

Impact of shipwrecks on the morphology of world coasts: A Review

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Received 1 October 2013; revised 30 October 2013

Role of the grounded ship MV River Princess in activating erosion along the Candolim to Sinquerim coast of Goa, India, is evaluated. Beach and dune system was severely affected, as over a kilometre long strip of coastal sand dunes were destroyed. Results suggest that the wreck acted like an offshore breakwater, trapped sediment around the site, and created a sediment deficit with consequent erosion south of the site. Coastal retreat occurred at a rate of 7 to 8 m/year, over a period of 10 - 12 years, along 1.5 km of sea front. A comparison of the impact of similar grounded vessels around the globe confirms that shipwrecks in shallow seas have the potential of drastically altering the face of the coast, often within a short time. Major factors that determine the fate of the coast subsequent to a shipwreck are: distance of the wreck from the shore, the depth of water, the span of time when the wreck remains aground, the orientation of the vessel with respect to the shore, the direction and intensity of prevailing winds, the consequent wave regime, the resultant littoral currents and the disruption of sediment transfer along the shore. The kind of short-term coastal erosion witnessed in Goa as a consequence of a marooned vessel appears unprecedented in comparison to similar examples found worldwide.

[Keywords: Shipwrecks, Coastline, Satellite images, MV River Princess, Goa]

Introduction

For some, the study of shipwrecks forms a passion, whereas for others abandoned vessels are sites of historical or archaeological importance. At places, shipwrecks are even included in tours operators' programs. Literature is replete with data that such situations can also create grave hazards to the seaside infrastructure in general and beach users in particular.

Shipwrecks can be found on deserted beaches, on coral reefs, at uninhabited remote islands or sunk in the ocean. The story behind the wrecks can be diverse (<http://www.visible-shipwrecks.nl>). The United Nations estimates that there are more than 3 million shipwrecks around the world, both sunken and beached. Ships that once ruled the seas, now serve as a windows into our past (<http://www.gadling.com/haunting-shipwrecks-around-the-world>). The world's largest online wreck database has 142.650 wrecks, 31.380 images, and 1600 maritime charts (<http://www.wrecksite.eu>).

In general, shipwrecks are mostly treated as culprits from the pollution aspect. NOAA is working to determine which of the more than 30,000 coastal shipwrecks identified worldwide contain fuels that could cause ecological damage, if they spring a leak. The harm from those boats, the tankers in particular, is still significant (<http://baltimore.cbslocal.com/>

shipwrecks-effect-on-environment-probed). The impact of a wreck on the aesthetics of the coast is also debated¹. On the other hand, old boats lying under the sea hold unknown treasures, and its steel structure offers a good foundation for corals. An accidental shipwreck thus becomes an artificial reef (or a site for treasure hunters), and soon turns into new habitats with distinct communities living in them².

However, the damage that shipwrecks can eventually inflict on the infrastructure in general and/or the coastal landforms in particular has rarely been investigated. Having experienced the drastic consequences that grounded vessel did create on the coast of Goa over a period of 12 years³, it was found worthwhile to study and compare similar incidents elsewhere in the world. In view of the above, an attempt is made to (a) identify shipwrecks in the near shore zones, (b) study each case with respect to morphological alterations it has caused along the coast over time.

Materials and Methods

In the case of MV River Princess, multi-dated IRS satellite imageries were used to delineate the shifts in the shoreline (Fig. 1). In the case of all other examples, available multi-temporal satellite imageries from Google Earth were used to demarcate the

shorelines (Figs 2, 3, 4 and 5). As the satellite imageries belong to the pre and post grounding time, the effect of the grounded ship on the shoreline and the adjoining area were studied. Simple digitization and image interpretation tools were used to extract the shorelines from the different images. All those extracted shorelines were overlaid together in GIS environment, so that the extent of erosion and accretion at different parts of the study region can be appreciated. Shorelines of different years and the corresponding satellite image are kept in a map layout and final maps were prepared with the use of cartographic techniques.

Consequence of grounded vessels on coastal landforms

A super tanker MV River Princess ran aground off the Candolim coast in central Goa, India, in June 2000. Within a few years, profound changes in the morphology of the beach dune system were observed

during the monsoon of 2005 and 2006. Frontal sand dunes were demolished and vegetation was uprooted leaving 4 to 6 m high gaping vertical scarps in the dunes; these features are still visible at present. A detailed study was therefore conducted along a 1.5 km stretch of the beach between Candolim and Sinquerim³.

Satellite imageries of the years 1999, 2006, and 2011, wave model (DHI) results, and field measurements have been used to evaluate the relation between the stranded vessel and erosion that followed its grounding³. Fig 1 shows the shoreline position in 1999, 2006, and 2011. Analysis of the imageries indicates that in November 1999, before the grounding of the ship, the shoreline was almost a straight. Symptoms of erosion along the southern part of the coast and deposition on the lee side (between the ship and the shoreline) were visible within a short time. This process continued and eventually, by 2006 erosion has attained alarming proportion; shoreline

Table 1—Details of some of the shipwrecks that caused significant modifications in the morphology of the shore front around the world. The incident of MV River Princess in Goa, India, appears to be the most serious of all the cases, as far as the coastal retreat is concerned (Sources: Mani Murali *et al*³; Coastwise⁴; Alidu⁵; Seifart⁶; Jayappa, pers. comm.; Google Earth images; <http://www.visible-shipwrecks.nl>; <http://www.gadling.com/haunting-shipwrecks-around-the-world>; <http://www.wrecksite.eu>).

Shipwreck	Location	Grounding time/ depth	Impacts on shoreline	Present state of wreck	Present state of coast
MV River Princess	Candolim, Goa, India	June 2000, 5 m	Tombolo, severe erosion, 85 m in 12 years	Partly removed in 2012	A 60 m wide beach noted in August 2013
MV Denden	Tannirbhavi, Mangalore, India	June 2007, 8-10 m	Accretion in south, erosion in north	Wreckage still underwater	A bulge in shoreline (2012)
Unknown	Bengere, Mangalore, India	In 1990's, 5 m (?)	Erosion adjacent to breakwater	Metal parts are still seen at low tide	Fluctuations in the shoreline are noted
Unknown (tanker)	Kakinada, Andhra Pradesh, India	June 1998, 1-2 m	A large patch of sand around vessel in 2002	Removed in 2003	A normal beach noted at present
Black Rose	Paradip, Orissa, India	Sep 2009, 5 km away	No visible impact	Tilted ship seen above sea level	No change
MV Farah III	Mallaithivu, NE Sri Lanka	In 2009, 0-1 m	Accretion in south, erosion in north	Wreck is still in place	Configuration of beach not improved in 2011
Seli One	Blouberg, Cape Town, South Africa	September 2009, 500 m off the beach	Sedimentation between vessel and beach	Vessel split in 2011	Shoreline retreat in north (2012)
SS Maheno	Fraser Island, Australia	July 1935, 1-2 m	-----	Remnants seen	Minor shoreline changes
SS Kwinana	Kwinana, W. Australia	In 1922	Tombolo, accretion in north, erosion in south	Wreck used as a platform	Slow retreat of coast since decades
Dimitrios	Gythios, Greece	December 1981, 1-2 m	Accretion around wreck	Vessel has disintegrated	Tombolo formation
William Eggerts	Beira, Mozambique	In 1885, along beach	Accretion around wreck	Few pieces seen	A bulge in shoreline
MT Ray	Lekki, Nigeria	February 2010, 500 m off the beach	Severe erosion, coconut trees uprooted	Ship has sunk into sand	Erosional scarps, 50-70 m retreat in 5 months
Costa Concordia (cruise liner)	Port Giglio, Italy	January 2012, 50 m off a cliff	No visible impact	Wreck now standing upright (Sep 2013)	No effect on rocky shore

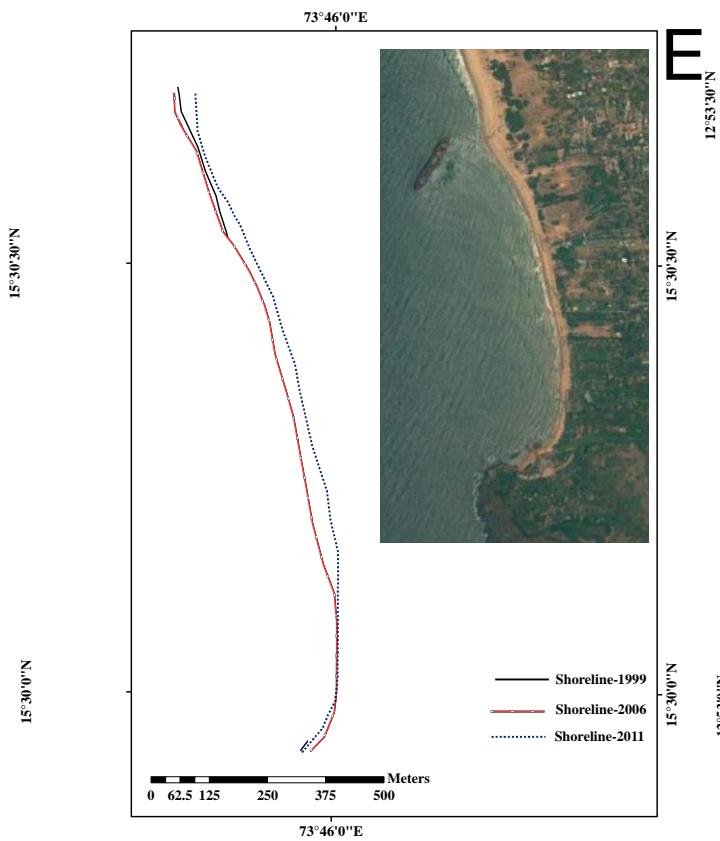


Fig 1—Positions of the shoreline along the Candolim coast in Goa, as identified in 1999 (before grounding), 2006, and 2011. Note that the mapping is based on IRS satellite imageries; the MV River Princess was responsible for a maximum shoreline retreat of 85 meters. The inset Google Earth image is given as reference

topography of the beach had altered. The maximum shoreline shift over a stretch of 1.5 km of coast is estimated at about 65 m in 2006, and attained about 85 m in 2011, over a period of 12 years. The wreck acted like an offshore breakwater that disrupted southward littoral drift leading to acute starvation of sediment south of the wreck. The orientation of the ship with respect to the coastline, its length, the distance of the ship from the coastline and, more importantly, the direction of the waves prevailing over the region, particularly during monsoon, are factors that governed the fate of coast posterior to the sinking of the tanker³.

A summary of some of the shipwrecks that caused substantial changes along the shorelines around the world is given in Table 1. Of all the cases examined, the incident of MV River Princess in Goa, India, appears to be the most serious, as far as the coastal retreat is concerned. Therefore, considering the alarming rate of erosion (85 m during 1999–2011),

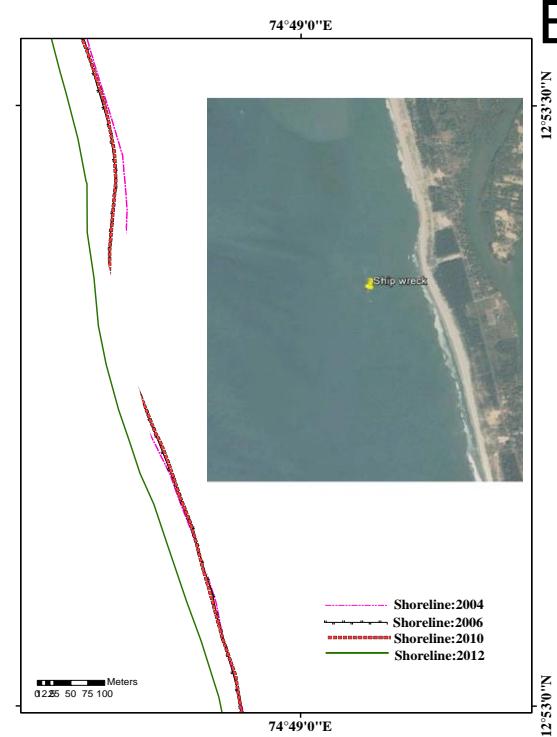


Fig 2—The sunken vessel that is lying at 10 m water depth off Tannirbhavi in Mangalore has induced a hump in the shore, a case of lee side accretion. The inset Google Earth image is given as reference.

large area of prime land lost to the sea over a decade, this phenomenon appears to be the first of its kind ever reported in India.

Since marooned vessels are a common sight in the near shore across continents, an attempt is made to compare the case of River Princess in Goa (described above), with similar incidents reported elsewhere in the world. For this purpose, our observations along Indian shores, a Google Earth search of vessels abandoned worldwide and related published work was used to make an assessment about the shift in shorelines following grounding of ships in shallow waters.

Off Tannirbhavi beach in Mangalore, a 180 m long vessel MV Denden was grounded about 200 m from the shore, in a water depth of 8–10 m (Jayappa, pers. comm.). The remnants of the wreck, oriented NNW–SSE trend, can still be identified. Fig 2 shows the shoreline changes wherein the lee side accretion zone of about 25 m and consequent retreat further north, is clearly identified from the shoreline of 2004.

Off Bengere beach at Mangalore, a sunken ship is located around 150 m from the shore. The vessel (name unknown) is in various stages of disintegration, and its top metal parts can be seen only at low tide.

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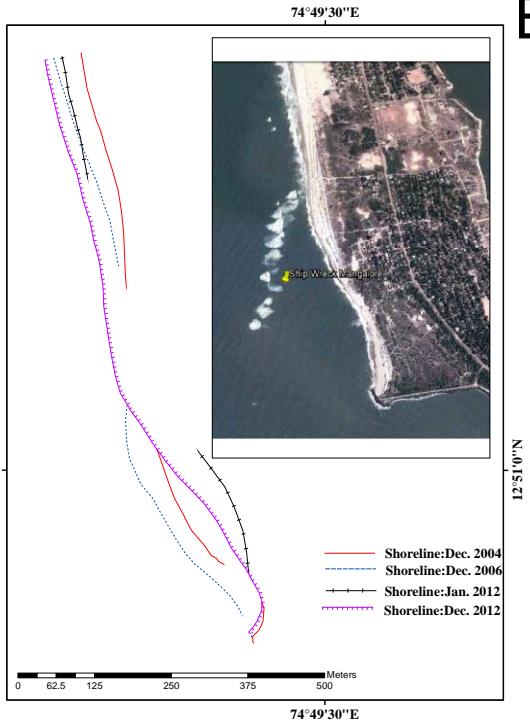


Fig 3—At Bengere in Mangalore, large fluctuations in the morphology of shoreline are observed as a result of a vessel that grounded in the 1990's. Here, in addition, the groyne also appears to control retention of sediment. The inset Google Earth image is given as reference.

Over the last 15 years, significant changes in the alignment of the coast are noted, particularly in the area leading to the rubble breakwater, southeast of the wreck. Based on the images of 2006 and 2012, a stretch of 500 m coastline shifted landward by about 100 m. Fig. 3 shows large fluctuations in the morphology of shoreline as a result of a vessel that grounded in the 1990's. Here, in addition, the groyne also appears responsible for and played a role in the retention of sediment.

Along the Kakinada coast of Andhra Pradesh, a huge bulk carrier ran aground during the cyclone of 1998. In 2002, the beached vessel was lying parallel to the coast. In the field, changes in the beach configuration were noted in the form of a large patch of accreted sand in the south, whereas in the north, the shoreline had shifted inland. At present (2013) however, the linear beach north of Kakinada is found to be normal. No specific studies were done at this site. Lately, a tanker Black Rose, 187 m long, sunk in the shipping channel of Paradip port. Although this vessel is presently found in a tilted position about 5 km away, there is no visible change on the adjacent coasts.

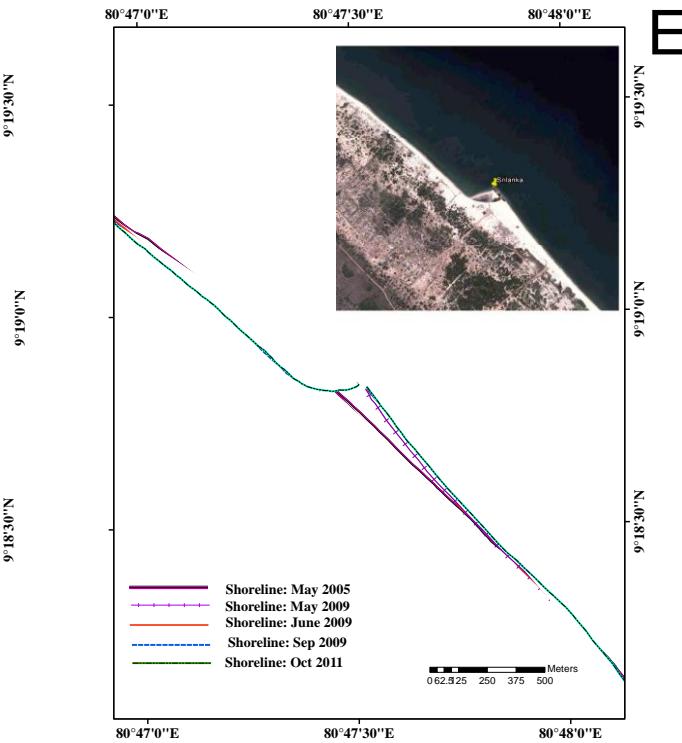


Fig 4—Shoreline changes induced by the shipwreck at Mallaithivu, east coast of Sri Lanka. The shift of shoreline occurred within a period of two years, and appears unchanged since then. The inset Google Earth image is given as reference.

Along the Mallaithivu coast of Northeast Sri Lanka, a tanker MV Farah III, stranded in 2009, is oriented NW-SE. The rusted wreck is presently lying parallel to, but along the beach. Images of 2005, 2009 and 2011 were used for finding out the impact of grounded ship at the location. As viewed in a Google Earth image (2009), the orientation of the 150 m long ship is NW-SE. The available image of 2005 shows a linear beach. At the time of grounding, the vessel was around 200 m from the shore (2009); the wreck is now linked to the beach (2011) (Fig. 4). The littoral current appears to flow from southwest towards northeast. Over a span of 2 years, around 200 m of the beach has accreted in the south, whereas in the north, an equal amount has eroded. The wreck acted as a barrier to natural sand transport. The effects of grounding in terms of altering the shoreline occurred in less than 2 years.

A review of Google Earth images show distinct geomorphological changes triggered by shipwrecks on coasts worldwide. A small bulge in the shoreline can be noted in the case of the wreck seen along the beach of Beira in Mozambique. In comparison, the SS

Maheno ship wreck is identified along the Fraser Island, east coast of Australia, is not showing any recent impact probably because the vessel is presently in pieces after its grounding in 1935. Since the ship has disintegrated, the shore has probably regained its original profile.

Seifart⁶ presented an intricate study on the role of a sunken vessel on the adjacent coast. In September 2009, a 178 m long bulk carrier Seli One ran aground off the coast of Blouberg in South Africa and has remained stranded approximately 500 m off the beachfront. Seifart⁶ reveals that an immediate effect was observed in the form of erosion on the northern side resulting directly from the shipwreck wherein 15-18 m of beach disappeared relatively rapidly, within two months of the vessels arrival. Further, accretion of approximately 27 m in the lee of the shipwreck is reported immediately after grounding. The hydrodynamic and beach morphological changes⁶ that occurred as a result of this grounded boat are shown in Fig 5. Through the analysis of simulation results, it was concluded that the shipwreck has resulted in a significant reduction in the net long shore sediment transport rate in her lee, resulting in sediment deposition in this area. It was further concluded that the vessel did not result in the complete blockage of long shore sediment transport, and that sand is able to periodically pass through the lee of the vessel⁶.

Likewise, published reports⁴ reveal that the wreck of the SS Kwinana has modified the morphology of Kwinana beach in Western Australia since 1922. The hull of the ship was stranded parallel to the beach and resulted in an artificial tombolo and in accretion in the north and erosion in the south. The coast south of the wreck has been receding for several decades, probably soon after the grounding of the ship. Recently, along the coast of Lekki in Nigeria, an otherwise stable beach, came under the grip of severe erosion after the MT Ray ran aground in February 2010, about 500 meters from the coast. Around 10 to 15 m of land was lost every month; about 50 to 70 m of beach has vanished in five months at different areas of the coast. A large number of coconut trees were uprooted⁵.

Results and Discussion

Coastal structures like sea walls, groynes, jetties, breakwaters, barrages and piers are known to activate changes in shorelines with consequent beach erosion⁷⁻¹⁰.



Fig 5—A detailed presentation of post grounding effects of Seli One in Blouberg, Cape Town, South Africa; sediment deposition, erosion and accretion are clearly demarcated after Seifart⁶.

The pattern of erosion versus accretion reflects the natural processes of wave-induced long shore currents and sediment transport^{7,9}. However, serious beach erosion is also found to have occurred due to unusual meteorological conditions. An increased wave attack generated by unique significant changes in wind direction, wave action and extreme sea levels also exacerbate erosional activity¹¹.

The kind of short term coastal erosion witnessed in Goa, as a consequence of a marooned vessel, appears unprecedented in comparison to examples cited above. This study confirms that shipwrecks in shallow seas drastically alter the face of the coast. Such situations create grave hazards to the seaside tourism related activities and regular beach users in general and beach – dune ecosystems in particular. Goa is an important tourist destination. The large shoreline retreat as observed in Goa caused a sort of economic issue, as a 1.5 km strip of coast was virtually closed for tourists since there was virtually no beach left even at high tide.

Based on our investigation, and the shoreline changes due to grounded vessels across the globe (Figs 1 – 5), it is obvious that several parameters govern the fate of the morphology of the coast and the ensuing shoreline changes that occur. These parameters are listed below:

Distance of the wreck from the shore—This parameter plays the most important role as far as the lee side sedimentation is concerned. Ships grounded even 500 m from the coast have induced lee side accretion as observed at Blouberg beach in South Africa⁶. Similar features were observed at Kakinada, Andhra Pradesh, in 2002, and also along the Tannirbhavi beach, Mangalore. During extended periods with low waves, the bars (in our case the wrecks) may weld to the shoreline and completely fill in the landward trough between the bar and the beach¹⁰. The ship stuck on the beach at Mallithivu in Sri Lanka may fall under this category. The case of the shipwreck in Goa further proves this contention, as during low tide, the beach was connected to the vessel³.

Orientation of the vessel with respect to the shore—It appears that vessels oriented at an angle to the coast are liable to create greater impact onshore. The ship SS Maheno, grounded at Fraser Island in Australia since decades, is lying very close and parallel to the beach. The shoreline changes appear negligible. In comparison, the MV River Princess, oriented 208° from North and hence oblique, resulted in perceptible alterations in sediment distribution. The southward littoral drift¹² was blocked, resulting in sediment starvation south of the vessel; this stretch came under the grip of severe erosion³.

Depth of water—This factor may be tricky to discuss as the depth of water in front and aft may vary in the case of ships lying oblique or perpendicular to the coast. The vessel at Tannirbhavi in Mangalore, sunk in 2007 in 10 m water depth, has shown appreciable effects in the form of lee side sedimentation, and erosion in the northern side.

Span of time when the wreck remains aground—Obviously, the disintegration of wrecks over time should have allowed coastal processes to be restored, but the reality proves otherwise. The ship remnants at Bengere in Mangalore still appear to interfere in near shore processes. If the shoreline changes are examined minutely, rapid fluctuations in the orientation of the shoreline are observed over an 8 year period (Fig. 3). Lack of a definite trend may also be attributed to the presence of a perpendicular rubble wall breakwater that interferes with littoral sediment transport.

Direction and intensity of prevailing winds—

The wind patterns have been studied in detail in the case of the MV River Princess in Goa. In general, two prevailing wind directions are observed. During the fair weather, from September to May, winds blow from North-West where as during monsoon; the wind regime gets stronger and blows mostly from the West. The average wind speed during the southwest monsoon is about 35 km/h whereas during fair weather winds blow at around 20 km/h¹³. These factors ultimately determine the processes that operate on the coast.

Consequent wave regime—Sea waves are wind driven. The west coast of India experiences high wave activity during the southwest monsoon with relatively calm sea conditions prevailing during rest of the year¹³. Northwesterly waves characterize the region during winter, and pre-monsoon seasons (January–May), and westerly–southwesterly winds during the southwest monsoon. The maximum wave height of 2.59 m is attained during July when the southwest monsoon winds reach a maximum³.

Resultant littoral currents—The winds and the wave fronts that lash the shore determine direction of the along shore currents that govern the littoral drift. Along the west coast of India, the sediment transport is mostly towards south^{12, 13}. Therefore, any interference with the natural flow of alongshore currents can induce substantial changes in sediment deposition.

Disruption of sediment transfer along the shore—In the case of MV River Princess, the sunken ship acted as offshore detached break water which resulted in blocking sediment movement. In this sector, the littoral drift during fair weather is southwards. As such, the grounded ship triggered the formation of a sand bar on the lee side of the ship. Offshore hard structures invariably cause lee side erosion or accretion^{7,9}. Due to the combined effect of both the ship and lee side accretion, the area between the ship and the shoreline became a sheltered zone that obstructed the southward littoral currents. Hence, the southward littoral drift was reduced, and there was negligible sand supply due to which the beach experienced sand deficiency. This sand starvation is manifested in the form of erosion³. Therefore, disruption of natural sediment transport and nourishment is the primary cause why all the beached ships can cause profound changes in the coastal morphological setup.

In summary, marooned vessels have the potential of significantly altering local long shore sediment transport characteristics in general and the sandy shorelines in particular. Lee side sedimentation⁶ or tombolo formation³ is one such feature. The initial shoreline changes occur at a rapid rate^{5,6}; the Sri Lankan example, MV Farah III, beached in 2009, created pronounced changes on the beach orientation caused due to disruption of sand deposition. Such drastic geological changes may pose significant risks to seaside infrastructure, fishing activities, tourism or leisure, due to the formation of rip currents. Eventually, the removal of the shipwreck from near shore waters turns into a difficult task; this aspect was witnessed in Goa.

The wreck of MV River Princess was removed in 2012 with great difficulty and a huge loss to the exchequer. Therefore, so as to prevent damage to the beach - dune system in the form of rapid shoreline erosion, any grounded vessel needs to be removed as quickly as possible. The shipwreck MV River Princess in Goa has already taught us grave lessons.

Acknowledgements

Authors are grateful to the two anonymous reviewers for their suggestions and constructive comments on the manuscript. R. Choudhury is acknowledged for preparing the figures. The NIO contribution No is 5597.

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