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SHORELINE CHANGE RATES ALONG THE ALMANARRE BEACH

NGUYEN TRONG TU[(1)], THAN VAN VAN[(2)], YVES LACROIX[(3)]

[(1)]*Faculty of Civil Engineering and Institute of Civil Engineering (ICE) - Thuyloi University (TLU)*
175 Tay Son, Dong Da, Ha Noi, Viet Nam
email: nguyentrongtu@tlu.edu.vn

[(2)]*Faculty of Civil Engineering and Institute of Civil Engineering (ICE) - Thuyloi University (TLU)*
175 Tay Son, Dong Da, Ha Noi, Viet Nam
email: thanvanvan@tlu.edu.vn

[(3)]*SEATECH, avenue G. Pompidou, 83162 La Valette du Var, France and MEMOCS,*
Università Degli Studi dell'Aquila, Palazzo Caetani,
04012 Cisterna di Latina, Italy;
email: yveslacroix83400@gmail.com

ABSTRACT

The Almanarre Beach in Toulon is submitted to shoreline erosion. We use statistical methods from Digital Shoreline Analysis System in order to better understand the historical and future shoreline changes. The End Point Rate method is used to estimate the shoreline change rates. The results show the annual shoreline change rates for four sectors of the Almanarre Beach. The average annual rate of erosion from -0.01 ± 1.29 to -0.33 ± 0.34 m/year was estimated in the northern part of the Almanarre Beach. The maximal rate of shoreline retreats along some transects in northern part of the Almanarre Beach can reach -0.56 ± 0.34 m/year.

Keywords: *Almanarre Beach, shoreline erosion, shoreline retreat, Digital Shoreline Analysis System (DSAS).*

1. INTRODUCTION

The Almanarre Beach is located at the western tombolo of Giens in the Hyères Township in the Var department, France. It has a total extent of 4 km along the Salt Road (Figure 1).

The coastline of the Almanarre Beach has been classified into four sectors corresponding to their limiting landmarks (Figure 1 and Table 1) (Lacroix, Than et al. 2015).

Table 1. Sectors of the coastline of the Almanarre Beach (Lacroix, Than *et al.*, 2015)

Sector	Limiting
1	Northern end of the shoreline and B01 to B03
2	B03 to B16
3	B16 to B23
4	B23 to B46, southern end of the shoreline

The sector 1, which is about 1.1 km of the coastline of the Almanarre Beach, stretches from the extreme northern end of the shoreline which includes landmarks B01 to B03. Then, the sector 2 covers about 1.3 km, from the landmark B03 to B16. The sector 3 is about 0.7 km, from B16 to B23. The shoreline of the sector 4 is the longest, about 3 km.

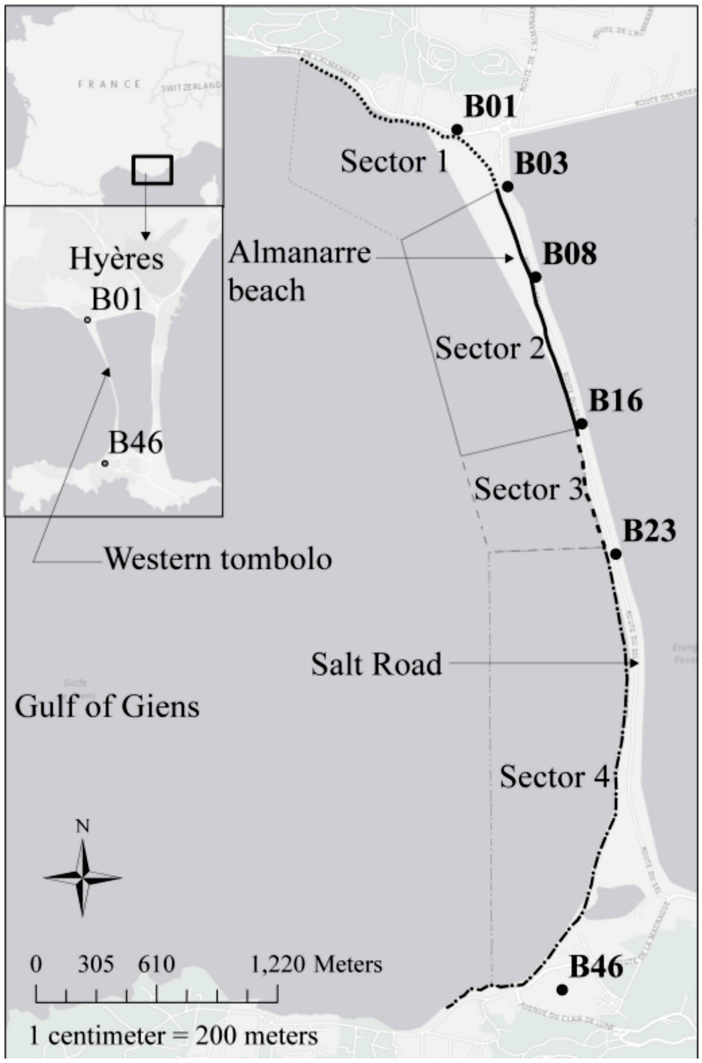

Figure 1. Location of four sectors 1-4 from north to south of the coastline of the Almanarre Beach

The shoreline evolution is of primary interest from the coastal manager's areas and includes three overall categories: eroding, equilibrium, and accreting (Salghuna and Bharathvaj, 2015). The average shoreline retreat estimate for 3000 years is -0.1 m/year in the Almanarre Beach. CEREMA (2016) shows a mean rate of erosion along the Almanarre Beach of 0.5 m/year. Our work provides a much better analysis of the situation.

The focus on this paper is the application of Digital Shoreline Analysis System (DSAS) to calculate rate of changes, predict future trends of shoreline movements, with long, medium, and short term.

2. MATERIALS AND METHODS

Firstly, the shoreline positions will be collected. Secondly, the workflow methodology will be presented. Finally, the configuration of DSAS will be examined.

2.1. Data Acquisition

In our work, the 1920 to 1998 coastlines data used for our work are acquired from CEREGE (Centre de Recherche et d'Enseignement de Géosciences de l'Environnement) association. The shoreline positions were extracted from aerial photographs by some organisms, namely IGN, Centre Camille Jullian (CNRS, Aix-en-Provence), Société Aérial (Aix-Les Milles). The different steps of data processing of these aerial photographs are: selection of a reference picture, geometric rectification of the aerial photographs available, and finally digitization of the coastline and error estimate.

The 2000 to 2012 coastlines were extracted from GPS, DGPS and LiDAR surveys (bathymetry and topography data) from Étude et Observation du Littoral (EOL) and Service Hydrographique et Océanographique de la Marine (SHOM) association, respectively.

All shoreline data were projected to the same geographical system "Lambert 93". A shoreline data is a shapefile "*.shp". The shoreline must have date, length, ID, shape, and uncertainty attributes. The shoreline uncertainty was calculated and entered for the uncertainty attribute. The other attributes (length, ID and shape) were automatically generated in ArcGIS, once a shapefile was created. Finally, a collection of shoreline positions was obtained under shapefile format for the entire period 1920-2012.

The total positional uncertainties (U_t) were used as weights (weighted linear regression or weighted least squares) in the shoreline change analysis in the DSAS. The total positional uncertainties for historical position shorelines were estimated ± 10 (m). The annualized uncertainty (U_a) is the error for the shoreline change rate, in m/year. It was calculated as the square root of the sum of the squares of total positional uncertainty for each shoreline divided by the analysis period, as in [1]:

$$U_a = \pm \frac{\sqrt{\sum_1^n U_{ti}^2}}{T} \qquad [1]$$

where i is index of the shoreline, U_{ti} is the total positional uncertainty for each shoreline i, and T is the period of analysis.

2.2. Workflow Methodology

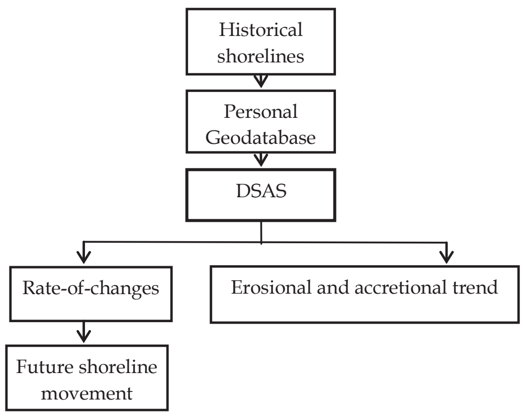

Figure 2. Workflow for the rate-of-changes estimation and prediction of shoreline changes

Firstly, the historical shoreline positions were collected. Secondly, the DSAS tool was used to estimate shoreline change. The annual rate of shoreline changes (rate-of-changes, in m/year) is calculated at each transect by End Point Rate (EPR) method. The short, medium, and long term rate-of-change are calculated. Then, the erosional and accretional trend is examined. Finally, an extrapolation of the average annual rate-of-change was applied to determine the future shoreline movement (Figure 2).

2.3. Implementation of DSAS

The period of calculation was divided into a short and medium and long term periods. The long term period is 92 years (Than, 2015). The time intervals of the short and medium term periods vary from 11 to 40 years corresponding to the human impacts on the Almanarre Beach. It is enough to analyze the shoreline changes in the study area. The short term period is from 1960 to 1971 (installation of gabions, construction of the Salt Road). The medium term periods are from 1920 to 1960 (without human impact) and from 1971 to 2012 (the establishment of wooden palisades, riprap revetment, "ganivelles", etc. the complete removal of riprap revetment, annual reconstitution of the sand dune).

DSAS tool, an extension for ArcGIS software, uses the statistical techniques to compare shoreline positions through time and calculate shoreline changes. The EPR is determined by dividing Net Shoreline Movement by the time period elapsed, as in [2]:

$$R = D/T_e \qquad [2]$$

where R is in m/year, D is in meters and T_e is the time period elapsed between the oldest and the most recent shoreline (years).

The implementation of DSAS is divided into four main steps:

- First of all, a baseline defined in a shapefile format (*.shp) with many attributes (name, type, geographic properties) was created from north to south almost parallel to general orientation of the shoreline, through the landmarks B01-46 of French Electricity (EDF). This baseline is located onshore and used to calculate the distance from a shoreline to it at each orthogonal transect.

- Then, a collection of shorelines and baseline was generated in ArcGIS. All shoreline for each selected period were appended to a single shapefile. The Feature Class of the shoreline and baseline were built in each Personal Geodatabase that was created by using ArcCatalog for each period.

- After that, the orthogonal transects equidistant perpendicular lines to the baseline were created at a specified spacing alongshore by using DSAS, once the Personnal Geodatabase was ready in ArcGIS. A total of 246 orthogonal transects was cast along the baseline from north to south of the Almanarre Beach at a 25 m spacing alongshore. The length of transect is 200 m. These transects span the entire coastline of Almanarre Beach. They are numbered with Transects ID 1-246 ordered from north to south (Figure 3). The transects that do not intersect at least three shorelines are not included in the shoreline change estimation.

- Finally, after the creation of the orthogonal transects, DSAS calculates the rates of shoreline change along each transect for each period by using EPR method. The regional rate-of-changes is calculated by averaging the rate-of-changes from all transects in each selected sector.

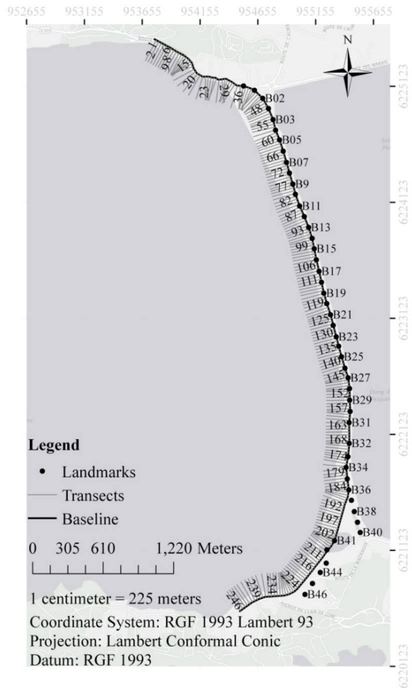

Figure 3. Baseline and position of transects on system landmarks.

3. RESULTS

Firstly, the annual rate-of-changes is exposed. Then, the erosional and accretional trends are examined. Finally, the future shoreline movement is presented.

3.1. Annual Rate-of-changes

The results are presented for each sector. Table 2 summarizes the rate-of-change for each studied period.

First of all, in the sector 1, only 9% of transects are erosional and 30% are accretional in the long term (Table 2). The average long term rate-of-change for all erosional transects in the sector 1 is -0.02 ± 0.15 m/year (Table 2). The maximal long term rate of shoreline erosion (-0.03 ± 0.15 m/year) was found at transect number 47 (near landmark B02) (Table 2). The sector 1 is accreting at an average long term rate of 0.06 ± 0.15 m/year (Table 2). The maximal long term rate of shoreline accretion (0.14 ± 0.15 m/year) was found at transect number 38 (near landmark B01). Along the sector 1 of coastline, the long term rates have similar trends with the short term ones (Figure 4). About 9% of transects are erosional, and 30% are accretional from the long term rate (Table 2). The maximal short term erosion rate (-0.01 ± 1.29 m/year) was found at transect number 47 (near landmark B02) (Figure 4). The maximal accretion rates were found at transect number 53 (about 0.93 ± 1.29 m/year) for short term period (Table 2). In sector 1, the average medium term rate (1971-2012) indicates more erosion than the average long term rate (Figure 4).

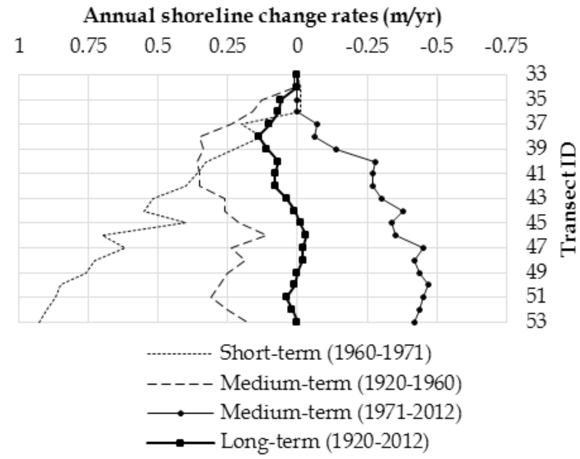

Figure 4. Short, medium, and long term annual shoreline change rates in sector 1 of the Almanarre Beach (Negative and positive values indicate erosion and accretion, respectively)

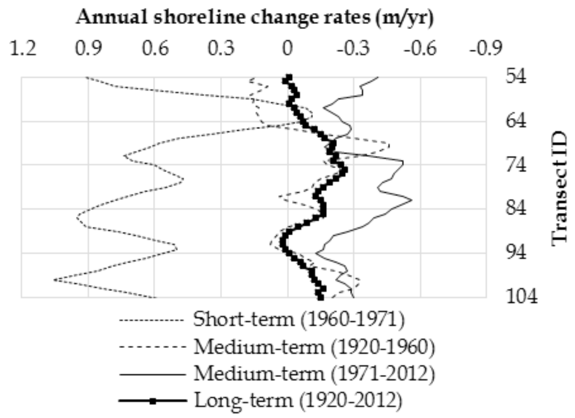

Figure 5. Short, medium, and long term annual shoreline change rates in sector 2 of the Almanarre Beach (Negative and positive values indicate erosion and accretion, respectively)

Then, sector 2 is highly erosional because of its exposure to the strong waves, winds and rip currents of the western and south-western regimes in number of transect erosion. At sector 2, majority of shorelines were eroded. Sector 2 is the most erosional sector of the Almanarre Beach (Table 2 and Figure 5). The middle of sector 2 from transects number 65 to 88 are erosional in the long and medium terms period except the short term period. Erosion is the general long term trend of the sector 2 (Figure 5). About 90% of transects are erosional in the long term period. Sector 2 has the lowest rate of accreting beach (0%) of the four sectors in the medium term period (1971-2012) (Table 2). The average long term erosion rate is -0.12 ± 0.15 m/year (Table 2). The maximal long term erosion rate (-0.26 ± 0.15 m/year) was calculated at transect number 73 (near landmark B08) (Figure 5). Other areas also have significant long term erosion rates. The medium erosion rates in sector 2 are the most erosional rates of the four sectors.

Approximately 100% of the short term rates are accretional, the highest percentage for the four sectors (Table 2 and Figure 5). The accretion rates have increased after the beach nourishment in short term period of 1960-1971 (Figure 5). The average short term accretion rate (0.65 ± 1.29 m/year) was estimated for the short term period.

Table 2. Shoreline change trends of the Almanarre Beach

Parameters \ Period	Short term	Medium term		Long term
	1960-1971	1920-1960	1971-2012	1920-2012
Sector 1 (North Zone)				
Number of transects erosion	4	0	17	5
Number of transects accretion	17	21	4	16
Beach erosion (m)	75	0	400	100
Beach accretion (m)	400	500	75	375
Rate beach erosion (%)	8	0	32	9
Rate beach accretion (%)	32	40	8	30
Minimal rate of erosion (m/year)	-0.01 ± 1.29	0.00 ± 0.35	-0.06 ± 0.34	-0.01 ± 0.15
Average rate of erosion (m/year)	-0.01 ± 1.29	0.00 ± 0.35	-0.33 ± 0.34	-0.02 ± 0.15
Maximal rate of erosion (m/year)	-0.01 ± 1.29	0.00 ± 0.35	-0.47 ± 0.34	-0.03 ± 0.15
Minimal rate of accretion (m/year)	0.13 ± 1.29	0.01 ± 0.35	0.00 ± 0.34	0.01 ± 0.15
Average rate of accretion (m/year)	0.56 ± 1.29	0.23 ± 0.35	0.00 ± 0.34	0.06 ± 0.15
Maximal rate of accretion (m/year)	0.93 ± 1.29	0.36 ± 0.35	0.00 ± 0.34	0.14 ± 0.15
Sector 2 (North-central Zone)				
Number of transects erosion	4	32	51	46
Number of transects accretion	47	19	0	5
Beach erosion (m)	75	775	1250	1125
Beach accretion (m)	1150	450	-25	100
Rate beach erosion (%)	8	63	100	90
Rate beach accretion (%)	92	37	0	10
Minimal rate of erosion (m/year)	-0.06 ± 1.29	-0.03 ± 0.35	-0.13 ± 0.34	-0.01 ± 0.15
Average rate of erosion (m/year)	-0.09 ± 1.29	-0.20 ± 0.35	-0.32 ± 0.34	-0.12 ± 0.15
Maximal rate of erosion (m/year)	-0.11 ± 1.29	-0.46 ± 0.35	-0.56 ± 0.34	-0.26 ± 0.15
Minimal rate of accretion (m/year)	0.04 ± 1.29	0.01 ± 0.35	0.00 ± 0.34	0.01 ± 0.15
Average rate of accretion (m/year)	0.65 ± 1.29	0.10 ± 0.35	0.00 ± 0.34	0.01 ± 0.15
Maximal rate of accretion (m/year)	1.06 ± 1.29	0.18 ± 0.35	0.00 ± 0.34	0.02 ± 0.15
Sector 3 (Central Zone)				
Number of transects erosion	20	27	12	27
Number of transects accretion	7	0	15	0
Beach erosion (m)	475	650	275	650
Beach accretion (m)	150	0	350	0
Rate beach erosion (%)	74	100	44	100
Rate beach accretion (%)	26	0	56	0
Minimal rate of erosion (m/year)	-0.06 ± 1.29	-0.07 ± 0.35	-0.02 ± 0.34	-0.06 ± 0.15

Parameters \ Period	Short term 1960-1971	Medium term 1920-1960	Medium term 1971-2012	Long term 1920-2012
Average rate of erosion (m/year)	-0.73 ± 1.29	-0.37 ± 0.35	-0.19 ± 0.34	-0.17 ± 0.15
Maximal rate of erosion (m/year)	-1.20 ± 1.29	-0.73 ± 0.35	-0.35 ± 0.34	-0.35 ± 0.15
Minimal rate of accretion (m/year)	0.05 ± 1.29	0.00 ± 0.35	0.03 ± 0.34	0.00 ± 0.15
Average rate of accretion (m/year)	0.24 ± 1.29	0.00 ± 0.35	0.35 ± 0.34	0.00 ± 0.15
Maximal rate of accretion (m/year)	0.51 ± 1.29	0.00 ± 0.35	0.52 ± 0.34	0.00 ± 0.15
Sector 4 (South Zone)				
Number of transects erosion	9	81	2	67
Number of transects accretion	83	24	107	42
Beach erosion (m)	200	2000	25	1650
Beach accretion (m)	2050	575	2650	1025
Rate beach erosion (%)	8	70	2	58
Rate beach accretion (%)	72	21	93	37
Minimal rate of erosion (m/year)	-0.01 ± 1.29	-0.24 ± 0.35	-0.01 ± 0.34	-0.02 ± 0.15
Average rate of erosion (m/year)	-0.01 ± 1.29	-1.08 ± 0.35	-0.06 ± 0.34	-0.17 ± 0.15
Maximal rate of erosion (m/year)	-0.01 ± 1.29	-1.63 ± 0.35	-0.11 ± 0.34	-0.35 ± 0.15
Minimal rate of accretion (m/year)	0.01 ± 1.29	0.01 ± 0.35	0.02 ± 0.34	0.01 ± 0.15
Average rate of accretion (m/year)	1.50 ± 1.29	0.31 ± 0.35	0.32 ± 0.34	0.08 ± 0.15
Maximal rate of accretion (m/year)	3.60 ± 1.29	0.67 ± 0.35	0.69 ± 0.34	0.14 ± 0.15

Negative and positive values indicate erosion and accretion, respectively.

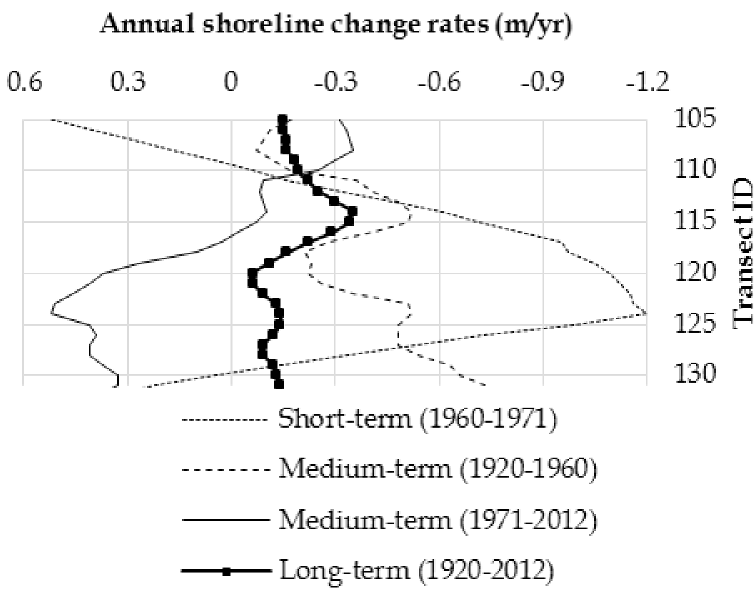

Figure 6. Short, medium, and long term annual shoreline change rates in sector 3 of the Almanarre Beach (Negative and positive values indicate erosion and accretion, respectively)

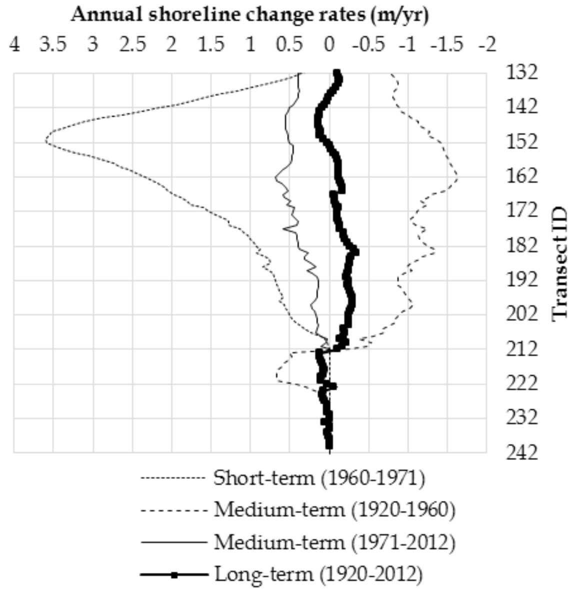

Figure 7. Short, medium, and long term annual shoreline change rates in the sector 4 of the Almanarre Beach (Negative and positive values indicate erosion and accretion, respectively)

After that, sector 3 is slightly erosional in the long term period (Figure 6). The average long term rate in sector 3 is erosional at -0.17 ± 0.15 m/year (Table 2). Approximately 100% of transects are erosional in the long term period (Table 2). The maximal long term erosion rate of -0.35 ± 0.15 m/year was estimated at transect number 114 (near landmark B19) (Table 2 and Figure 6). In opposition to long term analysis, the medium term approach (1971-2012) suggests a stable or accreting beach. We observed that the medium term period of 1971-2012 in sector 3 indicates a trend of accretion (Figure 6). The average of medium term accretion rates (1971-2012) is 0.35 ± 0.34 m/year (Table 2). The maximal medium term accretion rate (0.52 ± 0.34 m/year) was estimated at transect number 120 (near landmark B20). Finally, the sector 4 presents trends of accretion in contrast to sector 2, except the medium term period of 1920-1960 (Figure 7). About 58% of transects are erosional in the long term approach (Table 2). The average long term erosion rates were approximately stable at -0.17 ± 0.15 m/year (Table 2). The maximal long term erosion rate (-0.35 ± 0.15 m/year) was found at transect number 184 (near landmark B36) (Table 2 and Figure 7). This sector is accretional at 37% of transects, suggesting a general trend of erosion (Table 2). The sector 4 experienced accretions at average long term rates of 0.08 ± 0.15 m/year (Table 2). The sector 4 showed the highest long term accretion rate about 0.14 ± 0.15 m/year at transect 147 (near landmark B36) (Table 2 and Figure 7). The medium term rates of 1920-1960 are opposite to the short term rates (Figure 7).

4.2. Erosional and Accretional Trends

Figure 8 shows the rates of change for long term period. Sectors 1 and 2 present trends of erosion in contrast to the sectors 3 and 4. These trends are closely comparable to the trends from the literature. The maximal long term rate of shoreline retreats is -0.35 ± 0.15 m/year at transect number 114 (between landmarks B18 and B19, Figure 8). The average annual rate of shoreline recession is estimated between -0.01 ± 0.15 and -0.56 ± 0.34 m/year in sector 2. The highest long term accretion rate about 0.14 ± 0.15 m/year was found at transect 147 (near landmark B26) (Figure 8). The average annual rate of shoreline accretion vary from 0.01 ± 0.15 to 3.60 ± 1.29 m/year in the sectors 3 and 4 of the Almanarre Beach.

3.3. Future Shoreline Movement

Our works aim to forecast shoreline changes. A linear regression with a slope of an average annual rate-of-change was used. The extrapolations of the shoreline are made from the average rate of shoreline changes for the period from 1971 to 2012. The average rate of shoreline retreats vary from -0.32 ± 0.34 to -0.35 ± 0.34 m/year for the sectors 1 and 2. The average rate of shoreline accretion varies from 0.32 ± 0.34 to 0.35 ± 0.34 m/year for the sectors 3 and 4. Table 4 represents the trends of shoreline movement of the Almanarre Beach with different time scales (year 2022, 2032 and 2052). The coastline in year 2022 in sectors 1 and 2 was predicted to retreat at least –3.3 ± 3.4 m comparable with the shoreline in year 2012. The coastline in year 2032 along sectors 1 and 2 would retreat at a distance of -6.6 ± 6.8 m from the shoreline in year 2012 (Table 3).

Table 4. Prediction of trends of shoreline movement for the Almanarre Beach

Sector	Average rates from 1971 to 2012 (m/year)	Distance from the future shoreline to the shoreline in year 2012 (m)		
		2022	2032	2052
1	-0.33 ± 0.34	-3.3 ± 3.4	-6.6 ± 6.8	-16.5 ± 17.0
2	-0.32 ± 0.34	-3.2 ± 3.4	-6.4 ± 6.8	-16.0 ± 17.0
3	0.35 ± 0.34	3.5 ± 3.4	7.0 ± 6.8	17.5 ± 17.0
4	0.32 ± 0.34	3.2 ± 3.4	6.4 ± 6.8	16.0 ± 17.0

Positive and negative values indicate accretion and erosion, respectively.

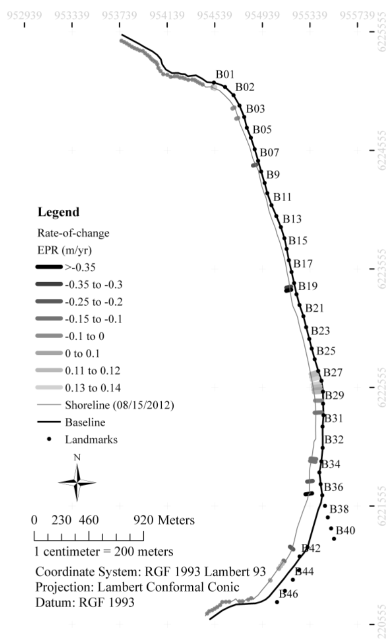

Figure 8. Long term annual rate-of-changes for Almanarre Beach
(Negative and positive values indicate erosion and accretion, respectively)

4. CONCLUSIONS

We suggest that DSAS is effective to identify the zone of accretion/erosion and to evaluate the historical shoreline change by using the extracted shorelines. DSAS is helpful for the coastal management.

The annual historical rate-of-changes were estimated along orthogonal transects by DSAS. The average rates of shoreline erosion are calculated to be from -0.01 ± 1.29 to -0.33 ± 0.34 m/year in sectors 1 and 2. The average rates of shoreline accretion are from 0.01 ± 0.15 to 3.6 ± 1.29 m/year in the sectors 3 and 4. Individual rate-of-change in sector 2 of the Almanarre Beach can reach as high as -0.56 ± 0.34 m/year. The calculated rate-of-change is closely comparable with the trends noted in the literature.

The prediction of future shoreline movements was carried out by using a linear extrapolation of the average annual historical rate-of-changes. The coastline in year 2022 in the sectors 1 and 2 would retreat at a distance of –3.3 ± 3.4 m from the shoreline in year 2012. The coastline in year 2032 along sectors 1 and 2 was predicted to retreat about -6.6 ± 6.8 m comparable with the shoreline in year 2012.

The shoreline change rate estimation in the Almanarre Beach helps to identify the key factors driving the shoreline evolution and propose possible solutions to stabilize the coastline. We consider that our approaches can be used for other coasts.

5. ACKNOWLEDGEMENT

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