# Quantification of shoreline changes along the entire Indian coast using Indian Remote Sensing satellite images of 2004–06 and 2014–16

**R. Ratheesh*, Preeti Rajput, H. Bhatti, A. S. Rajawat and D. Ram Rajak**

Geo Sciences Division, GHCAG, Space Applications Centre, Indian Space Research Organisation, Ahmedabad 380 015, India

**The coastal region of India is highly vulnerable to various threats, including coastal erosion, due to natural processes enhanced by anthropogenic influences. Shoreline change inventories are the pre-requisite for identifying the coastal stretches subjected to erosion. In this study, the shoreline of the entire Indian coast was delineated at a scale of 1 : 25,000 using IRS LISS-IV images of 2004–06 and 2014–16 time frames. The spatial shift between the shoreline of two time frames was estimated in the GIS platform and a database of shoreline changes was prepared. The eroding, accreting and stable length of the shoreline were calculated for the Indian coast along with the area of erosion and accretion. This study discusses the imperative results of shoreline mapping and the status of shoreline changes on the Indian coast. The shoreline changes in terms of erosion and accretion were assessed for 7549 km of the Indian coast. It was found that the coast is eroding along 1144 km and accretion of the coast is along 1084 km, while 5321 km of the coastline shows no changes between the two time frames. The coastal land area lost due to erosion was 3680 ha; however, the increase in land area as a result of coastal deposition was 4042 ha. The regional coastal processes and the associated shoreline changes and coastal issues related to anthropogenic impacts are also discussed in this study. The inventory of shoreline changes has been used to prepare six volumes of *Shoreline Change Atlas* covering the entire Indian coast. The shoreline change database forms the baseline data for planning any coastal development activity by the maritime authorities apart from the potential use by the scientific community.**

**Keywords:** Coastal erosion and accretion, high tide line, remote sensing, shoreline changes.

THE world's shoreline undergoes relentless modification through coastal erosion and accretion as a result of natural processes, while coastal constructions hinder the natural coastal sediment transport enhancing the shoreline changes. The anticipated sea-level rise, increased wave activities and projected increase in the frequency and intensity of tropical cyclones under the climate change scenario are likely to cause enhanced shoreline changes in the near future[1,2]. A recent study shows that we may lose half of the world's sandy beaches by the end of this century because of coastal erosion driven by the rise in sea level[3]. The shoreline undergoes dynamic changes with the interaction of coastal processes induced by waves, tides and the coastal currents that result in the movement of coastal sediments. Coastal geomorphic environments naturally maintain the balance in sediment supply along the coast. However, high wave activities during monsoons, cyclones and anthropogenic influences like coastal construction, dam construction and the subsequent reduction in sediment input tend to disturb the sediment equilibrium, resulting in shoreline changes.

Mentaschi *et al.*[4] have estimated on a global scale the coastal changes in terms of erosion and accretion over 32 years. Luijendijk *et al.*[5] reported that 24% of the sandy beaches are eroding. Shoreline changes are of serious concern along the coastal regions of India, as a large community depends on the coastal resources for their livelihood. An increase in the coastward migration of the population is expected by 2100, which can add further pressure to the coastal regions[6]. With more than 26% of the total population residing in the coastal regions, India has been classified into areas with the highest coastal ecosystem service product values for altered or semi-altered ecosystems that show the anthropogenic influence along the Indian coastal regions[7].

The Indian peninsula manifests into a long coastline with the Arabian Sea on its west and the Bay of Bengal on its east. Shoreline changes along the Indian coastal regions are studied as site-specific works. Rajawat *et al.*[8] were the first to use satellite data from two periods (1989–91 to 2004–06) to map the shoreline changes of the entire Indian coast and provide the shoreline change status. Inventory of shoreline changes is the primary requirement for any planning measures to carry out sustainable development activities along the coastal regions. In this context and at the behest of the Coastal Protection and Development Advisory Committee, the shoreline change maps are updated using recent satellite images. The present study discusses results from the mapping of shoreline changes for the Indian coastal regions using recent satellite images.

*For correspondence. (e-mail: unnirathesh@gmail.com)

## Data and methodology

We have considered the high tide line (HTL) as the shoreline, as defined by the Coastal Regulation Zone notification (2011 and 2019). HTL is delineated from LISS-IV images with a spatial resolution of 5.8 m corresponding to 2004–06 and 2014–16 time frames on-board Resourcesat-1 and 2 respectively. Image-to-image co-registration of LISS-IV images of both time frames was carried out by considering LANDSAT orthorectified datasets as the base map, with an error of +/– 1 pixel.

HTL of the maritime States, Union Territories (UTs) and the islands of India were mapped on a 1 : 25,000 scale. Under different coastal environments, various geomorphic indicators represent HTL like the landward extent of the dune/berm, mangroves, supratidal mudflats, cliffs, seawalls, permanent vegetation lines, headlands and cliff[9,10]. These geomorphic indicators are used to delineate HTL, where on-screen digitization technique has been implied. Based on the National Natural Resources Management System (NNRMS) standards[11], a polyconic projection system for the vector layer was selected with a 6.25 m planimetric accuracy and 3.125 m weed tolerance. Spatial shifts among HTLs of the two time frames were computed using a GIS-based spatial analysis technique. The spatial change analysis was carried out only along the main shoreline that excluded analysis along the mouth of the river/creek and the inner parts. A 10 m buffer zone was considered on either side of HTL 2004–06. The coastal regions where HTL 2014–16 was within the buffer zone were considered stable. The coastal regions with a landward shift in HTL 2014–16 beyond the buffer zone were classified as eroding coast and the coastal stretches with seaward shift were classified as accreting coast.

A standard map composition and layout was finalized based on the Survey of India topo-grid at 1 : 25,000 scale to prepare shoreline change maps using the digital database. The shoreline change of the entire Indian coast has been shown in 618 map grids. The shoreline change map displays the coastal stretch under erosion, accretion or stable. In addition, shoreline protection measures carried out by the respective maritime States and UTs, major coastal habitations, rail and road networks are also shown on the map.

## Results and discussion

### *Shoreline change status*

Shoreline change assessment was carried out along 7549 km, where Andaman and Nicobar (AN) Islands have the longest shoreline (2157 km), while the shortest is for Lakshadweep Islands. Shoreline change analysis has classified the shoreline into eroding, accreting and stable. Figure 1 shows the shoreline changes along the entire Indian coast and the state-wise percentage distribution of the eroding, accreting and stable coasts. Table 1 gives the status of the shoreline change analysis. Around 15% (1144 km) of the total shoreline is under erosion, 14% (1084 km) is accreting and 70% (5321 km) of the coast is stable. The AN Islands have the longest eroding (231 km) and longest accreting shoreline (256 km). Erosion is lowest in the Lakshadweep Islands (12 km), while the shortest length of the accreting shoreline is in Goa (7 km). The percentage of eroding shoreline is highest for West Bengal (WB; 36%), followed by Odisha (32%), Kerala (23%) and Andhra Pradesh (AP; 23%). The remaining maritime states have less than 20% of the shoreline under erosion and is minimum for Lakshadweep (8%). AP has the highest percentage of accreting coastline (26%), followed by Tamil Nadu (TN; 22%), Odisha (22%), WB (22%) and Kerala (21%). The remaining maritime states have less than 15% accretion and in Gujarat, accretion is the least (4%). The percentage of stable shoreline is highest for Gujarat (87%), followed by the Lakshadweep Islands (82%). Maharashtra and Goa have more than 80% of shoreline to be stable. Shoreline change is more along the eastern coast of the Indian peninsula than the western coast, while along the western coast, Kerala and Karnataka have a dynamic shoreline. Net erosion is observed for WB, Gujarat, Odisha and Goa, where the net loss of coastal area due to erosion is the largest for WB (252 ha). A gain in the coastal area has been estimated for TN, Maharashtra, Karnataka, Kerala, AP and the Lakshadweep Islands and the largest estimated is for the AN Islands (524 ha).

### *Shoreline change analysis of the Indian coastline*

For Gujarat, the stable shoreline is mainly along the Saurashtra coast, while the south Gujarat coast is eroding. Figure 2 *a* shows the eroding coast to the south of Dandi, Navsari district, Gujarat. High tidal current accompanied by wave activities and reduced sediment input is considered the major cause of erosion[12]. In Maharashtra, erosions are prominent in the northern region with intertidal mudflats and interleaving rivers/creeks. Figure 2 *b* shows the eroding coast at Navpur, Palghar district, Maharashtra. The central and southern coastal regions of Maharashtra have rocky cliffs and headlands, where shoreline changes are along pocket beaches and spits. The North Goa district is subjected to severe coastal erosion. Figure 2 *c* shows the eroding shoreline of Candolim Beach, Goa, where shipwreck-induced erosion has been reported[13].

In Karnataka, erosion is prominent in the southern parts. Figure 3 *a* shows erosion at Someshwara, Dakshina Kannada district, Karnataka, where a negative sediment budget was reported[14]. Figure 3 *a*1 and *a*2 show field photographs of the eroding coastline. The northern Karnataka coast is largely comprised of rocks, where 80% of the shoreline is stable. Among the western coastal states, Kerala shows maximum shoreline changes. Erosion is severe along the central and southern parts of the Kerala coast. Figure 3 *b* shows the

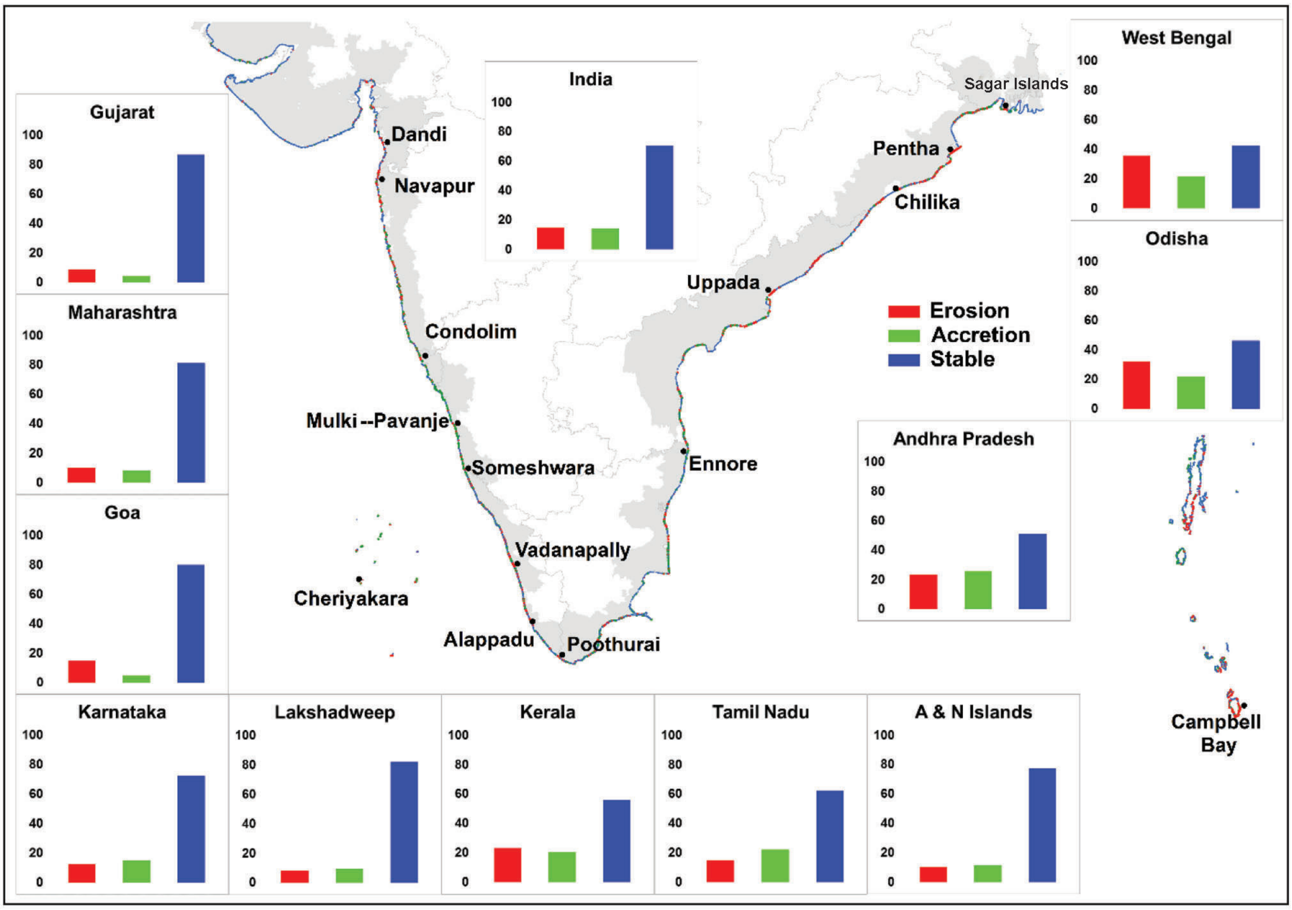


**Figure 1.** Shoreline change assessment of the Indian coast showing eroding, accreting and stable shoreline. Percentage wise distribution of eroding, accreting and stable shoreline of each state is also given.

**Table 1.** Length of eroding and accreting shoreline and shoreline with no change for the maritime states and union territories of India

| Maritime states and union territories* | Erosion length (km) | Accretion length (km) | Stable length (km) | Total length (km) | Erosion area (ha) | Accretion area (ha) | Net gain/loss* (ha) |
|---|---|---|---|---|---|---|---|
| Gujarat, Daman* and Diu* | 109.7 | 49.2 | 1051.4 | 1210.4 | 313.6 | 207.7 | –105.8 |
| Maharashtra | 75.1 | 60.3 | 588.6 | 724.1 | 104.7 | 209.9 | 105.2 |
| Goa | 21.7 | 7.1 | 116.7 | 145.6 | 28.8 | 13.6 | –15.2 |
| Karnataka | 40.2 | 47.7 | 230.9 | 318.8 | 72.0 | 111.4 | 39.3 |
| Kerala | 137.33 | 121.1 | 327.2 | 585.6 | 285.0 | 303.3 | 18.3 |
| Tamil Nadu and Puducherry* | 128.9 | 188.6 | 531.6 | 849.0 | 358.3 | 470.7 | 112.3 |
| Andhra Pradesh | 188.9 | 208.1 | 413.3 | 810.4 | 795.7 | 807.9 | 12.2 |
| Odisha | 143.6 | 98.8 | 208.2 | 450.6 | 831.3 | 753.5 | –77.8 |
| West Bengal | 56.3 | 33.9 | 67.2 | 157.4 | 393.7 | 141.2 | –252.5 |
| Lakshadweep Islands* | 11.6 | 13.1 | 115.8 | 140.6 | 16.6 | 18.4 | 1.81 |
| Andaman and Nicobar Islands* | 230.8 | 256.3 | 1669.7 | 2156.8 | 480.1 | 1004.0 | 523.9 |
| Total | 1144.3 | 1084.3 | 5320.7 | 7549.3 | 3679.91 | 4041.63 | 361.72 |

*Negative value indicates loss.

eroding coast at Vadanapally, Thrissur district, Kerala. Erosion in Kerala has multitude of reasons; high monsoonal waves[15], coastal constructions[16] and sand mining. Coastal erosion along TN is higher in the southern districts and the Kaveri delta region. Coastal structures influence shoreline modifications[17], where the Puducherry coast experiences severe coastal erosion (Figure 3 *c*). Shoreline changes along the AP coast are maximum in the Krishna–Godavari deltaic region, where sediment retention by the dams significantly influences erosion[18]. Uppada, located to the north of Kakinada spit, is severely affected by coastal erosion, mainly because of high northward longshore sediment transport[19] and deficiency of sediments from the south due to deposition at the Hope Island (Figure 4 *a*).

Erosion in Odisha is mainly along the Mahanadi–Dhamra deltaic region. The coastal stretch from Pentha to Bhitarkanika spit is the longest eroding shoreline which has a length of 33 km. The severe erosion at Pentha is reported as the result of interaction between the discharges from the adjacent rivers and tidal flow[20] (Figure 4 *b*). The inlet/river mouth along the Odisha coast has shifted significantly, leading to erosion/accretion to the banks of the mouths. WB has the least percentage of stable shoreline where wave exposure and high tidal currents, along with sediment deprivation and low-lying characteristics, have made the entire coastal stretch vulnerable to erosion[21]. Sagar Island is subjected to severe erosion that has a possible impact from the combined action of waves and strong currents from the river[22] (Figure 5 *a*). The Lakshadweep Islands are predominantly influenced by strong monsoonal wave energy[23]. These

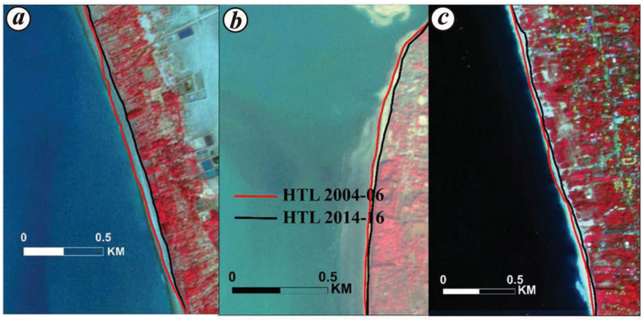


**Figure 2.** Erosional hotspots: (***a***) beach to the south of Dandi, Navasari district, Gujarat; (***b***) Navapur, Palghar district, Maharashtra and (***c***) Condolim, North Goa district, Goa.

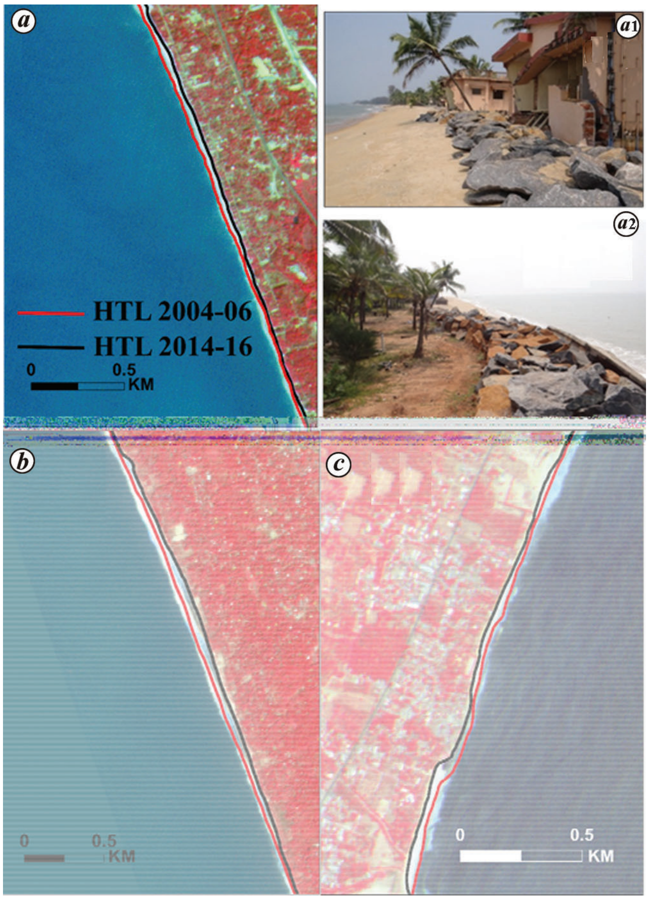


**Figure 3.** Erosional hotspots: (***a***) Someshwara, Dakshina Kannada district, Karnataka; (***b***) Vadanapally, Thrissur district, Kerala and (***c***) beach at Puducherry. (***a***1), (***a***2) Field photographs of eroding coast at Someshwara.

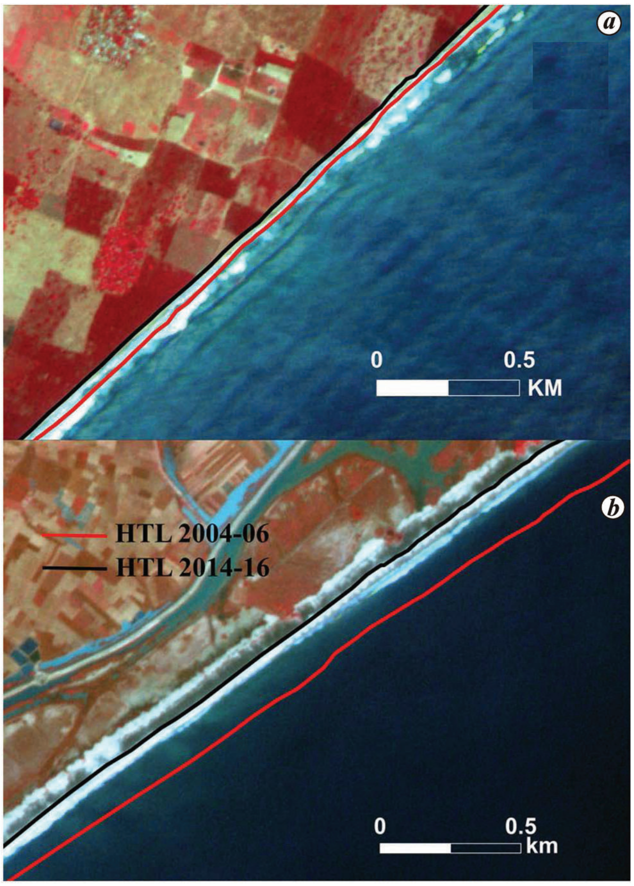


**Figure 4.** Erosional hotspots: (***a***) Uppada, East Godavari district, Andhra Pradesh and (***b***) Pentha, Kendrapara district, Odisha.

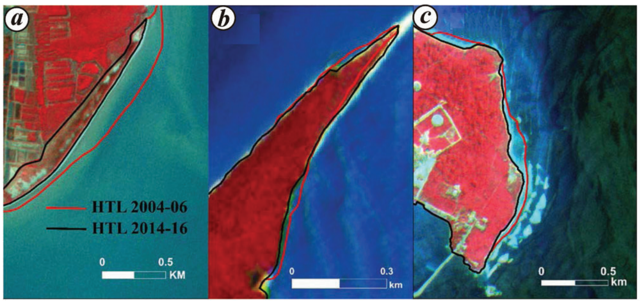


**Figure 5.** Erosional hotspots: (***a***) Sagar Island, South 24 Parganas district, West Bengal; (***b***) Suheli Cheriyakara Island, Kavaratti sub-district, Lakshadweep Islands and (***c***) Campbell Bay, Nicobar district, Andaman and Nicobar Islands.

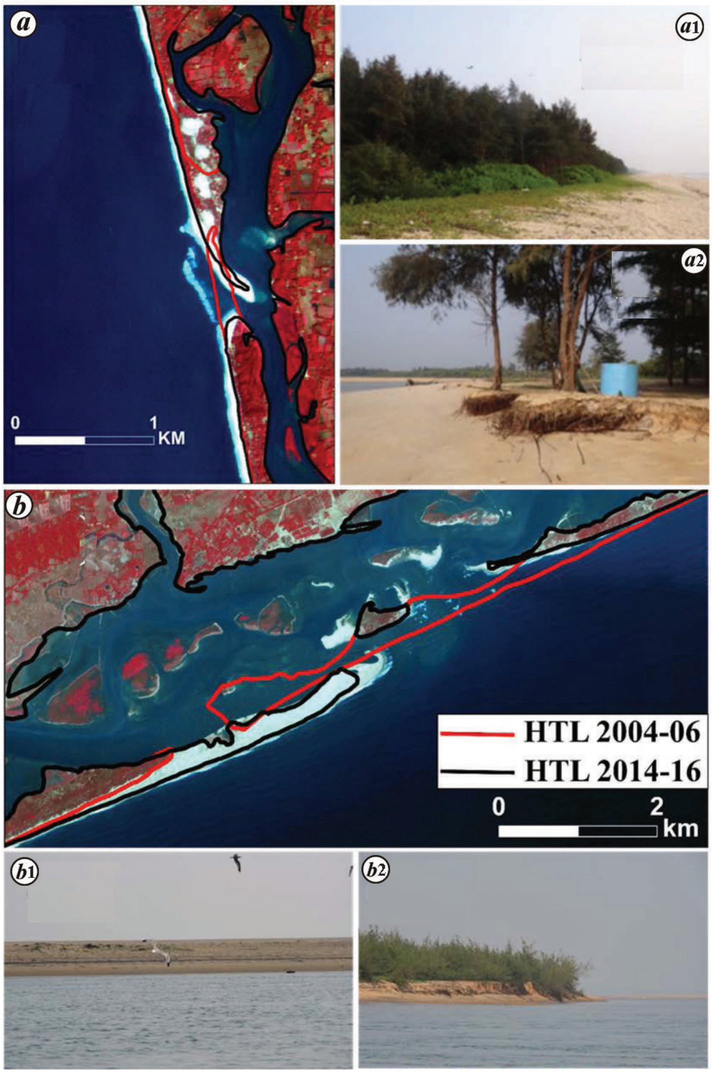


**Figure 6.** Shoreline changes associated with inlet shift at (***a***) Mulki-Pavanje estuary, Karnataka (Field photographs of (***a***1) accreting northern spit and (***a***2) eroding southern bank). ***b***, Chilika inlet, Odisha (Field photographs of (***b***1) accretion of the southern spit and (***b***2) erosion at the northern bank).

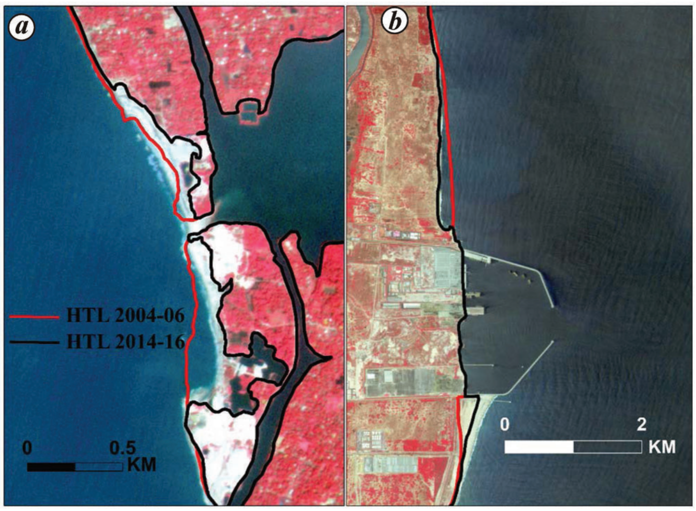


**Figure 7.** Shoreline changes associated with anthropogenic influences at (***a***) Alappadu, Kerala and (***b***) Ennore Port, Tamil Nadu.

islands are mostly exposed to the open ocean on one side and protected by a coral lagoon on the other. Figure 5 *b* shows the shift in the spit at Cheriyakara Island. The North and Middle Andaman districts of the AN Islands have an accreting shoreline, while erosion dominates in the South Andaman and Nicobar district. The 2004 earthquake resulted in coastal subsidence to the south of the AN Islands, and the coast has uplifted to the northern parts of the Island, resulting in significant changes in the coastal ecosystem[24]. Figure 5 *c* shows the shoreline changes at Campbell Bay of Nicobar Island, which was devastated due to the tsunami of 2004.

### *Coastal processes and shoreline change dynamics*

Coastal erosion is an outcome of the force exerted by waves, tides, and associated alongshore sediment transport. At river mouths, additional inputs from the river induce an alongshore shift in inlets/mouths, which is maximum at Mulki-Pavanje estuary, Karnataka and Chilika inlet, Odisha (Figure 6 *a* and *b*). The northern spit at Mulki-Pavanje estuary has grown 1 km southwards (Figure 6 *a*1), while the southern bank has eroded 0.75 km (Figure 6 *a*2). At the Chilika mouth, the southern spit has grown 2 km northwards (Figure 6 *b*1) and around 4 km of the northern bank has eroded (Figure 6 *b*2). Littoral drift near the Chilika mouth is northward and peaks during the southwest monsoon[25], while longshore sediment transport direction near Mulki-Pavange varies seasonally, with a net southward sediment transport[26].

Beach sand mining for rare earth minerals and land reclamation for development activities can extensively change the coastal geomorphology leading to undesirable shoreline changes. Figure 7 *a* shows the large-scale sand mining at Alappadu coast, Kerala and the associated coastal erosion. The natural movement of longshore sediment transport is hindered by coastal construction like breakwaters and groins that have induced high erosion of the coast to the leeward side of the sediment transport. Figure 7 *b* shows the shoreline changes at Ennore Port, TN. Siltation and erosion are major issues along the shoreline harbours of the eastern Indian coast[27]. Negative net sediment transport is observed along the northern beaches of the Ennore Port, while the southern beaches show positive net sediment transport values[28]. The AN Islands show large-scale shoreline changes; purportedly, the coast might be regaining shoreline equilibrium after the critical shoreline changes occurred due to the subsidence, uplift and tsunami during the 2004 earthquake. Mudbanks and their associated dynamics greatly influence the shoreline changes along the Kerala coast[29].

Albeit the eroding coastal length is more than the accreting coast, the area of accretion is estimated to be more than the area of erosion. Long-term shoreline changes are mainly induced by longshore sediment transport. Eroding shorelines are mostly accompanied by an adjacent accreting coast. Uppada, AP and Pentha, Odisha are examples where the coast is eroding severely with adjacent accreting spit. Along the shoreline with coastal constructions like breakwaters, the accretions at the windward side of the longshore drift are generally restricted to a shorter length of the coastal stretch, while a long stretch of shoreline is observed to erode to the leeward side. Moreover, the accreted area is usually large, near the breakwater, whereas the erosion, in general, is affected in smaller areas along a longer shoreline.

Inventory of the shoreline change analysis contributes towards a proper understanding of the shoreline dynamics of the Indian coastal regions. As mentioned, the western coast is more stable compared to the eastern coast. The rocky coastal stretches of Saurashtra, Maharashtra, Goa, and northern Karnataka make the coast stable in comparison to the deltaic coastal environment of AP, Odisha and WB. The southern swells are stronger along the coast of Karnataka, Kerala and TN, which makes the coastal regions more susceptible to shoreline changes.

## Conclusion

The Indian shoreline is subjected to coastal erosion and accretion under various natural and anthropogenic influences. An inventory of shoreline changes is prepared that classifies the shoreline into accreting, eroding and stable. The shoreline changes are analysed using the HTL of 2004–06 and 2014–16 time frames. The results show that around 1144 km of the Indian shoreline is eroding, about 15% of the total shoreline, and 3680 ha of the coastal land area has been eroded. However, 4042 ha of the coastal area has accreted within this time-period, leading to a net gain in the coastal regions. The deltaic and open sandy beaches of the east coast are more dynamic compared to the rocky and cliff beaches of the west coast. The shoreline dynamics is more along WB, while on the west coast, Kerala shows significant shoreline dynamics.

As coastal erosion is a serious threat to both the ecology and economy of the country, the shoreline change inventory will serve as the primary information required for planning coastal development activities. The *Shoreline Change Atlas* depicts changes in the shoreline, and planning should also encompass the assessment of shoreline changes anticipated under a climate change scenario.

1. Bamunawala, J. *et al.*, Twenty-first-century projections of shoreline change along inlet-interrupted coastlines. *Sci. Rep.*, 2021, **11**, 14038.
2. Leatherman, S. P., Zhang, K. and Douglas, B. C., Sea level rise shown to drive coastal erosion. *EOS*, 2000, **81**, 55–57.
3. Voudoukas, M., Ranasinghe, R., Mentaschi, L., Plomaritis, T., Athanasiou, P., Luijendik, A. and Feyen, L., Sandy coastlines under threat of erosion. *Nature Climate Change*, 2020, **10**, 260–263.
4. Mentaschi, L., Voudoukas, M., Pekel, J. F., Voudoukas, E. and Feyen, L., Global long-term observations of coastal erosion and accretion. *Sci. Rep.*, 2018, **8**, 12876.
5. Luijendjk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G. and Aarnikhof, S., The state of the world's beaches. *Sci. Rep.*, 2018, **8**, 6641.

6. Merkens, J. L., Reimann, L., Hinkel, J. and Vafeidis, A., Gridded population projections for the coastal zone under the shared socio-economics pathways. *Global Planet. Change*, 2016, **145**, 57–66.
7. Martinez, M. L., Intralawan, A., Vazquez, G., Maqueo, O., Sutton, P. and Landgrave, R., The coasts of our world: ecological, economic and social importance. *Ecol. Econ*., 2007, **63**, 254–272.
8. Rajawat, A. S. *et al*., Assessment of coastal erosion along the Indian coast on 1 : 25,000 scale using satellite data of 1989–91 and 2004–06 time frames. *Curr. Sci.*, 2015, **109**, 347–354.
9. Boak, E. H. and Turner, I., Shoreline definition and detection: a review. *J. Coast. Res*., 2005, **2**, 688–703.
10. NCSCM, *Manual on Demarcation of High Tide Line and Low Tide Line and Preparation of CZMP of the Coast of India*, National Centre for Sustainable Coastal Management Technical Report Series, 2015, 23B, pp. 4–14.
11. National Natural Resources Management System, NNRMS standards, a national standard for EO images, thematic and cartographic maps, GIS database and spatial outputs, NNRMS, Indian Space Research Organization, 2005, TR 112, pp. 5–44.
12. Mahapatra, M., Ratheesh, R. and Rajawat, A. S., Shoreline change analysis along the coast of South Gujarat, India, using digital shoreline analysis system. *J. Indian Soc. Remote Sensing*, 2014, **42**, 869–876.
13. Manimurali, R., Babu, M., Mascarenhas, A., Chaoudhary, R., Sudheesh, K. and Vethamony, P., Coastal erosion triggered by a shipwreck along the coast of Goa, India. *Curr. Sci.*, 2013, **105**, 990–996.
14. Shetty, A. and Kayappa, K., Seasonal variation in longshore sediment transport and its impact on sediment budget along the wave-dominated Karnataka coast, India. *J. Earth. Syst. Sci.*, 2020, **234**.
15. Kurian, N., Rajith, K., Shahul, H., Nair, S., Murthy, R., Arjun, S. and Shamji, V., Wind waves and sediment transport regime off the south-central Kerala coast, India. *Nat. Hazards*, 2009, **49**, 325–345.
16. Noujas, V. and Thomas, K., Erosion hotspots along southwest coast of India. *Aquat. Procedia*, 2015, **4**, 548–555.
17. Muthusankar, G., Jonathan, M., Lashumanan, C., Roy, P. and Raju, K., Coastal erosion vs man-made protective structures: evaluating a two-decade history from southeastern India. *Nat. Hazards*, 2017, **85**, 637–647.
18. Rao, K. N., Subraelu, P., Kumar, K. Ch. V., Demudu, G., Malini, H., Rajawat, A. S. and Ajai, Impacts of sediment retention by dams on delta shoreline recession: evidences from Krishna and Godavari deltas, India. *Earth Surf. Process. Landf.*, 2010, **35**, 817–827.
19. Raju, N., Kumar, A., Gowthaman, R., Kumar, S. and Kumar, J., Coastal processes along north Kakinada coast, Andhra Pradesh based on short-term study. Technical Report, NIO/TR-02/2004, National Institute of Oceanography, Goa, 2004.
20. Nishold, S. S. P., Sundaravadivelu, R. and Saha, N., Physical model study on geo-tube with gabion boxes for the application of coastal protection. *Arab. J. Geosci.*, 2019, **164**, 1–11.
21. Paul, S. and Das, C., Delineating the coastal vulnerability using coastal hazard wheel: a study of West Bengal coast, India. *Reg. Stud. Mar. Sci.*, 2021, **44**, 101794.
22. Mondal, I., Thakur, S., Juliev, M., Bandyopadhyay, J. and Kumar, T., Spatio-temporal modelling of shoreline migration in Sagar Island, West Bengal, India. *J. Coast. Conserv*., 2020, **50**, 1–20.
23. Suganya, G., Deepika, B., Madhumitha, R., Rajakumari, S., Purvaja, R. and Ramesh, R., Planform island changes assessment for inhabited Lakshadweep Islands. *Nat. Hazards*, 2019, **98**, 735–750.
24. Ratheesh, R., Gladston, Y., Kumar, L. K., Rajput, P., Murali, R. and Rajawat, A. S., Impact of 2004 co-seismic coastal uplift on the mangrove cover along the North Andaman islands. *Reg. Environ. Change*, 2020, **6**.
25. Pradhan, S., Mishra, S., Baral, R., Samal, R. N. and Mohanty, P., Alongshore sediment transport near tidal inlets of Chilika Lagoon: east coast of India. *Mar. Geodyn.*, 2017, **40**, 187–203; doi:10.1080/01490419.2017.1299059.
26. Shetty, A. and Jayappa, K., Seasonal variation in longshore sediment transport rate and its impact on sediment budget along the wave-dominated Karnataka coast, India. *J. Earth Syst. Sci.*, 2020, **129**, 234.
27. Sarma, K. G. S., Siltation and coastal erosion at shoreline harbours. *Procedia Eng*., 2015, **116**, 12–19.
28. Rao, V., Murthy, M. V., Bhat, M. and Reddy, N., Littoral sediment transport and shoreline changes along Ennore on the southeast coast of India: field observations and numerical modeling. *Geomorphology*, 2009, **112**, 158–166.
29. Noujas, V., Thomas, K. and Badrees, K., Shoreline management plan for a mudbank dominated coast. *Ocean Eng.*, 2016, **112**.

ACKNOWLEDGEMENTS. We thank N. M. Desai (Director, SAC, ISRO, Ahmedabad) and Dr Raj Kumar (Director, NRSC, Hyderabad) for support. We also thank Dr Haldar (Chairman, CWC) for his interest in monitoring the project activity; Dr I. M. Bahuguna and Dr R. P. Singh (SAC) for coordinating the atlas preparation, and the Chairman and members of CPDAC, CWC and the Director, Coastal Management, CWC for support.

Received 19 April 2022; revised accepted 21 November 2022

doi: 10.18520/cs/v124/i5/578-584