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ASSESSMENT OF EROSION ALONG THE COASTLINE BETWEEN SOLIMAN AND RADES (NORTHEAST OF TUNISIA), DIAGNOSIS BY DIGITAL PHOTOGRAMMETRY

M. Azizi [a,], H. Bahri [a], A. Ben Mansour[b],

[a] *King Abdulaziz University, Faculty of environmental design, Geomatics department, Jeddah, KSA*
[b] *University of Tunis El Manar, Faculty of Sciences of Tunis, Department of Geology, Tunis, Tunisia*

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ABSTRACT:
The present work consists in calculating the recoil velocity of the coastline in the small Gulf of Tunis over 22 years. This study was conducted in order to contribute to decision making for coastal protection against erosion. The regressive evolution of the beach profile disrupts the ecosystem and leads to the degradation of the landscape and touristic heritage of Tunisia. To quantify the phenomenon of coastal erosion we used multi-source data: field analysis, aerial photos, topographic maps and GIS (Geographic Information System). The analysis of orthophotos and the restitution of the coastline for the three missions of aerial photography show three types of coastal areas with different behaviour: regions with continued erosion, fattening areas and areas that moving from erosion to fattening. Then, to explain this evolution, we digitized the existing buildings in the vicinity of the coastline. We performed digital terrain models to calculate the volumes of dunes removed and we detected ocean currents acting on the sediment balance of the small Gulf of Tunis. Coastal degradation is quite complex. It is a function of both natural factors that govern the behavior of the ecosystem and anthropogenic factors that accelerate the erosion. The study of these factors helped us explain the behaviour of the coastal fringe, evaluate the effectiveness of protective structures, and propose solutions for areas where protective measures were not enough.

1. INTRODUCTION

At present, many beaches around the world are in recession. Nearly 70% of beaches in the world are eroding, 20% are stable and only 10% are in progradation (Zeggaf, 1999).
The coastline of the small Gulf of Tunis is no exception. It is subject to degradation resulting in a decrease of coastline from 1 to 2m/year, on average, but in some areas it may reach more than 10m/ year (El Arrim, 1996). The location of the shoreline and changing position of this boundary through time are of elemental importance to coastal scientists, engineers and managers (Douglas & Crowell 2000). The Coastal areas have become more prone and vulnerable to natural and human made hazards which lead to Coastal Erosion (Prasad, 2014). The evolution of the coastline is managed by natural and anthropogenic factors. Natural factors are basically of two types:
Hydrodynamic factors such as:
- Changing climatic conditions in the direction of increasing the strength and frequency of storms, resulting in amplification of the destructive power of waves (Ben Amor, 2001);
- The action of the wind at the coast is characterized by wind erosion;
- The rise in sea level
Biological factors:
- Submarine vegetal cover
As for anthropogenic factors, they are manifested by:
- The construction of dams on rivers that deprives beaches of much of the materials that used to be received normally before their construction
- Port facilities including jetties can disrupt sediment passage.
- The extraction of sand in the beds of streams, on beaches and bordering dunes
- Buildings that are very close to the shore, often located on the bordering dunes , Cause disruption of the exchange between the beach and dunes prisoners of the vertical structures .Thus , unable to contribute to the reshaping of the beaches.
- The accelerated release into the atmosphere of Carbon dioxide and other greenhouse gasses has resulted in a projected global warming of about 3˚C by the year 2030 (Davis & Fitzgerald 2013). This increase would be enough to raise the global sea level by as much as 5 m in a few centuries (Davis & Fitzgerald 2013)

The impacts of anthropogenic and natural factors result in an accelerated decline of beaches and shoreline degradation phenomena.

2. PRESENTATION OF THE STUDY AREA

The area subject of this study is the coastal of the small Gulf of Tunis from Rades to Soliman (Figure 1). The study area is located between 36° 44' and 36° 47' north latitude and 10° 17' and 10 ° 30' East longitude. The coastline extends for about 28km.

The morphological environment is characterized by alternation of plains and hills (Zeggaf, 1999) with sandy coasts.
The geological outcrops of the watershed of the Gulf of Tunis show the stratigraphic succession of the oldest to most recent as follows: Triassic, Jurassic, Cretaceous, Eocene, Oligocene and Quaternary. The geological formations exposed along the coast of the Gulf of Tunis are mostly age Oligo-Miocene and Plio-Quaternary (Zeggaf, 1999).
The climate of the Gulf of Tunis is semi-arid. With two contrasting seasons, a hot dries summer and a cold and wet winter. Rainfall is both rare and violent. The most frequent and strongest winds come from the north-west direction and can sometimes be very violent (28 m / year) (El Arrim, 1996).
The hydrological regime of the coastal fringe (Rades-Soliman) is controlled mainly by the rivers, Meliane, Soltan and Bezirkh. These rivers feed the beach and shallows with solid materials formed mainly of sand and gravel.

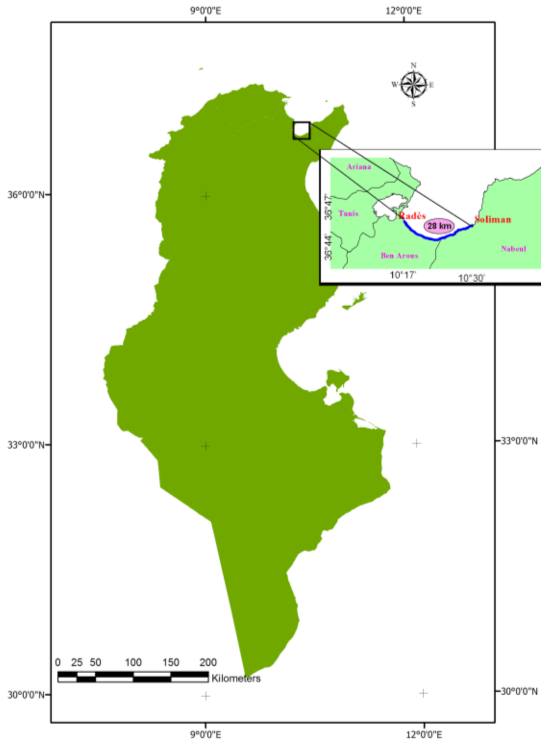

Figure 1: Localisation of the study area

3. METHODOLOGY

In order to study the morphodynamics of the coastal fringe between Rades and Soliman during the period 1974 - 1996, we have taken the speed of movement of the coastline and the dynamics of bordering dunes as quantifiable criteria. We have used the technique of aerial orthophotography to represent the basic data in one coordinate system to be able to cross information spread from aerial missions over the period (1974-1996).Once the data is georeferenced, we can establish our comparative study.

3.1 Data

At our disposal: aerial photographs covering the study area at different dates, field books and maps of Lagoulette (Table 1).

Document Type	Date of preparation	Scale	Number of photos	Number of band	Origin
Aerial photos	1974	1/25000	17	3	OTC
	1988	1/10000	20	3	OTC
	1996	1/10000	32	3	OTC
Topograph -ic map	1983	1/25000	----	----	OTC

Table 1: Data used in the study

The notebooks contain land sketches, the coordinates (X, Y) and altitude Z of control points. The maps are used to verify the existence of longitudinal and lateral recovery between adjacent images and successive bands.

3.2Orthophotography

The aerial orthophoto is a photography that has been rectified and resampled to make superimposed on a map at all points. (Kasser, 2011). The orthophotography seeks automatically in the photographs information of radiometry and borrows from the map its grid and sometimes overload an itinerary (Moisset, 2002). The accuracy that is obtained from digital ortho-images is significant. It is used to plan large-scale projects, assess the development of an area or phenomenon through time and identify agricultural and rural areas

3.2.1 Production of digital orthophotography

The steps of orthophotography production are summarized in the following diagram (Figure 2)

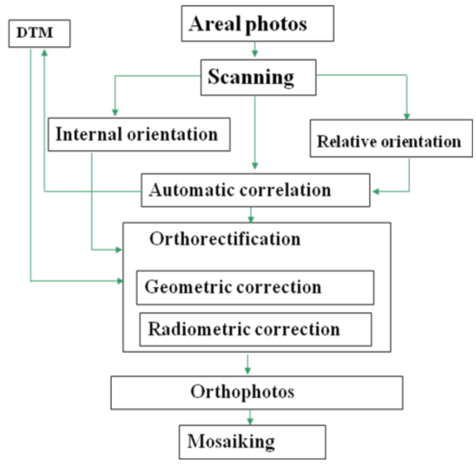

Figure 2: Production of digital orthophotography

Scanning:

Scanning was done directly on the images with DSW 500 scanner. DSW scanner is designed for digital photogrammetric work that requires high performance. This scanner offers a wide range of resolution reaching up to 4064dpi. The photos of the three aerial photography missions were scanned at a resolution of 508dpi in TIFF format.

Stereo-model:

This is the reconstruction of the object on a different scale (model generation) in order to proceed to the extraction of interest data. The generation of the model can be decomposed into three steps: internal orientation, relative orientation and absolute orientation

- **Internal orientation:** Between the time of acquisition and exploitation of the photo, it undergoes various treatments that affect its geometry (film developing, scanning). The internal orientation is the step that corrects these distortions. The objective is to restore the image state at the moment of observation.
- **Relative orientation:** The relative orientation is to position a picture against the other so that all the homologous rays intersect. In the case of a stereo pair, the operation must be carried out on both shots. At this point, homologous rays, that is to say, the radii of the two images of a point and their respective centres of perspective do not intersect in space. The purpose of the relative orientation is to ensure that these rays intersect as in the shooting.
- **Absolute orientation:** It aims to transform the coordinates of the measured points in the stereo-model to field coordinates. This transformation is equivalent to a basis change and can be modeled mathematically by a similitude; thus seven parameters are necessary for this operation (3 translations, 3 rotations and a scale factor) and knowledge of the coordinates of three points of the ground coordinate system, will solve the problem. Two points must be known in XYZ to define the translation and making of the scale and a point in Z to define failover.

All these operations are carried out in the digital photogrammetric station by the photogrammetric software (SOCET SET).
When the operation of absolute orientation is complete, we start the restitution of the coastline under the Micro-station software.

Mosaicking operation

A mosaic is a collection of corrected images (Figure 3). Thus, the process of mosaicking provides an overview of the territory which is strongly recommended for development projects, land occupation, and the follow up of natural evolution. The collection of the photos is no longer via the juxtaposition of two images but rather:

• Reconciliation of radiometric histograms of images to be connected to the common area.
• Automatic determination of a smaller gap line.
• Collection based on the final connecting line.

We have applied the mosaicking operation on the three aerial photographic missions. We got three images covering the study area in 1974, 1988 and 1996. The mosaics were used to digitize the building layer.

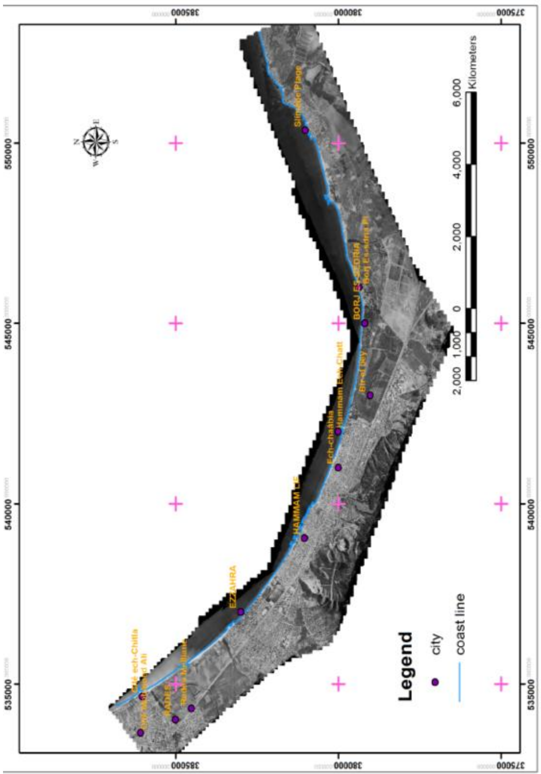

Figure 3: mosaic of orthophotos for the mission 1996

3.3 Extraction of Digital Terrain Models (DTM)

A DTM is a numerical description of the shape and position of the topographic surface. It consists of a well known set of points in X, Y and Z above. The development of DTM has two phases, which are: - the input of the relief information
- the structuring of the DTM

3.3.1 The input of the relief information:

The seizure of the relief is done in two different ways: the automatic photogrammetric survey and the manual photogrammetric survey. In our case we have combined both methods. The photogrammetric survey is done automatically by digital image correlation. We used the extraction of the point elevation according to regular mesh.

Principle of Correlation: The correlation can search for identical points (homologous) in two different images. So, we define a reference matrix A in the first image and a research matrix B in the second image. We will then calculate a correlation coefficient r for all positions (n, m) that the reference matrix A can take in the research matrix. A_k is the k^{th} pixel radiometry of the matrix A that is traveling from right to left and from top to bottom.

k = j + i.Col
i was the line number; j was the column number
Col is the number of pixel.

The correlation coefficient

$$r = \frac{\sum_{i=1}^{n} A_i . B_j - \frac{1}{n}(\sum_{i=1}^{n} A_i).(\sum_{i=1}^{n} B_i)}{\sqrt{(\sum_{i=1}^{n} A_i^2 - \frac{1}{n}(\sum_{i=1}^{n} A_i)^2)\ (\sum_{i=1}^{n} B_i^2 - \frac{1}{n}(\sum_{i=1}^{n} B_i)^2)}} \quad (1)$$

The maximum value of r defines the most probable position of A in B.
The manual photogrammetric survey is to monitor the peaks and trough of the dunes, as well as lines of slope change.

3.3.2 The structuring of the DTM

It aims at reorganizing the data of relief to make it easy to operate. In most cases, there is a regular square mesh or a triangular mesh (TIN). This phase implements techniques of interpolation or approximation. In our case the interpolation method used is kriging, the kriging method, developed by Matheron (1970), is called stochastic or geostatistical method. It is based on the theory of regional variability (Jankowski & Chang, 2002). The interpolated value, Z ', is estimated by the following formula:

$$Z' = \sum_{i=1}^{n} wiZi \quad (2)$$

Where Zi is the value measured or sampled, Wi is the neighborhood function that depends on the distance between the points. Having developed the DTM to the dunes they are superimposed in pairs to calculate the differences in volumes between the two successive missions. The superposition, the calculation of differential volume is done in Covadis software.

4. RESULTS AND DISCUSSION

The evolution of the shoreline over time provides very important information that can help us understand the coastal behavior vis-avis natural and anthropogenic actions to which it is subject (El Arrim, 1996).

4.1 Evolution of the coastline between 1974 and 1988

The coastal strip from Rades to the former debouche of the river Meliane has a recoil velocity of 0.36m/year to 1.07 m /year (Figure 4).
This speed is comparable to the values of average velocity in the Gulf of Tunis presented in other previous work, which range from 0.2m/year to 1.8m/year (Zeggaf, 1999).
Thus, the deviation of the river Meliane could be the cause of the sediment deficit since this area is devoid of sediment deposited by the river Meliane. Between the river Meliane and the two breakwaters of Ezzahra the beach has fattened. The coastline has advanced from 5 to 40m with a speed that varies between 0.36m/year and 2.86m/year (Figure 4).

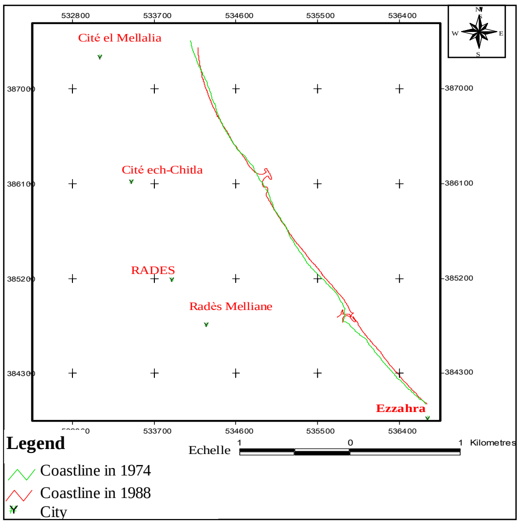

Figure 4: Evolution of shoreline from Rades to Ezzahra between 1974 and 1988

The progress of the coastline could be due to the genesis of a trapezoidal sedimentation area behind the breakwaters of Rades which interrupts the coast transit (south-east to north-west), by promoting accumulation of sand and therefore the advancement of the coastline.

Going from the two breakwaters of Ezzahra to the south-west, we notice the decline of the coastline along the densely urban areas. The speed of decline varies from 0.28 to 1.21m/year. This erosion has imposed the establishment of a rock cordon in the high beach to protect the city of Ezzahra.

A recoil value equal to 8m/ year was noticed in Ezzahra between 1962 and 1976 (El Arrim, 1996). Along the cord riprap the beach is absent and the waves break directly on the rocks. At Hammam Lif, we have a series of eight breakwaters whose length ranges from 100 to 185m. Behind the breakwaters, we observe the formation of an area of 40 to 100m of width. Between Hammam lif breakwaters and Ech-chabia the shoreline presents a fall at a rate of 0.42 to 1.29m/year (Figure 5).

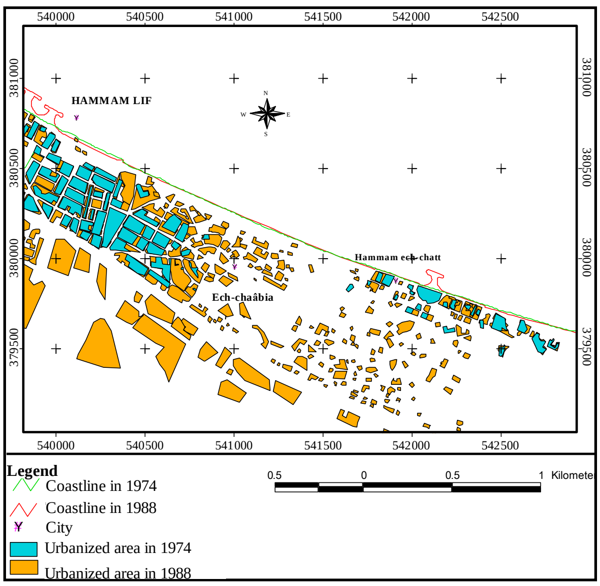

Figure 5: Evolution of shoreline from Hammam lif to Hammam ech-chat between 1974 and 1988

Along the zone Ech-chaabia, the coast is more or less stable, however it has a speed of advance in the order of 0.28 to 0.71m/year across areas of low urban density.

Reaching Hammam Echatt, buildings are very close to the shoreline. To protect these buildings, a linear riprap cord of 520m has been added to Hammam esh-chatt breakwaters. It intercepts the quantities of sand mobilized by longshore drifts currents, and rip currents associated to the swell which contributed to the formation of a beach of 70m width behind the breakwater. Between The Breakwaters Hammam esh-chatt and Bir el Bey, we measured a recoil velocity of the shoreline of about 0.14 to 0.71m/year (Figure 6).

Thus the coastline recedes as a result of the returns current that provides a frontal transportation. These currents are very active in this coastal region.

The coastline Bir el bey _ Borj-cedria shows no remarkable change: rather, it is generally stable (Figure 6).

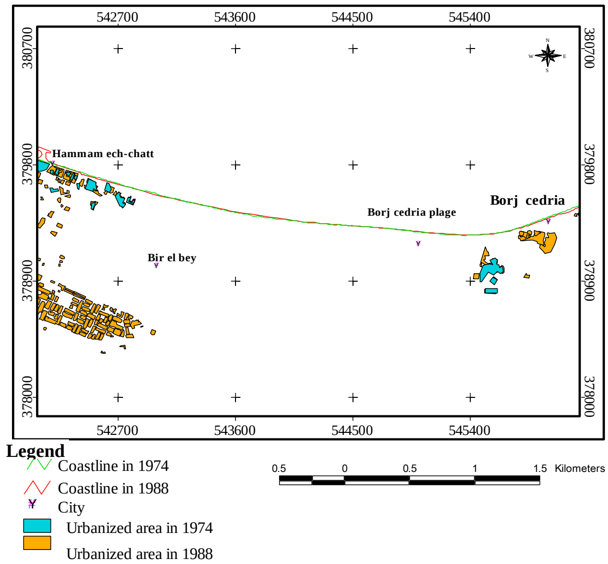

Figure 6: Evolution of shoreline from Hammam ech-chat to Borj-cedria between 1974 and 1988

The area Borj cedria - Soliman has the largest shrinkage values of the coastline. Between Borj-cedria and the mouth of the river Soltan we measured regression speed reaching 2.14m/year (Figure 7).

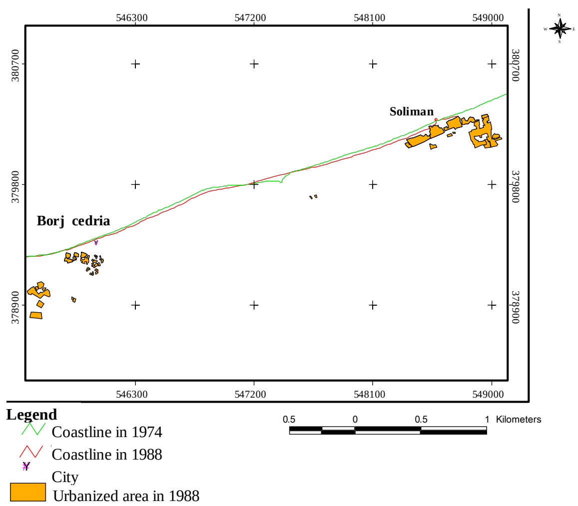

Figure 7: Evolution of shoreline from Borj-cedria to Soliman between 1974 and 1988

This erosion appears to be related to urban construction that is destroying the dunes which used to feed and ensure the regulation of the volume of the beach and on the other hand accomplishing the role of a barrier against the exchange between bordering dunes and the beach. The comparison of the DTM of dune in Borj-cedria presents a remarkable decr-ease in the volume of sand between 1974 and 1988 (figure 8)

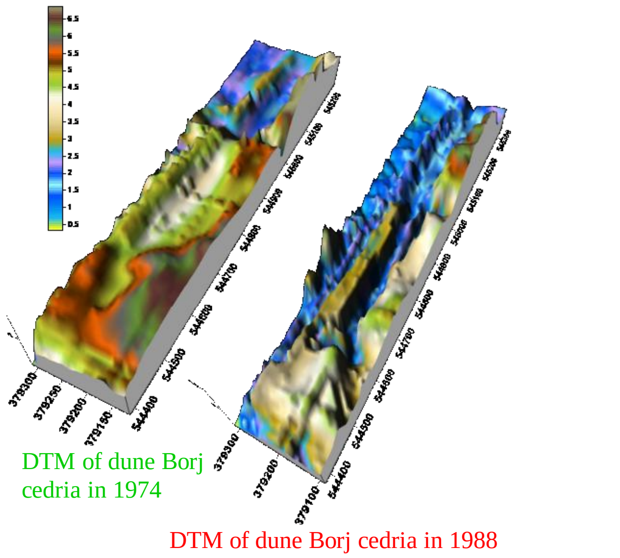

Figure 8: Evolution of dune in Borj-cedria between 1974 and 1988

At the mouth of the river Soltane the coastline appears stable. The balance achieved in this area can be justified by the accumulation of sediments transported by the river.

4.2 Evolution of the coastline between 1988 and 1996

Between Rades and the river Meliane as for the period 1974 -1988, the coastline continues to decline at a rate ranging from 0.87 to 1.25m/year. A value of recoil velocity of 1.2m/year in the same area was presented by (El Arrim, 1996). The coastline of the area between the river Meliane and the breakwaters of Ezzahra presents a progress that varies from 17 to 20m. We notice that the rate of accumulation of sand behind Ezzahra breakwaters increases in comparison to the period (1974-1988). Indeed, the region behind the two breakwaters grow longitudinally and tend to fuse, giving rise to a large beach of over 60m of width.

The shoreline is generally stable at Hammam Lif. The first three breakwaters have a size relatively smaller than the rest. They are relatively far apart compared to the rest of the breakwaters. There is no change in the volume of sand accumulated behind these breakwaters. Indeed, the action of the breakwater is not optimal. The last five breakwaters intercept sediment in motion under the effect of return currents, thus developing a wide beach sometimes going beyond 80m of width.

The coastline from Hammam lif to Ech-chaabia is marked by an advanced coastline from 3 to 7 m, at a speed of 0.37 to 0.87m/year. This is probably due to an accumulation of sediments transported by the longshore drift with South-East North-West direction.

Protection installation for Hammam lif intercepted a large amount of sediments, to promote fattening band downstream. Between Ech-chaabia and Hammam esh-chatt the coastline is stable. The breakwaters of Hammam esh-chatt intercept more sediment, which leads to a longitudinal extension of the beach. In the downstream of the breakwaters there is a beach that develops at the same band of rock. The fattening of this part of the coast is due to the interruption of transit through the coastal breakwater of Hammam esh-chatt.

The progress of the coastline at the riprap varies from 3 to 10 m. The area between the riprap of Hammam-echatt and Bir el bey is characterized by its advanced coastline at a speed of 1 to 1.87m/year. The advance of the shore continues to appear between Bir el bey and Borj-cedria but with lower speeds from 0.37 to 0.75m/year (Figure 9). After the construction of defences against beach erosion, the eroded beaches have generally stabilized: HammamPlage and Hammam lif beach (Sliti, 1990).

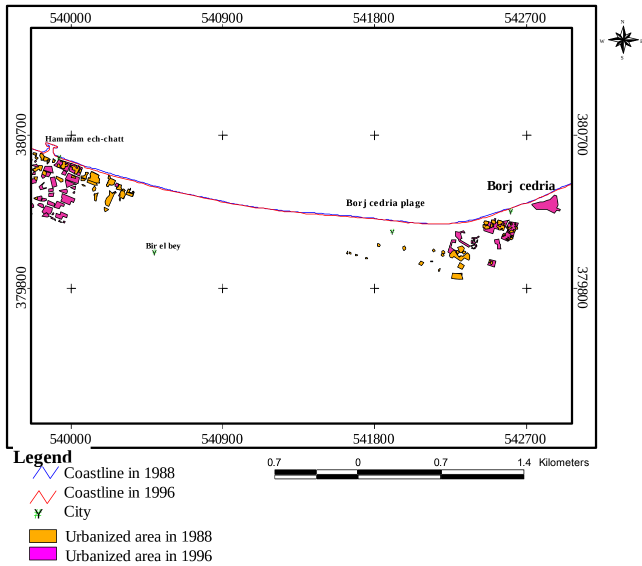

Figure 9: Evolution of shoreline from Rades to Ezzahra between 1988 and 1996

Going from Borj-cedria in the direction of Soliman, the beach remains in decline. The withdrawal reaches 50m at a speed of 6.25m/year (Figure10). The breakwaters settled in this region have slowed down the recoil velocity, but they have failed to thwart the phenomenon of coastal erosion. The high speed of decline is measured in the vicinity of urban areas that are in perpetual extension.

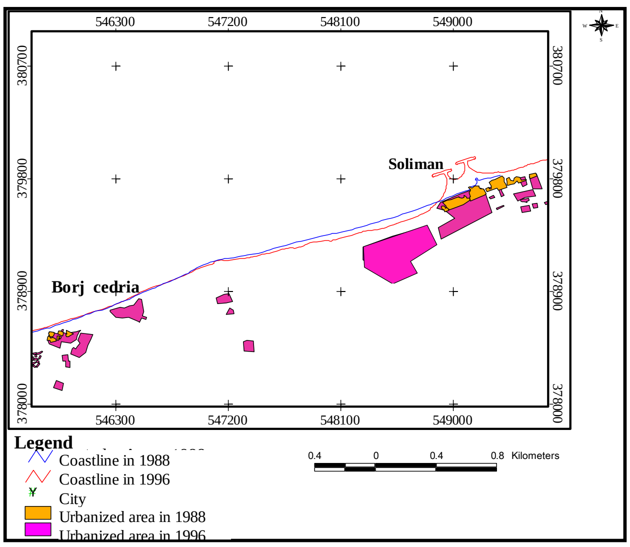

Figure 10: Evolution of shoreline from Borj-cedria to Soliman between 1988 and 1996

The establishment of five breakwaters in Soliman (only three are functional) caused extensive erosion upstream of these structures due to the interruption of coast transit East/ West by the sedimentation region behind breakwaters. The installation of a large urban area behind the first three breakwaters contributes to beach erosion, which varies between 80 and 110m with a recoil velocity of 5.71 and 7.86m/year. The values given by other authors are consistent with the speeds mentioned above. Indeed, (El Arim, 1996) described the shoreline of the Gulf of Tunis as subject to erosion, with a decline of the coastline from about 1 to 2m/year on average, but could reach in some areas, more than 10m/ year.

Behind the last two breakwaters, the accumulation of sand is not obvious. Thus these installations have not accomplished the purpose for which they were installed. This could be due to poor design or poor interpretation of the sedimentary dynamics of this area.

The analysis of the evolution of bordering dunes shows an excessive degradation of dunes which is about 358000m^3. The removal of huge amount of sand is the result of resorts facilities built in this region. These facilities substitute the dunes not only by using sand dunes as building materials, but also by becoming an artificial barrier between the dunes and the coast. Indeed the erosion of the beach of Soliman seems to be related to the degradation of dune following the developments made near the shoreline.

5 Conclusions:

The shoreline of the small golf of Tunis is a dynamic sedimentary system highly scalable. We use the method of digital orthophotography to study the morphological dynamics of the coastline and quantify the recoil velocity or the advance of the coastline.

Using the technique of orthophotos seems well suited for studying the spatial evolution of coastal erosion:

- It takes a relatively short running time;
- It puts into consideration the spatial heterogeneity of erosion;
- It allows us to locate and calculate with more details the volumes of accumulation and erosion.

The comparison of coastline plots from the orthophotos based on aerial photography of the years 1974, 1988 and 1996 shows three types of coastal areas with different behaviors:

- The coastal fringe of the river Meliane-Rades and Borj cedria -Soliman show a decline of coastline throughout the study period from 1974 to 1996. The recoil velocity reaches more than 7 m /year in the area of Soliman. That is increasing the amounts of sediments in the beaches of these areas.
- The coastal fringe between the breakwaters Ezzahra and the river of Melian, Hammam lif-Ezzahra and Bir el Bey-Borj cedria have a coastline advance that reaches 2.8 m /year leading a coastline fattening.
- Areas of breakwaters Ezzahra- Ezzahra hotel and Hammam lif-hammam ech chatt are alternating between erosion and fattening. Thus, during the period 1974-1988, there has been a decline reaching 1.21 m / year. This situation is reversed during the period 1988 / 1996 when there was a rather advanced feature of the coast with speeds reaching 0.87 m / year. This shift from erosion to fattening is favoured especially by the implementation of protection installations (breakwaters) which intercept sediments mobilized by the littoral transit from Soliman to Rades.

The movement of sediments is led by the drift littoral currents. Monitoring the evolution of bordering dunes shows an accelerated degradation of these sedimentary stocks. These dunes are almost absent all along the coastline from Rades to Hammam ech chatt. The dunes of the area between Hammam ech chatt and Soliman are subject to an accelerated degradation. The volume of degraded dunes in Soliman is equal to 358000m^3 during the period 1988 / 1996.

Sediment dynamics of the coastal fringe Rades-Soliman depends on the combination of natural factors, such as wind and fluctuating characteristics of the swell, and interference of man. Indeed, the construction of dams on rivers which flow into the study area and especially on the river Meliane, deprives the shoreline of a large sediment load.

Degradation of bordering dunes as a result of urban expansion prevents the re-balancing of beaches through sedimentary dune-beach exchange.

However the implementation of protection installations along the coast Rades-Soliman has stabilized a large extent of coastline.

Nevertheless, some breakwaters appear ineffective. The last two breakwaters of Soliman are a living example. The implementation of these barriers is really costly. Therefore, we must conduct a thorough detailed study of sediment dynamics before implementing them. Because of the instability on the coast of Soliman, colossal efforts must be done to stop this erosion phenomenon. The stabilization of this area can be achieved by reducing urban sprawl, artificial recharge of the area most affected by erosion and the establishment of more efficient protection installation like spikes.

- Recommendations to use this approach for other areas

Closer shots and increase the scale of observation linking these results with granulometric analysis to verify the origin of sediments.

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