Assessment of Tropical Cyclone and Its Impact on the Shoreline Change Using Digital Shoreline Analysis System (DSAS) in Southeast Coast of India

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Abstract

The main focus of the present study is to predict the cyclone induced shoreline changes occurred along the Tamil Nadu coast in the past decade (2008 to 2018). Cyclones are one of the major disasters which affect the coastal parts of India almost every year and causes loss of lives and properties. Tamil Nadu is one of the states on the east coast of India that is more vulnerable to Tropical cyclone hazards. Shoreline change rates were calculated with respect to the cyclones Nish-2008, Thane-2011, Nilam-2012, Madi-2013 and Gaja-2018. The rate of erosion and accretion were estimated with respect to the each cyclone. Totally 66 transects were generated with 50m spacing and the length of each transect was 500 m. The major erosion and accretion rate were observed with respect to the Madi cyclone. The maximum long-term erosion and accretion rate obtained is -5.03 m/year and 3.17 m/year, short-term erosion and accretion rate is -4.94 m/year and 4.36 m/year and Net shoreline movement erosion and accretion rate is-50.36 m/period and 44.38 m/period. The results obtained in this research show that the Pondicherry and Vedaranyam coast are generally experiences erosion, with anthropogenic influenced accretion.

Keywords: *LRR, EPR, NSM and SCE, Erosion and Accretion, Tropical Cyclone.*

1. INTRODUCTION

Coastal erosion is a global problem affecting almost every country in the world having a coastline. This problem is expected to accelerate in the future due to the global warming, which most likely will cause a sea-level rise and increase the number of storm events around the globe. Causes of coastal erosion can differ from location to location, however, it can be generalized into two different major types; natural or human-induced erosion. Coastal erosion problems are often a result of both. Natural erosion is normally caused by either long-shore transport or cross-shore transport of sediment, the former is caused by waves breaking at an angle to the shore and the latter generated by waves breaking straight to the beach (CEM 2006). Human-induced erosion can be due to a number of reasons; sand mining along beaches, rivers contributing with sediment to the beach, constructions built to prevent erosion can cause erosion further down the beach by blocking the sediment transport along the shoreline, and by destroying corals reefs and mangroves (Masalu 2002). The processes implicated in the beach dynamics of the area of the study are complex and not yet clarified. The actual definition of shoreline, mapping and using them is a complicated task (Nayak, 2002). Ron Li *et al.* (2001) and testimony that the shoreline is the most unique feature of the earth surface.

The length of the coastline in Tamil Nadu is about 980 km and it is the second-largest coast in India. Two monsoon periods namely, the Southwest monsoon (June to September) and Northeast monsoon (October to January) influences the shoreline oscillations. In general, Tamil Nadu state is exposed to cyclones almost every alternative year. Joshi (1995) and Rufus et al (1999) have considered the problem of coastal erosion in north Chennai and reported that a total of 20 villages and hamlet settlements all along the shore from south to north are facing the threat of sea erosion every year.

Sundaresh *et al.* (2006) performed the shoreline changes along with the Poompuhar Tranquebar Region of the north Tamil Nadu coast. Hong Yeon Cho *et al.* (2004) used satellite data to perform the coastal wetland and shoreline change mapping of Pichavaram, along the Tamil Nadu coast. Meijerink (1971) had studied the coastal land use and shoreline changes that occurred in the Cauvery delta since 6000 years B.P and discovered that the oldest beach ridge was located near Thirthuraipoondi, nearly 35 km from Point Calimere on the east coast of India. Coastal erosion is one of the major concerns in the entire coastline of Pondicherry and Vedaranyam.

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2. MATERIALS AND METHODS

2.1. Study Area

The area of the study is located on the East coast of India, bounded in the East by the Bay of Bengal (Fig 1). It is extending between Pondicherry in the North and Vedaranyam in the South and lies between the latitudes 11˚ 54' N to 10˚ 16' N and longitudes 79˚ 49' E to 79˚ 49' E and form part of the Coromandal coast which encompass the coast of Andhra Pradesh and Tamil Nadu in India. The length of the seashore of the area of the study is 243km.

2.2. Cyclones

In meteorology, a cyclone is a large scale air mass that rotates around a strong centre of low atmospheric pressure. Cyclones are categorized by inward spiralling winds that spin about a zone of low pressure. Tropical cyclones are a threat to the coastal environments of Tamil Nadu. Among the Tropical Cyclone in the decade, Nisha-2008, Thane-2011, Nialm-2012, Madi-2013 and Gaja-2018 caused significant disasters. The pre and post-cyclone shoreline position were acquired and used to estimate the influence of cyclone over accretion and erosion process in the study area (Table 1).

Table 1 List of Cyclones

S. No	Cyclone Name	Month / Year
1	Nisha	Nov – 2008
2	Thane	Dec – 2011
3	Nilam	Oct – 2012
4	Madi	Dec – 2013
5	Gaja	Nov - 2018

2.3. Satellite Imageries

The survey of India toposheet 57 P 16, 58 M / 10, 13, 15, 16, and 58 N 4, 7, 8, 11, 13, 14, and 15 are utilized as a secondary data resource. The satellite imagery used for a different time period to evolve shoreline profile was listed in Table 2. The satellite imageries were obtained from the United States Geological Survey (USGS). These radiometrically corrected satellite imageries had been geometrically corrected (georeferenced). The available geomorphologic and shoreline features were interpreted by adopting standard procedure and the interpreted features were checked in the field. The shorelines were vectorised using the GIS software and these recognized shorelines of different years were over imposed and the change was detected and estimated.

2.4. Digital Shoreline Analysis System (DSAS)

The shoreline change analysis was done by using the USGS provided DSAS 4.3 (Digital Shoreline Analysis System) which is an 'Extension' of Arc GIS (v10.1). This method computes rate-of-change statistics from multiple historic shoreline positions inherent in a GIS environment. The created layers of multi-date Shorelines will be used as an input for the DSAS model for calculating the rate of change since 1972 for a period of 46 years. Baselines were created at ~1 km landward of the 1972 shoreline excluding the smaller creeks and areas such as river mouths and spits. With reference to the baseline, seaward shift of the shoreline along the transect was considered as accretion (deposition), while the landward shift was considered as erosion. The single Transect (ST) methods were used to calculate shoreline change rates. Single Transect calculates shoreline change rate and uncertainty at each transect. Single Transect uses various methods like EPR, LRR and NSM to fit a trend line to the time series of historical shoreline positions. The rate of long-term shoreline variations has been calculated using Linear Regression Rate (LRR), short-term shoreline variationation has been calculated using End Point Rate (EPR) and the Net Shoreline Change has been attained by Net Shoreline Movement (NSM) method in the ARC-GIS environment to identify erosion and accretion areas along the coasts of the study area.

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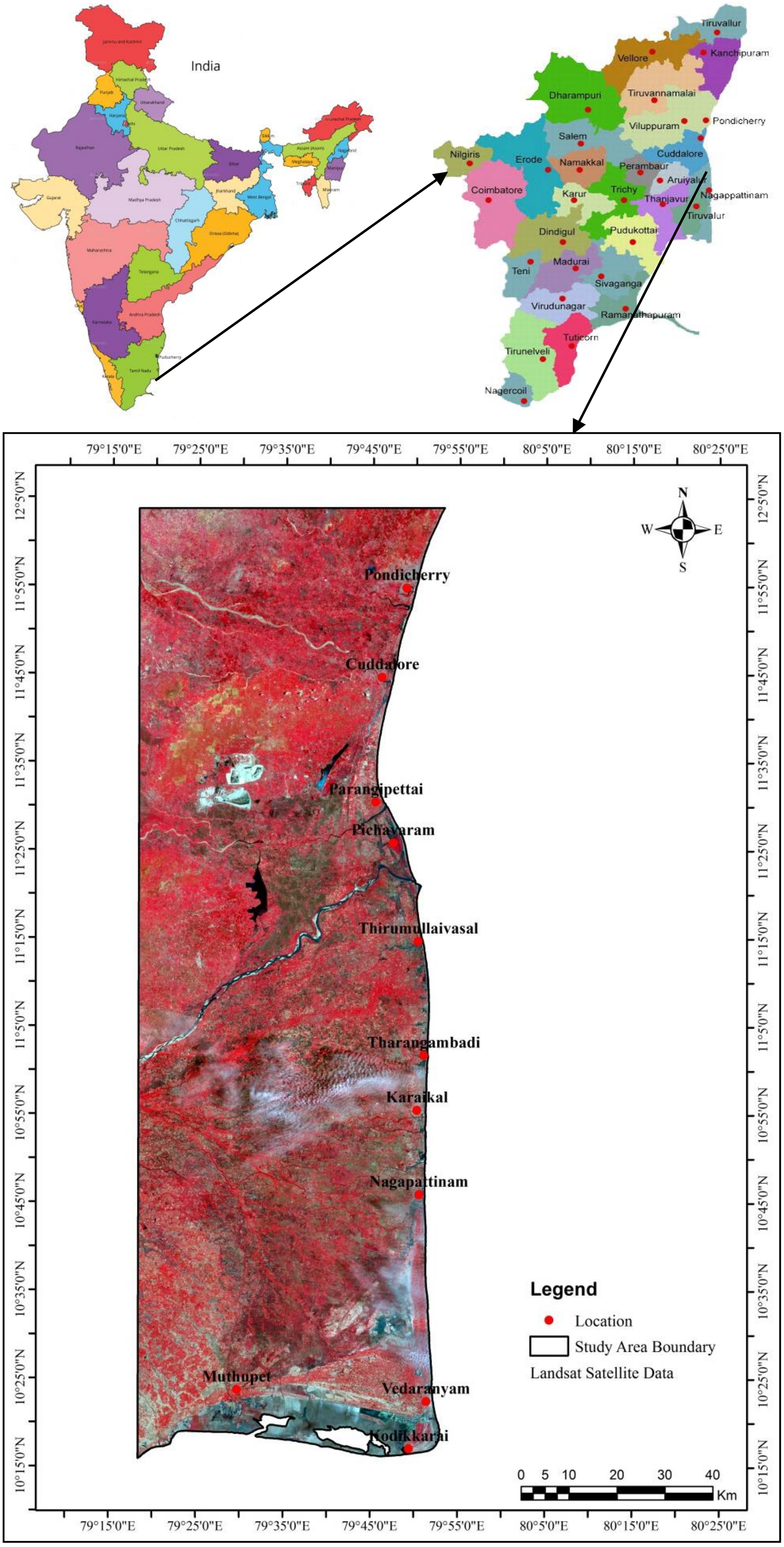

Figure 1 Location Map of the Study Area

Table 2 List of Satellite data

S. No	Satellite	Sensor	Path / Row	Resolution(m)	Date
1	LANDSAT_7	ETM+	142 / 052	30	25/09/2011
					16/02/2012
2	LANDSAT_7	ETM+	142 / 052	30	03/11/2008
					07/02/2009
3	LANDSAT_7	ETM+	142 / 052	30	13/10/2012
					17/01/2013
4	LANDSAT_8	OLI_TIRS	142 / 53	30	22/03/2013
					18/04/2014
5	LANDSAT_8	OLI_TIRS	142 / 53	30	20/09/2018
					10/01/2019

3. RESULTS AND DISCUSSION

3.1. Shoreline change analysis

Beach erosion is chronic trouble along most open ocean shore of the India. As the coastal population continues to increase and infrastructure is threatened by erosion, there is increased demand for accurate information regarding past and present trends and the rate of shoreline movement. There is also a need for a complete analysis of shoreline progress that is steady from one coastal region to another. In order to address the national needs, the present study is proposed to analyze historical shoreline changes along the coastal part of Tamil Nadu. The results of the shoreline change analysis are presented in this section.

The shoreline of years 1972, 2008, 2011, 2012, 2013, and 2018 was extracted as a vector layer. These shoreline vectors of the respective years were superimposed over the base map and the shoreline changes were quantified. The shoreline position during 1972, 2008, 2011, 2012, 2013, and 2018 are given in Table 3.

Based on the data are given in the rates of erosion/accretion parallel to the shoreline were computed for the study area and the results are furnished in Table 3. A total of 66 transects were generated with 50m spacing and an average change rate calculated from 1972 to 2018 with respect to five tropical cyclones. The shoreline analysis revealed that most of the beachfront underwent erosion within small patches of accretion.

(a) Linear Regression (long-term) Rate (LRR)

Long-term rate of shoreline changes was calculated at each transect as the slope of the linear regression through all shoreline positions from 1972 to 2018. The linear regression rate (LRR) shoreline analysis of pre and post-Nisha cyclone before and after showed a mean of -3.95 m/year and -4.07 m/year, Pre and post Thane cyclone expresses mean rate of -3.9 m/year and -3.99 m/year, Pre and post Nilam cyclone rate is -4.08 m/year and -4.15 m/year, Pre and post-Madi cyclone rate is -5.03 m/year and -4.12 m/year and Pre and post-Gaja cyclone rate is -4.09 m/year and -3.96 m/year (Table 3). The linear regression method of determining shoreline change rate represents a linear trend of change between the earliest (1972) and latest (2019) shoreline dates. The linear trend of shoreline change rates has not remained constant through time (Fig 2, A, B and C). The LRR express 74% of transects are of erosion and 26% are of accretion (Table 3). The long-term shoreline fluctuation in the study area is dominated by the erosional process than the accretion of sediments

Table 3 Shoreline Accretion/Erosion in the study area

Transect Id	Village Name		LRR	EPR	NSM	SCE
1	Adirampattinam	Erosion	0	0	0	0
		Accretion	2.93	4.26	43.40	45.54
2	Andarmullippallam	Erosion	-6.09	-4.48	-45.62	0
		Accretion	0	0	0	88.34
3	Ariyakoshti	Erosion	-11.48	-8.43	-85.85	0
		Accretion	0	0	0	161.60
4	Bahour	Erosion	-2.52	-3.05	-31.04	0

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		Accretion	0	0	0	56
5	Bommayapalayam	Erosion	-4.71	-4.88	-49.75	0
		Accretion	0	0	0	71.28
6	Chinnakudi	Erosion	-2.16	-3.90	-39.67	0
		Accretion	0	0	0	81.33
7	Cuddalore_M	Erosion	-1.28	-1.44	-14.70	0
		Accretion	0.95	0.66	6.77	60.60
8	Eripurakarai	Erosion	0	-1.82	-18.56	0
		Accretion	0.97	1.79	18.20	46.16
9	Gunduppalavadi	Erosion	-2.34	-2.17	-22.08	0
		Accretion	0	0	0	51.90
10	Kadinevayal	Erosion	-4.44	-5.60	-57.06	0
		Accretion	0	0	0	82.21
11	Kalamanallur	Erosion	-2.43	-3.93	-40.03	0
		Accretion	0	0	0	73.00
12	Kalapet	Erosion	-5.67	-6.44	-65.56	0
		Accretion	0	0	0	81.39
13	Karaikal	Erosion	-2.85	-2.53	-25.75	0
		Accretion	0.79	0.98	10.02	85.59
14	Kattur	Erosion	-3.68	-3.65	-37.21	0
		Accretion	0	0	0	93.37
15	Kayalpattu	Erosion	-1.59	-1.98	-20.19	0
		Accretion	0.20	0	0	50.20
16	Keelaiyur	Erosion	-1.15	-2.04	-20.79	0
		Accretion	0.70	3.14	32.02	83.14
17	Kilpudupatti	Erosion	-0.78	-0.89	-8.96	0
		Accretion	0	0	0	11.04
18	Kodiakarai	Erosion	-7.40	-5.72	-58.01	0
		Accretion	4.26	2.88	29.28	144.41
19	Kothattai	Erosion	-5.19	-3.23	-32.94	0
		Accretion	0	0	0	67.46
20	Kottakuppam	Erosion	-1.69	-2.08	-21.15	0
		Accretion	2.13	1.67	16.96	49.35
21	Kovilpathu	Erosion	-5.00	-7.18	-73.07	0
		Accretion	0	0	0	78.35
22	Kudikkadu	Erosion	-8.70	-10.81	-110.05	0
		Accretion	0	0	0	125.50
23	Madalpattu	Erosion	-1.85	-3.00	-26.60	0
		Accretion	0	0.04	0.78	46.64
24	Manikkapangu	Erosion	-2.29	-2.66	-27.12	0
		Accretion	0	0	0	71.29
25	Muthupet_Rf	Erosion	-3.85	-3.56	-36.24	0
		Accretion	1.74	3.00	30.54	72.58
26	Nagapattinam_M	Erosion	-4.57	-4.99	-50.87	0
		Accretion	0.67	0.70	7.17	96.20
27	Nalavedapathi	Erosion	-8.08	-8.80	-89.57	0
		Accretion	0	0	0	129.32
28	Pachchyankuppam	Erosion	-2.69	-5.32	-54.22	0
		Accretion	1.22	2.41	24.59	68.64
29	Palanjur	Erosion	0	0	0	0
		Accretion	4.67	5.36	54.61	60.37
30	Parangipettai	Erosion	-11.32	-12.95	-131.87	0

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		Accretion	14.68	19.80	201.63	200.53
31	Periyakuthagai	Erosion	-1.72	-2.37	-24.16	0
		Accretion	0.48	0	0	80.21
32	Periyapattu	Erosion	-4.93	-3.40	-34.63	0
		Accretion	0	0	0	78.45
33	Perunthottam	Erosion	-3.02	-3.95	-40.21	0
		Accretion	0	0.60	6.09	82.95
34	Pillaiperumalnallur	Erosion	-2.18	-1.84	-18.71	0
		Accretion	0	0	0	64.28
35	Pondicherry	Erosion	-3.67	-2.97	-29.96	0
		Accretion	1.40	1.79	18.93	84.29
36	Prathabaramapuram	Erosion	-1.79	-3.16	-32.14	0
		Accretion	1.43	0.58	5.94	74.23
37	Pudupattinam	Erosion	-8.58	-9.64	-98.22	0
		Accretion	0	0	0	156.62
38	Pushpavanam	Erosion	-3.35	-4.96	-50.48	0
		Accretion	0	0	0	87.96
39	Rajamadam	Erosion	-1.39	-2.21	-22.47	0
		Accretion	6.72	7.19	43.52	69.66
40	Serttaikkadu_Creek	Erosion	-3.12	-3.33	-33.92	0
		Accretion	1.70	2.37	24.18	92.98
41	Silambimangalam	Erosion	-5.15	-2.17	-22.06	0
		Accretion	0	0	0	85.00
42	Subauppalavadi	Erosion	-2.06	-0.86	-8.78	0
		Accretion	0	0	0	54.03
43	Tapputturai	Erosion	-2.03	-2.29	-23.27	0
		Accretion	0	0	0	68.51
44	Thambikottai_Maravakad	Erosion	0	-0.97	-9.89	0
		Accretion	3.36	3.18	32.40	49.12
45	Thambikottai_NS	Erosion	0	0	0	0
		Accretion	3.70	3.10	31.59	46.00
46	Thambikottai_Vadakadu	Erosion	0	-0.14	-1.41	0
		Accretion	2.18	2.31	23.56	42.95
47	Thandavankulam	Erosion	-1.76	-2.61	-26.62	0
		Accretion	0.21	0	0	89.15
48	Thandavarayan cholanganpettai	Erosion	-1.93	-1.87	-19.01	0
		Accretion	0	0	0	119.44
49	Tharangabadi_TP	Erosion	-2.96	-2.44	-24.80	0
		Accretion	0.66	2.67	27.22	90.49
50	Tharangambadi	Erosion	-0.95	-1.28	-13.04	0
		Accretion	0.46	0.37	3.76	63.86
51	Thennampattiam	Erosion	-5.62	-5.85	-59.53	0
		Accretion	0.81	0.35	3.57	114.87
52	Therkupoigainallur	Erosion	-2.03	-1.95	-19.86	0
		Accretion	0	0	0	66.06
53	Thirumullaivasal	Erosion	-3.16	-3.53	-35.95	0
		Accretion	0	0	0	64.46
54	Thiruppoondi_East	Erosion	-2.97	-5.16	-52.52	0
		Accretion	0	0	0	73.19
55	ThuraikkaduRF	Erosion	0	0	0	0
		Accretion	6.72	6.82	69.44	94.44
56	Tiruchchepuram	Erosion	-1.76	-0.93	-9.43	0

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		Accretion	0.26	0.01	0.13	77.03
57	Tiyagavelli	Erosion	-1.99	-2.32	-23.58	0
		Accretion	0.15	0.25	2.52	72.85
58	Vadakkupoigairallur	Erosion	-3.64	-4.69	-47.76	0
		Accretion	0.52	0.56	5.71	104.28
59	Vanagiri	Erosion	-3.75	-3.90	-39.69	0
		Accretion	1.34	4.59	46.77	85.24
60	Vedaraniyapuram	Erosion	-5.18	-5.36	-54.61	0
		Accretion	0	0	0	87.38
61	Velankanni_TP	Erosion	-2.42	-3.78	-38.45	0
		Accretion	0	0	0	61.65
62	Vellapallam	Erosion	-3.79	-3.84	-39.13	0
		Accretion	0	0	0	85.28
63	Vettaikkaraniruppu	Erosion	-3.78	-6.47	-65.87	0
		Accretion	0	0	0	78.31
64	Vettangudy	Erosion	-4.29	-5.11	-51.99	0
		Accretion	0	0	0	67.08
65	Villiyanallur	Erosion	-6.66	-3.35	-34.10	0
		Accretion	0	0	0	97.40
66	Vizhunthamavadi	Erosion	-4.20	-6.74	-68.69	0
		Accretion	0	0	0	78.15

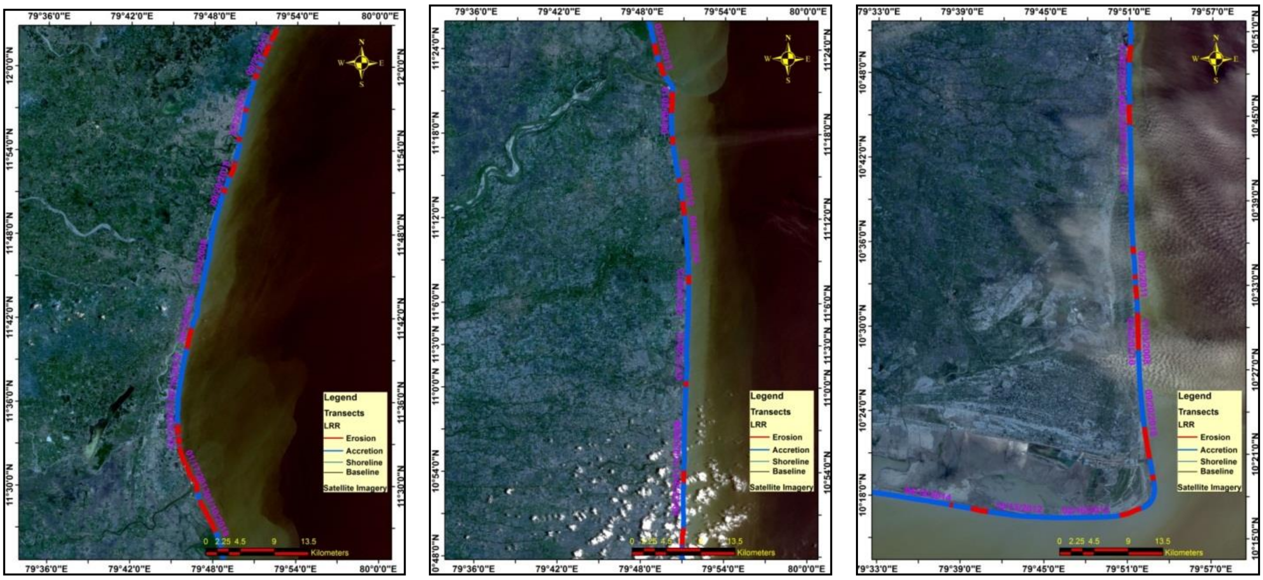

Figure 2 (A-C) Long-term rate of Shoreline change (LRR m/year) along the shore from 1970 to 2019

(b) End Point (Short-term) Rates (EPR)

Short term rate of shoreline changes was calculated at each transect using an End point rate (EPR) between shoreline position for 1972 through 2008 and the recent shoreline (2019) to provide an approximately mean shoreline change of Pre and post-Nisha showed mean of -4.17 m/year and -4.31 m/year, Pre and post Thane cyclone rate is -4.25 m/year and -4.23 m/year, Pre and post Nilam cyclone rate is -4.34 m/year and -4.33 m/year, Pre and post-Madi cyclone rate is -4.94 m/year and -4.23 m/year and Pre and post-Gaja cyclone rate is -4.38 m/year and -4.33 m/year for 12 to 30 years short term rate (Table 3). The EPR results show 45 Transects (or) 74% of the study area experienced erosion and 21 transects (or) 26% with accretion (Fig 3, A, B and C). Thus, the EPR also conveys that erosion is a dominating feature over that of accretion.

(c) Net Shoreline Movement (NSM)

The Net shoreline movement (NSM) revealed mean shoreline change of Pre and post Nisha cyclone is -42.46 m/period and -43.86 m/period, Pre and post-Thane cyclone rate is -43.24 m/period and -42.83 m/period, Pre and post Nilam cyclone rate is -44.16 m/period and -44.05 m/period, Pre and post-Madi cyclone rate is -50.36 m/period and -43.07 m/period and Pre and post-Gaja cyclone rate is -44.6 m/period and -44.09 m/period respectively from 1972 to 2019 (Table 3). The NSM reports the distance between the oldest and youngest shorelines of each transect. The NSM results are also articulate 74% of the coastal tracts are experienced erosion, and 26% with accretion (Fig 4, A, B and C).

3.2. Tropical Cyclone Accretion and Erosion in the study area

Considerating shoreline change rates and trend of shoreline erosion and accretion, most of the beach underwent erosion while some part of the beach experiences accretion during the study period. The shoreline was exposed to natural shoreline phenomena such as waves, tides and periodic storm surges apart from the coastal tectonics activities.

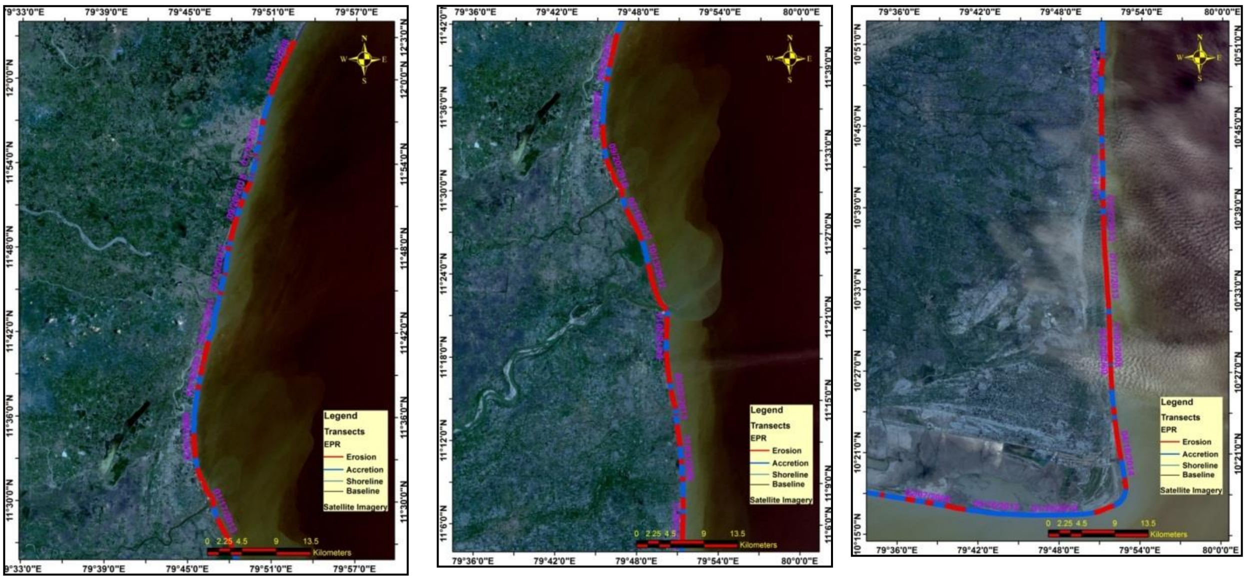

Figure 3 (A-C) Short-term rate of Shoreline change (EPR m/year) along the shore from 1970 to 2019

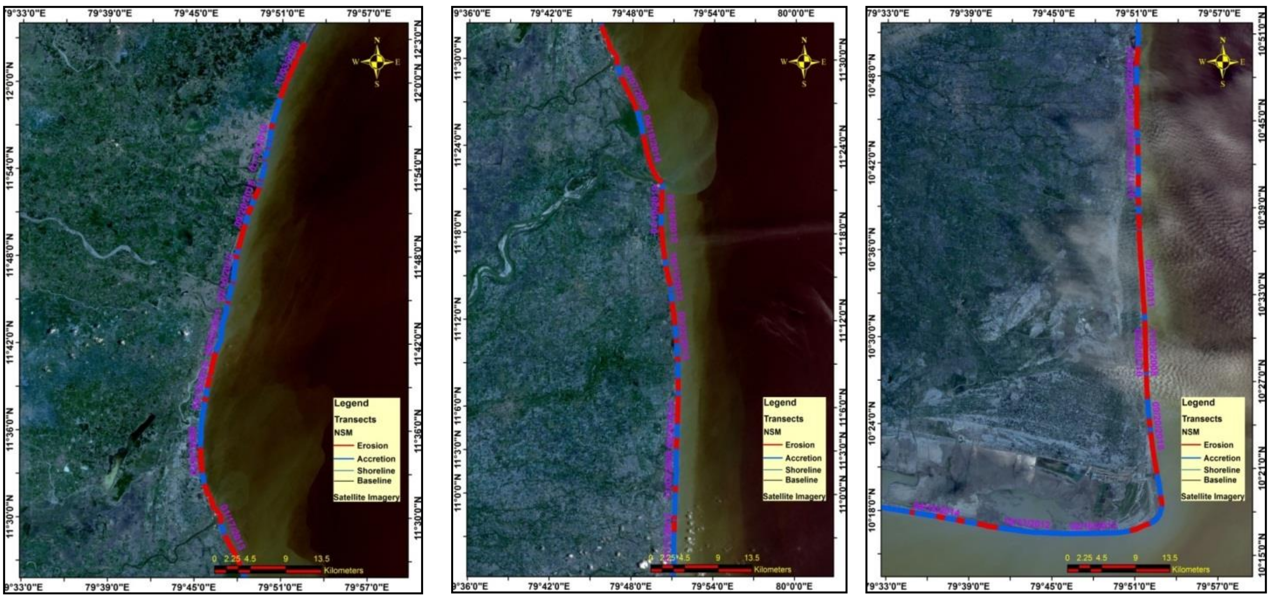

Figure 4 (A-C) Total Rate of Shoreline change (NSM m/period) along the shore from 1970 to 2019

A) Accretion in the Study Area

In the coastline stretch from Pondicherry to Vedaranyam, accretion was occurred in Madalpattu to Tiyagavelli stretch, Karaikal to Vadakkupoigairallur stretch and Kodiyakarai to Rajamadam stretch at a significant level. The maximum and minimum accretion that occurred in the long-term rate of accretion was found maximum as 14.68 m/year at Parangipettai and minimum as 0.15 m/year at Tiyagavelli (Table 3). With the short-term accretion of 19.80 m/year in Parangipettai as maximum and 0.01 m/year in Tiruchpuram as a minimum (Table 3). The second accreted stretch was Villiyanallur to Ariyakoshti with the maximum value of 229.94 m and a minimum value of 50.89 m for the same period (Table 3). The amount of accretion of 201.63 m/period in Parangipettai as maximum and 0.13 m/period in Tiruchpuram as Minimum. As a whole, it is found that a total shoreline length of 51 km was subjected to accretion. The Presence of Mangrove swamp and vegetative barriers like Casuarinas, bamboos etc along with low coastal processes (tide and wave height) are responsible for the accretion nature of the coast at different parts of the study area. The tropical cyclone was also influencing the rate of accretion within the study area. Amongst the five cyclones, Pre and Post Thane and Nilam cyclones express very gentle accretion and the tropical cyclone Madi has influenced a significant amount of accretion of sediments (Table 4A; Fig 5).

Table 4 (A) Overall Shoreline Changes for Cyclones (Accretion)

Cyclone Name	Lowest pressure(hPa)	Wind Speed(km/h)	LRR(m/year)	EPR(m/year)	NSM(m/period)
Nisha	996	85	2.81	3.32	31.94
Thane	969	140	3.01	3.43	32.23
Nilam	990	85	2.98	3.57	33.28
Madi	986	120	3.07	4.04	39.42
Gaja	976	130	2.33	2.78	27.78

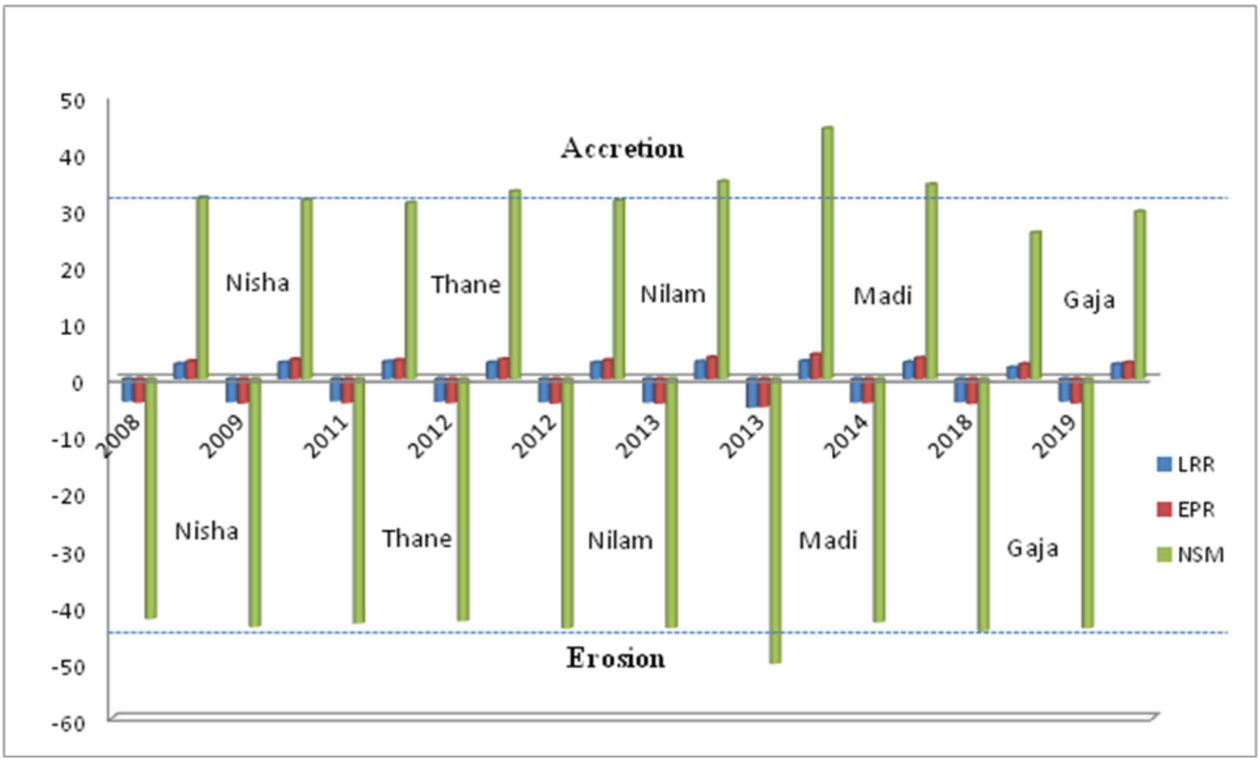

Fig 5 Overall Shoreline Changes for Cyclones

b) Erosion in the Study Area

In the coastline stretch from Pondicherry to Vedaranyam, erosion occurred at a significant level. The amount of erosion occurred in the coastline stretch of cyclones with a maximum value of -131.84 m and a minimum value of -1.41 m for the period of 1972 to 2019. The long-term rate of erosion in this stretch was worked out to be -11.48 m/year as maximum and -0.78 m/year as a minimum (Table 3) with the short-term erosion rate between -12.95 m/year as maximum and -0.14 m/year as a minimum. It is found that amongst the total shoreline length of 243, 192 km of shoreline are subjected to erosion. Amongst the five tropical cyclones, Madi has an expressing good amount of accretional nature (Table 4B; Fig 5). Land use pattern and other human activities like the construction of ports and comparatively straight flatter shoreline might have caused erosion apart from the short-term influence of tropical cyclones.

Table 4 (B) Overall Shoreline Changes for Cyclones (Erosion)

Cyclone Name	**Lowest pressure** (h/Pa)	**Wind Speed** (km/h)	**LRR** (m/year)	**EPR** (m/year)	**NSM** (m/period)
Nisha	996	85	-4.01	-4.24	-43.16
Thane	969	140	-3.95	-4.24	-43.03
Nilam	990	85	-4.12	-4.34	-44.11
Madi	986	120	-4.58	-4.59	-46.71
Gaja	976	130	-4.03	-4.36	-44.35

4. CONCLUSION

The study area progrades and eroded during tropical cyclone events. The shoreline fluctuation display similar spatial patterns in the location of erosion and accretion. In general, it is found that a total shoreline length of 51 km was subjected to accretion. The Presence of Mangrove swamp and vegetative barriers like Casuarinas, bamboos etc., along with low coastal processes (tide and wave height) are responsible for the accretion nature of the coast at different parts of the study area. Amongst the 243km of the study area stretch, a total shoreline length of 191 km is subjected to erosion. The shore currents, wind and waves are also regularly aiding to the shape of the coastal features to some extent apart from the tropical cyclones. Net shoreline movement statistics calculated by DSAS shows that the tropical cyclone Madi was the more influential event than that of other tropical cyclone events in the study area within the study period.

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