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Spit Evolution and Shoreline Changes Along Manamelkudi Coast Using Geo-Spatial Techniques and Statistical Approach

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Abstract: The historical shoreline changes from 1980 to 2020 along the Manamelkudi coast is studied using toposheet, satellite time-series Landsat data, and observed data. An attempt is made to recognise possible factors which are responsible for shoreline changes and spit growth at south Manamelkudi coast (Palk Strait), Eastern part of Pudukkottai district, Tamilnadu. During 1980–2020, the regions showed distinct spatio-temporal variability, which is discussed in relation to spit evolution and shoreline changes. The study also generated a long-term (1980-2020) shoreline change statistics (EPR, LRR, SCE and NSM, WLR) using the Digital Shoreline Analysis System (DSAS) at every 150 m interval for the Manamelkudi coast covering 42 km, identified the erosion and accretion and divide the shoreline into different classes of erosion and accretion. Identified lengths of shoreline with high erosion, low erosion, stable, low accretion and high accretion are, respectively, based on LRR. The results indicate that spit evolution is predominant along the Manamelkudi coast, with the highest percentage of erosion and accretion.

Keywords: Spit; Shoreline change; DSAS; Manamelkudi coast; Erosion; Accretion.

Introduction

The shoreline is one of the best indicators of erosion/accretion pattern and environmental change (Morton, 1996) along the coast, and is an easily understood feature representing the historical movement of the Sea. Coastal zones are socially and economically growing areas that are inhabited by millions of people. These zones are affected by the coastal accretion, erosion, sediment transportation, sediment redistribution, environmental intervention, human intervention, and coastal evolution modification on long- and short-term scales (Boak and Turner, 2005; Shetty et al., 2019; Vousdoukas et al., 2020). The coastal geomorphological zone of southern Tamilnadu is composed of various depositional and erosional land features such as beaches, spits, mudflats, sand dunes, sea caves, wave cut platforms and marine terraces. The evolution of many spits can also be modified or even halted by the presence of nearby artificial structures (Teodoro and Gonçalves, 2011, 2012). Marine scientists around the world are particularly concerned about the morphological processes of the sand spits because they influence the socio-economic development such as flood control, environmental issues, saline intrusion and channel accretion (Pradhan et al., 2015). Spits are unique natural

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environments whose evolution is linked to the adjacent coast and near shore morphology, sediment supply, coastal dynamics and sea-level change. Sand spits often appear in many places, for example at estuaries, bay mouths and lagoons around the world, with different shapes, dimensions and dynamics (Escudero et al., 2019). This becomes a major social, economic and environmental concern to a large number of countries along the coast, where it poses a serious problem to the environment and human settlements (Becker et al., 2012; Adarsa et al., 2013). The Eustatic sea level rise due to global warming is predicted to be about 42 to 98 cm by 2100 (IPCC, 2013) which necessitates the identification and protection of vulnerable sections of coasts (Siva Sankari et al., 2015). After the Indian Ocean tsunami (26 December, 2004), different morphological changes and variations in sea level were frequently observed along this coastal area. The recent Indian Ocean Tsunami induced sudden erosion dissimilar to seasonal variations along the southeast coast of India (Chandrasekar and Immanuel, 2005; Mujabar and Chandrasekar, 2011). Spits are highly mobile coastal land forms that respond rapidly to environmental change. They, therefore, represent a signature of past environmental change and provide a landform indicator of climate change.

The examination of geomorphological peculiarities and geological structure of large barrier accumulative features promotes the reconstruction of the evolution of the entire coastline. Previous research has shown the general identity instructors of many linearly extended marine features; this identity is seen in the longitudinal zonal situation of their principal geomorphological elements with respect to the shore. Spits are very dynamic coastal features steered by the complex formation and evolution processes. Many processes involved in their evolution and, in many cases, the lack of reliable historical data, especially in relation to the associated submerged domain, hamper our understanding. We conjecture that spits are formed under the influence of two main processes: wave induced along and cross-shore sediment transport (Leatherman, 1979; Kongeswaran and Karikalan, 2016). Like other barrier systems, spits have a subaqueous platform and a sub-aerial environment consisting of beach, dune, and marsh deposits (Ollerhead and Davidson-Arnott, 1995). Spits are the prominent coastal geomorphic systems, shaped by accretion of sediments and occur when alongshore drift reaches a section of the headland. The morphology (location, shape and size) of spits is controlled by several factors such as longshore drift (Johnson, 1925). Globally, qualitative and quantitative analysis of shoreline evolution is helpful to predict the future positions of the shoreline to relieve the impact of forthcoming disintegration processes that have gained prominence by several authors (Addo et al., 2008, 2012; Fan et al., 2018; Ciritci and Turk, 2020). These studies elucidated that integrating GIS and DSAS can be effectively used to assess temporal shoreline evolution. The accuracy of shoreline change rate estimation reflects actual changes and the prediction of future changes depends on several factors, such as the accuracy in shoreline position data, variability of the shoreline movement, and a number of measured shoreline data points (Kumar et al., 2010). In the present study, an attempt has been made to evaluate the morphological changes of Manamelkudi spit using ancillary data, satellite image analysis and statistical techniques. Quantitative estimations, in terms of size and the areal extent of the spits, have been carried out to understand the dynamics and factors responsible for their formation and evolution elsewhere and have contributed substantially to the modification of the shoreline. The use of remote sensing and GIS for mapping and analyzing shoreline changes over a period of time has gained prominence in recent years as high-resolution satellite data have become readily available (Adegoke et al., 2010). The present study is to understand the historical shoreline change along the Manamelkudi coast from 1980 to 2020, to examine the coastal spit evolution and shoreline changes with help of the satellite data to generate long-term (1980-2020) shoreline change statistics (EPR, LRR, SCE and NSM) at every 100 m interval for the Manamelkudi coast covering 42 km stretch and to assess the erosion and accretion.

Study Area

The study area Manamelkudi, Palk Strait is a small coastal village in Aranthangi Taluk of the Pudukkottai district. Manamelkudi is located in the eastern part of the Pudukkottai district in Tamilnadu. Manamelkudi is located along latitude between 10°00′00″ and 10°05′ 00″ and longitude between 79°12′30″ and 79°17′00″. It forms a survey of India toposheet number 58N/4 of 1:50,000 scale. Pudukkottai District is bounded on the northeast and east by Thanjavur District, on the southeast by the Palk Strait, on the Southwest by the Ramanathapuram and Sivaganga districts and Northwest by Tiruchirappalli. Pudukkottai District is well endowed with natural resources of land and sea, bounded by the marine hedge of the Bay of Bengal in the east and conjoined by the southern districts viz, Trichy, Sivaganga, Ramanathapuram and Thanjavur. Coastal length of Pudukkottai district is 42 kms. The northern limit of the Palk Strait is formed by the low-lying coast between Vedaranniyam and allows point to project east near Manamelkudi. The depositional features are identified as the occurrence of spits, beach and progradation of the Manamelkudi coastline (Figure 1). The enlargement of Manamelkudi sand spit and the emergence of sand banks between Point Calimere and Point Pedro (Sri Lanka) across the entrance of the Palk Bay, are the evidence of the depositional features occurring in this region (Kumaraguru et al., 2008). Palk Strait is bounded by Sri Lanka on the east, by Mannar Island and Pamban Island on the south and by the coastal district of Tamil Nadu state on the west. The Palk Strait covers the four coastal districts of Tamil Nadu namely Ramanathapuram, Pudukkottai, Thanjavur and Nagapattinam.

Palk Strait is a relatively shallow strait between the Tamil Nadu state of India and the Mannar district of the island nation of Sri Lanka. The Palk Strait connects the Bay of Bengal in the northeast with the Palk Bay.

Data and Methods

Datasets

In order to investigate the shoreline changes along the Manamelkudi coast, Survey of India (SOI) toposheet 58N/4 (1978), time series satellite data (1980–2020) and observed shoreline data were used (Table 1). Multi resolution Landsat (ETM+ and TM) satellite data with 20% cloud cover were acquired from USGS (https://earthexplorer.usgs.gov/) as the images are provided by USGS at no cost. The details about data acquisition

Table 1: Satellite image and acquisition year

Satellite data & sensor	*Year of pass*	*Spatial resolution*	*Producer*	*Product scale*
LANDSAT (MSS)	1980	83 m	USGS	1:50,000
LANDSAT (MSS & TM)	1990	30 m	USGS	
LANDSAT (MSS, TM&ETM+)	2000	30 m	USGS	
LANDSAT (MSS, TM&ETM+)	2010	30 m	USGS	
LANDSAT (MSS, TM&ETM+)	2015	30 m	USGS	
LANDSAT (MSS, TM, ETM+&OLI)	2020	30 m	USGS	

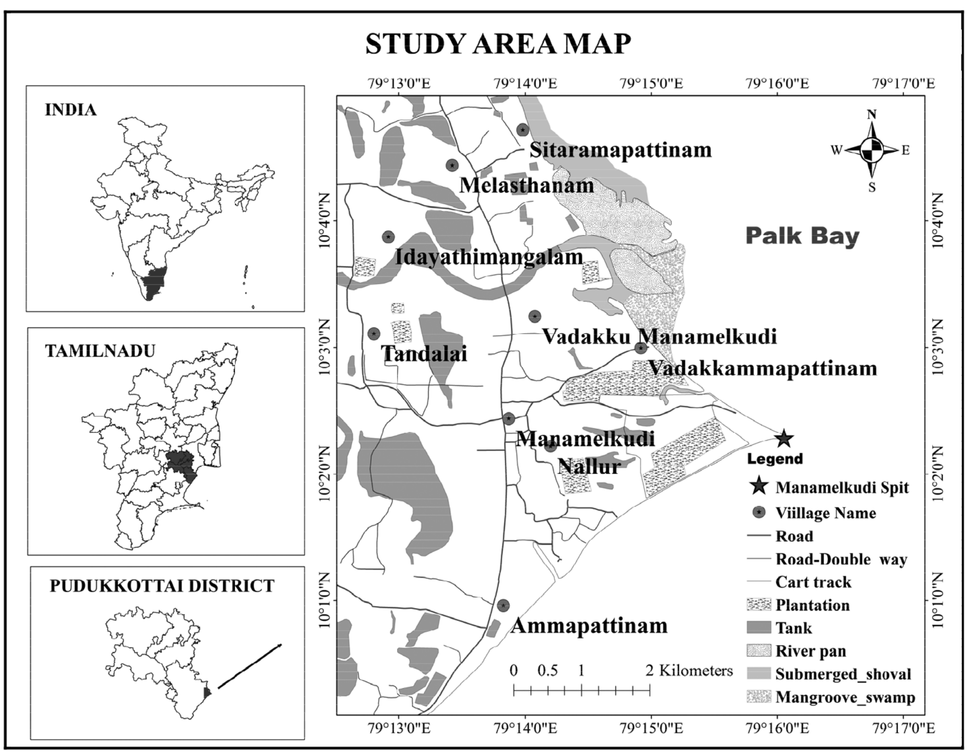

Figure 1: Map showing the location of study area.

and their sources are listed in Table 1. The Landsat data period mostly included the dry season in the study region in order to get cloud-free satellite data. Observed data for the dry season are also used for a coherent data analysis and a comparative study dataset indicates their acquisition during low tide time, which is also the case during observation.

Methods

Figure 2 depicts the schematics of the detailed methods followed for shoreline change analysis. The satellite images are ortho-rectified with projection UTM 44 N and datum WGS 84. SOI toposheet 58N/4 (1:50,000 scale) was used as the base map for the study. On-screen digitization of the shorelines for each data was performed. The highest high tide line is considered the shoreline indicator for toposheet /satellite data.

DSAS Statistics

Shoreline changes along the Manamelkudi coast were evaluated using Digital Shoreline Analysis System (DSAS) version 5.0 Developed by USGS. DSAS is add-on software, which works under the ArcGIS platform of ESRI that enables a user to calculate rate of change statistics from multiple historical shoreline positions.

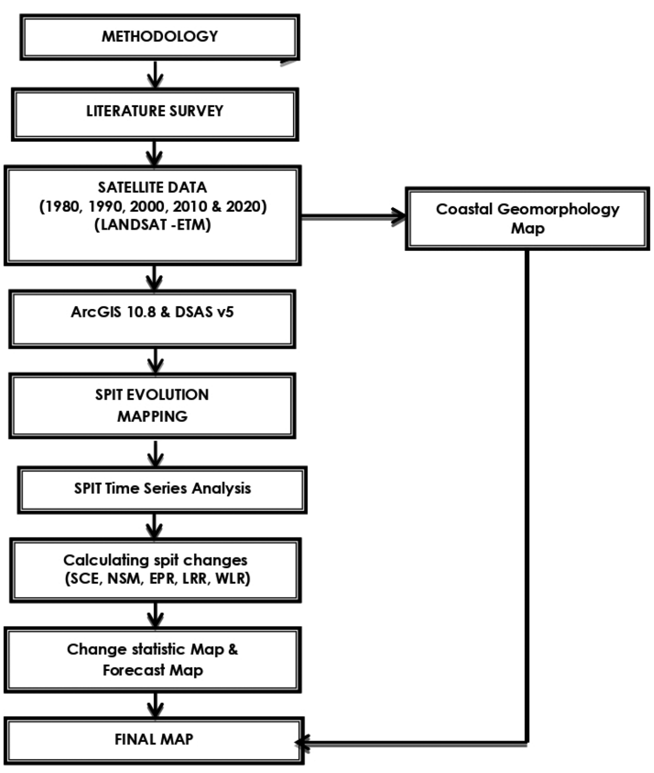

Figure 2: Flow chart showing the methodology of the study area.

It provides an automated method for establishing measurement locations, performs rate calculations, provides the statistical data necessary to assess the robustness of the rates, and includes a beta model of shoreline forecasting with the option to generate 10 and/ or 20-year shoreline horizons and uncertainty bands. A user-friendly interface guides the user through the major steps of shoreline change analysis (Aaid et al., 2020). A pre-created reference baseline onshore and the extracted shorelines were imported to a personal geodatabase. The shoreline from Manamelkudi is taken into account for shoreline calculation. In total, 241 transects were generated with 150 m. The Landsat ETM data map is registered in the GIS environment and the shoreline of 1980 was digitized to buffer 150 m in ArcGIS10.8. It was issued as a base line in Digital Shoreline Analysis System (DSAS v5) (Thieler et al., 2009). To assess the shoreline changes for the past decades from 1980 to 2020 using various satellite data. The statistical parameters of shoreline changes such as End Point Rate (EPR), Linear Regression Rate (LRR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE) were computed in DSAS. SCE is defined as a measure of the total change (Ciritc and Turk, 2019) and represents the distance between the nearest and farthest shorelines with respect to the baseline for each transect without any relationship to time period. NSM value considers the distance between the oldest and newest shorelines (Oyedotun et al., 2014; Burnigham and French, 2017; Kongeswaran and Karikalan, 2021). The NSM value indicates in which direction and how much net shoreline movement are relative to the baseline, while SCE represents the largest distance between all shorelines intersecting with a given section. SCE is always positive since there is no indication of the total distance between the two shorelines. EPR is the ratio of net shoreline movement to the time elapsed between the oldest and the most recent shoreline (Raj et al., 2019). The EPR method provides a short-term analysis of the shoreline by considering the youngest and oldest shorelines. The LRR method is a measure of the linear regression rate of change statistics by fitting the least square regression line to all shoreline points for a particular transect. The LRR method has several features and a number of advantages. It uses all the available data sets and allows highlighting the long-term evolutionary trend of the shoreline. EPR and LRR represent the rate of change of shoreline which shows almost similar results (Barik et al., 2019), and hence in the present study, the shoreline change rate has been computed using both the methods and the values have been compared by determining the correlation between the two methods, which indicate a 99% significance level. The shoreline change rate obtained using EPR and LRR were classified into five categories (Velsamy et al., 2020; Mahapatra et al., 2014). The five categories are High erosion: –4 m/yr, Low erosion: –4 to –1 m/yr, Stable: –1 to 1 m/yr, Low accretion: 1 to 4 m/yr, High accretion: 4 m/yr.

Uncertainty

Several factors such as tidal condition, error during digitisation and geo-rectifications have impacts on the accuracy of the shoreline position delineation. Hence, the uncertainty in shoreline position was estimated (Rooney et al., 2003; Fletcher et al., 2003; Genz et al., 2007; Romine et al., 2012). The total uncertainties (Ut) in shoreline position can be evaluated by using the equation:

$$U_t = \pm\sqrt{E_s^2 + E_t^2 + E_p^2 + E_r^2 + E_d^2 + E_{ts}^2}$$

where Es represents the seasonal error associated with shoreline change in response to near shore processes (Fletcher et al., 2012). In the present study, all the images are considered for the dry period. Hence, there is no such seasonal activity on shoreline positions and Es is not considered. Et represents the tidal calculation error from the horizontal movement in shoreline position due to tidal variation during both tidal phases (Fletcher et al., 2012). Ep is the spatial resolution of the satellites. The satellite images (Landsat and IRS P6) are provided as rectified, and hence, geo-rectification error (Er) is not considered. The digitization error (Ed) is the error that occurs during digitisation of shoreline positions. Ets is the toposheet plotting error and includes measured distance and planet-able plotting (Fletcher et al., 2012).

Results and Discussion

The shoreline of the study area has been detected from multi-temporal satellite imageries of different years (1980, 1990, 2000, 2010 and 2020). SCE, NSM, EPR, LRR and WLR change rate methods are used here. In all, five shoreline positions were extracted for change detection. The change rates were calculated for every period between 1980-2020. The results shown in Table 2 provides the change rate statistics of the 241 transects from the north to south. Maximum erosion of 827.3 m was found during 1990-2000 and maximum accretion of 805.2 m was found during 2000-2010. Overall shoreline changed between 1980-2020, the maximum erosion rate is -3.85 m and accretion is 846.03 m. Where negative values represent erosion and positive values represent accretion. The minimum, maximum and average change rates for different dates are illustrated in Table 2. The average rate is -84.20 m for erosion and 269.6 m for accretion. The minimum rate is -298.2 m for erosion and 4.2 m for accretion (Figure 3).

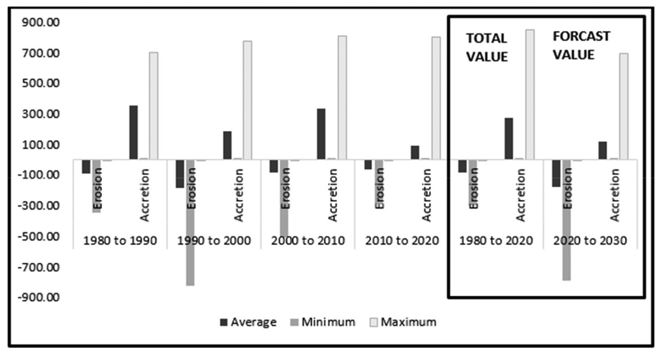

Figure 3: Bar chart of erosional and accretion transects in the study period between years of 1980-2020 and forecast value between years of 2020-2030.

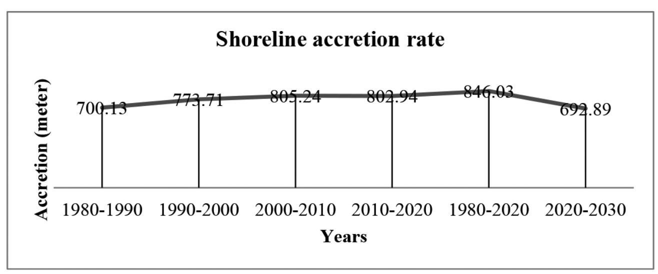

Figure 4: Shoreline accretion rate (in meter).

Table 2: Shoreline fluctuation with distances from 1980 to 2020

Max/Min/Ave	*1980 to 1990*	*1990 to 2000*	*2000 to 2010*	*2010 to 2020*	*1980 to 2020*	*2020 to 2030*
Minimum	-347.14	-827.36	-511.74	-292.82	-298.92	-790.77
Average	-91.85	-183.06	-84.43	-62.92	-84.2	-177.83
Maximum	700.13	773.71	805.24	802.94	846.03	692.89

Note: Negative values indicate erosion, while positive ones indicate accretion in meters.

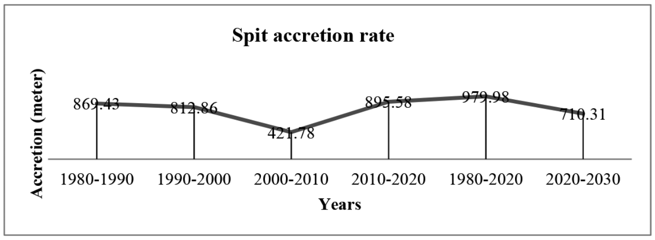

Figure 5: Spit accretion rate (in meter).

Shoreline Change Rate (SCE, NSM, EPR, LRR and WLR)

Table 4 indicates the rate of shoreline change using SCE, NSM, EPR, LRR and WLR. It is observed that overall erosion and accretion. A shoreline change map is used for coastal zone management authorities and coastal engineers in the regulation of coastal zones (Mageswaran et al., 2015; Kongeswaran and Karikalan, 2019). The shoreline distance and statistics was predicted between 2020 and 2030. The prediction results were used to calculate the maximum accretion along the shoreline, which will be 692 m, whereas erosion of 790 m will be as estimated in the study area. The spatial pattern of the predicted shoreline changes is illustrated in Figure 6. The maps show that the southern coastal stretch will face severe erosion and accretion. A similar study was conducted by Shanmugam et al. (2014) from Puducherry to Villupuram coast reports high erosion from 1984 to 2014, which was caused by the construction of the port and other related human activities. As reported by the Natesan et al. (2013), the Vedaranyam coast is accreting naturally due to the sediment source from the Kodiyakkarai, whereas the Kodiakkarai coast is faced with high erosion. Another study by Natesan et al. (2015) and Thangaraj and Karthikeyan (2021) confirm that the beach ridge occurrences with continuous sediment supply from the adjacent rivers along the Vedaranyam coast indicate the pro-grading of shoreline in the seaward direction. The other reason for the development of Point Calimere spit may be due to the fact that the littoral current has changed which was reported after the tsunami.

Conclusion

The historical shoreline changes of the Manamelkudi coast for the period 1980–2020 are studied using time series satellite data (1980, 1990, 1995, 2000, 2005, 2010, 2015 and 2020) of Landsat as well as observed data in an ArcGIS platform. Shoreline changes at Manamelkudi coast. Shoreline change statistics namely, end point rate (EPR), linear regression rate (LRR), shoreline change envelope (SCE), and net shoreline movement (NSM) are generated using a digital shoreline analysis system (DSAS) developed by USGS, which works under ArcGIS platform of ESRI. Shoreline change rates have been studied using four different statistics of DSAS due to different important applications of each statistic, discussed in detail under section. However, in this section results on shoreline change rate and erosion/ accretion status of Manamelkudi coast is discussed based on results of LRR due to its important features and advantages. About 241 shores with normal transect 150m spacing are generated to compute the shoreline changes on the Manamelkudi coast. Manamelkudi coast between 1980, 1990, 2000, 2010 and 2020, the dynamic shoreline is found to be 30 km. Maximum erosion has

Table 3: Spit fluctuation with distances from 1980 to 2020

Max/Min/Ave	*1980 to 1990*	*1990 to 2000*	*2000 to 2010*	*2010 to 2020*	*1980 to 2020*	*2020 to 2030*
Minimum	-275.59	-869.44	-670.51	-577.84	-256.50	-795.59
Average	296.93	-28.29	-124.36	158.87	361.74	-42.64
Maximum	869.44	812.86	421.79	895.59	979.98	710.31

Note: Negative values indicate erosion, while positive ones indicate accretion in meters.

Table 4: Shoreline change statistics from 1980 to 2020

Max/Min/Ave	*1980-2020*				
	SCE	*NSM*	*EPR*	*LRR*	*WLR*
Minimum	0	-728.89	-23.06	-12.5	-12.5
Average	208.7272	-13.4051	-0.06336	-0.25477	-0.25477
Maximum	831.24	788.16	107.58	17.38	17.38

Note: Negative values indicate erosion, while positive ones indicate accretion in meters

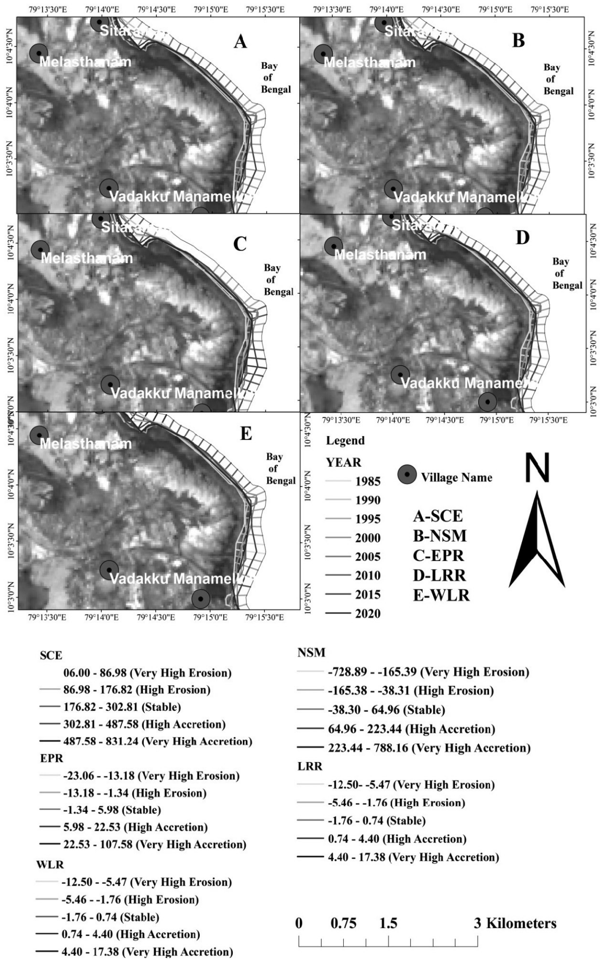

Figure 6: Shoreline changes map (SCE, NSM, EPR, LRR & WLR) in various years.

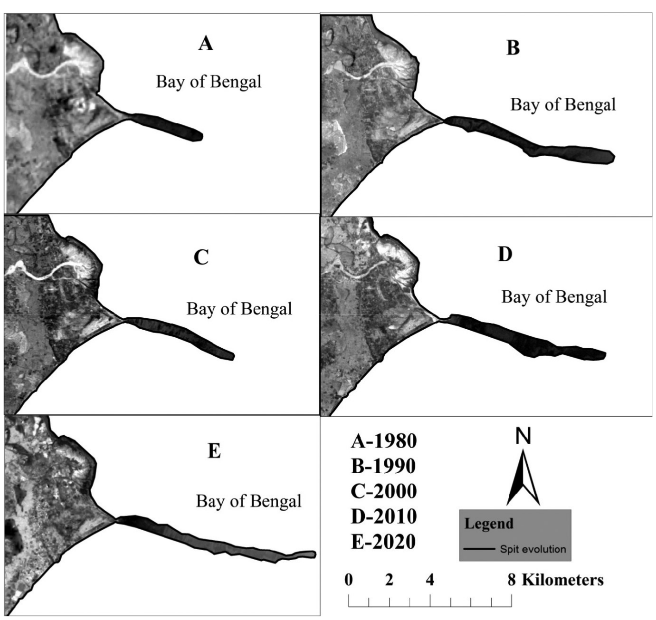

Figure 7: Spit evolution year wise images.

been observed during the year 1990 to 2000 and is about 1.30 m and Maximum accretion is 805.24 m in the period of 2000 to 2010 at different transects. In the year between 1980-2020, spit evolution was maximum accretion observed at 895.51 m (2010-2020) (Table 3). Due to the 2004 south Indian ocean tsunami impact, spit was reduced to 421.79 m. Erosion, accretion and stable coastal stretches in Manamelkudi spit evolution were observed (Figures 4 and 5). In the year between 1980 and 2020 shoreline changes in erosion and accretion are -3.85304 and 846.03 m, respectively, at adjacent Manamelkudi. The overall maximum accretions and maximum erosions are computed as 846.03 m and -511.74 m, respectively. Manamelkudi coast acts as the major sedimentation found along the coastline. Shoreline change analysis from field check and GIS analysis as well as DSAS study confirms that Manamelkudi coast is accreting in naturally. The identification of spit evolution in Manamelkudi coast provides the reason for the growth of spit and the results can be used to prepare the coastal zone management maps. Overall, the results based on the Manamelkudi spit growth and shoreline changes were successfully identified (Figure 7). SCE and NSM also corroborate the erosion/accretion pattern observed using EPR/LRR. The study helps to identify distinct shoreline changes along the Manamelkudi coast with significant spatio-temporal variability. The important processes/factors including manmade coastal structures and extreme weather events are the important factors behind the shoreline change and are operating at a highly regional scale. The study, while filling the data gaps on shoreline change. Therefore, it is imperative to undertake future studies with long time series of satellite data at a higher resolution to address some of the complex and region-specific issues and to prepare an appropriate shoreline management plan for the Manamelkudi coast.

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References

Aaid, G., Al-Zubieri, I. and Ghandour, M., 2020. Shoreline evolution between Al Lith and Ras Maha sin on the Red Sea Coast, Saudi Arabia using GIS and DSAS techniques.

Journal of the Indian Society of Remote Sensing, **48(10):** 1455-1470.

Adarsa, J., Arkoprovo, B., Maiti, S. and Bhattacharya, A.K., 2014. Shoreline changes in response to sea level rise along Digha Coast, Eastern India: An analytical approach of remote sensing, GIS and statistical techniques. *Journal of Coastal Conservation,* **18(3):** 145-155.

Adegoke, J.O., Fagbeja, M., James, G., Agbaje, G. and Ologunorisa, T.E., 2010. An assessment of recent changes in the Niger Delta coastline using satellite imagery. *Journal of Sustainable Development,* **3(4):** 277-296.

Avinash, K., Deepika, B. and Jayappa, K.S., 2013. Evolution of spit morphology: A case study using a remote sensing and statistical based approach. *Journal of Coastal Conservation*, **17(3):** 327-337.

Bateman, M.D., McHale, K., Baytun, H.J. and Williams, N., 2020. Understanding historical coastal spit evolution: A case study from Spurn, East Yorkshire, UK. *Earth Surf. Process. Landforms,* **45:** 3670-3686.

Barik, K.K., Annaduari, R., Mohanty, P.C., Mahendra, R.S., Tripathy, J.K. and Mitra, D., 2019. Statistical assessment of long-term shoreline changes along the Odisha Coast. *Indian Journal of Geo Marine Sciences,* **48(12):** 1990-1998.

Becker, M., Meyssignac, B., Letetrel, C., Llovel, W., Cazenave, A. and Delcroix, T., 2012. Sea level variations at Tropical Pacific Islands since 1950. *Global and Planetary Change,* **80-81:** 85-98.

Biswas, A. and Jana A., 2013. Shoreline changes in response to sea level rise along Digha Coast, Eastern India: An analytical approach of remote sensing, GIS and statistical techniques. *Journal of Coastal Conservation,* **18:** 145-155. 10.1007/s11852-013-0297-5

Burningham, H. and French, J., 2017. Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation. *Geomorphology,* **282:** 131-149, doi:10.1016/j.geomorph.2016.12.029.

Chandrasekar, N. and Immanuel, J.L., 2005. GIS supported categorisation of tsunami experienced beaches along the southern east coast of India: Usage in mitigation activities. *In:* Proceedings of the National Seminar on GIS Application in Rural Development, Hyderabad, India.

Ciritci, D. and Turk, T., 2019. Automatic detection of shoreline change by geographical information system (GIS) and remote sensing in the Göksu delta, Turkey. *J. Indian. Soc. Remote Sens.,* **47(2):** 233-243. doi: 10.1007/s12524-019-00947-1

Connell, K.J., Hanson, H., Larson, M. and Kraus, N.C., 2011. Representation of Long-Term Coastal Spit Evolution in the GenCade Model. Paper presented at the ASPBA 2011 National Coastal Conference.

Deigaard, R. and Fredsøe, J., 2005. The shape of equilibrium coastlines. Proceedings of International Coastal Symposium. Innovation Center of East-Iceland, Höfn, Iceland, pp. 134-149.

Escudero, M., Silva, R., Hesp, P.A. and Mendoza, E., 2019. Morphological evolution of the sandspit at Tortugueros Beach. Mexico. *Marine Geology*, **407:** 16-31.

Fisher, R.L., 1955. Cuspate spits of Saint Lawrence Island, Alaska. *J. Geol.,* **63:** 133-142.

Fletcher, C.H., Rooney, J.J., Barbee, M., Lim, S.C. and Richmond, B., 2003. Mapping shoreline change using digital ortho photogrammetry on Maui, Hawaii. *J. Coast. Res.,* **38:** 106-124.

Fletcher, CH., Romine, B.M., Genz, A.S., Barbee, M.M., Dyer, M., Anderon, T.R., Lim, S.C., Vitousek, S., Bochiccino, C. and Richmond, B., 2012. National Assessment of Shoreline Change: Historical Shoreline Change in the, Hawaiian Islands, US Geological Survey Open File Report 2011-1051. US Geological Survey: Reston, VA.

Gandhi, S.M. and Kasilingam, K., 2017. Distribution of benthic foraminifera, sediment characteristics and its environmental conditions in and around Manalmelkudi Spit, Palk Strait, Tamil Nadu, East coast of India. *Indian Journal of Geo-Marine Sciences,* **46(4):** 893-906.

Genz, A.S., Fletcher, C.H., Dunn, R.A., Frazer, L.N. and Rooney, J.J., 2007. The predictive accuracy of shoreline change rate methods and along shore beach variation on Maui, Hawaii. *J. Coast. Res.,* **23(1):** 87-105.

Guilcher, A. and King, C.A.M., 1961. Spits, tombolos and tidal marshes in Connemara and West Kerry, Ireland. *Proc Royal Irish Academy,* **61:** 283-338.

Kongeswaran, T. and Karikalan, R., 2016. Mapping of shoreline changes in between Devipattinam and Kilakkarai, Tamilnadu, Southeast Coast of India. *Journal of Ocean Sciences*, **2:** 12-19.

Kongeswaran, T. and Karikalan, R., 2019. Assessment of shoreline changes between Cuddalore and Nagapattinam Coast, East Coast of Tamilnadu, India using geospatial techniques. *Disaster Advances,* **12(2):** 28-36.

Kongeswaran, T. and Karikalan, R., 2021. A study on the evolution of coastal geomorphology between Rameshwaram and Kilakkarai, east coastof India. *Indian Journal of Geo Marine Sciences*, **50(1):** 67-70.

Kumaraguru, A.K., Edwin Joseph, V., Rajee, M. and Blasubramanian, T., 2008. Palk Bay - Information and Bibliography, CAS in Marine Biology, Annamalai University, Parangipettai and Centre for Marine and Coastal Studies, Madurai Kamaraj University, Madurai. 227 pp.

Leatherman, S.P., 1979. Migration of Assateague Island, Maryland, by inlet and overwash processes. *Geology*, **7:** 104-107.

May, J.P. and Tanner, W.F., 1973. The littoral power gradient and shoreline changes. *In:* Coates, D.R. (Ed.), Publications in Geomorphology. Binghamton State University of New York, pp. 43-60.

Mahapatra, R., Ratheesh, A.S. and Rajawat, R., 2014. Shoreline change analysis along the coast of South Gujarat, India, using digital shoreline analysis system. *Indian Soc. Remote Sens.,* **42(4):** 869-876.

Morton, R.A., 1996. Geoindicators of coastal wetlands and shorelines. *In:* Geoindicators: Assessing rapid environmental changes in earth systems (eds). Berger A R and Iams W J, Rotterdam, A.A. Balkema, pp. 207-230.

Mujabar, S. and Chandrasekar, N., 2011. A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India, using digital shoreline analysis system. *Geospatial Information Science,* **14(4):** 282-293. DOI: 10.1007/s11806-011-0551-7

Natesan, N., Thulasiraman, N., Deepthi, K. and Kathiravan, K., 2013. Shoreline change analysis of Vedaranyam coast, Tamil Nadu, India. *Environ Monit Assess,* **185(6):** 5099-5109. doi: 10.1007/s10661-012-2928-y

Natesan, U., Parthasarathy, A., Vishnunath, R., Kumar, G.E.J. and Ferrer, V.A., 2015. Monitoring longterm shoreline changes along Tamil Nadu, India using geospatial techniques. *Aquatic Procedia,* **4:** 325-332.

Ollerhead, J. and Davidson-Arnott, R.G.D., 1995. The evolution of Buctouche Spit, New Brunswick, Canada. *Mar Geol.,* **124(1-4):** 215-236.

Oyedotun, D.T., 2014. Shoreline geometry: DSAS as a tool for historical trend analysis. *Geomorphol. Techn.,* **3(2.2):** 1-12.

Pianca, C., Holman, R. and Siegle, E., 2015. Shoreline variability from days to decades: Results of long-term video imaging. *Journal of Geophysical Research: Oceans,* **120:** 2159-2178.

Prabakaran, K. and Anbarasu, K., 2010. Coastal Geomorphology and Evolution of Rameswaram Island, Tamil Nadu, India. *Res J Earth Sci*, **2(2):** 30-35.

Pradhan, U., Mishra, P., Mohanty, P.K. and Behera, B., 2015. Formation, growth and variability of sand spit at Rushikulya river mouth, south Odisha coast, India. *Procedia Engineering*, **116:** 963-970.

Rabehi, W., Guerfi, M., Mahi, H. and Rojas-Garcia, E., 2019. Spatio-temporal monitoring of coastal urbanization dynamics: Case study of Algiers Bay. *Journal of the Indian Society of Remote Sensing,* **47:** 1917-1936.

Raj, N., Gurugnanam, B., Sudhakar, V. and Francis, P.R., 2019. Estuarine shoreline change analysis along The Ennore river mouth, south east coast of India, using digital shoreline analysis system. *Geodesy and Geodynamics,* **10(3):** 205-212. https://doi.org/10.1016/j.geog.2019.04.002

Rasha, M., Abou Samra, A. and Ali, R.R., 2020. Applying DSAS tool to detect coastal changes along Nile Delta, Egypt. *J. Remote Sensing Space Sci.,* **24(2021):** 463-470.

Romine, B.M. and Fletcher, C.H., 2012. A summary of historical shoreline changes on beaches of Kauai, Oahu, and Maui, Hawaii. *J. Coastal Res.,* **29:** 605-614.

Rooney, J., Fletcher, C., Barbee, M., Eversole, D., Lim, S.-C., Richmond, B. and Gibbs, A. 2003. Dynamics of sandy shorelines in Maui, Hawaii: Consequences and causes. *Coastal Sediments 2003 Proceedings,* Clearwater Beach, Florida.

Roy, S., Mahapatra, M. and Chakraborty, A., 2018. Shoreline change detection along the coast of Odisha, India using digital shoreline analysis system. *Spat. Inf. Res.,* **26:** 563-571. https://doi.org/10.1007/s41324-018-0199-6.

Shanmugam, D., Krishnamurthy, R., Sivakumar, K. and Subramani, N., 2014. An Integrated Study on the Impact of Anthropogenic Influenced Coastal Erosion in Puducherry and Villupuram Coasts, Bay of Bengal, South India. *Envirogeochimica Acta.* **1:** 437-445.

Sheik, M. and Chandrasekar, N. 2011. A Shoreline Change analysis along the Coast between Kanyakumari and Tuticorin, India using Remote sensing and GIS. *Arabian Journal of Geosciences,* **6:** 647-664. 10.1007/s12517-011-0394-4

Shetty, A., Jayappa, K.S., Ramakrishnan, R. and Rajawat, A.S., 2019. Shoreline dynamics and vulnerability assessment along the Karnataka Coast, India: A geo-statistical approach. *Journal of the Indian Society of Remote Sensing,* **47:** 1223-1234.

Siva Sankari, T., Chandramouli, A.R., Gokul, K., Mangala Surya, S.S. and Saravanavel, J., 2015. Coastal vulnerability mapping using geospatial technologies in Cuddalore-Pichavaram Coastal Tract, Tamil Nadu, India. *Aquatic Procedia,* **4:** 412-418. https://doi.org/10.1016/j.aqpro.2015.02.055

Thangaraj, K. and Karthikeyan, S., 2021. Assessment of shoreline positional uncertainty using remote sensing and GIS techniques: A case study from the east coast of India. *Journal of the Geographical Institute "Jovan Cvijic", SASA*, **71(3):** 249-263. https://doi.org/10.2298/IJGI2103249T

Thangaraj, M., Mohan, R., Selvan, S., Arumugam, T., Tune, U. and Kankara, R.S., 2015. Assessment of shoreline changes along Nagapattinam coast using geospatial techniques. *International Journal of Geomatics and Geosciences,* **5:** 555-563.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L. and Ergul, A., 2009. Digital Shoreline Analysis System (DSAS) Version 4.0-An ArcGIS Extension for Calculating Shoreline Change. Woods Hole, Massachusetts: U.S. Geological Survey Open-File Report 2008–1278.

Thomas, T., Lynch, S.K. and Phillips, M.R., 2014. Long-term evolution of a sand spit, physical forcing and links to coastal flooding. *Applied Geography*, **53(2014):** 187-201.

Velsamy, S., Balasubramaniyan, G., Swaminathan, B. and Kesavan, D., 2020. Multi-decadal shoreline change analysis in coast of Thiruchendur Taluk, Thoothukudi district, TamilNadu, India, using remote sensing and DSAS techniques. *Arabian Journal of Geosciences,* **13(17):** 1-12.

Venkatarathnam, K., 1970. Formation of the barrier spit and other sand ridges near Chilka Lake on the east coast of India. *Mar. GeoL,* **9:** 1165-1190.