was facing severe erosion beyond the newly constructed sea wall using Tetrapods.

**Conclusions**

The aim of this study was to determine the coastline variation associated with sand spit dynamics in the Keri beach of the Goa state from 2002 to 2013. The growth of the sand spit at the confluence of Terekhol River and Arabian Sea shows a common trend of sand spits present along the west coast of India. A decrease in the supply of the sediments from the river created a unsteady mass equilibrium, because the quantity of the sediment discharge is less than that moved by the littoral drift. The sand spit

present in the northern part of the shoreline plays a vital role in the variation of the shoreline drastically. Further investigations over the sand spit dynamics in relation to the adjacent shoreline changes are needed in conjunction with the surf zone hydrodynamics.

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