Seasonal influence on Cuddalore shoreline change: Remote sensing, GIS and statistical approach

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(*Received 4 May 2016, Accepted 7 December 2018*)

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सार – इस शोध पत्र में भारत के कुड्डलूर तट की तटरेखा की स्थितियों में हो रहे बदलाव का विश्लेषण विशिष्ट क्षेत्रीय पैमाने पर तटरेखा के पर बदलाव पर मौसमी प्रभाव का निर्धारण करने के लिए किया गया है। एक डिजिटल तटरेखा विश्लेषण प्रणाली (DSAS) टूल का उपयोग करते हुए कुड्डलूर के 73 कि.मी. की तटरेखा वाले क्षेत्र को जनवरी 1991 से अक्तूबर 2015 तक की अवधि को दो मॉनसूनी मौसमों के रूप में वर्गीकृत किया गया है। इन आँकड़ों से पता चलता है कि तटरेखा तट को प्रभावित करने वाली (मौसम वैज्ञानिक) मौसमी स्थितियाँ भिन्न-भिन्न रूप में प्रभावित करती हैं। यहाँ परिवर्तन की दर में और अवधि जिसमें तटीय रेखा की स्थिति में परिवर्तन हुआ है, उसमें विशिष्ट अनुमानित अंतर पाया गया है। यहाँ सांख्यिकीय दृष्टिकोण से तटरेखा की स्थिति में हुए परिवर्तनों की जाँच की गई है जैसे: अंतिम बिन्दु दर (EPR) और रैखिक समाश्रयण दर (LRR)। सांख्यिकीय उपागम परिणामों से संकेत मिलता है कि मौसम परिवर्तनों के द्वारा तटीय रेखा में होने वाली भिन्नता प्रभावित होती है। यह अध्ययन क्षेत्रीय पैमाने पर तटरेखा में परिवर्तन लाने वाले कारकों के समझने के महत्व को दर्शाता है और इसका उपयोग तटीय इंजीनियरिंग और जलवायु परिवर्तन के लिए तटरेखा की प्रतिक्रिया के अध्ययन के लिए किया जा सकता है।

ABSTRACT. Changes in shoreline positions of the Cuddalore coast, India, are analyzed to determine the seasonal influences of shoreline movements at a regional specific scale. Using a Digital shoreline analysis system (DSAS) tool, 73 km shoreline stretch of Cuddalore is mapped on two monsoonal seasons from January, 1991 to October, 2015. These data show that the coastline responds differently to seasonal (meteorological) forcing along the coast. An estimated difference takes place especially in the rate of changes and in the time duration in which the shoreline moves into a different position. Here changes in shoreline position are examined with respect to statistical approach *viz.*; End point rate (EPR) and Linear regression rate (LRR). Statistical approach results indicate that variability in shoreline influence by seasonal changes. This study demonstrates the importance of understanding the drivers of shoreline changes at a regional scale and has applications in studies concerned with coastal engineering and shoreline response to climate change.

Key words – Shoreline change, Seasonal influence, Meteorological force, End point rate, Linear regression rate.

1. Introduction

In both spatial and temporal scales, the shoreline undergoes change at a wider range. This is due to the various coastal processes such as wave action, wind direction, storms etc. These coastal processes interact with each other and lead to the change in the shorelines of both erosion and accretion present along one another at some time may show controversial change pattern at some other time. Therefore understanding these processes is an important pre-requisite for coastal engineering and its related projects (Addo *et al*., 2011). It is highly important at a regional specific scale, where coastal management decisions are made and better understanding is required (Esteves *et al*., 2006). One of the notable issues associated with development of the shoreline is the effect of short-term extreme events like tsunami surge, floods, cyclones etc. Thus, for many practical applications, it is essential to develop accurate techniques to determine the maximum intensity of the shoreline fluctuations.

Many studies in Cuddalore noticed coastal processes at a region specific scale. Many analysis have been limited to discrete monitoring in selected places (Saxena *et al*., 2012). Satellite images are also limited to particular monsoonal periods. Only recently has the use of the Digital shoreline analysis system, an extension tool of ArcGIS software coupled with satellite data taken (Mahendra *et al*., 2011; Saxena *et al*., 2013)in the months of monsoonal climate along the cuddalore coast for studying the shoreline changes (Kench *et al*., 2009). Cuddalore experiences two monsoon climates. They are,
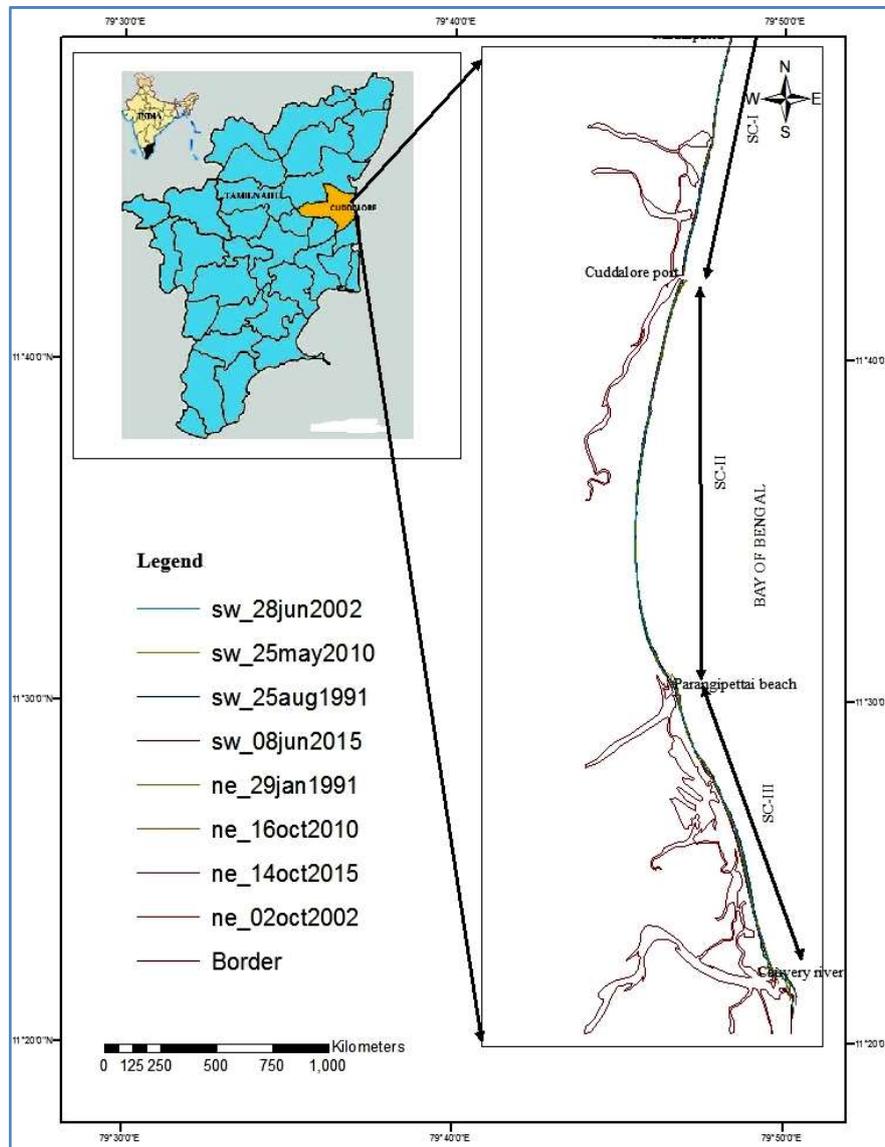
Fig. 1. Study area map represents the shoreline (1991-2015), both the northeast and southwest seasons shorelines, sediment cells (SC-I to SC-III) and its borders

Southwest (SW) - (June to September) and Northeast monsoon climates (NE) - (October to November). In the present study, the eight sets of Land sat data (Four data products pertaining to NE and another four image pertaining to SW monsoon) are downloaded from the USGS website (Drake and Bristow, 2006). The shoreline of about 73 km length is mapped eight times from 1991 to 2015. The shoreline spatial variability with respect to seasons is monitored in a region specific scale (Loo *et al.*, 2015; Kankara *et al.*, 2015). Results presented here are intended to improve understanding of relationships between the forcing conditions that affect the morphology

of a shoreline and to have a national wide broad application at other sites.

2.   **Study area**

The cuddalore coastal stretch of about 73 km is chosen for study stretch. It lies between 11°51′ to 11°11′ N and 79°46′ to 79°56′ E. It starts from Madalpattu to north side of the Cauvery river mouth (Fig. 1). The region is fully flat in nature with huge deposits of alluvial and black soil. The Pennaiyar River runs on the northern side of cuddalore town. This study area has two monsoon
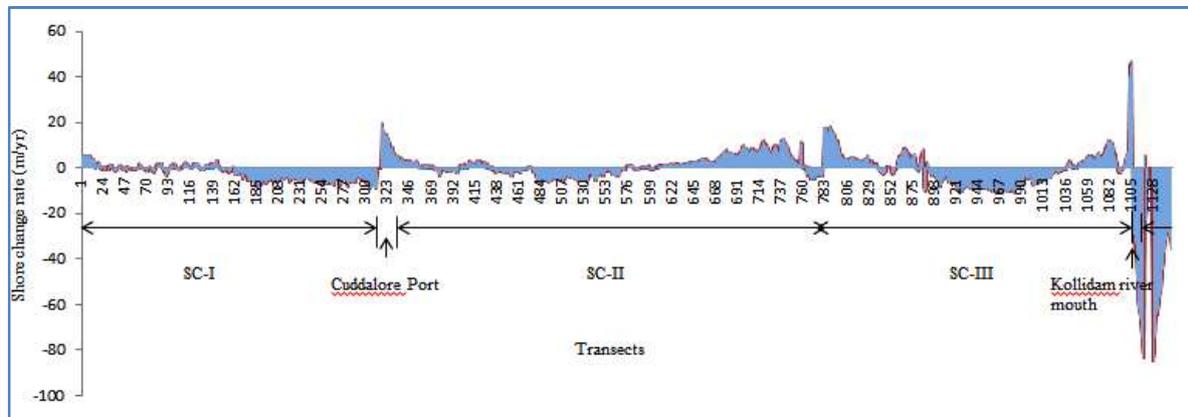
Fig. 2. Sectional view of the chosen stretch of Cuddalore coast and representation of sediment cells along the stretch

seasons. They are southwest and northeast monsoon seasons. The SW monsoon starts in June month and continues till September. The northeast monsoon starts in October and it goes upto January month. Comparatively, the southwest monsoon rainfall is lower than the northeast monsoon season (Punithavathi *et al*., 2012).

The study area extends from the Pondicherry union territory in the north to the Nagapattinam in the south. This shore is a part of a large coastal plain. It is formed and shaped by the Quaternary sea-level fluctuations that results in sediment intrusions of various sources like Ponnaiyar, Gadilam, Uppanar, Vellar and Coleroon (Viveganandan *et al*., 2012). This coastline has an approximate NE-SW orientation and indicates a narrow continental shelf and slope with a gentle gradient upto about 3000 m water depth (Murthy *et al*., 2006).

3.   Materials and method

This study adopts shoreline positions that were demarcated in 1991 (January 29), 2002 (October 2), 2010 (October 16), 2015 (October 14) - Northeast monsoon; and 1991 (August 25), 2002 (June 28), 2010 (May 25), 2015 (June 8) - Southwest monsoon to determine patterns of shoreline and shoreline change intensity at a regional scale due to the influence of monsoon. Initially, the pre-processing of images such as geometric correction, projection, etc. was carried out by ERDAS Imagine software. False colour image or pseudo colour image was generated by using respective band combination for the Landsat data which clearly displayed the water/land interface (Mageswaran *et al*., 2015). Further, the demarcation of shoreline was done in the ArcGIS platform (Kumaravel *et al*., 2013). The digitized shoreline was saved in a personal geo database that led to further process like appending the shoreline layer and creation of a baseline. The shoreline change analysis was carried out to

find the accretion and erosion rate by using Digital shoreline analysis system. The chosen coastal stretch is divided into three sediment cells namely SC-I, SC-II and SC-III.

Sediment cells are defined as nearly self-contained pockets inside which sediment flows and essential in identifying the discontinuities in rate or direction of sediment transport (Bray *et al*., 1995). It is also used to know the interaction processes and movement of shoreline at the region specific scale. The coastal stretch of the study area is widely classified into three SCs, namely; SC-I, SC-II and SC-III (Figs. 1&2). The cell boundaries are demarcated based on intervening rivers, estuaries, sand spits and port/harbours (Deepika *et al*., 2013). The boundaries of the four SCs are: (*i*) SC-I of 16 km, chosen a stretch between the Madalpattu to cuddalore port (north side); (*ii*) SC-II of 22 km, between the southern bank of Cuddalore port to Parangipettai harbor (north side); and (*iii*) SC-III of 16 km, between south side of Parangipettai beach and north side of the Cauvery river mouth. Table 1 gives the details of data products that are adopted for the analysis.

3.1.   *Digital shoreline analysis system*

DSAS is a freely available software extension tool that works within the ArcGIS software. It computes rate-of-changes statistics for a time series of shoreline data (Theiller *et al*., 2009). It can be used within Arc Map environment to construct transect location and calculate change statistics. Many statistical methods are available for estimating the shoreline change rate, but the commonly adopted methods for finding shoreline change rate and movements are End point rate (EPR) and Linear regression rate (LRR). Researchers *viz*.; Natesan *et al*., 2015; Kim *et al*., 2014 and Aedla *et al*., 2015 suggested the above said methods for finding the shore change

TABLE 1

Details of data products

S. No.	Data products	Acquisition date (dd/mm/yyyy)	Type of format	Resolutions(in m)
I. Northeast monsoon				
1.	Landsat 5 TM	29 January, 1991	Tiff	30
2.	Landsat 5 TM	2 October, 2002	Tiff	30
3.	Landsat 7 ETM	16 October, 2010	Tiff	30
4.	Landsat 8 OLI	14 October, 2015	Tiff	30
II. Southwest monsoon				
5.	Landsat 5 TM	25 August, 1991	Tiff	30
6.	Landsat 5 TM	28 June, 2002	Tiff	30
7.	Landsat 7 ETM	25 May, 2010	Tiff	30
8.	Landsat 8 OLI	8 June, 2015	Tiff	30

TABLE 2

Scale of classification of shoreline

S. No.	Classification of shoreline	Range of shore change rate - Northeast monsoon(m/yr)	Range of shore Change rate-Southwest monsoon(m/yr)	Symbol
1.	High Erosion zone	>-3	-30 to -4	▬
2.	Low Erosion zone	-3 to -1	-4 to -2	▬
3.	Stable zone	-1 to 1	-2 to 0	▬
4.	Low Accretion zone	1 to 5	0 to 4	▬
5.	High Accretion zone	5 to 23	4 to 19	▬

analysis. The following are the details of the aforesaid methods.

3.1.1. *End point rate (EPR)*

The end point rate is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the very recent shoreline. The main advantages of the EPR method are the ease of computation and lesser requirement of only two temporal shorelines.

3.1.2. *Linear regression rate (LRR)*

A linear regression rate-of-change statistics can be determined by fitting a least-squares regression line to all shoreline points for a corresponding transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. Table 2 shows the

scale of shoreline classification that is adopted in the present study.

4.   Results and discussion

4.1. *Estimation of shoreline change rate in northeast and southwest monsoon*

Shoreline pattern is generally dynamic, depict temporal and spatial changes that are influenced by an accelerated or decelerated accretion of sediments along the coast. The complex interaction of a number of factors such as wave energy, sea-level changes, climate, sediment supply and budget, morphological properties are responsible for shoreline change (Rooney and Fletcher, 2004), while river flow and wave breakers play an important role in orientating and modifying them (Kunte and Wagle, 1991). Accelerated accretion or decelerated erosion results from greater sediment deposition, whereas decelerated accretion or accelerated erosion indicates greater sediment transport (Morton, 1979). Further,
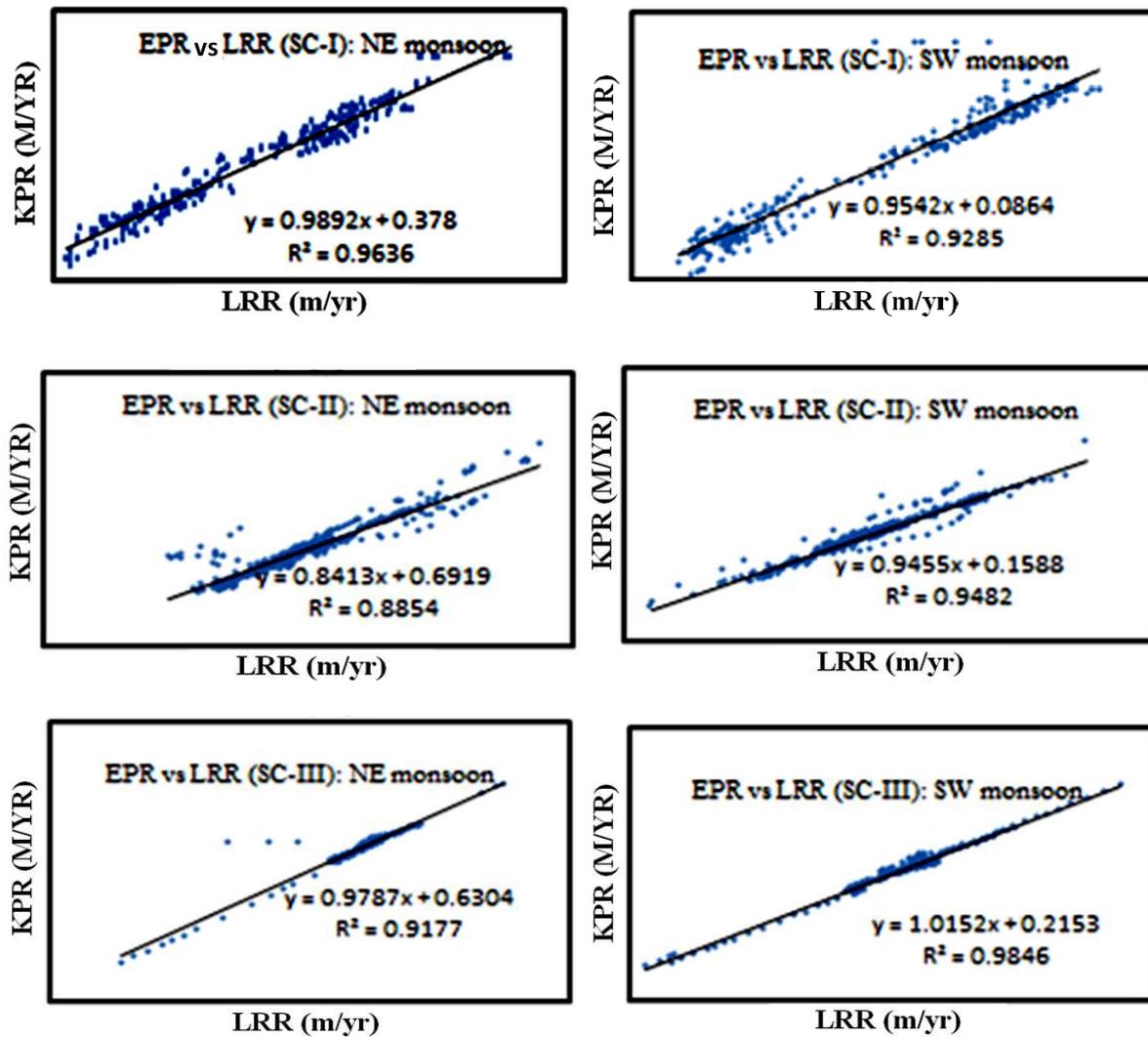
Fig. 3. Comparisons of rates by EPR and LRR methods for every transects taking 1972 toposheet shore position as a base reference. The inclined line represents the similarities between these two statistical methods and R^2 value near to 1 represent good correlation between these statistical methods

shoreline changes of the Cuddalore coast are influenced by both the natural processes (waves, littoral currents, offshore relief, river mouth changes and sea-level changes) and anthropogenic activities (construction of coastal structures, sand mining and dredging of navigation channels) (Mohanty *et al*., 2015; Elmousthapa *et al*., 2007; Paul and Pillai 2014; Demir *et al*., 2004; Kudale, 2010; Darson and Alexis, 2014and Chu *et al*., 2015). The figure (Fig. 2) indicates that the sediment cells present in the chosen coastal stretch. Shore change rate details of all SCs with respect to monsoonal climates, statistical outputs for the SCs shoreline positions taking 1972 shoreline as a reference, role of correlation coefficient on shoreline change are illustrated in Fig. 3.

4.1.1. *Sediment cell- I (SC-I)*

(*i*)   *NE monsoon*: In this cell, the involved transects are from 1 to 310, from which the 1 to 20 transects, low accretion is noticed about 1 km (from Madalpattu towards Cuddalore port) and the maximum accretion value is noticed as 2 m/yr for both LRR and EPR. Further, from transect No. 21 to 145, an alternate recession and progradation of shoreline are seen. Erosion segments are seen from the transects 146 to 310, from which high erosion transects starts from transect 300. Nearly 0.5 km stretch undergoes high erosion in the northern banks of the Cuddalore port. The maximum erosion EPR value is estimated as -4 m/yr. The correlation Graph (Fig. 3) is
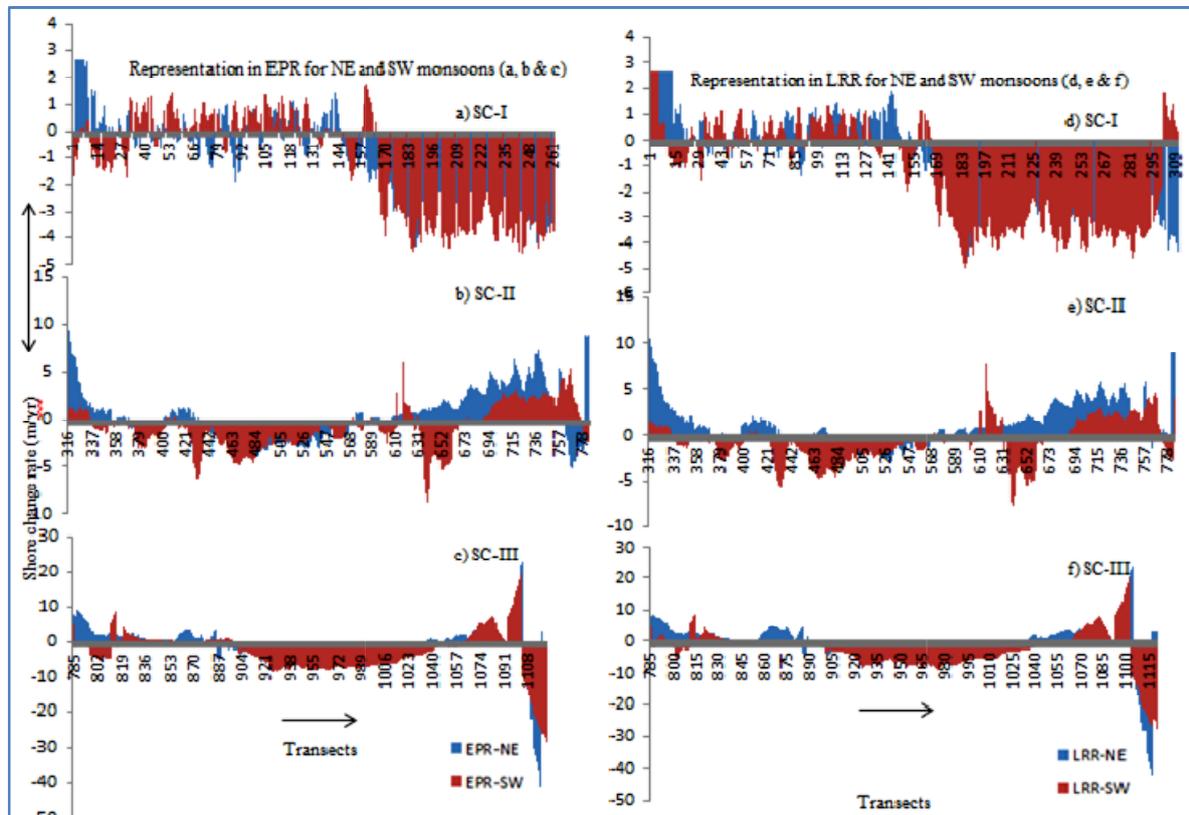
Figs. 4(a-f). (a-c)Representation of EPR for NE and(d-f) LRR for SW monsoon

plotted for this season and it gives high degree of correlation between EPR and LRR such as 0.9636.

(*ii*) *SW monsoon*: In this SC-I, there is an alternation recession and progradation of shoreline is noticed, in which minor erosion is noticed from transects 302 to 310 (on the northern side of the Cuddalore port). Nearly 6.5 km stretch is classified as a low erosion zone in this cell, that represents the color yellow [Table 2 and Figs. 5(a-d)]. Similarly, the values of EPR and LRR are plotted the arrived for SW monsoon and the estimated regression coefficient value is 0.9285 (Fig. 3).

4.1.2. *Sediment cell- II (SC-II)*

(*i*)   *NE monsoon*: Here, in this cell, from transects 316 to 323, high accretion transects are noticed and it is in the southern side of Cuddalore port. Moreover, upto the transect No. 338, a low accretion transects (nearly 0.65 km stretch) are identified. An alternate low erosion and low accretion are noticed from transects 339 to 715. In northern bank of Parangipettai beach, the transect from 781-784 shows a high accretion. The similarities between

EPR and LRR for NE and SW monsoon are illustrated in Figs. 4(a-f).

(*ii*) *SW monsoon*: In this cell, about 50 m (transect No. 316) of stretch undergoes high accretion (southern bank of Cuddalore port). And the subsequent transects of this cell shows a stable continuous zone of 5 km stretch and nearly 3.5 km of low accretion zone. A high accretion zone of about 0.2 km (transect from 781-784) is identified near the northern bank of Parangipettai beach. EPR and LRR plotted for SW monsoon and they give results of regression coefficient and the value was 0.9846 (Fig. 3).

4.1.3. *Sediment cell-III (SC-III)*

(*i*)   *NE monsoon*: This cell, starts from the southern side shore of Parangipettai (785-795), 0.55 km and undergoes a high accretion. The estimated maximum EPR and LRR value are 9 and 8 m/yr. As a whole of SC-III, the maximum positive EPR for NE and SW monsoon are 23 and 19 m/yr. The Pichavaram mangrove forest comes under this cell, *i.e.*, transect from 893-1022. But is 6.5 km, lower to high erosion is noticed. A high erosion is also seen in both the banks of Cauvery river mouth (Kollidam region).
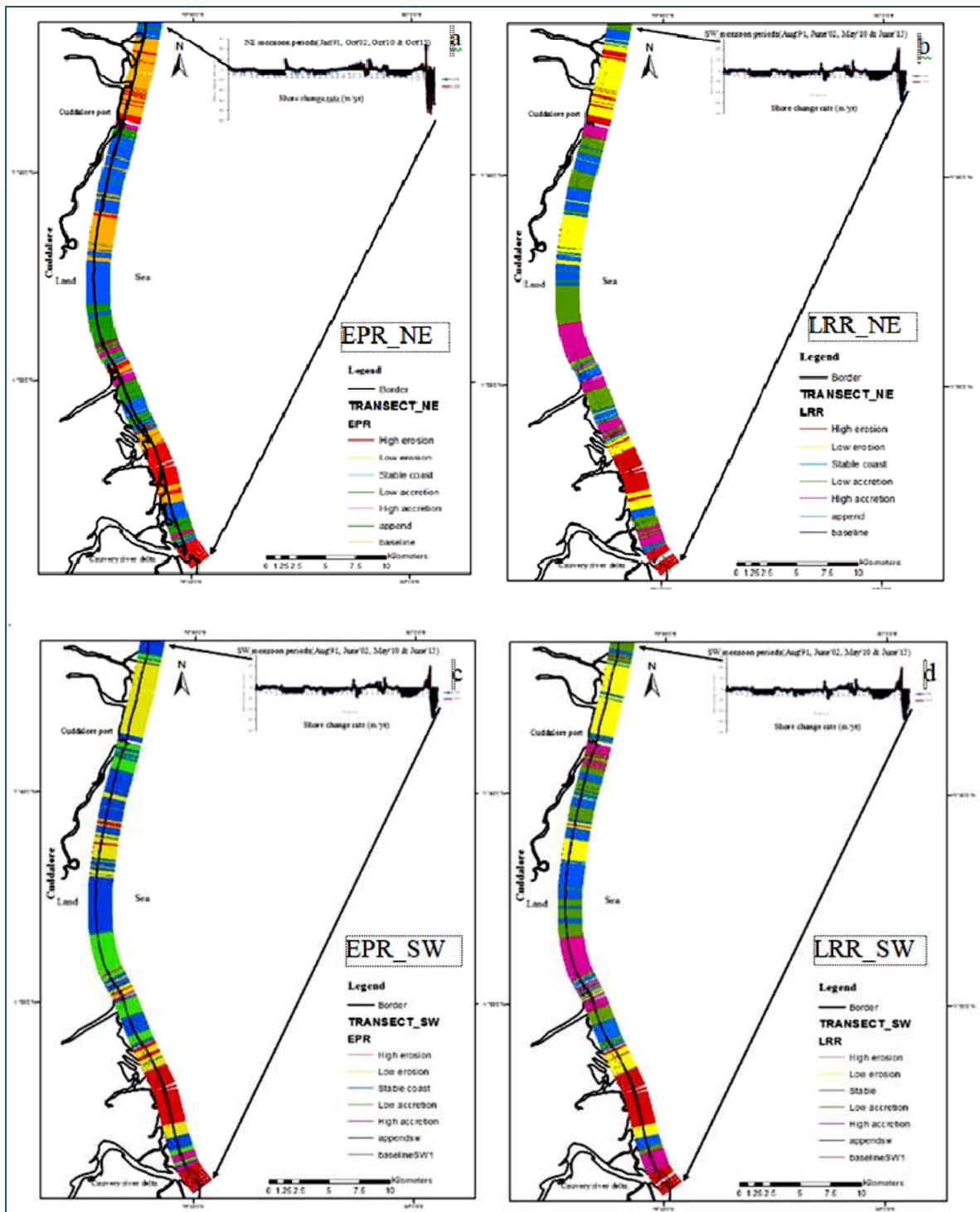
Figs. 5(a-d). a, b, c and d represents the shoreline change rate (EPR and LRR) for chosen stretch of Cuddalore coast in northeast and southwest monsoon

(*ii*) *SW monsoon*: This cell, starts from the southern bank of Parangipettai beach and experienced low accretion for a stretch of about 1.45 km (transect from 788-816). In this SW monsoon analysis, the Pichavaram mangrove

TABLE 3

Overall summary of all three sediment cells in both the monsoons

S. No.	Shore related statistical parameters	Northeast monsoon			Southwest monsoon		
		SC-I	SC-II	SC-III	SC-I	SC-II	SC-III
1.	Involved no. of transects	1-310	316-784	785-1121	1-310	316-784	785-1121
2.	Total no. of transects	310	469	337	310	469	337
3.	Length of shoreline (km)	16	22	16	16	22	16
4.	Maximum change rate of shore (m/yr) EPR LRR	2/-4 2/-4	9/-4 10/-2	23/-40 23/-42	1/-4 2/-4	5/-8 7/-7	19/-28 20/-27
5.	Transects undergone to high erosion EPR LRR	30	13	101	-	11	129
6.	Transects undergone to low erosion EPR LRR	129	97	54	130	86	56
7.	Transects undergone to stable coast EPR LRR	140	225	82	96	242	70
8.	Transects undergone to low accretion EPR LRR	11	97	82	84	122	60
9.	Transects undergone to high accretion EPR LRR	-	37	18	-	08	22
10.	Percentage of transects undergone to high erosion EPR LRR	9.6	2.7	29.9	-	2.3	38.2
11.	Percentage of transects undergone to low erosion EPR LRR	41.6	20.6	16.0	41.9	18.3	16.6
12.	Percentage of transects undergone to stable coast EPR LRR	45.1	47.9	24.3	30.9	51.5	20.7
13.	Percentage of transects undergone to low accretion EPR LRR	3.5	20.6	24.3	27.0	26.0	17.8
14.	Percentage of transects undergone to high accretion EPR LRR	-	7.8	5.3	-	1.7	6.5

forest is lower to high erosion transects that is same as NE monsoon [Figs. 5(a&b)]. Two sides of the Cauvery river mouths undergo high erosion (transect 1103-1147). The maximum EPR and LRR values are estimated as -28 and -27 m/yr respectively.

The scale values of shoreline classification was mentioned in the Table 2. And the Figs. 5(a-d) give the clear pictures of shoreline classification and its change rates in both the monsoons is based on EPR and LRR.

5.   Conclusions

Shoreline change analysis is done for 25 years along the Cuddalore coast supported by remote sensing, GIS and statistical approach as contributed a better understanding of rates-of-change to evaluate spatial and temporal variation due to the seasonal influences. Shoreline change rates of SC-I, SC-II and SC-III are estimated using EPR and LRR methods. The methods suggest that the high degree of correlation between LRR *vs.* EPR values are noticed for both the monsoons (Fig. 3). Moreover, both erosion and deposition are observed at all the three SCs [Figs. 4(a-f)]. The erosion observed is not continuous all along the SCs. Comparatively high erosion occurred at Pichavaram mangrove forest and the river mouth of Cauvery. This is because of interactions between wave, tides and river water flows. High erosion in the north side and high accretion on the south side of Cuddalore port is observed in the NE monsoon. But in the SW monsoon, the intensity of erosion and accretion is less in nature near the Cuddalore port. A high accretion is noticed in the south side of the Parangipettai beach during NE and SW monsoon analysis. But the high accretion transects is noticed in the northern side and stable to low erosion transects were seen in the southern side of the Parangipettai beach during SW monsoon. The variation in the river mouth and artificial structures were quite remarkable. This was because of the construction of breakwaters was commissioned which is very close to the Parangipettai beach. Such breakwaters/oil jetties acts as a barrier for the northerly long-shore current. Hence, this scenario was noticed in this select stretch of Cuddalore coast. The result revealed that about more than 70% of the shoreline undergone stable or erosion and the remaining shoreline experienced varying intensity of accretion. It is concluded that the Cuddalore coast is more eroding in NE monsoon compared to SW monsoon from the present analysis. Thus the intensity of SW monsoon is lesser than NE monsoon [Table 3 and Figs. 5(a-d)]. Hence the study depicts that shoreline change is primarily due to coastal process, geo-morphological dynamics and also monsoon that attributes the coast.

Disclaimer

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of their organizations.

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