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Evolution of the coastline of Saidia - Cap Water (Northeastern Morocco)

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Abstract: *the north-eastern coast of Morocco is a fragile area and vulnerable to the coastal erosion. This is due to a deficit of sediment load caused by the construction of the dams on the Moulouya river which ensures fattening the beach on one side and the coastal tourist developments that destroy the coastal dune system on the other.*
The use of the geographic information systems (GIS) allows us to study the evolution of the coastline since the late fifties. This study is carried from aerial photography in a several periods, of the topographic map of Triffa to 1 / 50 000 and Spot satellite images.
The results show a strong retreat of the Saidia-Cap Water coastline that reaches about 10m / year at the mouth of the Moulouya and 0.5m to 1m at Saidia. This withdrawal is a real risk to the entire coastal zone and which must be carefully studied in order to measure its position in the future, especially in the context of the current climate change and the likely sea level rise in the coming years.
Keywords: *Coastline, erosion, shoreline, diachronic evolution, GIS*

I. Introduction

The coastline of Saidia- Cap Water (locally called Ras Kebdana) is a fragile ecosystem of ecological interest and an important socioeconomic area. it is under an increasing attendance that threatens directly it's environment. It has undergone several improvements, but remains the least anthropized compared with other coast of Morocco: urbanization, tourism projects, aquaculture companies (SAM, now abandoned), port of Cap Water (in 1983) port of Saidia (1998) in 4 km east of the mouth of the Moulouya, and lately, the big tourism project Mediterranea Saidia. This area also houses a site of biological and ecological interest, of undeniable heritage value because it is the estuary of the largest river in the Mediterranean slope of the Maghreb and the mouth of the longest river in Morocco. It contains several notable plant species including 13 Moroccan endemic, 10 rare and remarkable species and nearly 86 endangered species such as the Juniperaie, Tamariçaie and sansouires groups. This site also provides a refuge 2/3 idle and fauna species in Morocco, including 65 rare species, 44 remarkable species and 25 endangered species, including 8 mammals, 7 birds, 6 reptiles and amphibians and 4 invertebrates (TRIPLET Patrick et al. 2010).

The combined action of natural and / or human factors generates a serious imbalance in these environments. Resource degradation results in loss of species, habitats and ecological values including the bordering dunes.

Coastal erosion is one of the major environmental problems facing the coastline faces. This problem is manifested by the decline in the shoreline, decreasing the width of the beach and the degradation or even the disappearance of the dune. The erosion rate of the coastline varies from 8 to 10 m / year at the mouth of the Moulouya and 0.5 to 1m at Saidia.

The goal of this study is to highlight the evolution of the trait of Saidia- Cap Water coastline on a temporal mesoscale and participate in the realization of the fate of an evolving database of Moroccan sandy coasts.

II. General Framework Of The Study Area

The coastal plain of Saidia-Cap Water is located in the extreme northeastern Morocco between latitudes 35 ° 5 'and 35 ° 8' north and longitudes 2 ° 14 'and 2 ° 26' west. It starts from Morocco-Algerian border in the east until Cap Water in the west of about 20km. The general morphology of this coast is very varied. In the middle of the coastal plain of Saidia - Cap Water, the Moulouya river divides the coast into two parts. This marks the essential source of the deposits of the plain. The beach is formed by fine sands that form a beautiful beach. The backshore of this area is formed by sand dunes west-east bound direction. At the coastal plain, the topography drops to less than 2m (Fig. 1). The coastal plain stretches to the foot of the mountains of Ouled Mansour 4-5 km wide. At the left bank of the Moulouya river, dead cliffs mark the limits of dunes and the beach

profile is approximately 200m stall. In the back, the landscape is marked by a relief system hacked by a river system whose the seasonal rivers outfalls drain the coastal plain during the periods of precipitation.

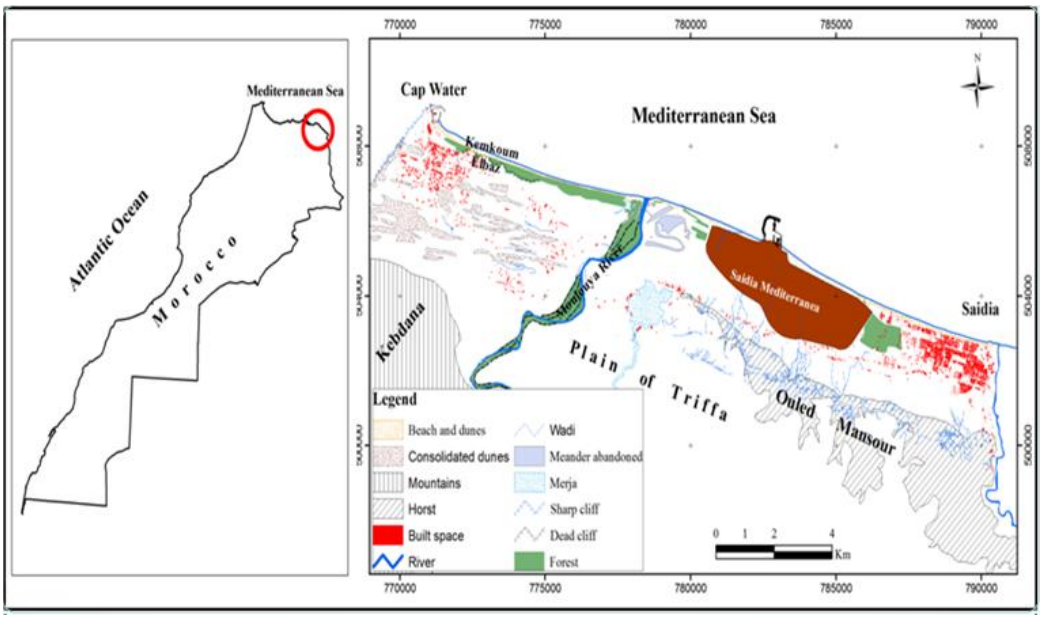

Figure 1: Location of the study area

The accumulation of the sand along the coast of Saidia - Cape Water leads to the formation of dune massifs. Beach deposits are higher Ouljien Mellahien age and they constitute the elongated strip at the foot of Ouled Mansour.

The major climate change during the Miocene and Pliocene transgressions and regressions accentuate the mechanical erosion. Therefore, large sedimentary masses are produced and old are elongated dunes at the foot of mountains of Ouled Mansour and back-Kebdana beach. This global historical change appears in the current geomorphological framework.

The climate of the coastal plain is defined by an inter-annual variability and intra-seasonal rainfall and dry summer season which explain the fluctuations of water. It is a dry Mediterranean climate, warm and humid in summer and cool in winter. It is characterized by large seasonal temperature changes and low rainfall (319 mm Saidia) and irregular. Rain falls in forty days with sometimes heavy showers.

The thermal regime is relatively mixed. January is the coldest month of the year (11.1° C), while August is the hottest month (22.3° C). The annual average temperature is 15.8° C. The proximity to the sea, with its frequent coastal fog, makes the summer heat more bearable and significantly softens the winters.

The prevailing winds are mainly of marine origin. They cover equally the ENE and WNW sectors, while the winds of continental origin are associated with the sector winds east and west. The average wind speed is 14.8 km / h. The maximum speed is recorded in March, April and May with approximately 16.6 km / h. In addition, the minimum recorded speed is 12.9 km / h in October and December (LASGAA, 2014).

In the offshore of the Alboran Sea, the most frequent swells are of northwestern and northeast. Their significant period is 5,7s and significant height of 1.67 m. At the coast, the most frequent waves arrive with a north-south direction. Their height is often significantly less than 2m except for periods of agitation and it is about 5s on average.

At the beach, sedimentary material consists mainly of fine and medium sands. The average diameter (D50) is between 0.2mm and 0.9mm. The sand fraction shows a grain size gradient from the mouth of the Moulouya river to the east (Saidia) and west (Ras Kebdana) resulting from a hydrodynamic medium high energy process (littoral drift). The finest fraction is transported from one hand to the mainland by the winds, feeding the dunes and accumulating beneath the walls of protection for urban and tourist developments; secondly, it is taken by the littoral drift (LASGAA, 2014).

III. Data And Methodology

The vertical aerial photographs from 1958 are the oldest documents spanning the coastal area of Saidia-Cap Water and after that the aerial photos of 1963 and 1980. To complete this study, we used the satellite images of 1986 Spot sensor up '2014.

The spatial resolution is increased from 20m to 5m for all spectral bands and 2.5m in panchromatic mode. The spectral ranges explored extend the visible, near infrared to mid infrared.

All these documents have been scanned with a resolution of 400 dpi that provides a pixel of 63.5 microns. It gives a size of 1.27 m on the ground for 1/20000 aerial photography and 3.175 m on the ground for aerial photography to 1/50000. The aerial photos of different missions explored are:

Table 1: Data used

Years	Document Type	Provider	Scale / resolution	Scanning
1958	Aerial photos	CADASTRE Rabat	1/50000	400 dpi
1963	Aerial photos	CADASTRE Rabat	1/40000	400 dpi
1980	Aerial photos	O.R.M.V.A.M. Berkane	1/20000	400 dpi
1986	Aerial photos	O.R.M.V.A.M. Berkane	1/40000	400 dpi
1989	Spot Image	ISIS project	20m	
1999	Spot Image	ISIS project	05m	
2002	Spot Image	ISIS project	05m	
2014	Image	Google Earth	nearly 1m	

We used the Arc GIS software to rectify all this documents. However, we used the map projection system "Lambert Conformal Conic Northern Morocco" and the transformation is linear polynomial of a first order type. The combined total error calculated by the software, however, is between 1.2 and 2.4m. All these documents were then converted into usable digital medium by the computer platform in TIFF format.

To digitize the coastline, we chose the instanious shoreline to trace the coastline. The choice of this reference line is easily spotted on vertical aerial photographs and satellite images with radiometric and visual differentiation between dry sand and wet sand in the intertidal zone.

After that, the analysis of the evolution of the trait of Saidia-Cap Water coast is performed using cross transects to define the advance and retreat of the coast (Fig. 2). These transects are 37 in number, spaced 250m and oriented to the north across the Saidia-Cap Water area for calculating the rate of change of the coastline between 1958 and 2008.

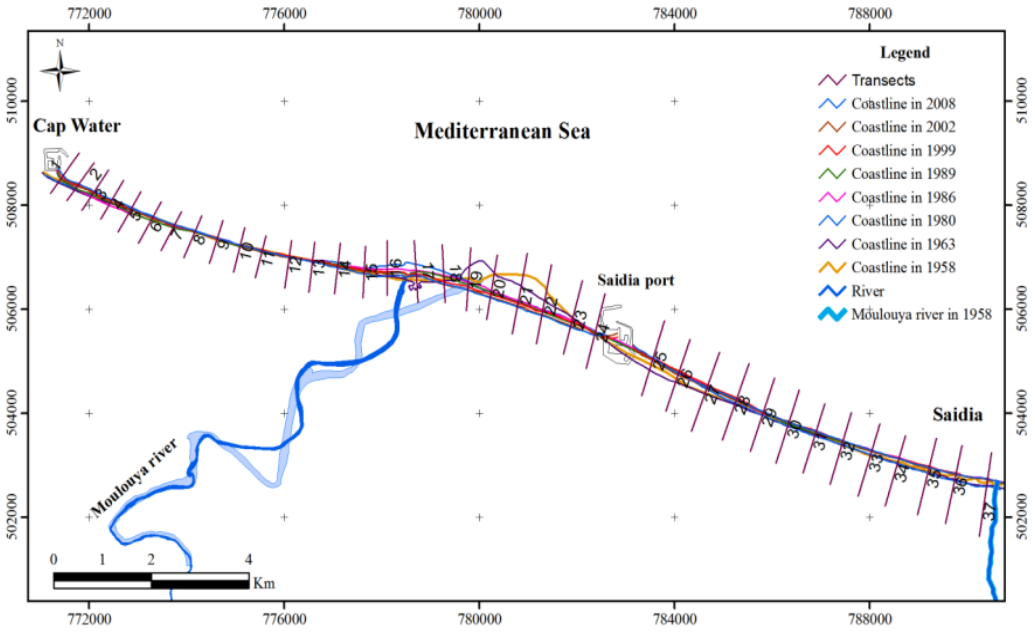

Figure 2: Location of the transects

IV. Results And Discussion

State of the Coastline In 1958

The study of aerial photographs from 1958 through GIS (Fig. 3) shows that the Moulouya river advancing in the sea after having a southwest to northeast orientation drift as a small delta. The analysis of this vertical aerial photography in a geographic information system confirms that the width of the Moulouya river in contact with the sea was more than 700m. On the both shores of Moulouya, there were traces of ancient rivers and backwaters that reflected a very important fluvial dynamic that continues to this day. Generally, the study of the state of the coastline Saidia - Cap Water in 1958 by aerial photographs with the GIS shows a blank space and very little urbanized.

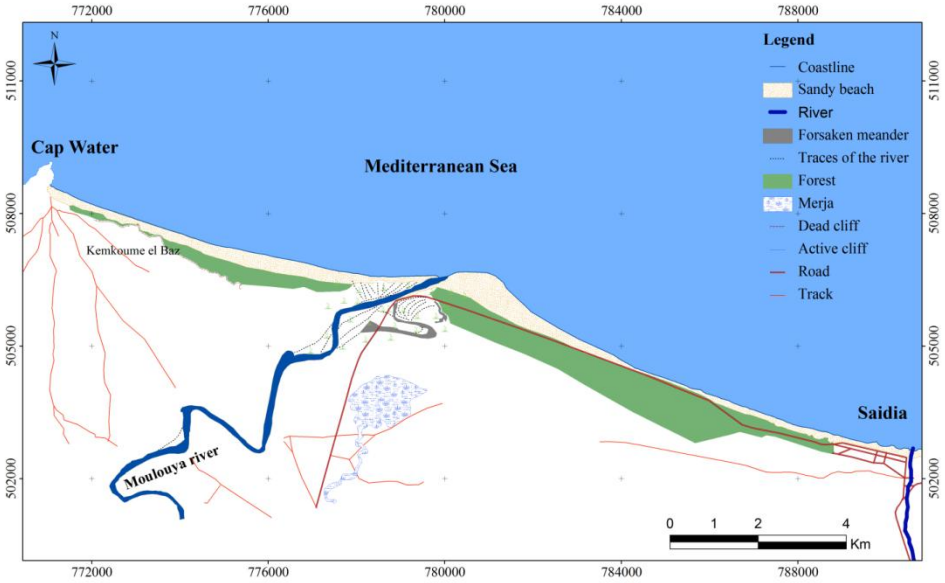

Figure 3: State of the coastline of Saidia - Cape Water in 1958

Evolution of the Coastline between 1958 And 1963

The 1963 aerial photographs were made just after a period of heavy rainfall leading high Moulouya flood (May 1963 flood) as evidenced by the width of the river that was over 886m (Fig. 4). We also observe that the floodplains of the Moulouya was backfilled by the flood, which pushed the river to dig a new, more direct passage to the sea in the coastal dune. These floods brought a large amount of suspended sediments that are clearly seen on aerial photos, with the color white at the sea.

If we superimpose the state of the coastline on aerial photographs from 1958 and 1963, we find that the shoreline has undergone several changes as shown in the figure below.

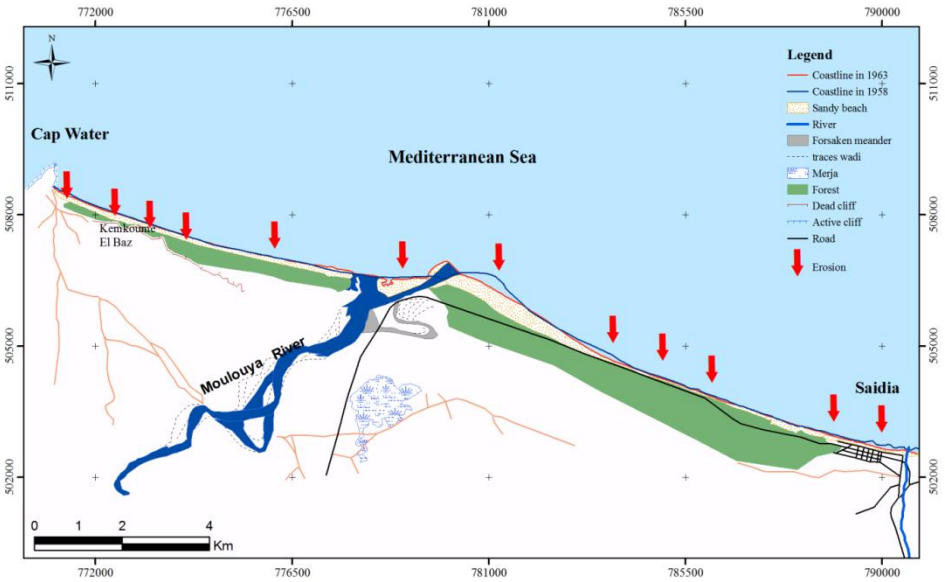

Figure 4: Evolution of the coastline between 1958 and 1963

During this period, a general landscape has affected the coast of Saidia - Cape Water. The decline of the coastline is clearly observable at the mouth of the Moulouya, Cap Water and Saidia (Fig. 4). This is due to the construction of the dam Mechraa Hammadi on the Moulouya river, which consequently slowed a large amount of sediment is expected to be transported to the beach, especially when we know that the Moulouya and its watershed remain the main source of sediment found on the beach.

Evolution Of The Coastline Of Saidia - Cap Water Between 1963 And 1980

These aerial photographs were taken in June 1980 where the flow of Moulouya appears much lower than on the aerial photos from 1958 and 1963. The width contacting the sea was very narrow and did not exceed 144 m. on the scale of the left bank of the Moulouya, the coastline has suffered almost continuous progression between Cape Water and the Tghaninte cliff and eroded part appears only slightly on some sites (Fig. 5). This positive development of the beach is only a redistribution of the old part of the delta in 1958 which was eroded by active hydrodynamic agents.

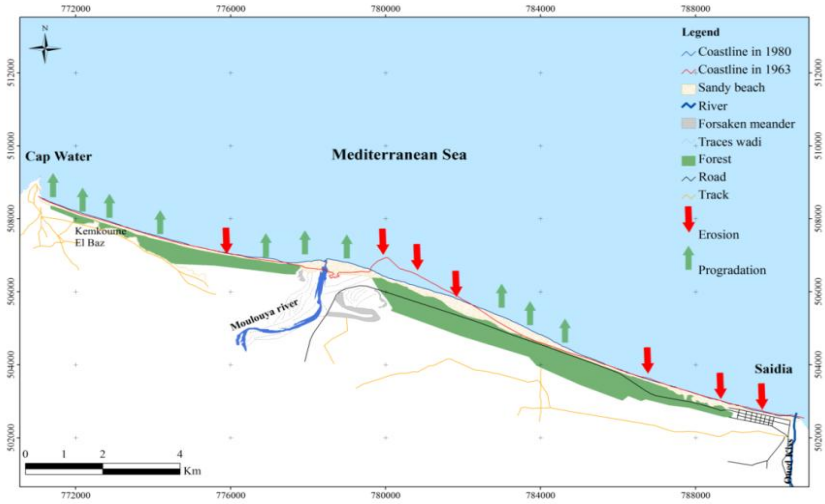

Figure 5: Evolution of the coastline between 1963 and 1980

At the mouth of the Moulouya, the former crossing the river (in 1958 and 1963) remains visible though definitively abandoned, forming an oxbow of the river. At that level, we note that the shoreline was down to 374m over the period 1963-1980 is 22m / year. For cons, the trait of the present mouth of coast rose slightly below its previous position because the backfilling of river inputs. At the same time, the coastline rose slightly on the right bank of the Moulouya until Saidia since 1963, which can be linked with the movement of the eroded portion at the mouth of the Moulouya to Saidia and from Cape Water.

Evolution of the coastline between 1980 and 1986

The satelittale image Spot of 1986 was taken in July. The erosive trend will continue over this period especially at the mouth of the Moulouya. There has also been a slight advancement of the coastline at Saidia and at the port of Ras Kebdana (Fig. 6).

The superposition of the coastline in 1980 on this image shows little change compared to the previous mission. However, there is a retreat at the mouth of the Moulouya, and a progradation at the port of Saidia. But overall, the coastline edged up its state since 1980.

During the period 1980-1986, it notes that there are three sectors. A sector in erosion, a stable industry and a sector growing. The first sector fell 85m (14m / year) at the cliff of Kemkoum El Baz and 161m at the mouth of the Moulouya river. In Cape Water, a spectacular growth of the coastline it occurs because of the installation of the port of Ras Kebdana and therefore hinders sediment carried westward by the longshore currents.

On the image satelittale of 1986, the Moulouya river appears straighter towards the sea. The width of the mouth in contact to the sea is about 34m.

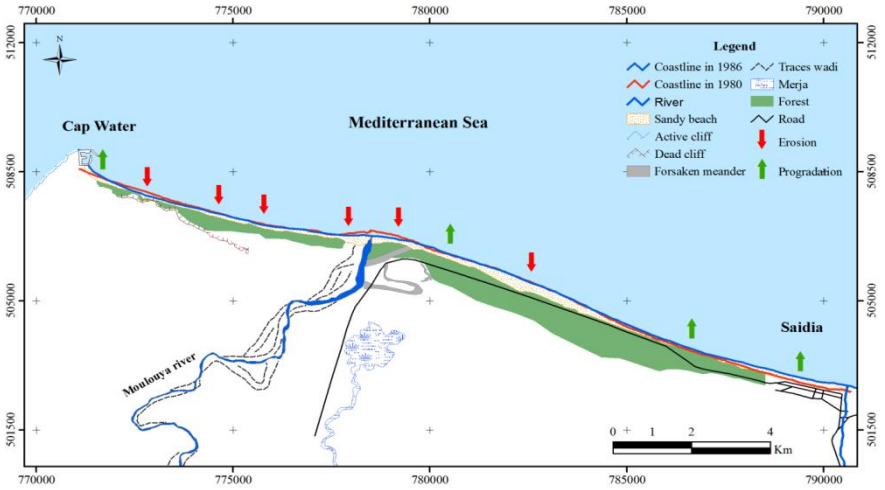

Figure 6: Evolution of the coastline between 1980 and 1986

Evolution of the Coastline between 1986 And 1989

This image was taken in March 1989. During the period between 1980 and 1989, the landscape has affected the majority of the coastline of Saidia - Cap Water (Fig. 7).

This image shows very well the effect of the port of Ras Kebdana on the accumulation of sediments from east to west forming sand spit to the sea. For cons, the port created in 1980 suffered silting considerable, which requires a regular dredging.

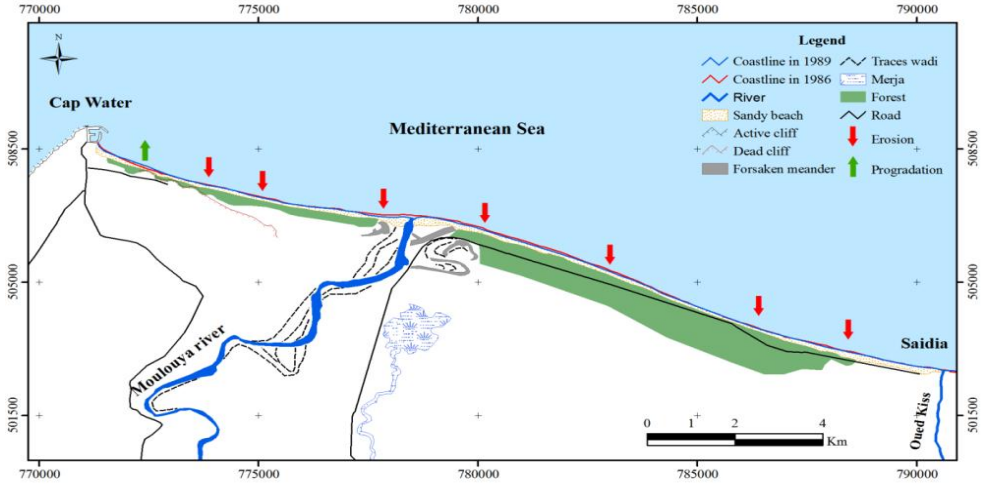

Figure 7: Evolution of the coastline between 1986 and 1989

The diachronic analysis in GIS of 1986-1989 appears clearly the degradation of the mouth of the Moulouya river. We note the decline of the delta in 200m at the level of the left bank and 172m at the right bank. This status indicates that marine erosion exceeds the alluvium of the river contributions. The width of Moulouya river in contact with the sea is about 30m. If these measures tell us anything, it is that the river intake materials decreases much more than before because of the dams and increased water demand for agriculture and urban needs.

In the area of Saidia, the situation is no different. We see the decline of the coastline along the coastline and spaces gain are very limited and do not exceed a few small meters.

Evolution of the Coastline between 1989 And 1999

The satellite image from 1999 was taken during spring (March). Over the period from 1989 to 1999, the decline of the coastline ruled at the mouth of the Moulouya. The advancement of the shoreline is slightly observed at Cape Water and at the port of Saidia, created in 1998 (Fig. 8).

The comparison of the state of the coastline in 1999 with that of 1989 indicates a withdrawal of -40m at the right bank of the Moulouya river. Similarly, the river width in contact with the sea fell up to 42m, which can be related with the drought that is combined with the abundance of rainfall and the decrease in the burden of alluvial Moulouya river because dams.

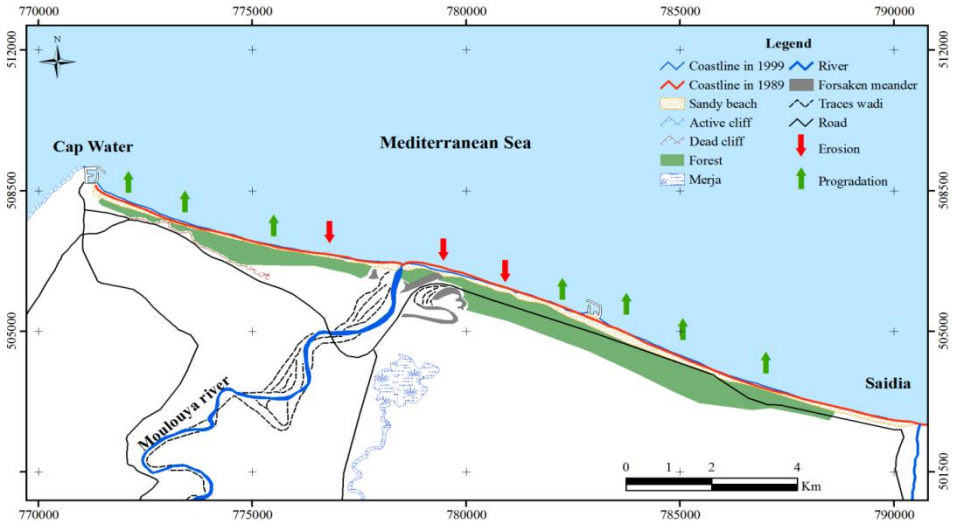

Figure 8: Evolution of the coastline between 1989 and 1999

Evolution of the Coastline between 1999 And 2002

This image was taken in August 2002. This period was the actual start of the development and urbanization of the coastal zone. We see the construction of the fishing port and marina Saidia and implementation of the coastal ring road between Saidia and Tanger.

During this period, general erosion has affected the coast of Saidia - Cape Water. The decline of the coastline is clearly observable at the mouth of the Moulouya, in Cap Water and Saidia (Fig. 9). This is due not only to the construction of the dam of Mechraa Hammadi and Mohammed V on the Moulouya river that have held back a large amount of sediment would be transported to the beach, but also because of the drought that affected the region over recent decades, increasing demand on water for agriculture and urban use.

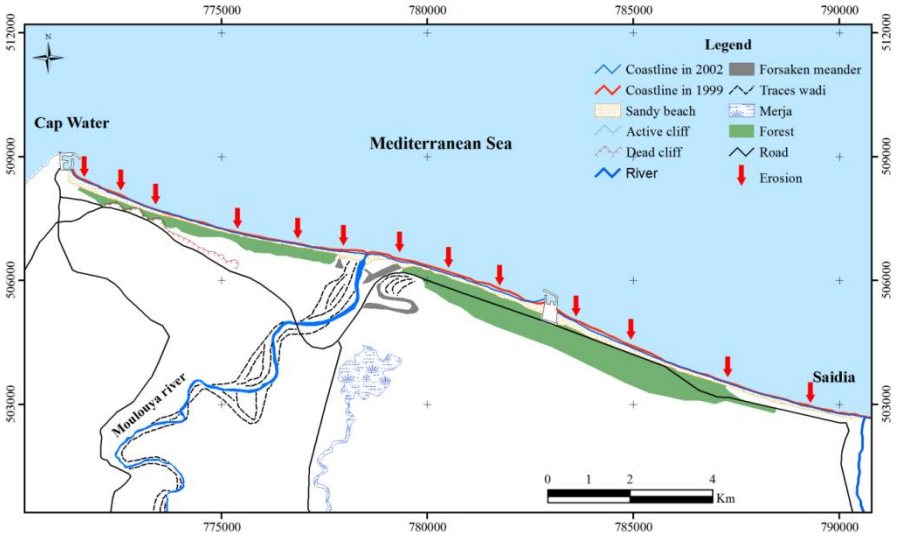

Figure 9: Evolution of the coastline between 1999 and 2002

Evolution of the Coastline between 2002 And 2014

The 2014 image shows a very different state of the coast of Saidia - Cape Water. Spatial changes (tourist facilities, equipment and urban sprawl) are clearly visible during this period. By cons, ecological and natural areas have disappeared Tazagrarte forest, decreased the beach. On this state, the coastal strip draws an almost straight line except at the port of Cape Water and Saidia where there is an advanced slight to the sea.

The analysis of this figure shows that the coastline has changed little since 2002 (Fig. 10). For cons, the shoreline has progressed much at the port of Saidia. There is a progression from the coast of approximately 250m west of the port and 142m to the east. This change is directly related to poor location of the port which consequently hinders sediment transported by longshore drift eastward and westward, thus contributing to its silting.

During this period, the coastline of Saidia underwent a clear decline due to the effects of human development on the coast, including the establishment of the port of Saidia holding back sediment transit to Saidia.

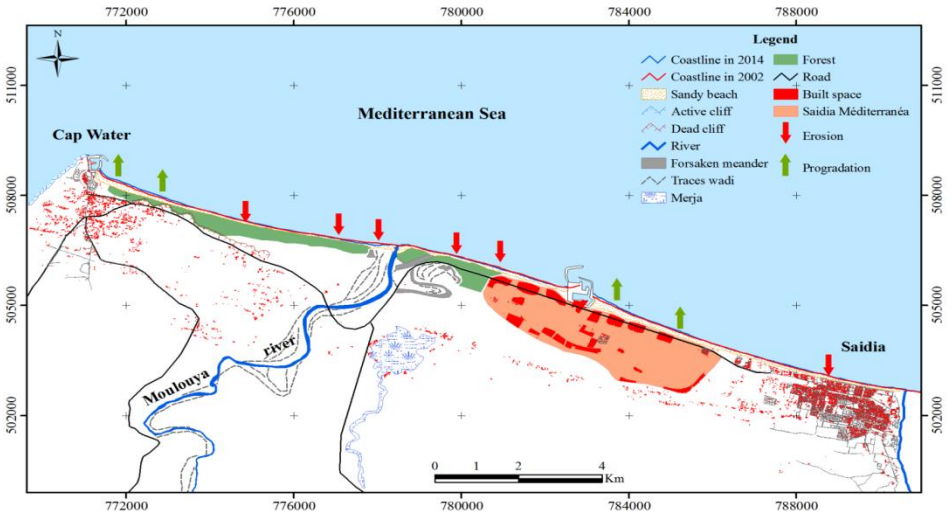

Figure 10: Evolution of the coastline between 2002 and 2014

Evolution Of the Transects

The analysis of the 37 transects (Fig. 11) allowed to observe and calculate the evolution of the coast of Saidia Cape Water between 1958 and 2014. However, we are seeing great changes in the coastline including at the mouth of Moulouya river, where we see the disappearance of the ancient delta and the emergence of a new mouth just next door to the west. Large spaces have been lost including wide Saidia and Cap Water between 1958 and 1963.

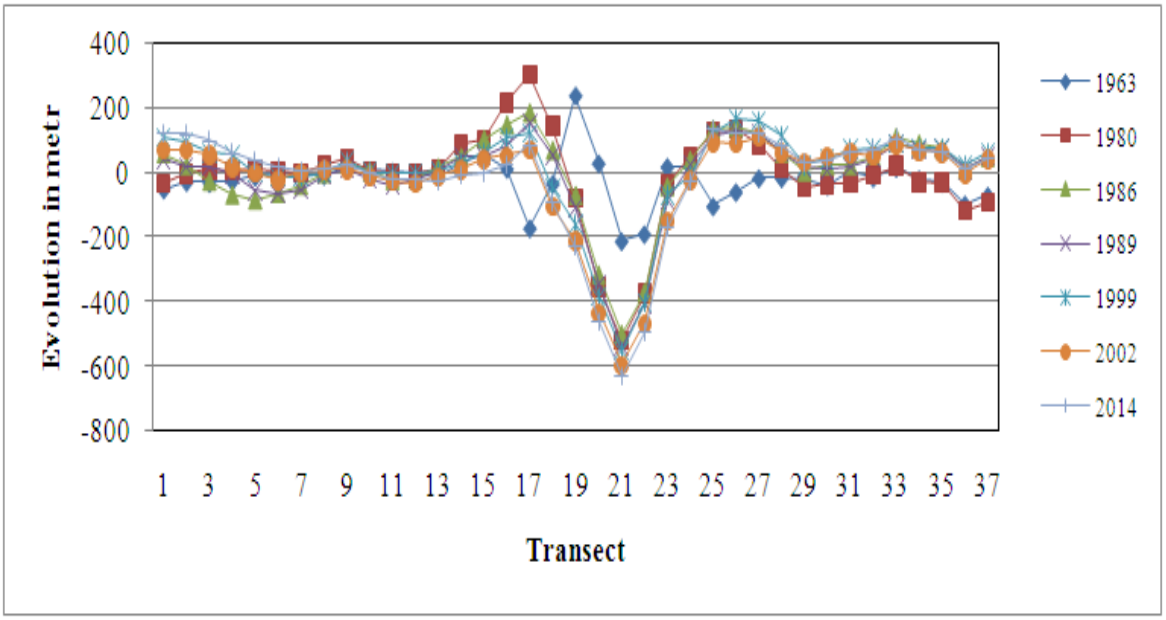

Figure 11: Transects variation of Saidia - Cap Water coastline

During the period of 1963-1980, the coastline continued to grow strongly at the mouth of the Moulouya, with a decline of more than 520m. In addition, the advancement of the shoreline is very pronounced at the biological and ecological site (SIBE) and the left bank of the mouth. Spaces earned are due to the redistribution of the eroded part of the ancient delta. Far from the mouth, the coastline has fallen below its position at Saidia and slightly across Cape Water due to the establishment of the port of Ras Kebdana.

Between 1980 and 1986, the coastline tends to fall on the entire coast between Cape Water and Saidia, with the exception of a few sites. Generally, two areas can be distinguished: a sector breakdown between the beach of Saidia and the dead cliff of Kemkoume El Baz, and an area up at the ports of Cape Water and in Saidia where the sediments settle to level piers ports causing their silting.

Generally, the coast of Saidia-Cap Water has experienced several spatial changes that are manifested by the construction of the port of Saidia and the establishment of the new tourist resort "Mediterranea Saidia" on more than 700 ha. These developments had a significant impact on the natural evolution of the coast. The measured transects show, the volume of these changes. However, we noticed a sharp decline in the biological and ecological site SIBE and the mouth of the Moulouya river and Saidia. We also observe a dramatic advancement of the coastline in the port of Saida. This progradation appears clearly on the satellite picture of 2008 by the accumulation of sediments on the west pier and the harbor. Over 300m was won in the west of the port. Furthermore, the coast of Saidia - Cape Water is exposed to other problems that can disrupt the natural functioning, namely the degradation of the site of biological and ecological interest of the Moulouya river, degradation of forests and anthropization the coastal strip.

The Impact of the Decrease in the Fluvial Load

The contributions of rivers are the most substantial, there volume varies with climate areas (R. Paskoff 1998). The Moulouya river catchment spreads over an area of 53,000 km^2 (Fig. 12), which makes almost 64% of the area of the region of Eastern Morocco. It is in semi-arid to arid climate with a Mediterranean-term. The aridity increases rapidly to the south. The rainfall pattern is quite contrasting; it is marked by the aggressiveness of rainfall and the poverty of the vegetation cover. Therefore, periods of heavy rainfall causing large floods loaded by various sedimentary material, due to the strong torrentiality. These floods move towards the sea, their final disposal.

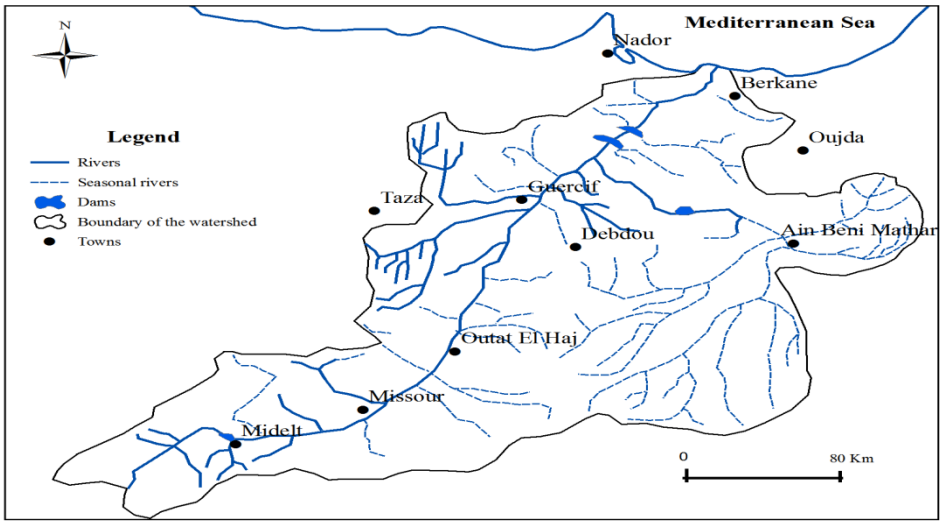

Figure 12: Moulouya watershed boundaries

The flow of the Moulouya is very variable. The average annual rate recorded between 1980 and 1995 is 5.68 m3/s; the measured minimum flow is 4.68 m3 / s in 1984 and the maximum value is 7.65 m3/s in 1993 (T. BOUMEAZA 2002).

Initially Moulouya river has behaved no dams blocking the sedimentary material, which indicates the importance of sediment deposited along the coastline. These sedimentary volumes gradually decreased dice the construction of the dams Machraa Hammadi in 1956 and Mohammed V in 1964. Therefore, the coastline from the mouth of the Moulouya declined since.

The concentrations stringers suspension measured at three stations situated upstream of the dam Mohammed V, range from 0.1 to 1.2 kg / m^3 for the basal and middle floods and 50 to 100 kg/m^3 during exceptional floods (such as 1963). Assuming a density of 1.8 for the materials constituting the watershed, so the average annual breakdown is 156 t/km²/year, corresponding to an erosion of 0.087 mm / year 2 (Lalhou A., 1984). The initial volume of the Mohammed V dam basin (726 million m3) has lost almost half its potential and is likely to be filled in 2030, sixty years after its creation (Boumeaza Taieb et al. 2010).

Before the construction of the dams, all resulted in sediment load downstream in the coastal plain. The current comes from alluvial plain deposited by the Moulouya river during the floods. During the recent Holocene allowed the construction of silt terraces that surround the current river bed. The analysis of aerial photographs shows that the mouth of the Moulouya built a delta lobe still visible on the 1958 aerial photo as that of 2008. The successive beach ridges, clearly visible on the aerial photographs, describing the progress of the coastline. They resisted to stream flow, promoting the development of meanders and cross-checking. The large dune cord induces the development of the wetlands.

V. Conclusion

The diachronic analysis of vertical aerial photography using a geographic information system of the coast of Saidia - Cap Water allowed to observing and studying its morphological evolution between 1958 and 2008. However, the superposition of the states of the former coastlines on more recent statements shows the great changes that have affected almost the entire coastal zone. However, catastrophic changes appear particularly at the mouth of the Moulouya where the decline of the coastline is more serious. Furthermore, the development of cross-cutting transects along the coast showed clearly the dramatic decline of the coastline beyond his previous position. In addition, we are also seeing some beaches progradation at Cap Water, especially after the establishment of the port of Ras Kebdana in 1980 and the port of Saidia in 1997. Among the factors behind this decline include natural causes that manifest by rising sea levels and aggressiveness of natural hydrodynamic agents (waves and swells ...). To this must be added the human activities manifested by urban development, hydraulic interest work on the river (dams, pumping ...) and excessive extraction of sand that have highly unbalanced the system Morphosedimentary of the coast.

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