DOI: 10.21120/LE/16/1/2 ***Landscape & Environment 16 (1) 2022. 15-30***

ASSESSMENT OF THE VULNERABILITY OF ZEMMOURI BAY TO COASTAL EROSION, DIACHRONIC STUDY BETWEEN 1957 AND 2017

NOUR EL IMÈNE MOUHOUBI*[1], RABAH BELKESSA[2], HOUSSEYN OTMANI[3]

[1, 2, 3] Ecole Nationale Supérieure des Sciences de la Mer et de l'Aménagement du Littoral university campus of dély Ibrahim, Algéria
*Email: nour.mouhoubi@gmail.com

Received 21 March 2021, accepted in revised form 21 October 2021

Abstract

Coastal change on sandy shores occurs at a variety of spatial and temporal scales. Gaining knowledge of beach change processes increases our ability to manage coastal erosion risks that affect the growing population living in coastal areas. This study focuses on detecting and analyzing historical changes in the shoreline position of Zemmouri Bay (Northern Algeria) between 1957 and 2017. The evolution of the coastline along the bay was studied from aerial photographs (1957, 1957, 1973, and 1988), google earth satellite images (2006, 2011, and 2016), and DGPS (Differential Global Positioning System) topographic surveys of 2012, 2015 and 2017. The correction of aerial photographs and satellite images was performed using remote sensing tools. The study area was divided into six sectors to achieve our objective. Then, net rates of change in shoreline position over time were calculated using several statistical methods: End Point Rates (EPR), Linear Regression Rates (LRR), and Weighted Linear Regression (WLR). These changes were measured for several time intervals and over a global period (1957e2017). The results revealed significant differences in shoreline position over the past 60 years, mainly on both sides of the Isser Wadi. The most observed coastline retreat is located in the eastern part of the coast, where the rate of change has reached -1.25m/year (Mazer Beach East), while the retreat of the coastline was above -1m/year in the center of the bay and -0.50 m/year towards the west. Over a mid-century period, the coast has experienced an overall average net rate of change equal to -1.35m/year. This coastline retreat is due to the combined action of the cumulative effects of the climate on the coast and various human activities on the coastal strip of Zemmouri.

Keywords: DSAS, Shoreline, GIS, Erosion, Accretion

1. Introduction

The evolution of the coastline is a natural phenomenon generated by the conjunction of processes (marine, continental and biological). It depends on the characteristics geomorphologic features of coastal systems (beaches are more sensitive to erosion than cliffs). However, these natural phenomena are exacerbated by anthropic actions that disturb the dynamic balance of the coastal environments (Daniel et al. 1996). Understanding coastal kinetics is essential in the following areas: the coastline's development because this coveted but fragile area is home to a large part of the population and economic activities.

The Algerian coastline of 1600 km is not immune from erosion. Several authors have studied this phenomenon (Boutiba 2006, Boutiba et al. 2006, Boutiba et al. 2009, Boutiba et al. 2011). The coast of the bay of zemmouri is an excellent site for its geographical context and the anthropic pressure which reigns there, translated by various constructions and tourist and industrial infrastructures. This coast, which stretches over 50km, mainly includes sandy beaches, not exempt from this regression.

Understanding coastal evolutionary trends are necessary for coastal zone environmental monitoring and management. (Natesan et al. 2015). Currently, it is easier to generate accurate coastline positions using GIS software. This study analyzed the coastline evolution for 60 years of the Zemmouri Bay coastline from 1957 to 2017, using geospatial techniques with an automatic calculation tool (DSAS). In this study, several statistical approaches were used to determine shoreline change rates, including Endpoint Rate (EPR), Linear Regression Rate (LRR), and Weighted Linear Rate (WLR) (Himmelstoss 2009, Moussaid et al. 2015, Natesan et al. 2015, Ayadi et al. 2015). This work's main objective consists of mapping and quantifying areas of erosion and accretion and assessing long-term rates of shoreline change along the bay's coast.

2. Materials and methods

Study area

The bay of Zemmouri (e.g., bay of Courbet) is located to the Bay of Algiers' immediate east. Widely open towards the north, it extends over some sixty kilometers (53.7 km), bounded to the west by Cap Matifou Est and the east by Cap Djenat (see Fig.1).

The shoreline is oriented SW-NE, and its Lambert coordinates are:

* 3°13′18′ and 3°43′24′′ East longitude.

* 36°52′45′′ and 36°48′48′′ North Latitude.

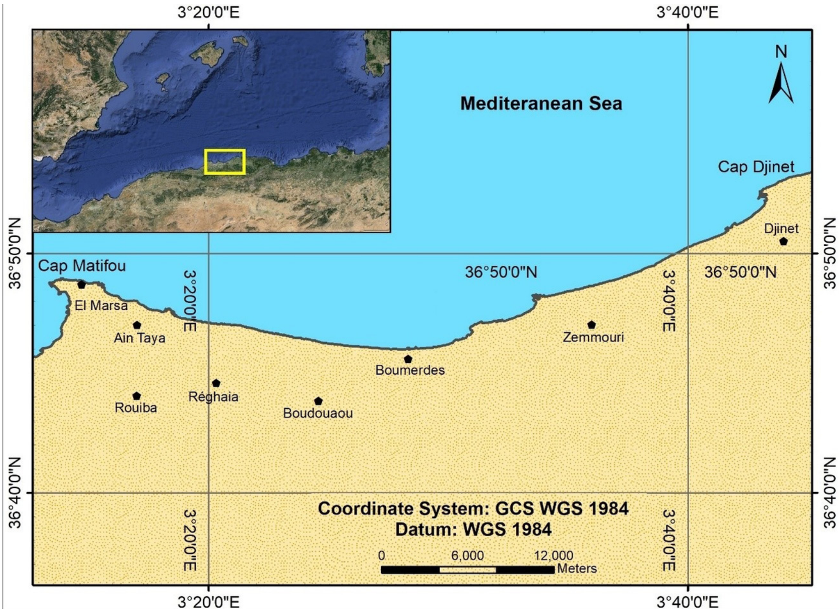


Fig. 1. The situation of the Zemmouri bay

Geology, climate, and underwater morphology of the study area

The coastline of our study area is characterized by several topographic units, which are represented by the Sahel of Algiers, the Mitidja plain, the coastal hills, and a mountainous area (Atlas Blideen) (Fig.2, Fig.4 and Fig.5). The large bay of Zemmouri belongs geologically to the Maghrebian zones (Fig.2), an orogenic segment of the Dinaric branch of the peri-Mediterranean Alpine orogen. (Durand-Delga 1969)

The same authors consider this internal domain as part of a plate called the "Alboran plate." This one is having an intermediate affinity between Africa and Europe. Structurally, the Maghrebids are subdivided into an internal zone (basement and Kabyle ridge with the Oligo-Miocene and flysch north of Kabyle) and an external zone consisting of layers of external flysch (Mauretanian, Massylian) and Tellian layers (Fig.3).

Meteorological and oceanographic factors are essential for understanding sediment transfer along the coast and its consequences on beach nourishment or erosion. The Mediterranean climate is characterized by four contrasting seasons, mild winter, spring, and autumn are sometimes very rainy, and dry and hot summer.

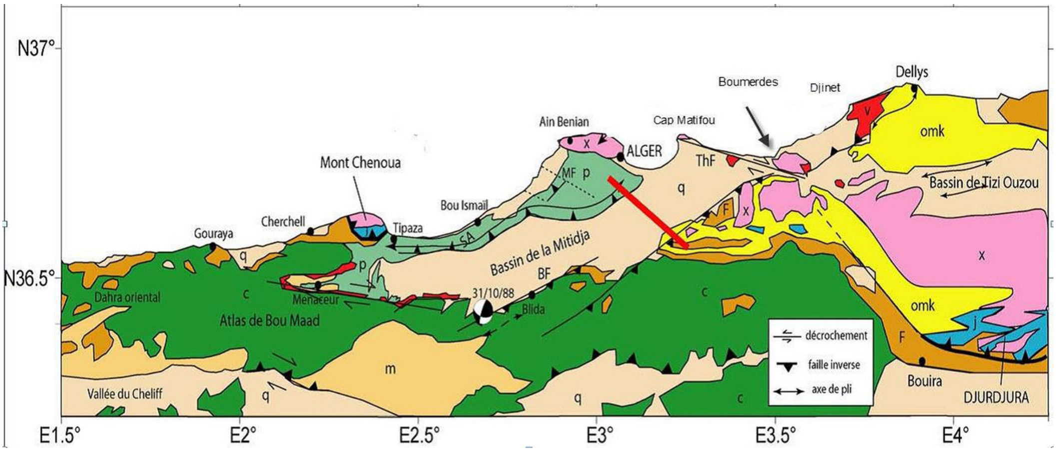


Fig. 2. Geological section showing the relationships between the different Maghrebian units (Bracène 2001)

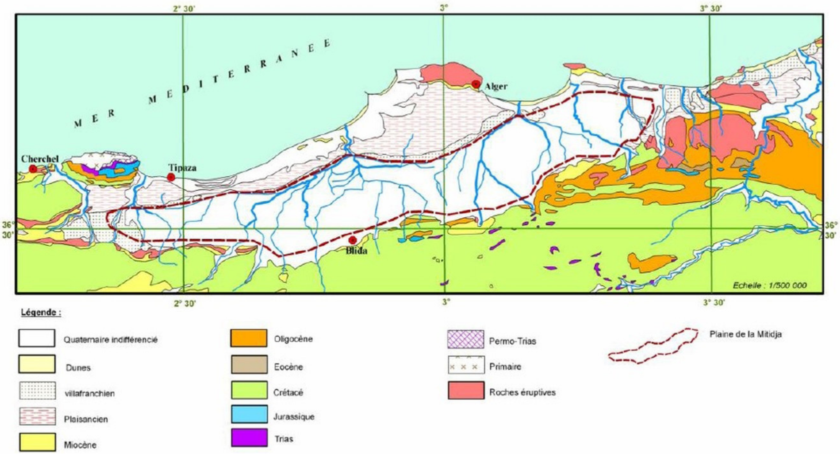


Fig. 3. Simplified geological map of the Mitidja plain

The narrowness of its plateau continental characterizes the bay: 1.5 km (Leclaire 1972), it narrows at the level of Mount Thénia where tectonics is active, its width does not exceed 3 km, moreover, in front of the low area of the wadi Isser, the width of the shelf can reach 15 km (Fig.5) , we find :

- A succession of submarine dunes reaching the area of Cap Blanc and the Black Rock: under the effect of the swell, the sediments of large submarine dune clusters are found only at the level of Cap Djennet and Cap Blanc (hydraulic dunes).
- A rocky plain surrounding the peninsula of Cape Matifou appears in the form of shreds forming the plateau of Agueli Island and Sanja Island.
- The rest of the bottom is made up of loose sediments with sometimes sparse vegetation.

The continental slope is intensely chiseled by a network of canyons (submarine valley of Zemmouri), which disturbs the plateau's regularity and the evolution of the coastline.

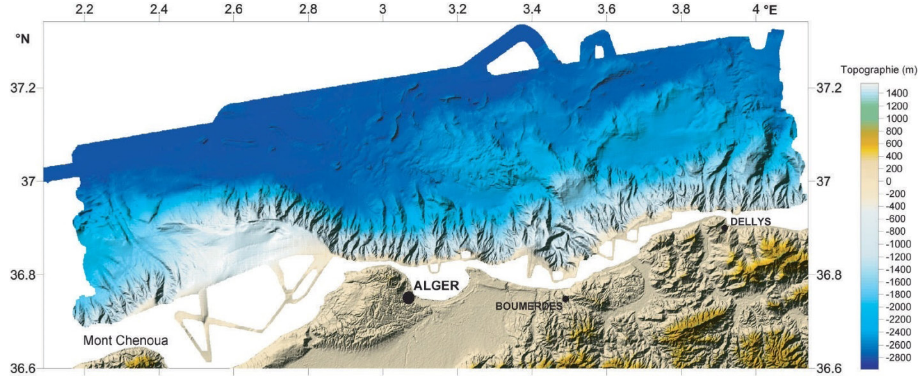


Fig. 4. Bathymetry and topography of the Algerian region

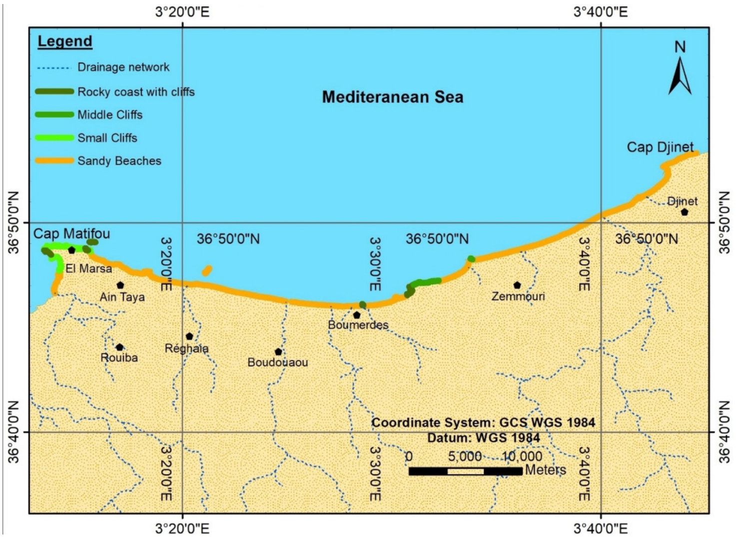


Fig. 5. Drainage network map and morphological classification of Zemmouri bay

Methodology followed

The methodology used in this work is based on traditional techniques for the digital processing of geographical information that has been widely tested in coastal kinematics. This part aims to detail and present the methodological approach that allowed us to extract shorelines and analyze the diachronic evolution of northern Algerian sandy coasts at a regional and local level.

The approach adopted to analyze the coastline's evolution in Zemmouri Bay involves exploiting the various coastlines digitized and collected by a tool called "DSAS." The DSAS tool is a GIS module that allows the evaluation of shoreline evolution. Indeed, evolution rate statistics are calculated on transects perpendicular to the shoreline, based on these historical shoreline surveys. DSAS automatically generates these transects.

In this work, the distance between the transects is 25 meters. The results are presented in the form of a map. The period for calculating shoreline evolution rates is 60 years when 1957 coast is available and is divided into 5 or 6 periods depending on the areas and data open (Table 1).

Shoreline change rates are calculated using EPR (End Point Rate) methods for a single transect in one year. Positive and negative points of change show beach accretion and beach erosion.

Choice of the reference shoreline

The analysis of coastline mobility at the local level is based on several markers chosen according to their relevance to the types, nature of available data, and sites studied. On the aerial photographs, the upper limit of the range was selected to measure the evolution of the coastline of the sites. On the other hand, in terms of satellite images, the only line used is the high sea line before the aerial shots in 2006, 2011, and 2016.

Image processing and rectification methods

External rectification

The digitized images contain various deformations inseparable from the mechanism of taking the aircraft and the relief overflown. It is necessary to correct them to compare the extracted coastlines to each other. Planimetric rectification (2D) corrects the radial distortions due to the optics and those caused by the movements of the aircraft (pitch, roll, rollover) (Dolan et al. 1980 , Anders et al. 1990, Crowell et al. 1991, Moore, 2000). It involves applying a rectification model by capturing homologous (bitter) points between two images, one being the image to be corrected, the other is an already georeferenced image. The reference is the orthophoto-plan (1984) and the Topographic Map at 1:25,000, produced by INCT, with a spatial resolution of 0.5 m and projected in UTM (WGS 1984 ellipsoid). The orthophotographs result from a 3D rectification that corrects the vertical deformations related to the relief, significant in continental areas, moderate on the coast (Dolan et al. 1978; Anders et al. 1990, Crowell et al. 1991).

Table 1. List of data used in this study

Date	Data type	Image scale	File type	Image type
1957 - 1959	Aerial photographs	1/25 000	Geo-TIFF	Black and white
1973	Aerial photographs	1/25 000	Geo-TIFF	Black and white
1980	Aerial photographs	1/10 000	Geo-TIFF	Black and white
2006 - 2011 - 2016	Satellite image	1 - 10m	Geo-TIFF	Color
2012 - 2015 - 2017	DGPS topographic surveys	/	XYZ	/

Internal Rectifications (Image Correction)

The representation of an image on the screen is important for a good photo interpretation, hence the importance of radiometric enhancement of an image in improving its visual appearance. Our improvement was based on the examination of the histogram of each image to mitigate the undesirable effects. But first, we had to assign a color to each of the three channels (red, green, blue) for the multispectral satellite images. The command " band combination " of the module " Raster " of Erdas Imagine was the tool of the attribution of the colors to the channels (Red to 1, Green to 2, Blue to 3).

As for the histogram, a selection was made on a band of a few hundred meters to apply a "general contrast meters to apply a "general contract" based on the "standard deviation of the selected area. The difference appears on the samples taken before and after radiometric enhancement of the same image.

Shoreline extraction and error evaluation

A dozen reference lines that can be assimilated to the coastline have been defined by Robin (2002). Some authors take the coastline as the limit of dune vegetation, the most appropriate indicator to observe and quantify shoreline mobility (Thieler et al. 1994, Robin 2002). Etymologically, the coastline is the line of the highest spring tides and thus delimits the Public Maritime Domain. On microtidal coasts where the tidal range is negligible, the coastline is often associated with the instantaneous shoreline (Suanez et al. 1993, Durand 1969), although the tide induces a margin of error, meteorological conditions (surge/surge) and the morphological variability of swash zones (fluctuations in their slope). This is why we chose to define the coastline by the radiometric difference between the dark pixels related to wet areas and the light pixels (Dolan et al. 1978 , Crowell et al. 1991, Douglas and Crowell 2000 , Thieler et al. 1994).

The accuracy of the coastline position and the percentage of extraction error is affected by two types of uncertainty: positional uncertainty related to the nature of the shoreline position

Table 2. Estimated errors for each shoreline data source

Source of uncertainly	Magnitude
Photo measurement uncertainty	
On-screen delineation (O)	3
RMS ortho-rectification	1,27 (0,5 - 3,5m)
Photo positional uncertainly	
Tide stage (t)	0,5
DGPS positional uncertainly	
The error in location <0,5 pixel	1
Total uncertainly	3,53m
Annualized uncertainly (60 years)	0,059 m/year

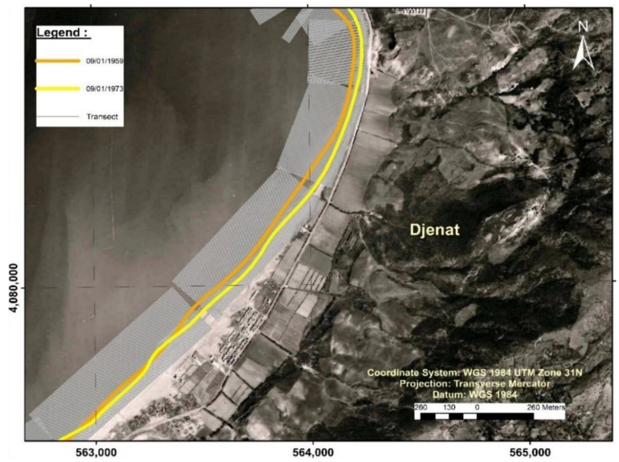


Fig. 6. Baseline and transects map for Djenat Familial beach)

at the time it was taken, the ortho-rectification process, and the on-screen delineation of the coastline reference feature, and the positional uncertainty of DGPS (Table 2).

These uncertainties are considered random and uncorrelated. Finally, the total uncertainty is given by the square root of the sum of the squares of the different variables (Fletcher et al. 2003).

$$Ut = \pm\sqrt{t^2 + RMS^2 + O^2 + DGPSRMS^2} \qquad \text{(eqt 1)}$$

Where :

U_t – Total uncertainties

t – Tidal stage uncertainty

O – On-screen delineation

RMS – Ortho-rectification uncertainty

DGPS – Error in location

Erosion rate calculation

The advantage of the DSAS tool is that it gives a graphical and statistical evolution of the coastline. It provides a standardized method to trace statistical evolution while analyzing past and present shoreline changes. The DSAS software requires preparing coastlines in vector format in a geodatabase and creating an imaginary baseline from which DSAS makes transects that will intersect the different coastlines. For this study, we used 25 m between the 200 m long transects as a measurement step. The sufficient mesh size (25 m) allows for a better appreciation of the coastline evolution in detail and to specify the coastline behavior locally (Fig.6).

3. Results and discussion

Results

The coastline changes provide information on coastal dynamics and sedimentary transfers along the coast (Thieler et al. 2005, Hakkou et al. 2011, Moussaid et al. 2015, Natesan et al. 2015). Considering the size of the bay of Zemmouri, which vastly exceeds 40 km, we divided it into six zones to have more visible results and decrease the duration of calculation.

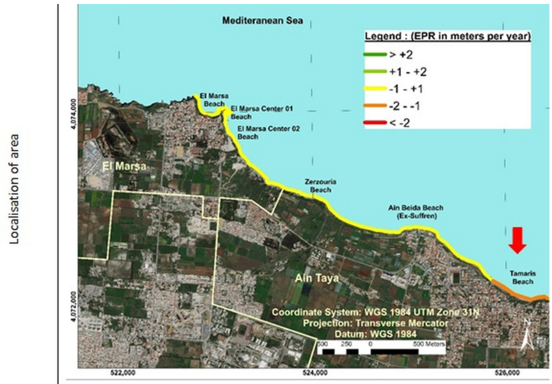
The evolution of the coastline since 1957 was traced using topographic surveys conducted in 2012, 2015, and 2017 (LEM, 2017) and satellite imagery (2006, 2011, and 2016) as well as a series of aerial photographs (1957, 1959, 1973 and 1980).

We measured this evolution over several time intervals (1957-1980, 1959-1980, 1959-1973, 1957-2006, 1959-2006, 1973-2006, 2006-2011, 2011-2015, 2012-2016, 2015-2016, and 2016-2017) and over an aggregate period (1957e2017). The study revealed disparate mixed results at spatial and temporal scales. The maximum coastal erosion recorded for 2012e2016 and 2016e2017 is 2.9 ha and 2 ha, respectively.

The following figures show the total evolution of the coastline, the "EPR," which means the annual change (m/year) over a global period (1957e2017) :

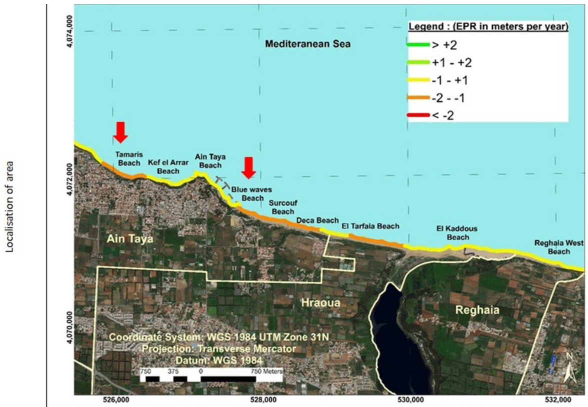
From Jean Bart to Boudouaou el bahri

The analysis of the maps of the evolution of the coastline has allowed us to reach the following findings ; from 1957 to 1959, and compared to the entire coastline examined between the islet Sandja and the eastern limit of El Kaddous, only the shoreline of the area located at the beaches of Tamaris, Surcouf, and Tarfaia has experienced an erosive change (an average loss of 68m of beach width). The rest has experienced a



Mean Evolution (EPR,m/an)	-0.462	-0.462	-0.116	-0.395	-1.20
Beaches	El Marsa	El Marsa Centre01	El Marsa Centre02	Zerzouria	Tamaris
Communes	El Marsa			Ain Taya	

Fig. 7. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Jean Bart toTamaris)



Mean Evolution (EPR,m/an)	-1.2	-0.166	-0.18	-1.66	-0.17	-0.5	-1 -0.17	-0.166	+0.15
Beaches	Tamaris	Kef el Arrar	Ain Taya	Blue Waves	Surcouf	Deca Beach	El Tarfaia	El Kaddous	Reghaia West
Communes	Ain Taya						Hraoua		Reghaia

Fig. 8. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Tamaris to Boudouaou el bahri)

retreat of about 10 meters or an erosion of about 0.35 meters per year. This comparison also highlights the impact of human activities on the coastline. Indeed, the construction of the breakwater of Ain Taya has induced very significant variations along the western coasts of this area. Since then, we assisted to the formation of a tombolo that leans against these structures by blocking all the sediment transit from the east (see Fig.7 and Fig.8).

The coastline of Boudouaou Marine, Réghaïa and Boumerdès

All the aerial missions from 1957 to 2006 have allowed us to trace the coastline's precise evolution and measure the coastline's speed of recession at the stations previously selected (five stations for the site of Réghaïa and ten for the area of Boumerdès).

Overall, from 1957 to 2003, we note that the recession of the coastline has been moderate and regular throughout these coastal portions (0.45 m to 1.9 m per year). From 1973 to 1980, the retreat of the coastline was maximum, locally more than 23 meters to Boumerdès and 57 meters in Réghaïa, for a period of 12 years. From 1980 to 2003, the trend of the demaigrissement of the beaches continues, the results shown in the table confirm in large part this erosive trend.

In March 2003, two short groins made of natural riprap were built along the Boumerdès seafront boulevard. This intervention of the man to modify the morphodynamics of this zone considerably. The groins have blocked the littoral transit of the high beach; erosion is developing downstream. After the construction of the breakwater in 2006, the average width of the beach has increased from 50m to 100m in 70 years (see Fig.11). In summary, on these two sites (Réghaïa and Boumerdès), the retreat of the coastline has been progressive since 1957. Along the Boumerdès seafront, the retreat of the shoreline at the level of the beaches is not very considerable. On the contrary, this part gained in width more than the other beaches of the bay of Zemmouri; nevertheless, the approximation of the dwellings and the installations at sea can be threatened (see Fig.9 and Fig.10).

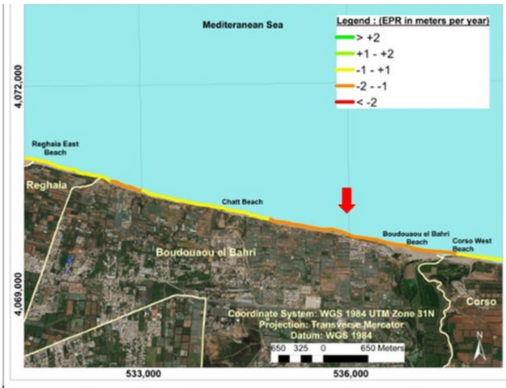
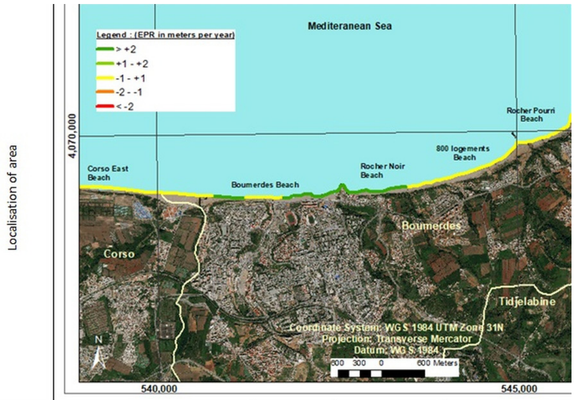
Localisation of area				
Mean Evolution (EPR,m/an)	-0.25	-1.70 0.35	-1.70	0.25
Beaches	Reghaia East	Chatt	Boudouaou el Bahri	Corso West
Communes	Reghaia	Boudouaou el Bahri	Corso	Corso

Fig. 9. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Reghaia to Corso)



Mean Evolution (EPR,m/an)	+0.25	+4.92	+4.92	+0.25	-0.17
Beaches	Corso East	Boumerdes	Rocher Noir	800 logements	Rocher Pourri
Communes	Corso	Boumerdes			

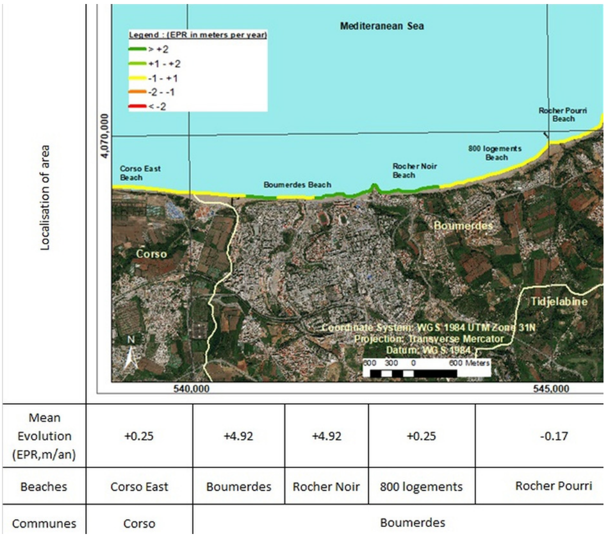
Fig. 10. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Corso to Rocher Pourri)

Fig. 11. Seafront of Boumerdes between 1980 and 2021

The coastline of Zemmouri El Bahri

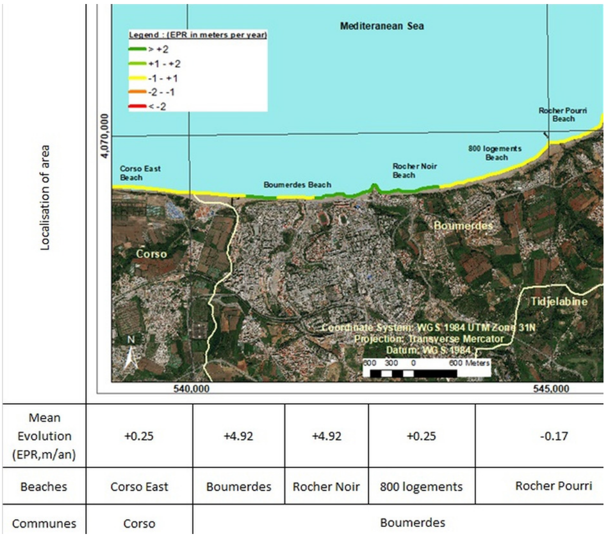
The recession of the coastline from 1957 to 1980 has been moderate and irregular along the coastline of Zemmouri El Bahri (-0.5 to -2.8 m / year). From 1973 to 2006 the recession was maximum (locally more than 5 m/year). Since 2006 the erosion has weakened (on average 0.7 to 1.2 meters per year), but it has become very irregular along the coast of Zemmouri El Bahri. Some stations of the coast have experienced, on the contrary, between 1980 and 2006 of the contributions of sand leading to the fattening of the coast, this is the case of the stations of the beaches of Sghirette and Figuier East. From 2006 to 2014, the trend of the recession continues virtually on the entire coast (see Fig.12).

The net rate of change of the coastline between 1957 and 2017 has been stable; we note an average change of -0.17 m / year.



Mean Evolution (EPR,m/an)	+0.25	+4.92	+4.92	+0.25	-0.17
Beaches	Corso East	Boumerdes	Rocher Noir	800 logements	Rocher Pourri
Communes	Corso	Boumerdes			

Fig. 12. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Figuier to Zemmouri)

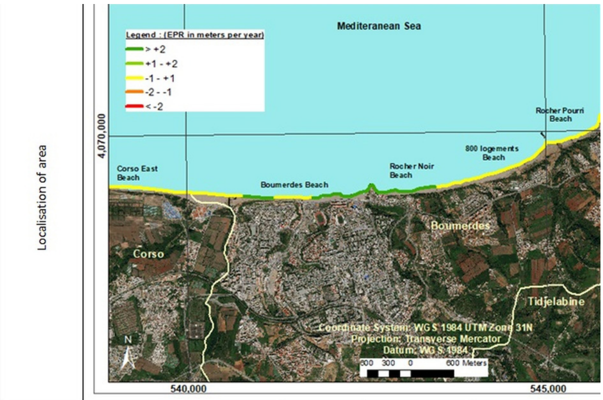


Mean Evolution (EPR,m/an)	+0.25	+4.92	+4.92	+0.25	-0.17
Beaches	Corso East	Boumerdes	Rocher Noir	800 logements	Rocher Pourri
Communes	Corso	Boumerdes			

Fig. 13. Shoreline evolution between 1957 and 2017 in the overall study area, (erosion and accretion) computed by the End Point Rate (EPR) (Zemmouri to Cap Djenat)

The coastline of Cap Djenat

From Zemmouri to Cap Djenat, we record in this sector a relatively progressive fattening of the beach from 1957 to 1973. This gain in the beach is variable and reaches by place the 45 meters at the level of the stations of Djenat beaches 01 and 02. To the west of the thermal station, we pass from a sector that was in fattening to a zone in erosion; net retreats of about 46 meters and 109 meters are recorded respectively at the level of the station's Mazer East and West. From 1973 to 1980, an apparent retreat of the coastline is recorded at all stations (locally more than 5 meters per year). From 1980 to 2017, a strong recession of the coastline reaching or exceeding locally 5 meters per year is observed at the Djenat 01 and 02 beaches stations. On the other hand, the accretion of the coast is important



Mean Evolution (EPR,m/an)	+0.25	+4.92	+4.92	+0.25	-0.17
Beaches	Corso East	Boumerdes	Rocher Noir	800 logements	Rocher Pourri
Communes	Corso	Boumerdes			

Fig. 14. Evolution of the coastline of Cap Djenat from 1959 to 2021

at the level of the stations of the beach Djenat Familial (locally more than 2 m / year). This change in the coastline evolution occurred following the establishment of the port of Djenat in 2009 (see Fig.14), which has modified the sedimentary transit in this area.The net rate of change of the coastline between 1957 and 2017 was strong and contrasted from one site to another, and we note an average change of -0.38 m / year with a maximum retreat locally of -2.80m / year and a maximum advance of +1.30m / year (Fig. 13).

The net rate of change of the coastline between 1957 and 2017 has been stable; we note an average change of -0.17 m / year.

Discussion

The net rates of annual change show a wide range of results both in intensity and direction (Fig. 15). As a result, 16 out of 38 beaches are eroding, while eight are accreting and 14 are more or less stable (Fig. 15)

The retreat of the coastline is detectable on practically all the stations except for some localized in Cape Djinet and Boumerdes. The intensity of the recession is very different from one site to another. But, given the margin of error admitted during the manipulation of aerial photographs estimated at +/- 0.5 meters and given the duration of the monitoring of the coastline (60 years), an ambiguity exists as to the reliability of the

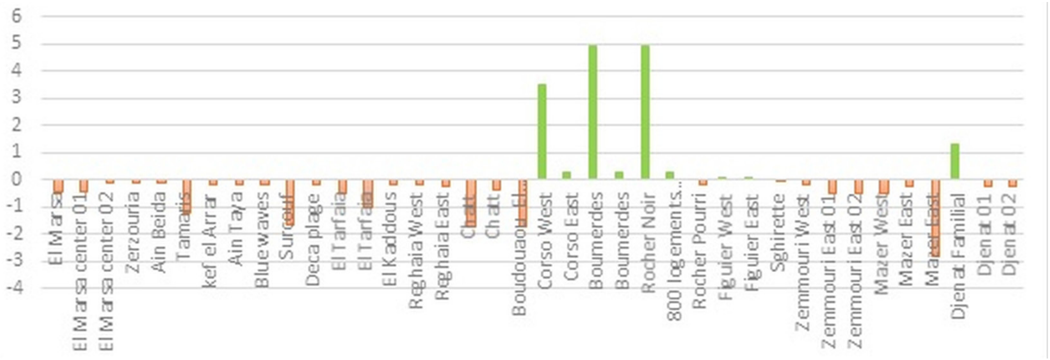


Fig. 15. Evolution of the coastline of Zemmouri Bay from 1959 to 2021

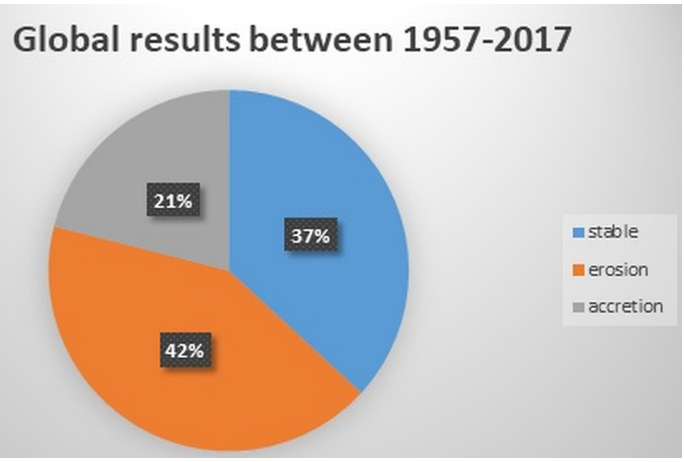


Fig. 16. The general tendency for all transects of the study area between 1957 and 2017

values of the net rate of change less than 0.05 meters per year. Thus, of the 38 stations studied, three have uncertain values that are difficult to discern on the scale of an aerial photograph.

The overall trend for the entire Bay coastline reveals that over the 60 years (1957-2017), 42% of the coastline is eroding, i.e., 21.5 km of coastline, compared to only 21% accreting, i.e., almost 11 km of linear coastline; stable areas account for only 37% with a distance of 19 km located at the level of promontories and rocky regions (Fig. 16).

The method used in this study appears to be an effective tool for assessing shoreline position changes along microtidal coastlines. This study revealed that shoreline change detection can be done using corrected aerial photographs, high resolution satellite data, and DGPS surveys by selecting transects spaced 25 m apart; with automatic computational tools (DSAS) to calculate shoreline changes.

4. Conclusion

The analysis of shoreline position variations over a period of 60 years requires the use of both modern and classical techniques (aerial photography, satellite images and DGPS topographic surveys). Theoretical concepts are presented in this study because we have little climatic and hydrodynamic data that can interpret the historical variations of the coastline.

The study of the evolution of the coastline between 1957 and 2017 has allowed us to identify three distinct sectors:

- The first sector includes the western part of the beach Tamaris to the beach of Boudouaou el bahri recorded the highest rates of recession reaching -1.66m / year. This same sector has experienced stabilization or even a small increase in size from the year 2003, just after the the implantation of the two breakwaters.
- On its side, the sector of the left bank of the oued Réghaia underwent, during this same period, considerable retreats in the position of the coastline. This recession is due. This retreat is due practically to the weak contributions carried by the oued Réghaia and the aggressiveness of the waves.
- Finally the third sector including the beach of Cap Djinet and the eastern part of Oued Isser Beach, has recorded the lowest rate of recession compared to the other two sectors. The values of the net rate obtained fluctuate between -0.17 to -0.64m/year.

To better interpret the changes in the coastline, we chose the most determining hydrodynamic factor hydrodynamic factor. Indeed, the different swells of the area show that the swells, which are that the northeast swells are the most determining, they generate sedimentary losses in the they generate sedimentary losses in the profile towards the open sea. The changes of the littoral along the coast of the bay of Zemmouri during the last 60 years depend also on the human intervention notably the illegal extraction of sand at the level of the beaches of Tarfaia, Kaddous..., but also the implantation of the coastal engineering works and the occupation of the back beaches. From the obtained results, the morphodynamic classification of the sandy beaches was carried out on our site of study while being based on Wright and short (1984), which makes reference in the field of the morphodynamic classification of the beaches the sandy bars. The results obtained from this classification show a sectorial organization of the morphology and morphodynamics along this coastal fringe. This image highlights the distinct functioning between three parts separated by the wadi Réghaia in the West and wadi Isser in the East, whose beach slopes and morphodynamic indices are different. From a methodological point of view, the results obtained show that the detailed analysis, assisted by GIS, of the position of the coastline on aerial photographs and satellite images is a handy tool for the study of coastal evolution in the medium and long term, showing in most cases a general agreement with the results of short-term topographic surveys. However, it should be kept in mind that modeling as a type of approach would not be entirely satisfactory but would support the detailed analysis of aerial photographs as an essential means to understand the general evolution and dynamics of coastal areas.

The results of this article also confirmed that the use of digital aerial photographs, satellite images (high resolution), geospatial techniques (GIS software), and automatic calculation code (DSAS) could be a tool to help the decision in the management against coastal risks. This study provides decision-makers with a reliable decision support tool that can help them assess coastal changes and develop coastal management plans. We must be set up a monitoring program of the evolution of the coastline of the bay of Zemmouri to supplement the existing data and better manage the coastline's recession.

Acknowledgments

This article is partly the result of a collaboration with the Laboratoire d'Etudes Maritimes (Bureau d'Etudes) and ENSSMAL to develop a method of vulnerability assessment adapted to the coasts of the Zemmouri's bay confronted with the coastal erosion and marine submersion hazard. Within the framework of the research works at the National School of Sea and Coastal Sciences (ENSSMAL-Algiers, EcoSysMarl Laboratory).

5. References

Anders, FJ. - D.W. Reed - E.P. Meisburger (1990) : "Shoreline Movements, Report 3: Tybee Island, Georgia, to Cape Fear, North Carolina, 1851 - 1983", Technical Report CERC-83- 1, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS, 177 p. OCLC: 986498390

Aubie, S. - Tastet, J.P. (2000) : Coastal erosion, processes, and rates: an historical study of the Gironde coastline, southwestern France. Journal of Coastal Research, 16(3),756-767. West Palm Beach (Florida) , ISSN 0749-0208.

Ayadi, K. - Boutiba, M. - Sabatier, F. - Guettouche, M.S. (2015) : Detection and analysis of historical variations in the shoreline, using digital aerial photos, satellite images, and topographic surveys DGPS: case of the Bejaia bay East Algeria. Arab J Geosci 9, 26 (2016). https://doi.org/10.1007/s12517-015-2043-9

Boak, E.H. - Turner, I.L. (2005) : Shoreline definition and detection: a review. J. Coast. Res. 21 4, 688e703. DOI: 10.2112/03-0071.1

Bouakline, S. (2009) : Variations historiques de la ligne de rivage et érosion côtière le long de la côte Est algéroise, entre Cap Matifou et l'embouchure de l'oued Réghaïa. Mémoire de Magistère. Université des Sciences et de la Technologie Houari Boumediene (USTHB), FSTGAT, Alger, p176.

Boutiba, M. - Bouakline, S. (2011) : Monitoring shoreline changes using digital aerial photographs, Quick bird Image and DGPS topographic survey: Case of the east coast of Algiers, Algeria. Algeria [J]. European Journal of Scientific Research, 48(3): 361–369

Boutiba, M. - Guendouz, M. – Guettouche, M.S. (2006) : Evolution du littoral jijelien (Est-Algérie) à travers l'analyse sédimentologique des dépôts quaternaires. Bull Serv Géol Nat 17(2):113–127.

Boutiba, M. - Zaourar, N. – Guettouche, M.S. – Briqueu, L. (2009) : Analyse par ondelettes des variations historiques de la ligne du rivage entre l'Oued Reghaia et l'Oued Mazafran (Wilaya d'Alger). Bull Service.

Boutiba, M. (2006) : Géomorphologie dynamique et mouvement des sédiments le long de la côte sableuse Jijelienne (Est Algérie).Thèse de Doctorat d'Etat en science de la Terre, Université des Sciences et de la Technologie Houari Boumediene (USTHB), FSTGAT, Alger, p252.

Bracene, R. (2001) : Géodynamique du Nord de l'Algérie : impact sur l'exploration pétrolière. Thèse de Doctorat, Univ. Cergy Pontoise, 101 p.

Crowell, M. - Leatherman, S.P. - Buckley, M.K. (1991) : Historical shoreline change: error analysis and mapping accuracy. Journal of Coastal Research, 7(3), 839–852. http://www.jstor.org/stable/4297899.

Aniel F., e t hubAud M. (1996). Érosion côtière des systèmes littoraux

Daniel, F. - Hubaud, M. (1996) : Érosion côtière des systèmes littoraux sableux, S.l.: ODEM.

Dolan, R. - Hayden, B.- Heywood, J. (1978): A new photogrammetric method for determining shoreline erosion. Coast. Eng. 2, 21e39. DOI:10.1016/0378-3839(78)90003-0

Douglas, B.C. - CROWELL, M. (2000) : Long-term Shoreline Position Prediction and Error Propagation. Journal of Coastal Research, 16(1), 145-152. Royal Palm Beach (Florida), ISSN 0749-0208. http://www.jstor.org/stable/4300019.

Dubois, J. - Bernatchez, P. - Bouchard, J.D. - Daigneault, B. - Cayer, D. - Dugas, S. (2005) : Évaluation du risque d'érosion littorale sur la Côte-Nord du Saint Laurent pour la période de 1996-2003, Conférence régionale des élus de la Côte-Nord, 359 pp.

Durand-Delga, M. (1969) : Mise au point sur la structure du Nord-Est de la Berbérie. Publ. Serv. Géol. Algérie, n°39, 89-131.

Fletcher, C. - Rooney, J. - Barbee, M. - Lim, S.C.- Richmond, B. (2003) : Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Hawaii. Journal of Coastal Research, 106–124. http://www.jstor.org/stable/25736602

Ford, F. (2013) : Shoreline changes interpreted from multi-temporal aerial photographs and high-resolution satellite images: wotje Atoll, Marshall Islands.Remote Sens. Environ. 135, 130e140. https://doi.org/10.1016/j.rse.2013.03.027

Gaillot, S. – Chaverot, S. (2001) : Méthode d'étude des littoraux à faible évolution. Cas du delta du Golo (Corse) et du littoral du Touquet (Pas de calais) en France. Géomorphologie: relief, processus, environnement, n ° 1, pp. 47-54. DOI: 10.3406/morfo.2001.1086

Genz, A.S. - Fletcher, C.H. - Dunn, R.A. - Frazer, L.N. - Rooney, J.J. (2007) : The predictive accuracy of shoreline change rate methods and alongshore beach variation on Hawaii. J. Coast. Res. 23 1, 87e105. DOI: 10.2112/05-0521.1

Guariglia, A. - Buonamassa, A. - Losurdo, A. - Saladino, R. - Trivigno, M.L. - Zaccagnino, A. - Colangelo, A. (2006) : A multisource approach for coastline mapping and identification of shoreline changes. Annals of Geophysics 49(1), 295e304. DOI: 10.4401/ag-3155

Hakkou, M. - Castelle, B. - Benmohammadi, A. - Zourarah, B. (2011) : Wave climate and morphosedimentary characteristics of the Kenitra–Bouknadel sandy coast, Morocco. Environ Earth Sci 64, 1729–1739 (2011). https://doi.org/10.1007/s12665-011-0977-0

Heathfield, D.K. – Walker, I.J. (2011) : Analysis of coastal dune dynamics, shoreline position, and large woody debris at Wickaninnish Bay, Pacific Rim National Park, British Columbia. Canadian Journal of Earth Sciences 48(7):1185-1198. DOI: 10.1139/e11-043

Himmelstoss, E.A. (2009) : DSAS 4.0 : Installation Instructions and User Guide. In: Thieler, E.R. - Himmelstoss, E.A. - Zichichi, J.L. and Ergul, A., Eds : The Digital Shoreline Analysis System (DSAS) Version 4.0—An ArcGIS Extension for Calculating Shoreline Change: US Geological Survey Open-File Report 2008-1278, ver. 4.2. 81 p. http://pubs.usgs.gov/of/2008/1278/

Jimenez, J.A. - Sanchez-Arcilla, A. – Bou, J. – Ortiz, M.A. (1997) : Analysing Short-Term Shoreline Changes along the Ebro Delta (Spain) Using Aerial Photographs. Journal of Coastal Research, 13(4), 1256–1266. http://www.jstor.org/stable/4298735

Kermani, S. - Boutiba, M. - Boutaleb, A. - Fagel, N. (2015) : Distribution of heavy and clay minerals in coastal sediment of Jijel, East of Algeria: indicators of sediment sources and transport and deposition environments. Arabian Journal of Geosciences 9(1). DOI: 10.1007/s12517-015-2155-2

Kermani, S. - Boutiba, M. – Guendouz, M. – Guettouche, M.S. – Khelfani, D. (2016) : Detection and analysis of shoreline changes using geospatial tools and automatic computation: Case of jijelian sandy coast (East Algeria). Arabian Journal of Geosciences 9, 1e13. https://doi.org/10.1016/j.ocecoaman.2016.08.010

Langfelder, L. - Staffond, D.B. - Amein, M. (1970) : Coastal erosion in North Carolina. Amer. Soc. Civ. Eng. Proc. 96, 531e545 paper 7306, Waterways and Harbs.Div.

Leclaire, L. 1972 : La sédimentation holocène sur le versant méridional du Bassin Algéro-Baléares (Précontinent algérien). Muséum national d'Histoire naturelle, Paris, 391p. (Mémoires du Muséum national d'Histoire naturelle, Sér. C – Sciences de la Terre (1950-1992) ; 24).

Maiti, S. - Bhattacharya, A.K. (2009) : Shoreline change analysis and its application to prediction: a remote sensing and statistics-based approach. Marine Geology. 257, 11e23. https://doi.org/10.1016/j.margeo.2008.10.006

Moore, L. (2000) : Shoreline Mapping Techniques. Journal of Coastal Research, 16(1), 111–124. http://www.jstor.org/stable/4300016

Morton, R.A. - Miller, T.L. - Moore, L.J. (2004) : National Assessment of ShorelineChange. Part1: Historical Shoreline Changes and Associated Coastal Land Loss along the US Gulf of Mexico. U. S. Geological Survey. Open File Report2004e1043. https://doi.org/10.3133/ofr20041043

Moussaid, J. - Ait Fora, A. - Zourarah, B. - Maanan, M. - Maanan, M. (2015) : Using automatic computation to analyze the rate of shoreline change on the Kenitra coast, Morocco. Ocean Engineering 102, 71e77. http://dx.doi.org/10.1016/j.oceaneng.2015.04.044

Natesan, U. - Parthasarathy, A. - Vishnunath, R. - Kumar, G.E.J. - Ferrer, V.A. (2015) : Monitoring long-term shoreline changes along Tamil Nadu, India using geospatial techniques.

Aquatic Procedia Volume 4, 2015, Pages 325-332. https://doi.org/10.1016/j.aqpro.2015.02.044

Ozturk, D. - Sesli, F.A. (2015) : Shoreline change analysis of the Kizilirmak lagoon series.

Ocean & Coastal Management Volume 118, Part B, December 2015, Pages 290-308. https://doi.org/10.1016/j.ocecoaman.2015.03.009

Paskoff, R. (1998) : The coasts. Impact of developments on their evolution. 3rd edition, coll.

Pilkey, O.H. - Hume, T. (2001) : The shoreline erosion problem: lessons from the past.Water Atmos. 9 2, 22e23.

Robin, M. (2002) : Télédétection et modélisation du trait de côte et de sa cinématique. – In : Le littoral : regards, pratiques et savoirs. Etudes offertes à Fernand Verger. – Ed. ENS., Paris: 95-117.

Schoonees, J.S. - Theron, A.K. - Bevis, D.(2006) : Shoreline accretion and sand transport at groynes inside the port of Richards Bay. Coastal Engineering 53(12). http://dx.doi.org/10.1016/j.coastaleng.2006.06.006

Scott, D.B. (2005) : Coastal changes, rapid. In: Schwartz, M.L. Ed., Encyclopedia of Coastal Sciences. Springer, The Netherlands, pp. 253e255.

Smith, G.L. - Zarillo, G.A. (1990) : Calculating Long-Term Shoreline Recession Rates Using Aerial Photographic and Beach Profiling Techniques. Journal of Coastal Research, 6(1), 111–120. http://www.jstor.org/stable/4297648

Suanez, S. - Provansal, M. (1993) : Etude des modifications morphosédimentaires du littoral à l'embouchure du Rhône: plages de Piémanson et Napoléon, Méditerranée, nos 3-4, pp. 43-56.

Thieler, E.R. - Danforth, W.W. (1994) : Historical Shoreline Mapping (I): Improving Techniques and Reducing Positioning Errors. Journal of Coastal Research, 10(3), 549–563. http://www.jstor.org/stable/4298252

Thieler, E.R. - Himmelstoss, E.A. - Zichchi, J.L. - Miller TL (2005) : Digital Shorline Analysis System(DSAS) version 3.0;An Arc Gis extension for calculating shorline change.US. Geological Survey Open-file Report 2005-1304 (http://woodshole.er.usgs.gov/project-pages/dsas)

Zuzek, P.J. - Nairn, R.B. - Thieme, S.J. (2003) : Spatial and Temporal Considerations for Calculating Shoreline Change Rates in the Great Lakes Basin. Journal of Coastal Research, 125–146. http://www.jstor.org/stable/25736603