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Sea-level rise impact on the evolution of a microtidal Mediterranean coastline without human-made structures—a case of the Port aux Princes-Sidi Daoued coastline, Gulf of Tunis, NE-Tunisia

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Abstract

The evolution of the natural and pristine Mediterranean coastline Port aux Princes-Sidi Daoued (Gulf of Tunis, NE-Tunisia) is studied during the period of 1887–2010 on the basis of an ancient minute of bathymetry (1887) and aerial photographs treated by numerical photogrammetric methods. Morphological changes of the coastline shows a general retreat despite the absence of the various anthropogenic actions. Adding to the drift currents and the currents of high energy that are generated by the N-W dominant waves along steeply sub-marine funds, the erosion is mainly due to the sea level rise which increased since the beginning of the 2000s. The Port aux Princes-Sidi Daoued coastline works as a single littoral cell limited by Jbel Korbous to the SW and the fishing harbor of Sidi Daoued to the N-E.

Key words: Mediterranean coastline, erosion, sea level rise, littoral cell, Gulf of Tunis, Tunisia

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1 Introduction

The marine erosion is a natural risk that threatens littorals in many parts of the world (Mignot, 1988). In fact, 70% of coastlines suffer from erosion, 10% are in accretion state and only 20% of them are in equilibrium (Paskoff, 2005). The perturbation of coastlines are mainly due to the natural factors such as the dominant waves, littoral currents, sub-marine morphology and various human interventions (destruction of littoral dunes due to the extension of urbanizations near the shorelines, installation of harbors and protective structures without previous environmental impact studies). Thus, coastal areas are considered as dynamic sectors which are in continuous evolution (Bird, 2000). They were studied by several researchers (Ottmann, 1965; Pope and Dean, 1986; Berenguer and Enriquez, 1988; Rosati et al., 1992).

The Gulf of Tunis (N-E Tunisia) which belongs to the Mediterranean coastlines did not escape from the erosion that was accelerated by various anthropogenic activities. It has been the subject of numerous research works (Nouri, 1979; Nouri and Paskoff, 1980; Sliti, 1984; Kouki, 1984; Bouhafa, 1985; Oueslati, 1993, 1994, 2004; Zeggaf-Tahri, 1993, 1999; El Arrim, 1996; Louati and Zargouni, 2009, 2013; Saïdi et al., 2012; Saïdi, 2004, 2013). The eastern coastline of the Gulf of Tunis which extends from Port aux Princes to Sidi Daoued is not subjected to important human-made structures. In fact, littoral dunes are well developed and there are no tourist and balneal urbanization, no industrial activities or pollution. But, despite the absence of anthropogenic interventions, this coastline suffers from perturbation. Unfortunately, there are no previously published studies on this sector. So, the present work aims to redress this situation by studying the coastline evolution from Port aux Princes to Sidi Daoued over a period of 123 years (from 1887 to 2010) to deduct principal factors that caused the shoreline retreat and try to divide the coastline into littoral cells.

2 Presentation of the study area

The coastline of Port aux Princes-Sidi Daoued is one of the littorals bordering the Mediterranean basin to the south. It is situated in the eastern part of the Gulf of Tunis (NE-Tunisia) (Fig. 1). It extends over a linear distance of about 29 km. It is limited to the south west by the mountain (anticline) of Jbel Korbous and to the north east by the fishing harbor of Sidi Daoued. It is crossed by the Abid River. This coastline has sandy beaches with very developed littoral dunes and important forests especially at Rtiba and Bir El Jadi.

According to the annual statistics of 2002–2004 (Gasdaoui, 2005), the dominant waves in the eastern part of the Gulf of Tunis, from Port aux Princes to Sidi Daoued, come from the northwest sector.

The coastal dynamics along the studied sector were studied using the numerical model of the University of Cantabria Coastal Modeling System (SMC) with bathymetric and hydrodynamic (waves) as input data (Saïdi et al., 2013). Between Port aux Princes and Sidi Daoued, the northwestern waves generate gyratory currents of high energy near the shoreline and opposite drift currents have a SW – NE direction in the Port aux Princes- Rtiba sector and a NE – SW direction between Bir El Jadi and Sidi Daoued.

During the period of 1993–2001, waves are important in winter when the significant height is about 3 m (Fig. 2) (http://

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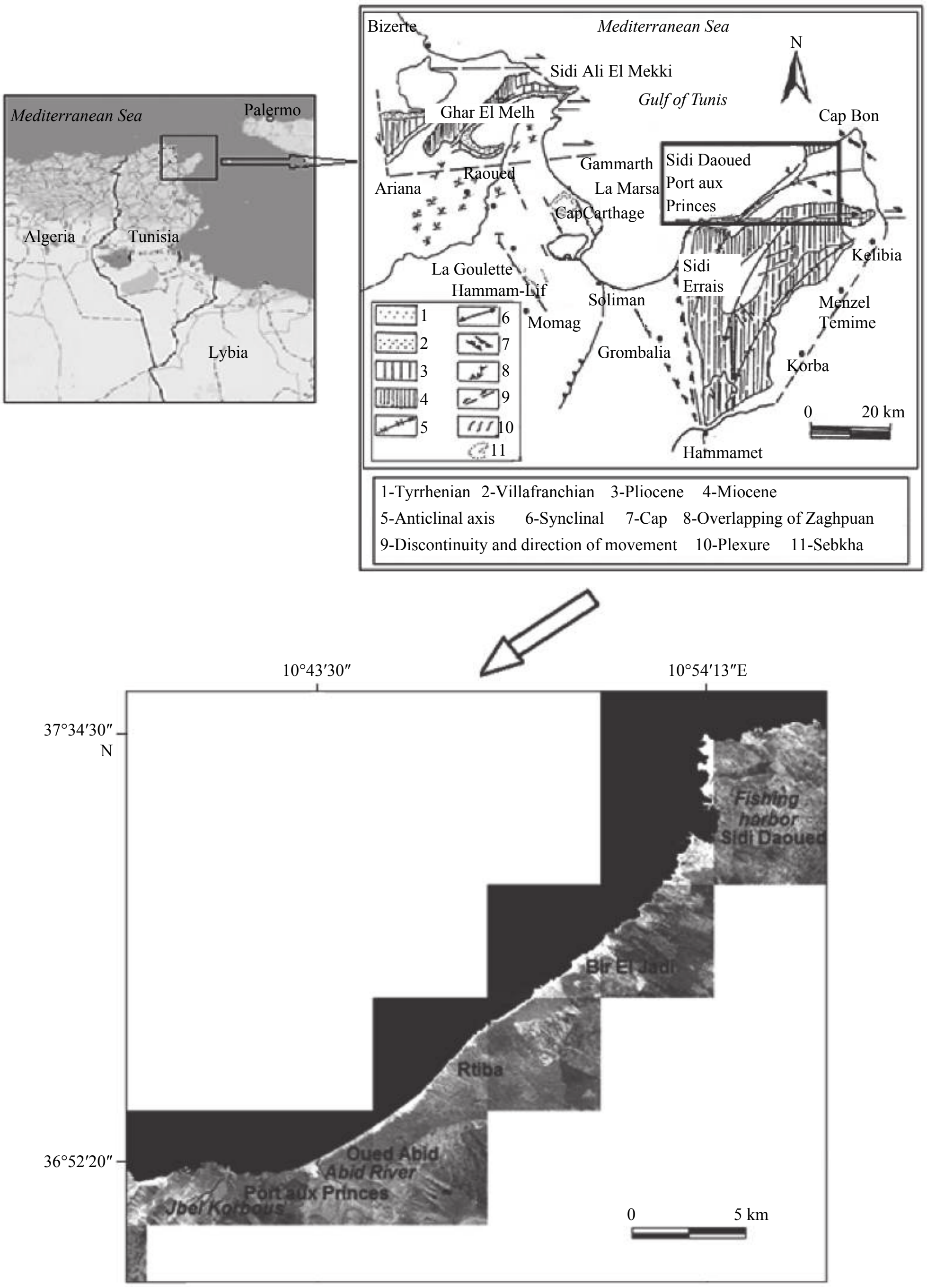

Fig. 1. Location map of the studied coastline.

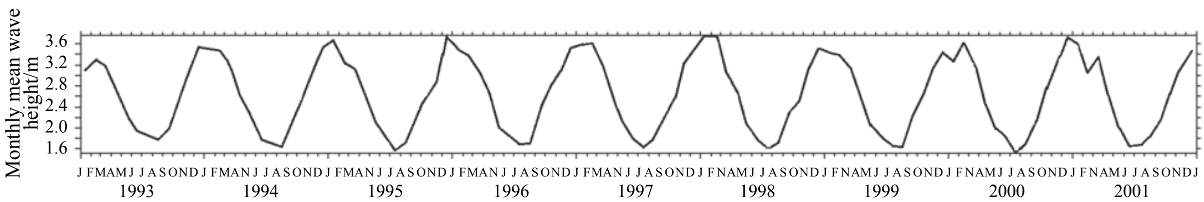

Fig. 2. Significant wave height in NE-Tunisia (http://www.knmi.nl/waveatlas). J–D represent January to December, respectively.

www.knmi.nl/waveatlas).

Being part of the Gulf of Tunis, this coastline is considered as microtidal. The tide amplitude does not exceed usually 35 cm (Oueslati, 1993).

The submarine geomorphology shows that the isobaths are very close to each other to confirm that the slopes are very steep (Fig. 3). Submarine funds (0–7 m) are covered by medium sands (Saïdi, 2013).

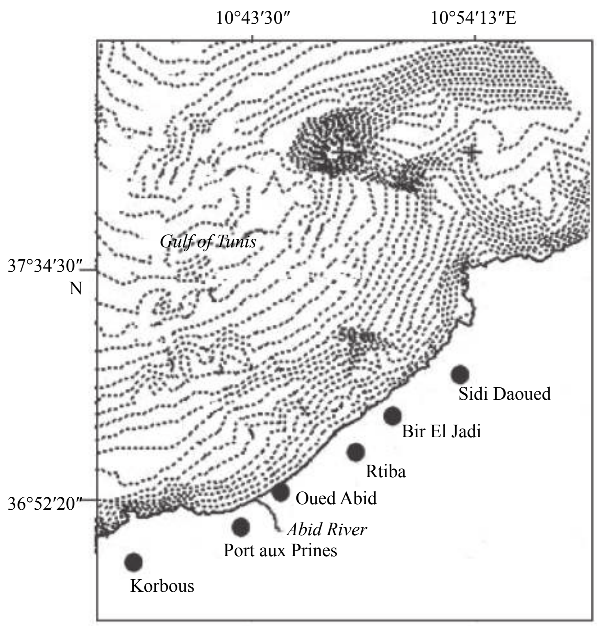

Fig. 3. Bathymetry of the eastern coast of the Gulf of Tunis, from Port aux Princes to Sidi Daoued (Saïdi, 2013).

Anthropogenic actions are absent along this coastline except the fishing harbor of Sidi Daoued which was constructed in 1983.

3 Materials and methods

The study of coastline evolution was done by aerial photographs (taken in 1974, 2000 and 2010 (with a scale of 1:25 000)) treated by numerical photogrammetric methods and by an ancient minute of bathymetry taken in 1887 (with a scale of 1:61 740 (the map 4191)). The correct location of coastlines were determined using the stereoscopy, by tracing lines in the ancient minute and the aerial photographs that were georeferenced.

The global error of mapping is about ±12 m for aerial photographs taken in two different dates. The error of mapping near the shoreline for the minute of the ancient bathymetry (1887) is ±20 m (according to Shom, 2004). So, the global error of mapping between the ancient minute and aerial photography is ±26 m.

The positions of coastlines were determined following 59 profiles perpendicular to the shore.

Gained and lost surfaces were determined by creating polygons coded manually as erosional and accretional areas. These latter as well as the distances of coastline retreat or advance were calculated by the ArcGIS software.

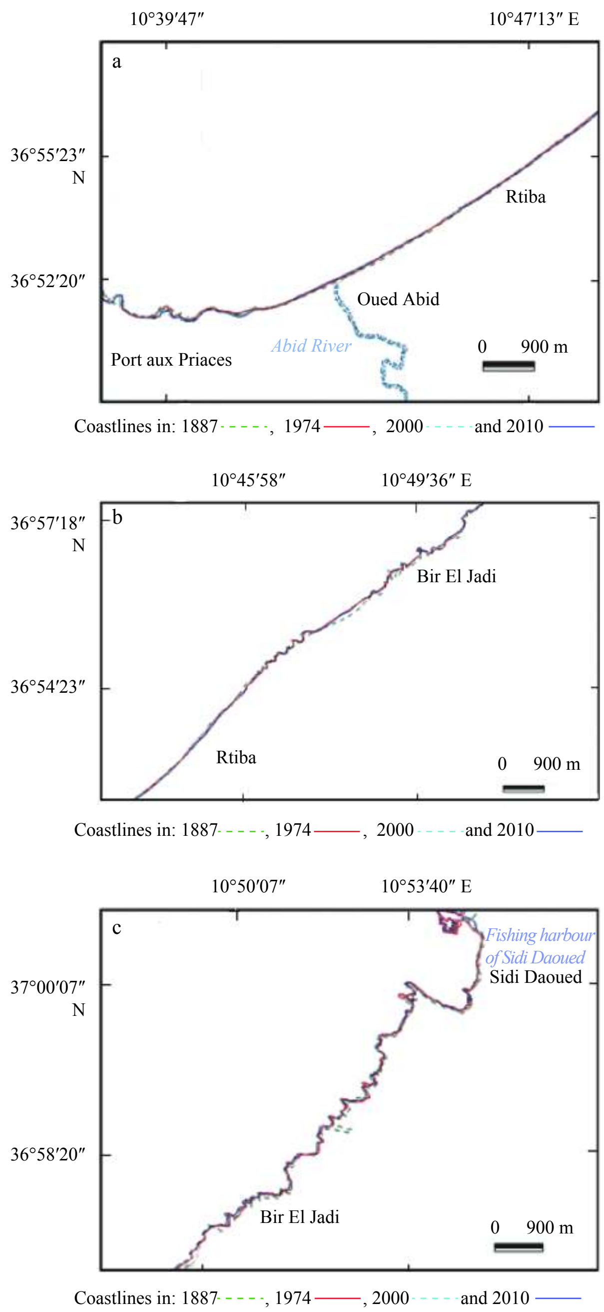

Fig. 4. Coastline evolution between Port aux Princes and Rtiba (a), Rtiba and Bir El Jadi (b) and Bir El Jadi and Sidi Daoued (c), during the period of 1887–2010.

4 Results and discussion

4.1 *Coastline evolution and estimation of gained/lost surface*

The coastline evolution was studied during the periods of 1887–1974, 1974–2000 and 2000–2010 (Figs 4a, b, c and Fig. 5).

During the period of 1887–1974, the coastline was generally in equilibrium state. In fact, erosion was very limited with a low erosion speed (0.43 to (1.15 ±0.29) m/a)) between Bir El Jadi and Sidi Daoued. Along the study area, the both gained and lost surfaces shows a positive sedimentary budget estimated to 7 400 m^2/a (Fig. 6a).

From 1974 to 2000, the coastline retreated between Port aux Princes and Rtiba (–1.35 to (–0.65 ±0.46) m/a) and advanced from Rtiba to Sidi Daoued (0.54 to (1.15 ±0.46) m/a).

Sedimentary budget was positive (5 410 m^2/a) along the entire area with a surface lost of about 1 133 m^2/a from Port aux Princes to Rtiba and a gain of 3 638 m^2/a, between Rtiba and Bir El Jadi, and about 2 905 m^2/a, from Bir El Jadi to Sidi Daoued (Fig. 6b).

During the period of 2000–2010, the coastline evolution shows an alternation of retreat and advance along the study sector. The accretion was of 1.8 to (2.4 ±1.2) m/a to achieve (7.8 ±1.2) m/a in Port aux Princes. Otherwise, the erosion is estimated at –5.7 to (–1.9±1.2) m/a.

The surface sedimentary budget was in deficit along the entire sector Port aux Princes- Sidi Daoued (Fig. 6c). It is estimated at –20 518 m^2/a (–3 365 m^2/a from Port aux Princes-Rtiba, –16 581 m^2/a between Rtiba and Bir El Jadi and –571 m^2/a from

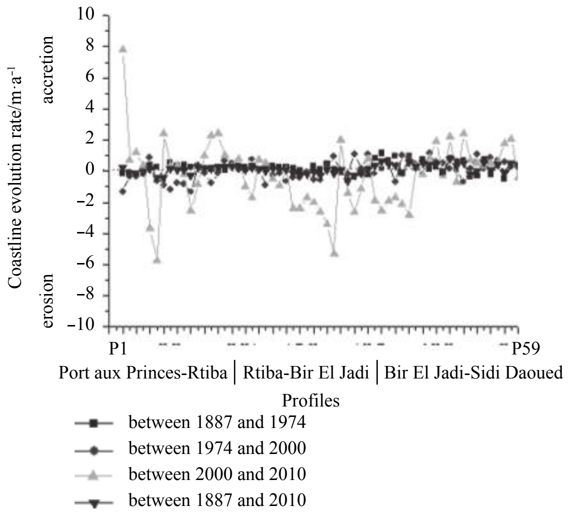

Fig. 5. Coastline evolution rate (m/a) between Port aux Princes and Sidi Daoued, during the period of 1887–2010.

Bir El Jadi to Sidi Daoued).

During the period of 1887–2010, over 123 years, the coastline evolution shows that erosion is generally located between Port aux Princes and Rtiba (–0.59 to (–0.24 ±0.21) m/a) with a little accretion observed along Rtiba-Sidi Daoued sector (0.28 to (0.79±0.21) m/a).

During this period, the variation of the surface sedimentary budget (m^2/a) shows a decrease to become negative in 2000–2010 (Fig. 7). The significant erosion can be explained by the sea level rise which became accelerated since the beginning of the 2000s. It is estimated at 3 mm/a (www.notre-planete.info/actualites/actu_2759_augmentation_niveau_mer_Mediterranee.php). According to Zerbini et al. (2017), the sea level rise in the northern Mediterranean Sea range between 1.2 and +1.3 mm/a, from the last decades of the 19th century through 2012, with a steady behavior during the period of 1960–1993. Other authors like Church and White (2006); Church et al. (2013) estimated the global mean rate of sea-level rise to +1.7 ± 0.2 mm/a, between 1901 and 2010.

4.2 *Causes of coastline erosion*

The sector located between Port aux Princes and Sidi Daoued suffered generally from coastline retreat, during the period of 1887–2010, despite the absence of anthropogenic actions that can perturb the littoral (extension of urbanizations on littoral dunes, marine water pollution). In fact, it is considered as a natural and pristine coastline. So the erosion can be explained by the steep slopes of the submarine funds where the north western dominant waves lead to gyratory currents of high energy near the shoreline giving rise to sediment loss. Indeed, a recent study in the Mediterranean (Fig. 8) shows that the contribution of waves is lager then those of storm surge for the distribution of water level maximum in the NE-Tunisia (Lionello et al., 2017).

The acceleration of erosion especially between 2000 and 2010 can be explained by the sea level rise that became important and accelerated since the year 2000. In fact, the Spanish Institute of Oceanography estimated that the sea level in the Mediterranean Sea had increased to become 15 to 20 cm during the 20th century (1.5 mm/a, 0.15 cm/a). The sea level rise has been accelerated since the beginning of the 2000s to be 3 mm/a. In fact, Bruun's formula from 1962 predicts a coastal retreat rate of 1–1.5 m per centimeter of sea level rise (Heberger et al., 2009).

4.3 *Coastal compartmentalization into littoral cells*

Littoral cells are defined as basic units, distinct entities and self-contained segments (Inman and Frautschy, 1966; Patsch and Griggs, 2006) with little or no sediment transport between them (Patsch and Griggs, 2006). They are confined by boundaries (natural barriers or human-made structures) (Lowry and Carter, 1982; Rijn, 2010) that can be: (1) fixed absolute boundaries like cliffs, long jetties, deep inlets, canyons, navigation channels, long harbors, heavy protective structures (breakwaters, groins); (2) fixed partial boundaries: bypassing or periodic throughput of sediments (soft rock/ compound cliff type headlands and shallow inlets); and (3) transient partial boundaries which have limited stability (spits, sand banks, shallow channels, short headlands, short breakwaters).

So coastal compartmentalization into littoral cells can be done by the identification of different boundaries. But, in the studied area, except Port aux Princes, Abid River and the fishing harbour of Sidi Daoued, there are no natural or artificial intermediate barriers.

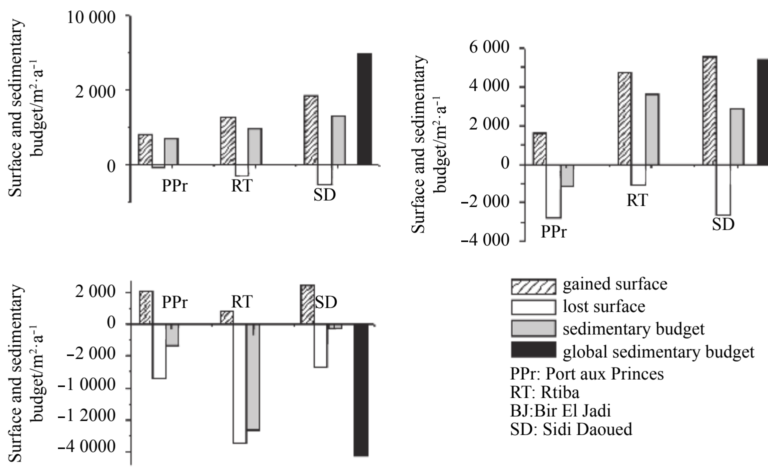

Fig. 6. Estimated gained and lost surface and sedimentary budget (m^2/a) along Port aux Princes-Sidi Daoued coastline, during the periods of 1887–1974 (a), 1974–2000 (b) and 2000–2010 (c).

According to Anfuso et al. (2011, 2013), it can be made, also, using alongshore distribution of erosion/accretion sectors. By referring to the estimated gained and lost surface and sedimentary budget along Port aux Princes-Sidi Daoued coastline, during the period of 1887–2010 (Fig. 7), it can be deduced that the sediment loss is located at Port aux princes-Rtiba coastline against an accretion between Rtiba and Sidi Daoud. This result shows a sediment transport starting from Port aux Princes. Thus, the studied coastline behaves as a single cell enclosed between Port aux Princes and the fishing harbor of Sidi Daoued (Fig. 9).

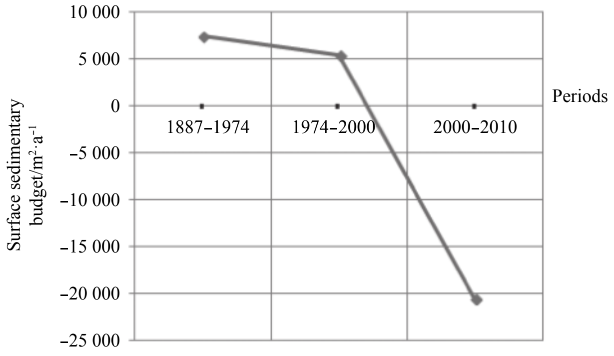

Fig. 7. Variation of the surface sedimentary budget along Port aux Princes-Sidi Daoued sector, during the period of 1887–2010.

5 Conclusions

The study of coastline evolution between Port aux Princes and Sidi Daoued, during the period of 1887–2010, allows to delimit erosion and accretion sectors. In fact, the coastline retreated generally along the studied area with a little accretion between Bir El Jadi and Sidi Daoued. With the absence of the major anthropogenic actions along the shoreline (urbanizations, harbors (except the fishing harbor of Sidi Daoued), protective structures), the general erosion is explained mainly by the acceleration of the sea level rise since the 2000s as well as the effect of hydrodynamic parameters in particular the N-W dominant waves which generate drift currents and gyratory currents of high energy near steeply submarine funds.

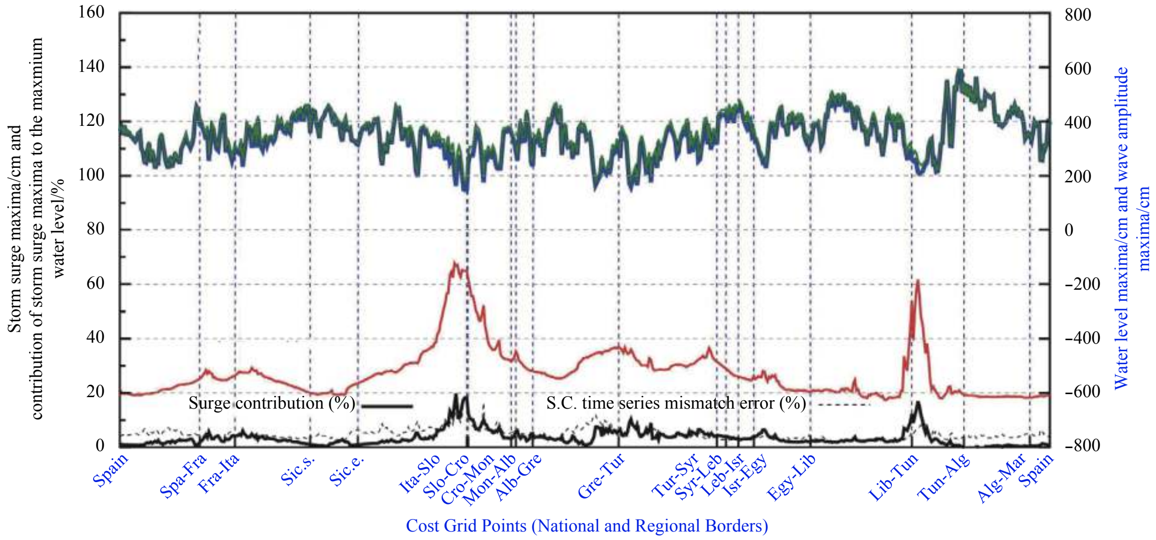

Fig. 8. Present distribution of water level maxima (green line), wave amplitude maxima (blue line), storm surge maxima (red line) and the percent contribution of storm surge maxima to the maximum water level (black line) in the Mediterrnean, during the period of 1971–2000 (Lionello et al., 2017).

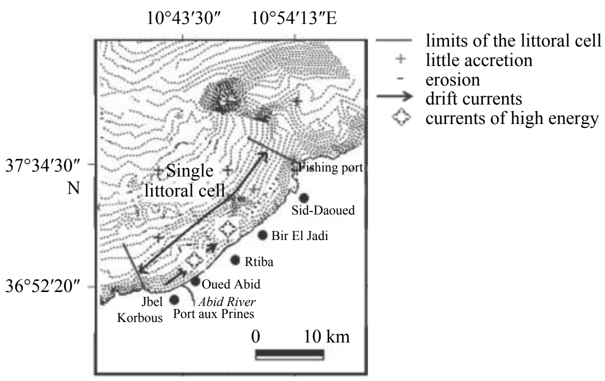

Fig. 9. Limitation of the single littoral cell between Port aux Princes and Sidi Daoued.

Thus, the present work shows that, with absence of anthropogenic actions, the pristine microtidal coastline changes are mainly due to the sea level rise in addition to dominant waves and currents. It also shows that a coastline can behaves as a single cell when intercalary natural and artificial barriers are absent.

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