

## STUDY OF MORPHODYNAMIC AND SEDIMENTOLOGICAL CHANGES IN THE OUALIDIA LAGOON (MOROCCO) USING BATHYMETRIC DATA: FIRST INVESTIGATIONS AFTER THE SEDIMENT TRAP DREDGING

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### ABSTRACT

Coastal lagoons are highly dynamic and physically complicated systems. They are environmentally productive and socio-economically valuable. Contemporary global development and management pressures require a better understanding of their dynamics and sustainability. The present study focuses on the problem of water confinement in the Oualidia lagoon (Atlantic coast of Morocco). This lagoon is characterized by an asymmetric tidal propagation, with a shorter duration of the flood (rising tide) than the ebb (falling tide). In the long term, this contributes to the reduction of depths and the confinement of water upstream. After extensive studies, a sediment trap was created in 2011 to trap the finest sediment in the upstream part of the lagoon. This study aims to analyze the morphodynamical and sedimentological changes in the lagoon of Oualidia, after the sediment trap dredging. For this purpose, bathymetric surveys covering 6 years between 2006 and 2012 were analyzed, providing sufficient data to identify the morphological changes that the lagoon has undergone during this period. The data analysis was followed by a study of the lagoon bed dynamics using profile lines extracted from the bathymetric data in a GIS environment. As a result, the findings partly show that over 6 years, an average height of +0.65 m was gained by the lagoon, while the average change in the eroded areas was estimated to be -0.42 m. In addition, the eroded area in the lagoon was estimated to be about 1,513,800 m<sup>2</sup> with an erosion volume of 633,383 m<sup>3</sup>, while the accumulated area found was about 2,699,396 m<sup>2</sup> with an accumulation volume of 1,765,866 m<sup>3</sup>. These changes can be related to the large input of marine sediment, mainly caused by tidal currents and waves, but also to the creation of a sediment trap in the upstream area of the lagoon.

### 1. INTRODUCTION

Environmental lagoons are shallow water bodies connecting to the open sea by one or more entrance inlets, with limited freshwater influence (Oliveira et al., 2006). They are common throughout the world, as they are aquatic shallow ecosystems developed at the border of land and sea coasts (Gonenc and Wolflin, 2004). Coastal lagoons are considered among the most valuable ecosystems in the world (Duck and da Silva, 2012; Knoppers, 1994), supporting important environmental services such as fisheries (Cañedo-Argüelles et al., 2012; Pauly and Yanez-Arancibia, 1994). Despite their interest in sustainability, these environments are still facing many challenges around the world due to their socio-economic interests which increase human pressure leading, in turn, to overuse of available natural resources and many environmental degradations (eutrophication, pollution, urbanization, and various forms of changes) (Apitz et al., 2007; Esteves et al., 2008; Wolanski et al., 2013). Around the world, the modification of their natural hydrology, in particular the artificial connection with the ocean, represents one of the most common threats affecting coastal lagoons (Conde et al., 2015).

Understanding natural and human-induced ecosystem changes and planning successful remediation projects needs an

understanding of depositional, and erosion processes (Jaffe et al., 2007). The Comprehension of temporal and spatial patterns of sedimentation, comprising deposition, transport and erosion processes, is essential for effective decision making on a diverse variety of management matters in estuaries and transition basins including lagoons (Apitz et al., 2007).

The sediment changes the water depth and, consequently, the extent and circulation of habitats. Therefore, changes in bathymetry influence tidal flow and tidal exchange patterns, that are important for the transport of sediments, salt, grubs and nutrients (Monismith et al., 2002; Uncles and Peterson, 1996). Modifications in the physical, hydrodynamic and geomorphological structure of lagoons have the potential to affect the environment's natural well-being, its characteristics and then the health of its inhabitants (Alademomi et al., 2020). On the other hand, driving forces such as sea-level rise (Ciavola et al., 2002), water flow and floods are affecting coastal areas, leading to the disappearance of salt marshes (Bellucci et al., 2007), interactive areas, and other negative environmental impacts (Adriano et al., 2005).

The Oualidia lagoon, which is the study area, is located on the Moroccan Atlantic coast (32°45.440 N - 09°00'.870 W; 32°44.950 N - 09°01'.520W) (figure1). This lagoon was classified by the Ramsar Convention as a protected area of

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international importance in 2005. Numerous studies have been done on the Oualidia lagoon in various fields of study, such as coastal integrated management, the pollution by heavy metals, modeling of the sediment exchange sea-lagoon using physical, geological, and biological samples (Bouchkara et al., 2021; Daghor et al., 2016; El Asri et al., 2015; El Khalidi et al., 2011; Hennani et al., 2014; Hilmi et al., 2009; Khoukhouchi et al., 2018; Laissaoui et al., 2018; Maanan et al., 2014; Makaoui et al., 2018; Mejjad et al., 2020a, 2020b, 2018, 2016; Natij et al., 2014; Zourarah, 2002; Zourarah et al., 2007).

The confinement of sediments in the Oualidia lagoon has been the subject of several studies (Khalid et al., 2011; Koutitonsky et al., 2012.; 2007.; 2006a). A first study of the hydro-sedimentary regime of the Oualidia lagoon by mathematical modeling was conducted in 2006 (Koutitonsky et al. 2006; 2007). Its objectives were to describe the hydro-sedimentary conditions in 2006 and evaluate the impacts of opening the downstream dike and the creation of a sediment trap. These studies had shown that the lagoon of Oualidia is characterized by an asymmetric propagation of the tide, with a duration of the flood (rising tide) shorter than that of the ebb (falling tide). Thus, for the same volume of water entering and flowing out, the maximum velocities of the flood (or ebb) currents are greater than those of the ebb (or flood) currents. The same investigations have also found that the transport of mud in the channel area is directed upstream. In the long term, this contributes to the decrease in depths and confinement of water upstream. Therefore, it was recommended in 2006 to create a sediment trap in the upstream area of the lagoon to trap the sludge transported upstream by the strongest currents during the flow. This sediment trap was built in 2011.

This study is aiming to investigate the spatial dynamics of the Oualidia lagoon in terms of sediment change, using bathymetric data (2006-2012), after one year of the creation of the sediment trap in 2011. The sediment balance and the rate of sediment evolution were calculated using 3D GIS analysis tools and the main differences in sedimentation between the two-time scales were also identified. Moreover, profile sections was also performed on the 2006 and 2012 bathymetric data and plotted in the GIS software to calculate the average evolution during the study period as well as the annual rate of change of erosion and accretion of the lagoon's main channel. Finally, the significance of the accretion variation with factors taking into account the uncertainty of the lagoon bottom dynamics is discussed.

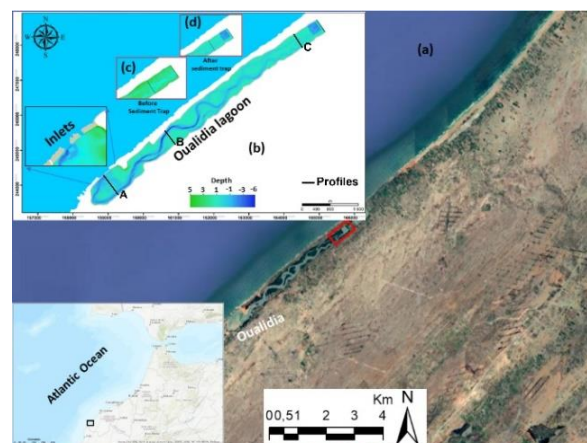
## 2. MATERIALS AND METHODS

### 2.1 Study site

#### 2.1.1 Geographic location

The Oualidia lagoon is located on the Atlantic coast of Morocco (32° 44'42 N - 9° 02'50 W) (Figure 1). It runs parallel to the coast for a distance of about 7 km. The lagoon is characterized by a warm temperate climate and medium rainfall, which varies according to the fluctuations of the natural rainfall regime. Its communication with the ocean is ensured by three entrances.

This lagoon is considered among the most important coastal ecosystems of the Moroccan Atlantic coast, as it is classified as a RAMSAR site (Convention on Wetlands of International Importance) since 2005.



**Figure 1.** (a) Overview of the study area (Oualidia lagoon).

The red box indicates the area of the sediment trap. (b) Bathymetry of the Oualidia lagoon. The red boxes show the state of the bathymetry before (c) and after (d) the sediment trap dredging.

#### 2.1.2 Sedimentology

The sediment granulometry of the Oualidia lagoon is coarse in the sandpit and the downstream part (sand and shell debris), where strontium and carbonate contents are high and trace elements remain low. However, the upstream part of the lagoon (schorre, slikke, and channels) shows a fine grain size (silt and mud and), with higher concentrations of trace elements and lower concentrations of strontium and carbonates (Bidet and Carruesco, 1982). Additionally, the same conclusions were highlighted by (Makaoui et al., 2018; Mejjad et al., 2020b; Zourarah et al., 2007), who also concluded that the spatial distribution of sediments in the Oualidia lagoon indicated that the upstream part of the lagoon presents muddy facies, whereas the downstream part is sandy. This type of sedimentation is strongly related to the asymmetric hydrodynamics in the lagoon (Koutitonsky et al., 2006a).

Vertically, the sediments of the Oualidia lagoon show a change in grain size distribution, the sediments are coarser (marine influences) in the bottom and finer in the surface (continental influences) (Bidet and Carruesco, 1982; Zourarah, 2002). This change in sediment facies along the depth was explained by a modification of conditions that control the distribution of sediment such as the sedimentation regime or hydrodynamics conditions (Mejjad et al., 2020b). Besides, the sediment accumulation rate and the sedimentation rate values were very low in the upstream part compared to the downstream which indicates that the hydrodynamic conditions control the distribution of sediments in the lagoon (Mejjad et al., 2020b). The human activities are the second factor controlling the distribution of sediment in this lagoon as presented in (Mejjad et al., 2020b) and influenced the sediment dynamic as the study chronology of human interventions into the lagoon in the period extending from 1945 to 2011 showed a good correlation with the sediment accumulation rates, sedimentation rates, and grain size evolution.

#### 2.1.3 Hydrodynamics

This lagoon is characterized by hydrodynamics relatively favored by the tidal currents, with a predominance of the semi-

diurnal component M2 (period of 12 h 25). The average speed of the currents, measured at the inlet of the lagoon in 2002, is relatively high (0.5 to 1 m/s) (GEME, 2003). In addition, during spring tide periods, the maximum velocity is about 0.77 m/s, the flooding time of the tide is 7 h 25 min and the ebb tide is also 5 h during ebb (Hilmi et al., 2005).

The renewal time of the waters of the Oualidia lagoon is an important parameter in understanding its hydrodynamic functioning as reported in (Koutitonsky et al., 2006a.; 2007). It was found that the local renewal time (LRT) of the Oualidia lagoon varies between 1 day near the lagoon's entrance inlets to 30 days at its artificial downstream dike and the integral renewal time (IRR) is 15 days on average. The temperature and salinity in this lagoon indicate a clear influence of the marine waters in the downstream zone of the lagoon and a decrease in salinity to the upstream part, due to the presence of numerous freshwater resurgences in the lagoon in permanent activity (Karim et al., 2017).

### 2.1.4 Geomorphology

Three morphological units can be distinguished from downstream to upstream of the Oualidia lagoon (Bidet and Carruesco, 1982; Zourarah, 2002).

- The main entrance inlet is about 150 m wide, which is permanent and operational all year round, a second entrance is 50 m wide, which is only active during spring tides and the sandpit. These three entrance inlets allow the lagoon to communicate permanently with the Atlantic Ocean.
- The main channel with a maximum depth of 5 m, secondary channels (maximum depth 1 to 1.5 m), and intertidal zones and schorres covered with halophytic vegetation.
- An artificial dyke separating the upstream side of the lagoon from the salt marshes.

### 2.2 Bathymetric Survey

The bathymetric data are provided by the Moroccan Directorate of Ports and Maritime Public Domain (DPDPM). Two bathymetric surveys were carried out in the Oualidia lagoon on two different dates 2006 and 2012, using the Global Positioning System (TRIMBLE 5700), and a single beam sonar (TRITECH PA 500), which is integrated to form an accurate lagoon depth survey system (Table1).

Initially, a reference point was used to adjust the GPS and to ensure centimetric precision topographic and bathymetric surveys (known in all 3 dimensions of space). This point is located on a concrete IGN bollard on the roadside in the center of Oualidia (9°01'43.087 "W/32°44'10.63600 "N). Afterward, this point was moved to the working area to measure a new reference point. The measured point is located on the terrace of the Pincloux establishments (9°01'25.21625 "W/32°44'46.4492 "N).

Thereafter, the acquisition of the measurements was controlled in real-time to optimize the survey in areas where there is a significant lack of data. The raw bathymetric files were edited under HYPACK then purified during the post-processing phases (loss of radio link, insufficient number of satellites). The processed file includes 3 components: depth (Z) and position (X, Y).

The areas studied are covering the entire lagoon, from upstream to downstream, including the salt marshes, as well as the marine part outside the inlets, to better understand the hydrodynamic mechanisms near the inlets and their impacts on the sedimentary distribution, without ignoring the adjacent beaches, whose dynamics also influence the evolution of the lagoon (figure 2).

FREQUENCY	MEASURING INTERVAL	INTERFACING
High frequency: 500 kHz with 6° emission beam opening.	0 – 50 M	Navigation software /Acquisition HYPACK

**Table 1.** Characteristics of the sounder used



**Figure 2.** Bathymetric survey in Oualidia lagoon, left (2006), right (2012).

### 2.3 Data analysis

In this study, two bathymetric data were used to map and evaluate the morphological change and sediment transport in the Oualidia lagoon over 6 years, between 2006 and 2012. For this purpose, a Geographic Information System (GIS) was applied, which consists in analyzing, modeling, managing, and editing the spatial data. The data were first analyzed using a method based on the interpolation of bathymetric points, which made it possible to elaborate bathymetric maps of the two dates (2006-2012). In this sense, the analysis of the dynamics of the lagoon bed was carried out using both the maps obtained and the profile lines extracted from the bathymetric data.

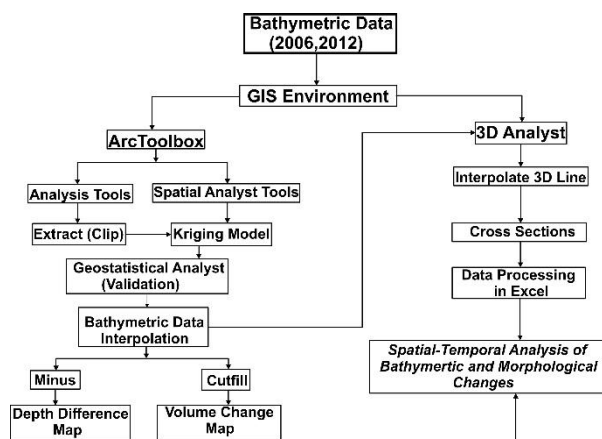
Bathymetric variation trends in the Oualidia lagoon have been identified by the elaboration of a differential map. This differential map was obtained by subtracting the two bathymetric maps of 2006 and 2012 in a GIS software.

The calculation of the deposited and extracted material volumes was carried out using the Cutfill tool of the GIS software. This is a procedure in which the elevation of a land surface is modified by the process of removing/adding surface material. It summarizes the areas and volumes changed at two different times, identifying areas where surface material has been removed and added, as well as the areas where the surface has not been changed. The results are obtained as a map that defines the sedimentary state of the study area with a calculation table of the different volumes and surface areas identified.

In order to provide more details on the evolution and sediment changes of the Oualidia lagoon, cross section of the main channel was also performed using the 2006 and 2012

bathymetric maps, this profile was plotted in a GIS software. The selection of profile was mainly based on the locality of areas where there were significantly more changes within the lagoon during the study period. This analysis was carried out to reveal the variability of the elevation patterns of the lagoon bed and the volume dynamics that occur along the profile lines.

The results of significant accretion and erosion within the lagoon were spatially analyzed to quantify the volume of sediment gain or loss on the lagoon bottom, this allowed us to verify the evolution of the morphological state of the lagoon to support decision making in this lagoon. The methodology followed in this study is summarized in figure 3.

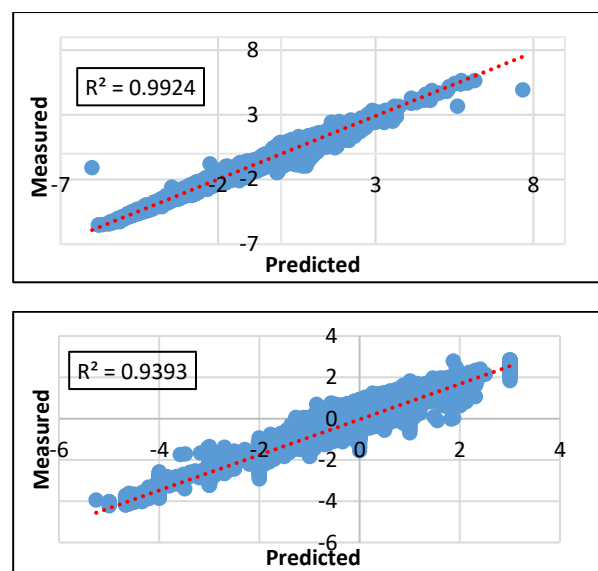


**Figure 3.** Flowchart of the morphosedimentary study of Oualidia lagoon.

## 2.4 Interpolation method choice

Determining the best interpolation method for bathymetric data, in particular, is very important. However, between different interpolation methods, such as IDW (Inverse Distance Weighting) and OK (Ordinary Kriging) that are available in the ArcGIS® Geostatistical Analyst toolbar, there is no real convergence on which method provides the best results. For example, Ineda et al., (2007) found that deterministic methods, such as the elliptical IDW method, can provide better results than geostatistical methods, such as the OK method. On the other hand, the study of Merwade et al., (2006) has proved that the kriging method was the most adapted method to map the bathymetry of the Yucatan underwater platform. Moreover, the study of Curtarelli et al., (2015) has also shown that the OK geostatistical method provided the best results for this Amazon reservoir case, compared to the IDW, LPI (Local Polynomial Interpolation) and RBF (Radial Basis Functions) algorithms. This could be due to the irregularly spaced depth measurements, for which the OK method is more suitable. Currently, both methods (IDW and OK) are extensively used throughout the literature (Henrico and Bezuidenhout, 2020; Li and Heap, 2008; Meng et al., 2013) and are commonly used to interpolate bathymetric data in a variety of water bodies (Ineda et al., 2007; Merwade, 2009; Merwade et al., 2006). Thus, the method to be used can be informed by the sampling design. Given the above, the interpolation of bathymetric data for this study is based on the Ordinary Kriging (OK) method. The OK method is a geostatistical method commonly used in the environmental sciences to describe spatial patterns and interpolate values of primary variables at unsampled locations, as well as to model

uncertainty or error in the estimated surface (Li and Heap, 2008). In this sense, the interpolation of the data by the OK method required a thorough validation between the measured and predicted samples. For this purpose, a geostatistical analysis tool was applied, which is based on a process of construction and performance evaluation of an interpolation model. As a result, the highest correlation coefficients of data,  $R^2 = 0.939$  (2006) and  $R^2 = 0.992$  (2012), respectively, showed a good agreement between the measured and predicted points, which confirms the results presented in the literature regarding the suitability of this method for the interpolation of bathymetric data (Figure 4).



**Figure 4.** 2D scatter-plot between measured and estimated depth values using OK Method, 2012 data (top) and 2006 data (bottom).

## 3. RESULTS AND DISCUSSIONS

### 3.1 Sediment budget calculation

The analysis of sediment budget change is presented in Table 2. The results have shown that the amount of accumulated sediment is greater than the amount of erosion on the lagoon bottom. It can be deduced from the Table 2 that 1,185,596 m<sup>2</sup> on the lagoon gained 1,132,483 m<sup>3</sup> of sediment volume between 2006 and 2012. As a result, the depth of sediment deposited on the area was calculated as follows (Sunday Alademomi et al., 2020):

$$\begin{aligned}
 \text{Volume} &= \text{area} \times \text{height} \\
 1,132,483 &= 1,185,596 \times \text{height} \\
 \text{Sediment gained} &= 1,132,483 / 1,185,596 \\
 \text{Average height of sediment gained} &= 0.65 \text{ m}
 \end{aligned}$$

In 6 years, the lagoon has gained an average height of +0.65 m. At this rate, this means that the evolution of the lagoon accretion has increased by +0.11 m per year. While the rate of erosion is about -0.42 m with an average of -0.07 m per year (figure 5). Accordingly, the spatial variability of erosion and accretion on the lagoon bed (Figures 5 and Table 2) shows that an area of about 2,699,396 m<sup>2</sup> was accretionary submerged with about 1,765,866 m<sup>3</sup> of sediment volume gained around the lagoon and an erosion volume of 633,383 m<sup>3</sup> with an area of 1,513,800 m<sup>2</sup>. This means that the Oualidia lagoon has

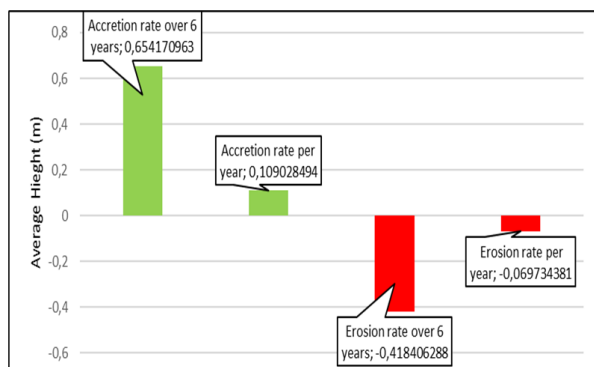


experienced a significant change from a morphological point of view, due to the strong erosion that the main channel has undergone during this period with an appearance of the other

so-called secondary channels. Moreover, it can be noted that the accumulation mainly concerns the sandpit and the north beach of the downstream part of the lagoon (Figure 7).

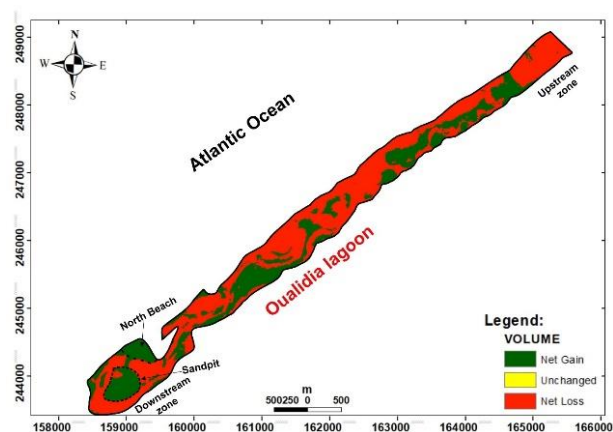
Sediment status	Volume (m <sup>3</sup> )	Area (m <sup>2</sup> )	%
Accretion	1,765,866	2,699,396	64.0700
Erosion	633,383	1,513,800	35.9210
Total accretion or erosion	1,132,483	1,185,596	

**Table 2.** Summary of calculated area and volume eroded/accumulated on the Oualidia lagoon water bed.



**Figure 5.** Chart showing the erosion/accretion rate changes in the Oualidia lagoon between 2006 and 2012.

In order to locate exactly the areas that have undergone accumulation or erosion, a distribution map of the calculated volumes has been established (figure6): the areas indicated in red determine the areas that have suffered a loss of sediment, and this coincides exactly with the main channel and some secondary channels as mentioned before. While the areas indicated in green show the localities that have undergone deposition of material, they mainly concern the sandpit and the north beach of the downstream part of the lagoon.



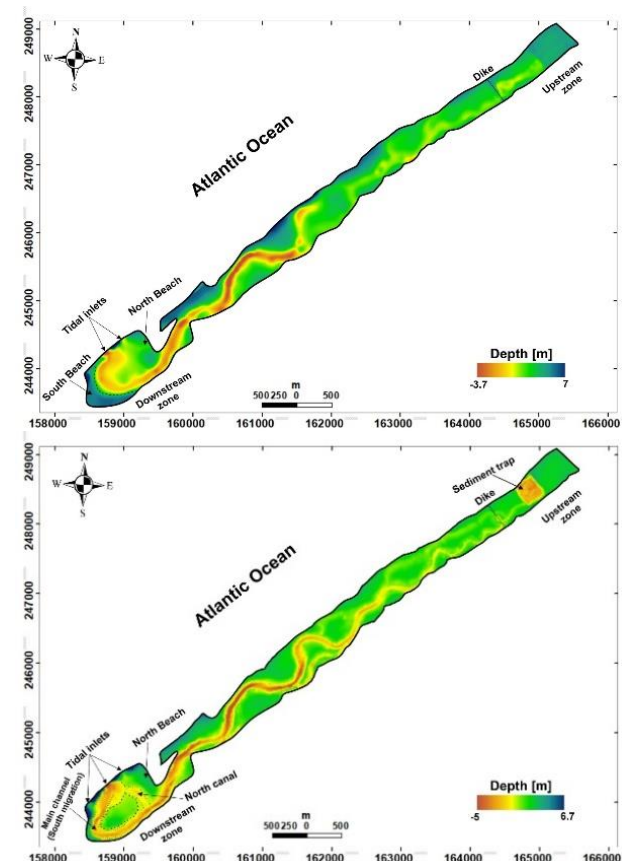
**Figure 6.** Spatial variability of sediment accretion and erosion in the Oualidia lagoon water bed based on 2006 and 2012 repeated bathymetric data.

### 3.2 Bathymetric Change Analysis

The lagoon ecosystem and its adjacent wetlands are dynamic at different spatial and temporal scales. Observation of depth

changes in lagoon environments over time can be used to understand sediment transport processes, salt, grubs, nutrients transport, their time scales, and implications for future ecosystem vulnerability (Thompson et al., 2015).

The lagoon of Oualidia has undergone an important evolution between 2006 and 2012. The bathymetric maps of the two periods studied provided a large number of interesting results, to have a good understanding of the state of the Oualidia lagoon in terms of sedimentary and morphological changes during 6 years between 2006 and 2012 (Figure 7). Consequently, the remarkable changes mainly concern three morphological units of the lagoon, namely the downstream part (sandpit and beaches), the main channel, and the upstream zone of the lagoon (dikes, sediment trap).



**Figure 7.** Bathymetric state of the Oualidia lagoon in 2006 (top) and 2012 (bottom).

The sediment transport in the lagoon is mainly concentrated in the area of the inlets and in the sandpit (downstream zone). The downstream zone of the lagoon shows an alternation of erosion and deposition patterns (Profile A; Figure 10) combined with

the migration of the main channel over the southern part of this sector, as a result of the interaction of waves and tidal currents during ebb tides (Koutitonsky et al., 2007). However, the migration of the channel has changed its morphology and contributed to the creation of a zone of significant sedimentation (sandpit), because of the sand deposited by waves. According to Koutitonsky et al (2007), the current velocity contributes to the transport of sand towards the main channel at the south of the sandpit. This sand is deposited on the north side of the main channel. During the ebb, strong tidal currents erode the sand on the south side of the channel.



**Figure 8.** Cross section of the Oualidia lagoon's channel (NE-SW).

This combination of (i) waves during the inflow and (ii) tidal currents during the outflow contributes to the migration of the main channel southward around the sandpit. This migration eventually ends with the channel being choked by wave-deposited sand and a new channel is created in the northern part of the sandpit. The new channel in turn migrates southward until it is choked and so on. This migration cycle lasts between 10 and 20 years or more. Moreover, the study by EL Khalidi et al (2011) on the morphological modifications of the sandpit showed the permanent existence of two channels of communication with the ocean: a southern channel (main) and a northern channel (secondary). This morphology was significantly marked by the advance of the main channel towards the south part of the lagoon, which allowed an individualization of the downstream in two zones, convex and concave (Yamna et al., 2014). In addition, the small adjacent beaches surrounding the sandpit have also changed. Indeed, the southern beach (concave zone) was confronted with erosion resulting from the southward migration of the main channel, while the northern beach (convex zone) of the lagoon gained a significant amount of sediment during this period. Generally, the morphological evolution of the downstream part of the Oualidia lagoon including the sandpit and the main channel, is mainly controlled by the tidal currents and waves (Koutitonsky et al., 2007; Yamna et al., 2014). These two hydrodynamic forces can set the sediment in motion on the sandpit during the inflow (waves) and on the main channel (currents) during the outflow.

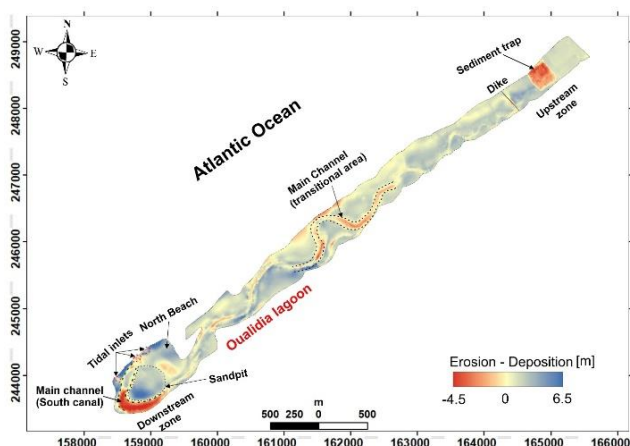
Towards the upstream zone, the main channel was extended into this area of the lagoon with a significant change in its shape (Figure 7). This channel was mainly affected by erosion over

almost the entire length of the lagoon and especially in south part and the transitional zone (Profile B and C; Figure 10; Figure 8), which confirms the observations made from the differential map and bathymetric maps, insofar as there is a deepening of nearly -1.16m with an annual average of -0.19m/year of the main channel due to the greater volumes of water circulating in the lagoon since the creation of the sediment trap in 2011. In addition, the channel has also experienced a moderately low deposition in various small localities, this deposition was estimated with an average value of +0.25m and an annual evolution rate of +0.04m/year (figure 8). These results confirm those of Koutitonsky et al (2012), who noted that the majority of the main channel is eroding, with the exception of a few isolated points of deposition due to the transport of mud to the upstream zone by asymmetrical tidal currents dominated by the flow. The strong contribution of sediments of marine origin caused by tidal currents and waves (GEME, 2003; Koutitonsky et al., 2006a.; 2007) can be considered as an origin of changes in the opening and closing of the channels and also in the shape of the curvature of the main channel (Yamna et al., 2014).

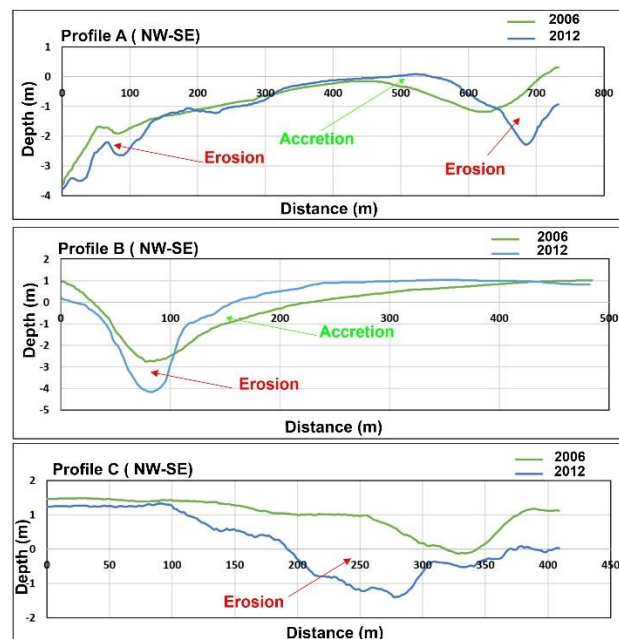
In 2006, the upstream part of the lagoon was characterized by the existence of a single channel which tends to decrease until it disappears completely with a depth ranging from -1m to 0m (Figure 8). This is due to the filling of this locality with fine sediments, which is strongly related to the weakening of the dominant currents and tidal currents, consequently the environment has become calm and favorable for the deposition of sediments. In the long term, this contributes to the reduction of depths and the confinement of upstream waters of the lagoon (Koutitonsky et al., 2006a.; 2012).

The studies of Koutitonsky et al (2006a ; 2007) revealed that the Oualidia lagoon has been dominated by flow, i.e., the flow (upward tidal currents) is of shorter duration than the ebb (downward tidal currents) and the speeds of the flow are higher than those of the ebb. This clearly explains why the transport of fine sediments and sludge is directed towards the upstream part of the lagoon, causing the confinement of the water.

The creation of the sediment trap in 2011 has induced an extension of the tidal currents of the Oualidia lagoon with an increase in their intensity, which has allowed more sediment to be brought into the basin. This management option increased the speed of the current inside the lagoon and facilitated hydrodynamics (Makaoui et al., 2018), which led to an augmentation of the depth in some areas and especially in the main channel of the lagoon (Figure 8, Figure 9). Continuity of the main channel was observed near the location of the sediment trap, which was not the case in 2006. We also noted a development of a few very shallow secondary channels next to the downstream dike that had completely disappeared following their filling. Moreover, an increase in water depth was also observed at the downstream dike and near to the sediment trap with an average evolution of  $-0.85\text{m}$  and an annual change rate of  $-0.14\text{m/year}$  in some localities.



**Figure 9.** The erosion-accumulation zones in the Oualidia Lagoon after 6 years (2006-2012).



**Figure 10.** Profiles A, B and C. Green – 2006 and Blue-2012. Profile locations are shown in figure 1.

#### 4. CONCLUSION

In this paper, we studied, using two bathymetric time scales (2006-2012), the implications resulting from the sediment trap dredging. The main objective was to assess the sediment dynamics following changes in the geomorphology of the Oualidia lagoon. Our present study has shown the value of bathymetric data for understanding sediment dynamics this semi-enclosed lagoon.

As shown in the description of the results, the changes in the Oualidia lagoon are significant. The main conclusions that can be noted are:

- The downstream area of the lagoon showed alternating patterns of erosion and deposition associated with the movement of the main channel on the southern part of this area.
- The majority of the main channel area is eroding, except a few isolated points of deposition. In 2012, the main channel continuity was observed near the sediment trap location, which was not the case in 2006.
- The small adjacent beaches around the sandpit also showed significant change. The southern beach eroded due to the southward migration of the main channel, while the northern beach of the lagoon gained a significant amount of sediment during this period.

These changes are probably related to the creation of the sediment trap in 2011, which can increase the current velocity inside the lagoon and facilitated hydrodynamics, leading to an increase in depth in some areas and especially in the main lagoon channel. Therefore, the change in the morphology and depth of the main channel has favored an asymmetry of the tide between the Atlantic Ocean and the lagoon, which is strongly dependent on its morphology. It can be noted that with this change, the lagoon has moved from a choked basin to a restricted lagoon after the dredging of the sediment trap.



The results presented in this paper should be complemented by a study of the hydro-sedimentary conditions of the lagoon in its current state, based on actual bathymetric surveys combined with hydrodynamic data including currents, temperature, and salinity throughout the lagoon, taking into account the sea level change.

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