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Environmentally- Friendly Proposals for Coastal Stability at Rosetta Promontory, Nile Delta

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Abstract

The coastal zone of Nile Delta Coast is a dynamic system which was in equilibrium or experienced huge amounts of sediment transported with the water discharges transfer from Nile branches to the Mediterranean Sea. A remarkable decrease in the sediment discharges arises with the construction of barrages, low Aswan dam, and Aswan High Dam south of the Nile river at beginning of the 20th century which trapped almost all the flood sediments behind. Consequently, the coastal zone has suffered from shoreline erosion, particularly at Rosetta, El Burullus, and Damietta. Not only erosion is the main challenge facing this coastal zones, but also, siltation inside the inlets discharge to the sea.

A depth-averaged model has been used after calibration and validation, to study morphological changes around the nourishment area at Rosetta promontory, and testing the validity of some alternatives proposed to mitigate the outlet problems. Among these alternatives: diversion of side channel from the sea to the Nile River, and finally, the sand motor technique.

The aim of this paper is to test different proposed alternatives and analyze it in terms of morph-dynamic processes to reach an applicable solution for the instability of the promontory.

Introduction

The Nile Delta was developed by sedimentary processes occurred between the Upper Miocene period and the present [1].The advance and recession of the shoreline are ruled by the sediment quantity of Nile river transmitted to the Mediterranean to those sediments that are wasted by other hydrodynamic processes of the wind, wave and current [2].

The study area mainly has two activities; fishing, and agriculture. The agriculture sector includes cultivating date palms, and fruit tree [3].

Fisheries activities represent an important source for income. Rosetta outlet is the only navigation path for the fishermen from the Nile river branch to the Mediterranean Sea. Although the fishing sector is vital to population, the city has no fishing port. No location for the fisheries association which is comprised of about 12000 members (40% of Rosetta population are fishermen) [4].

There are numerous fish cages at Rosetta branch allocated in ad hoc manner without any monitoring leads to different problems at the navigation path. Rosetta city still has low economical importance compared to other coastal cities such; Alexandria and Port Said. The study was based on essential parameters required for the development of global and local coastal cities [5].Although its low score, but more attention is given to Rosetta city to increase tourism.

Rosetta promontory extended seaward actively by14 km [1].Since the start of the twentieth Century, excessive shoreline erosion has occurred along different regions of the Nile Delta Coastal zone [6,7]. This occurs due to the building of many water control structures like; barrages, dams on the Nile river. During the last decades, great attention has been paid to the most vulnerable coastal zones represented in promontories: Rosetta as shown in Figure 1, and Damietta. Rosetta promontory experiences a severe erosion threatens seawall which protects the retreat of the coastline [8]. The other challenge is the gathering of the sediments inside the inlet that hinders the navigation and affects ecological system [9].

A substantial interest over the last years have been given to the coastal changes occurred along Rosetta promontory represented in different morph dynamic studies using field survey, land sat images, and numerical modeling to the study area.

Many types of research were performed to solve the siltation problem. Mahmoud et al. [10] used one-dimensional model (SOBEK) to address the closure of the outlet due to different extreme discharge during flood seasons. Ahmed [11] utilized Delft 3D software to study to mitigate the sedimentation problem inside the Rosetta inlet through proposing two jetties. Among different solutions, periodic dredging were executed to mitigate siltation inside the inlet, but the problem still occurs [12].

On the other hand, the erosion problem also was investigated through many attempts to overcome the migrated erosion downdrift of the eastern and western seawalls. Coastline erosion at the southwestern of the Rosetta headland was investigated numerically by [13] to preserve the existing seawall at the west of the promontory by proposing detached breakwater and groins). It was concluded that the detached breakwaters still cause extreme local scour in front of the western seawall, on the other hand the groins produce sedimentation that expected to stabilize the existing seawall. In addition, [14] concentrated on the eastern side of the Rosetta headland because, after finishing the construction of the eastern revetment, severe erosion took place east of the revetment. They checked groins system for protecting this important stretch of the promontory from severe erosion. To mitigate severe erosion in

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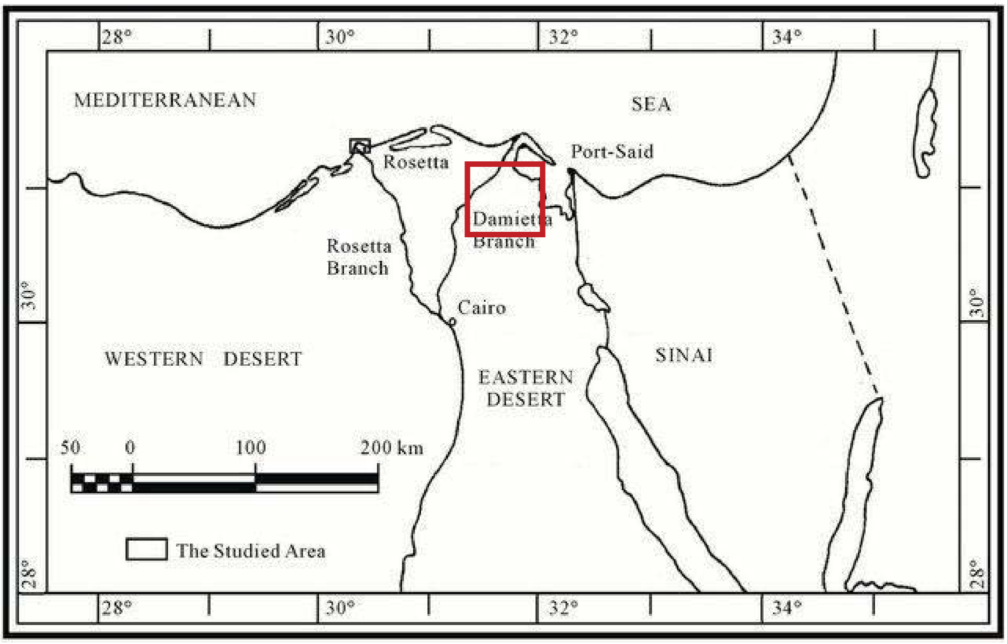

Figure 1: Location Map for Rosetta promontory from (Kaiser, Aziz, & Ghieth, 2014).

front of seawalls, different alternatives of soft and hard measures were investigated by [15-17].

Although, the process of building defenses against the sea has not yet exhausted the technological means available around the world, the “hard engineering” approach is strongly being challenged [18]. Due to lack of sustainability of the “hard engineering” approach, innovative concepts that build with nature provide a guideline for coastal protection techniques that lead to sustainability, at the same time maintaining ecological and socioeconomic conditions.

For this study, an innovative beach replenishment technique is known as “mega-nourishment,” was reviewed. It is based on putting huge amounts of sand every 20 years [19,20].It depends on re-distributing the sand along the shore by the wave and wind action. On the other hand, it provides an aesthetic and recreational beach than the typical tourist one [21].

The aim of this paper is to test other alternatives that build with nature and have a minimum ecological effect. These scenarios include testing1) sand engine technique that has recently been implemented in the Netherlands aiming to provide safety against flooding [22], and constructing a new channel from the sea to the Rosetta branch to provide the estuary with water discharges required for flush the accumulated sediments at the outlet of the River.

Numerical Simulation

Model description

Coastal Modeling System (CMS): CMS is a process-based package integrates hydrodynamics, sediment transport, and morphological changes through steering process of the two modules, CMS-Flow and CMS-Wave [23]. CMS-Flow passes the water level and current velocity to CMS-Wave. CMS-Wave is a spectral wave transformation model that solves the steady-state wave-action balance equation on a non-uniform Cartesian Grid. The wave model calculates wave refraction, shoaling, reflection, diffraction, and breaking. The radiation stress occurred by breaking is computed and passed to CMS-Flow to calculate wave-induced long shore current, which are necessary for calculating sediment transport due to the combined effect of waves and currents.

Depth- integrated continuity and momentum equations: The Coastal Modeling System (CMS-Flow) solves depth-integrated continuity and momentum equations using a finite-volume method [23]. The CMS-Flow 2D model equations are based on the shallow water equations.

Wave-action balance equation: The CMS-Wave is a spectral wave transformation model [24].It solves the steady-state wave-action balance equation on a non-uniform Cartesian grid.

Sediment transport equation: In this study, the non-equilibrium sediment transport model was used. In this model, the sediment transport is separated into current and wave-related transports, [25] Model schematization.

Grid and boundaries: The study area was surveyed between 2005 and 2006. Two CMS model grids were developed for representing Rosetta promontory, one for CMS-Wave, and the other for CMS-Flow and sand transport. In this study, CMS-Flow, and CMS-Wave were steered (single code) for model efficiency. The lateral extent of both CMS grids was extended 7 km offshore beyond the depth of closure which no considerable sediment movement. Additionally, the lateral extent (18 km) of the model domain was defined to include several focus areas of shoreline. The cross-shore length of the CMS-Flow, and CMS-Wave grids were built to the same location, which was set to the offshore location of the contour depth of the forcing (or wave data).

The inlet and near shore zone has a small grid size to accurately simulate of the sediment transport and the morphological change processes. Hence, a variable sized rectangular-cell grid system, with a spatial resolution ranging from 20*20 m around the inlet to 70*120 m near the sea boundary was created. Each CMS grid was forced along the

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ocean boundary, Figure 2. CMS-Wave propagates spectral waves from the offshore ocean boundary toward land. The forcing in the CMS-Flow grid for this project was a water-surface elevation for the period from October 2005 to May 2006, in addition, flow discharges from the outlet were included. The wave data are transformed from the offshore buoy at depth of 18 m to the model boundary at 11m depth using the maximum entropy code. The extracted wave data at 11m will be the input for the model.

Bathymetric data: The bathymetric survey including 50 profiles that have been utilized in the simulation was conducted in October 2005 during the formation of the spit inside the inlet and calibrated by field survey of May 2006. Figure 3 shows the bathymetric map of the promontory.

Wave, tide and sediment grain size data: The wave data are time series data (every six hours) which are the averaged wave climate of five years of actual measurements between 1986 and 1990. It is clear that the prevailing wave direction comes from NW [12]. Figure 4 shows the average wave height-direction distribution.

The water surface elevations used in the numerical model extend from October 2005 to October 2006 as a time series (every half hour). Figure 5 shows a sample of the measured water levels.

The sediment grain sizes (d_{50}) at study area range from 0.16 mm and 0.24 mm [26,27].

Model calibration and validation

Building CMS models, boundary conditions, sensitivity analysis, calibration and verification of the model were described in details by [28].

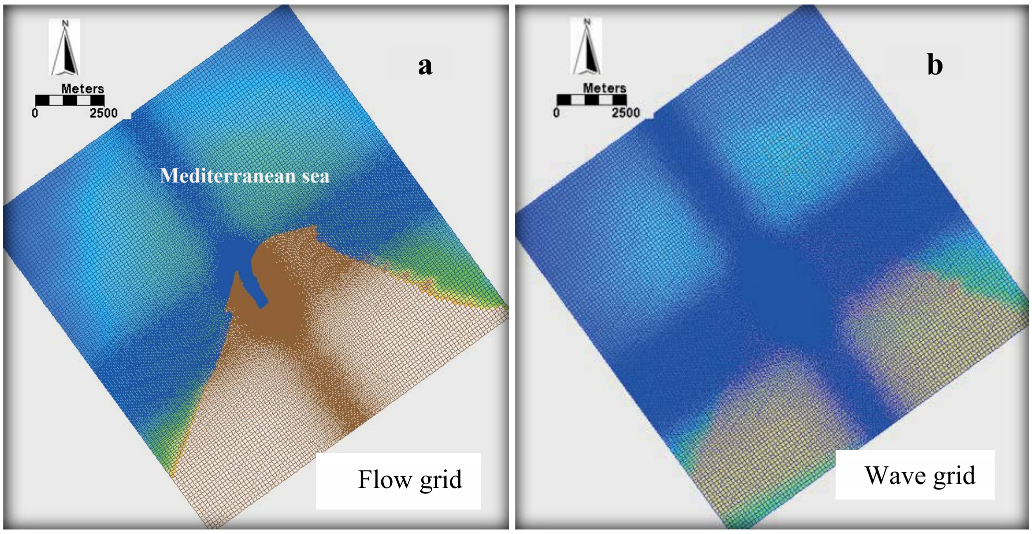

Figure 2: Model grids with boundary condition for Rosetta Promontory, resolution increases at the vicinity of the throat and the surf zone, (a) CMS-Flow grid, and (b) CMS-Wave grid after (Masria et al., 2014b).

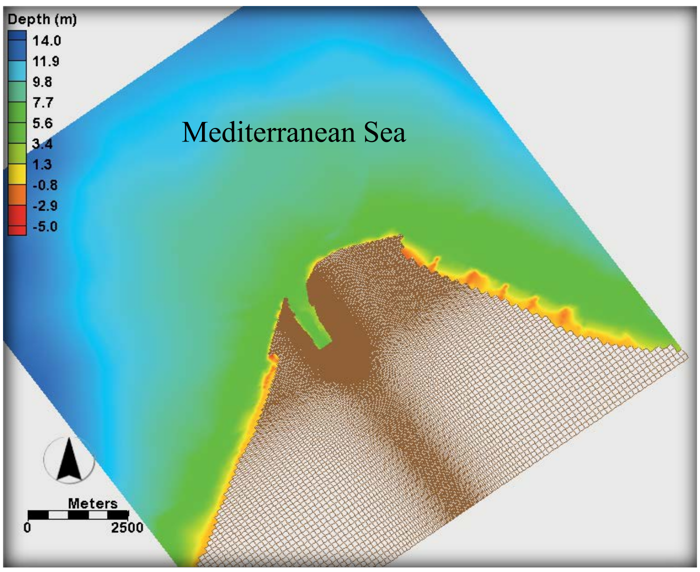

Figure 3: The model domain of Rosetta estuary.

The Tested Protection Scenarios

To mitigate the instability of the coastal zone at Rosetta promontory consisted of; shoreline erosion, and inlet accretion, three different alternatives have been investigated using: 1) diversion channel from the sea to the Nile River, and 2) the sand motor technique.

Diversion channel from sea to river

This scenario assumes a new channel path to divert flow discharges from sea to river in order to compensate Nile river flow discharges at the last reach of Rosetta branch. This proposal is supposed to enhance the circulation process from the river to the sea which required to mitigate siltation problem at the outlet. Two scenarios were investigated as shown in Figure 6. The first scenario is to divert the sea water to the river through a right channel (100 m width), and the other one through a left channel with the same width. The depth of both channels was also changed as 3m, and 5 m respectively.

Sand motor technique

Sand engine is a new innovative soft engineering intervention, that has recently been implemented in the Netherlands aiming to provide safety against flooding , and shoreline erosion as a result of the expected sea level rise and storms [29-32]. Such an approach could provide useful elements for other low-lying areas as it creates natural dune, and sustain coastal development (Weerdt, 2015).

The Sand Engine nourishment has been investigated numerically in Netherland to test the performance of local mega-nourishments as a countermeasure for the expected coastal recession in the 21st century [33]. According to the initial observations, a redistribution of the sand nourishing the adjacent coasts performed. It is expected to be more economical, efficient and environmentally friendly than the traditional measures at long term Figure 7a [22].

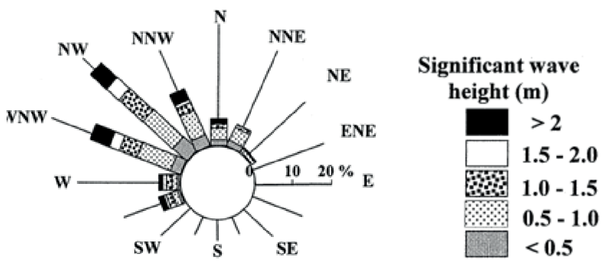

Figure 4: Average wave direction-height distribution at Rosetta area (O. Frihy & Dewidar, 2003).

In our study area, a sand engine technique was tested using CMS software package. It includes placing the nourishment material to a depth equal to 6m (distributed equally at each cell) in the eastern part of the promontory (the most vulnerable area of erosion in front of seawall) as shown in Figure 7b. The total volume of the sand engine is about 3.5M m^3.

Results And Discussion

Diversion channel from sea to river

Two observed points have been assigned inside, and outside the outlet, as shown in Figure 6 to extract the water elevation and current magnitude. Figure 8 shows the results of water elevation and current magnitude at the two observed points (for no action case, and in the existence of the diverted channel from the sea to the river) corresponding to different conditions of wave and tide. It is clear from these Figure 8, that the difference between water elevations at both points can be neglected, whereas the distinction in current magnitude is noticeable. To deeply investigate the validity of this proposal, a simulation over one year was performed to check the morphological change and wave heights at each point.

Morphological changes (channel on the right side): Figure 9 and Figure 10 show the morphological change and (bed evolution with current magnitude) after one year for the three tested scenarios. The first one is no action case, the second is to propose a diverted channel (100 m width) from the sea to the river with 3 m depth, and the last one is the same as the second, the only difference is the channel depth (5 m). It is clear from the Figure 9 and Figure 10 that erosion and accretion patterns are nearly the same as the no action case. The formation of the spit inside the inlet has not been changed, although the existence of a side channel. This is due to the accumulation of the sediment in front of the channel at the seaside that prevents the water to be discharged from the sea to the river. The accumulation of the sediments is a result of the littoral drift caused by the inclined dominant wave angle (WNW) with the shoreline orientation. Consequently, the wave height inside the diverted channel is almost zero as shown in Figure 11.

Morphological changes (channel on the left side): In this section,

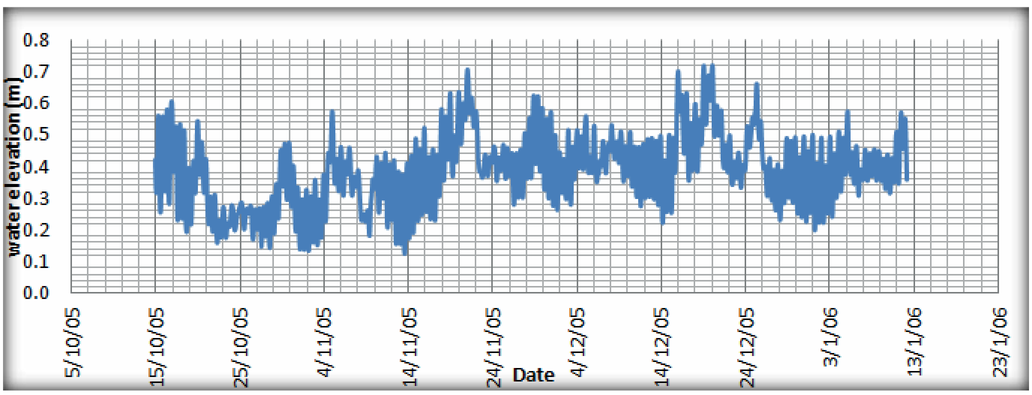

Figure 5: A sample of measured water levels data (at Abu-Quir station) by Coastal Research Institute, Egypt 2005, after (Masria, Negm, Iskander, & Saavedra, 2014c).

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two scenarios as the same previous section were proposed the only difference here is that the diverted channel is located at the left side instead of right one.

Figures 12-14 show the model results of morphological changes, depths (with current velocity), and wave height distribution after one year for the two scenarios compared with no action case. Figure 15 shows the current magnitude for the two cases. It is illustrated that tested scenarios enhance the situation locally, particularly in front of the channel from the river side, but with a limited effect on the sedimentation inside the inlet.

From the previous figures for the above-mentioned scenarios of the diverted channels, it is clear that there is no clear effect of it. In addition,

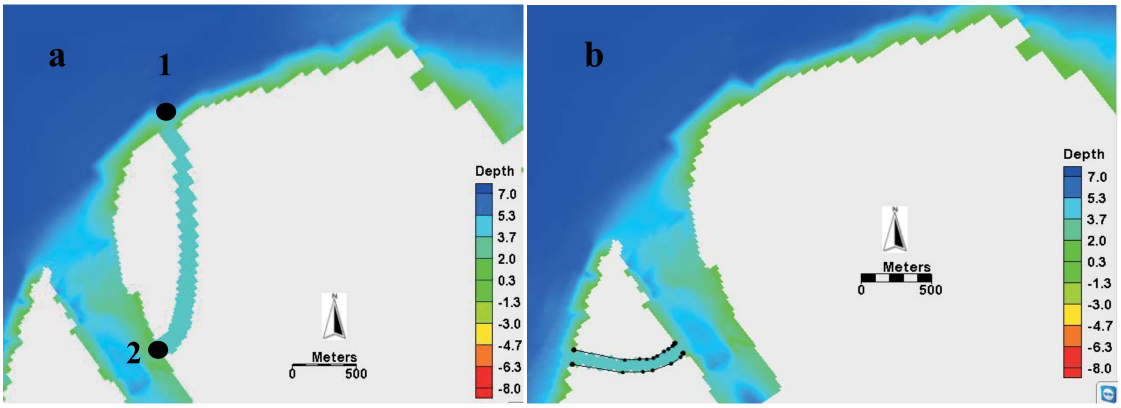

Figure 6: The two diverted channels: a) Right channel, and b) Left channel.

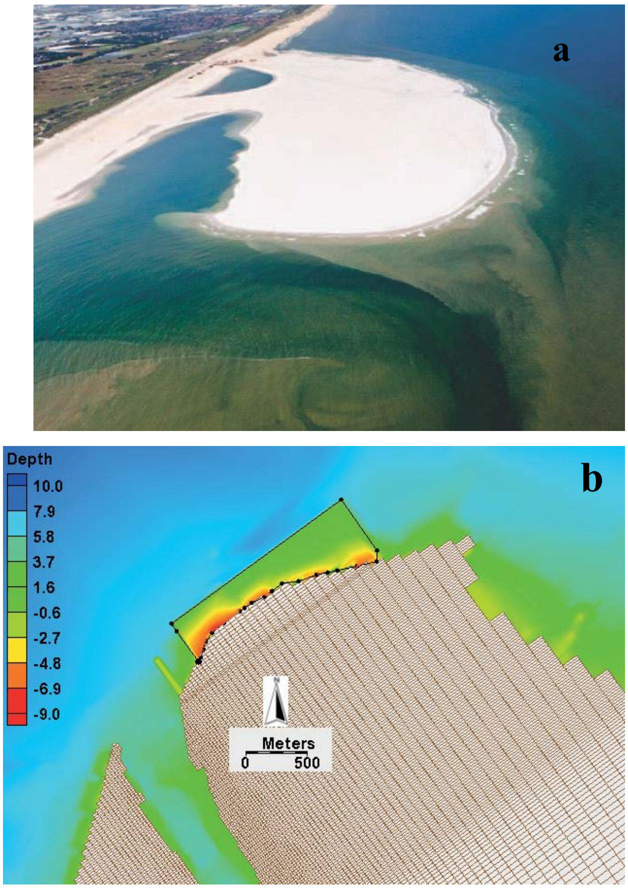

Figure 7: a) Aerial photograph of the Sand Engine after completion (September 2011) looking southward, after, (Stive et al., 2013a), b) Snapshot of the sand engine at Rosetta promontory.

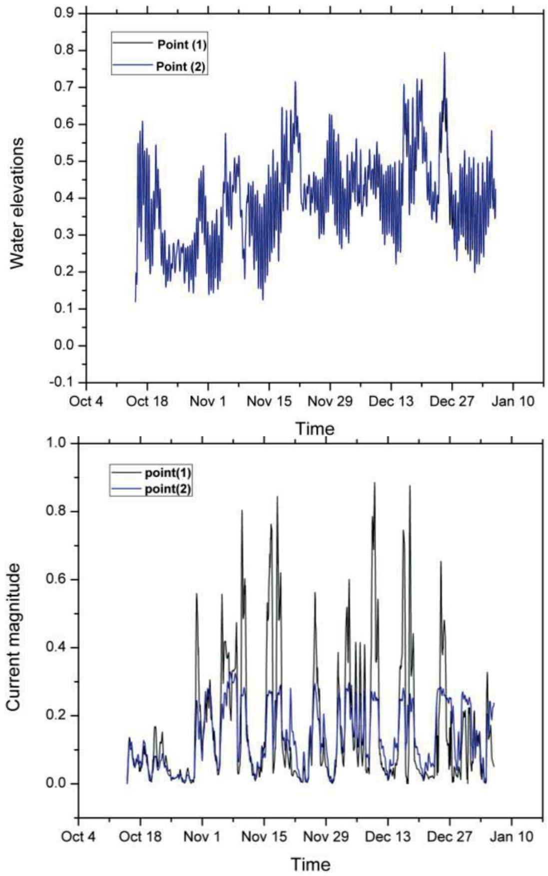

Figure 8: The water elevations, and the current magnitude at the different two points.

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according to the previous literature, constructing such channel may be dangerous. This is because the reduction is characterized by the important phenomenon of necking and part separation (at the left side). This channel may repeat the same failure scenario of the western part of the promontory that occurred previously [12].

The severe erosion rate was due to the phenomenon of necking and part separation. It is formed by the erosion of both sides of the western part of the inlet, i.e. the erosion by long-shore current on the seaside and by the reflected waves on the Nile side that hit the Nile eastern bank. When the width of the western part became narrow enough, Figure 16 it will be flooded and separated from the mainland by the action of high waves during the winter season. As a result of the gradual

Sand motor technique

The effect of forcing (tides and waves) on the Sand Motor was investigated numerically.

Bed evolution: Figure 17 shows the bed evolution of the promontory through a successive Snapshot for the water depths.

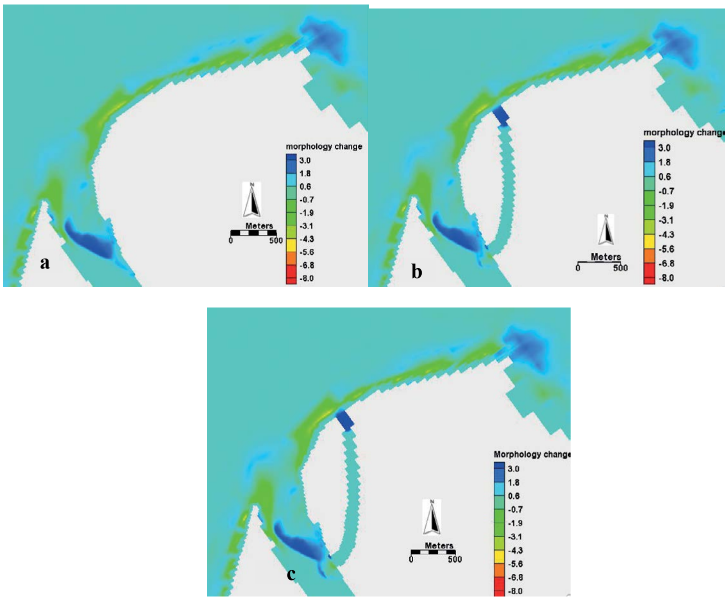

Figure 9: Model results of the morphological changes of different scenarios a) no action, b) diverted channel of 3 m depth, and d) diverted channel of 5 m depth. Negative values express erosion, and the positive ones express accretion.

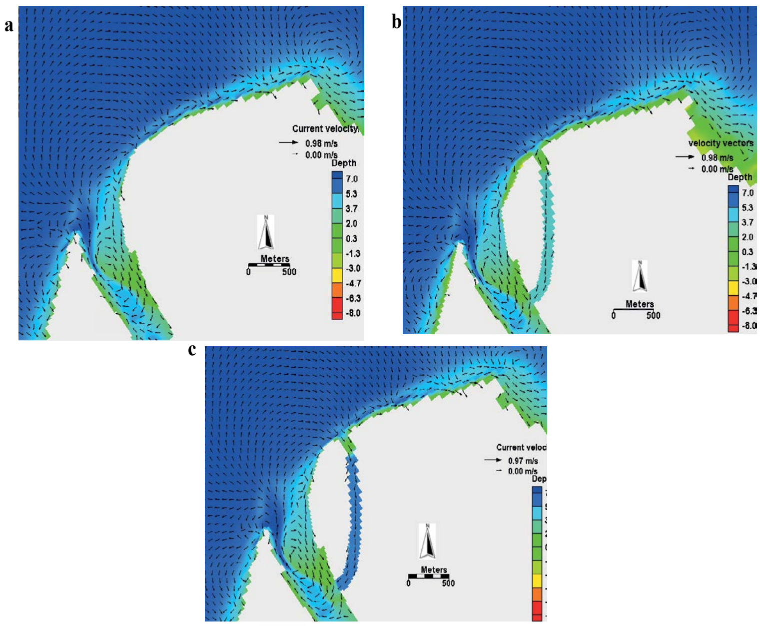

Figure 10: Model results of bed evolution with current velocity for different scenarios a) no action, b) diverted channel of 3 m depth, and c) diverted channel of 5 m depth.

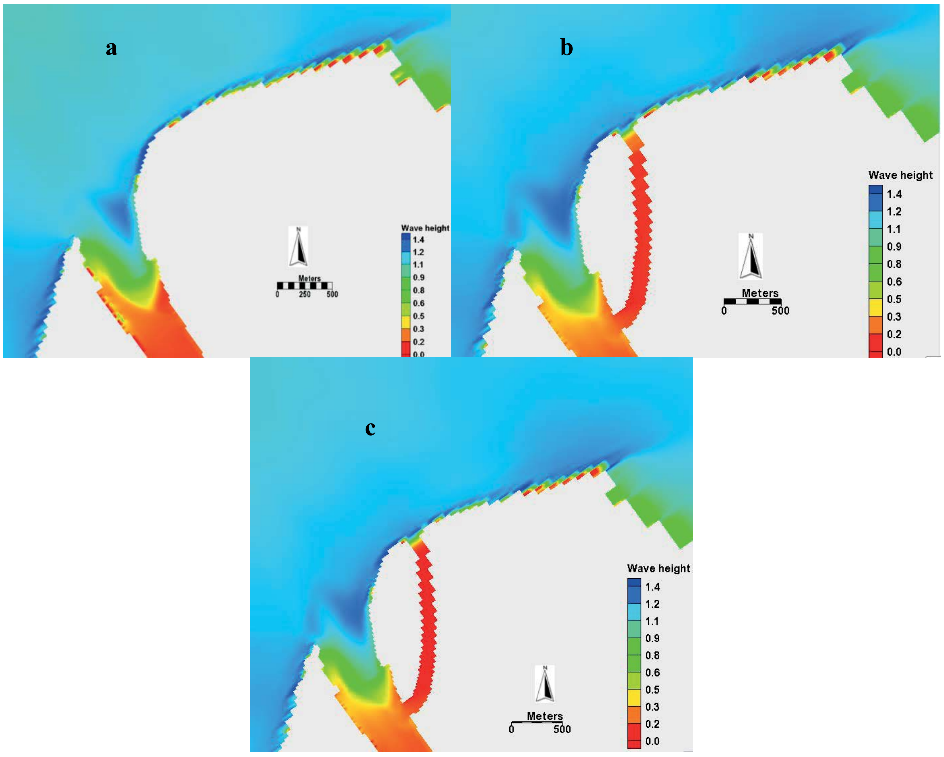

Figure 11: Model results of the wave height distribution of different scenarios a) no action, b) diverted channel of 3 m depth, and c) diverted channel of 5 m depth.

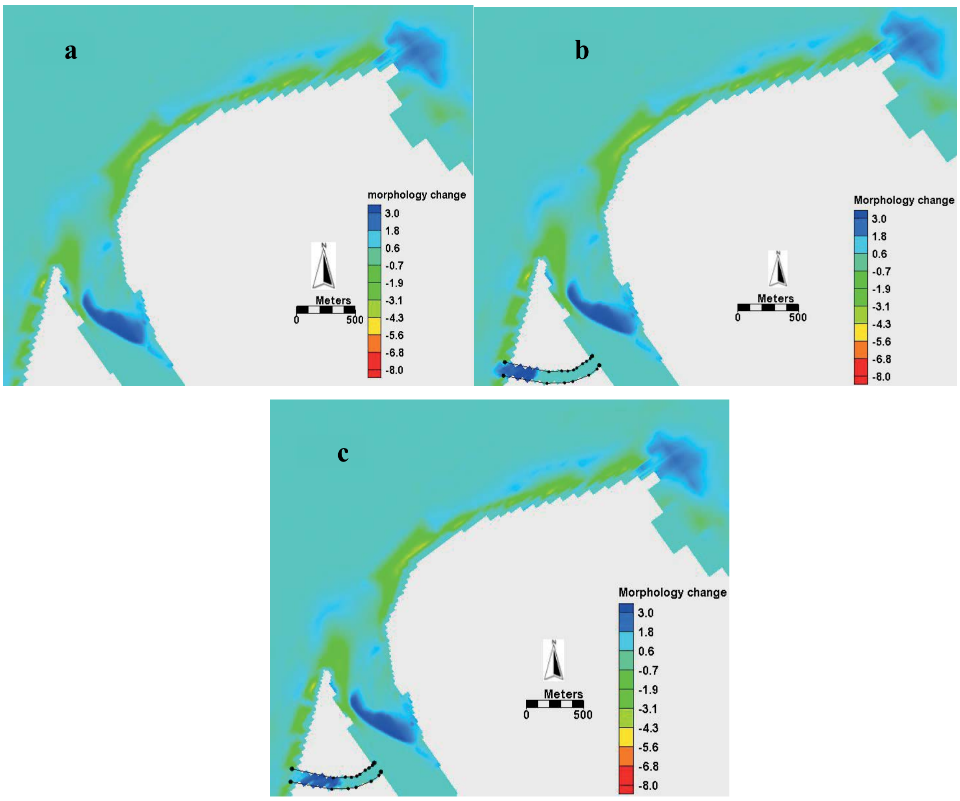

Figure 12: Model results of the morphological changes of different scenarios a) no action, b) diverted channel of 3 m depth, and c) diverted channel of 5 m depth. Negative values express erosion, and the positive ones express accretion.

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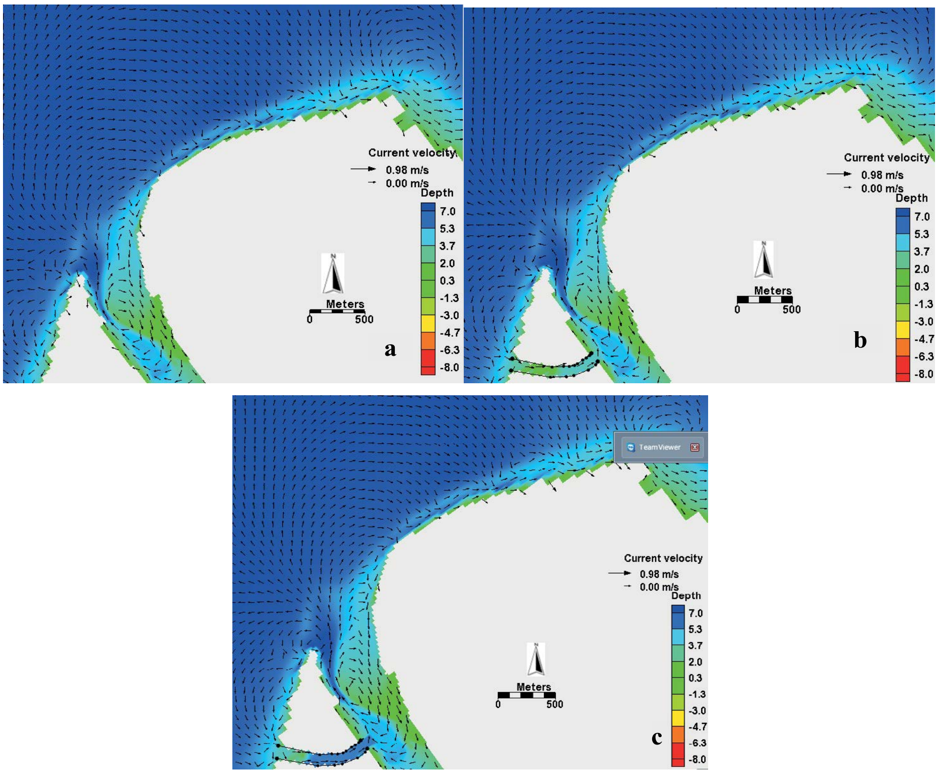

Figure 13: Model results of bed evolution with current velocity for different scenarios a) no action, b) diverted channel of 3 m depth, and c) diverted channel of 5 m depth.

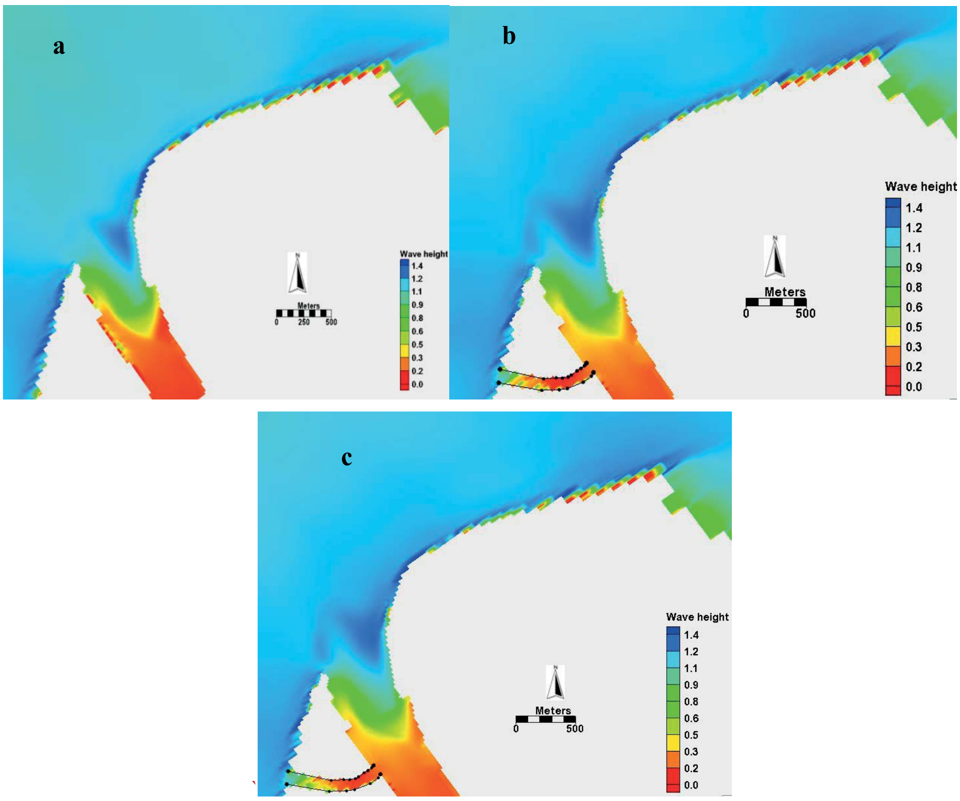

Figure 14: Model results of the wave height distribution of different scenarios a) no action, b) diverted channel of 3 m depth, and c) diverted channel of 5 m depth.

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Although it requires big amounts of the nourishment material, but it creates new beaches not only on the local level (Rosetta), but it may extend to farther distances. The existence of the sand motor will change hydro dynamics, accordingly, the total sediment transport at the outlet especially in front of the eastern seawall has been decreased as shown in Figure 18.

It is expected for the sand motor to be a great solution for overcoming sea-level-rise resulted in coastal retreat [33]. So, in order to deeply evaluate the effect of sand motor techniques, a long-term simulation for five years has been conducted. Figure 19 shows the results of bed evolution and the current velocities over two, and five years compared to the start of the run. The proposed concept of sand

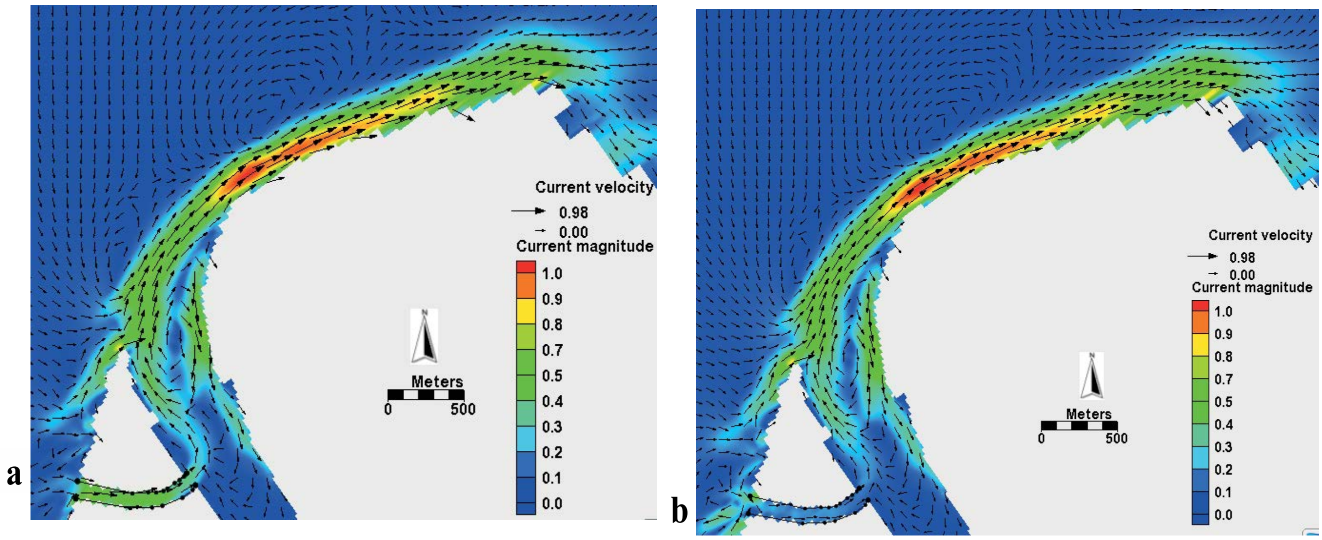

Figure 15: Model results of the current magnitude of the two scenarios a) diverted channel of 3 m depth, and c) diverted channel of 5 m depth.

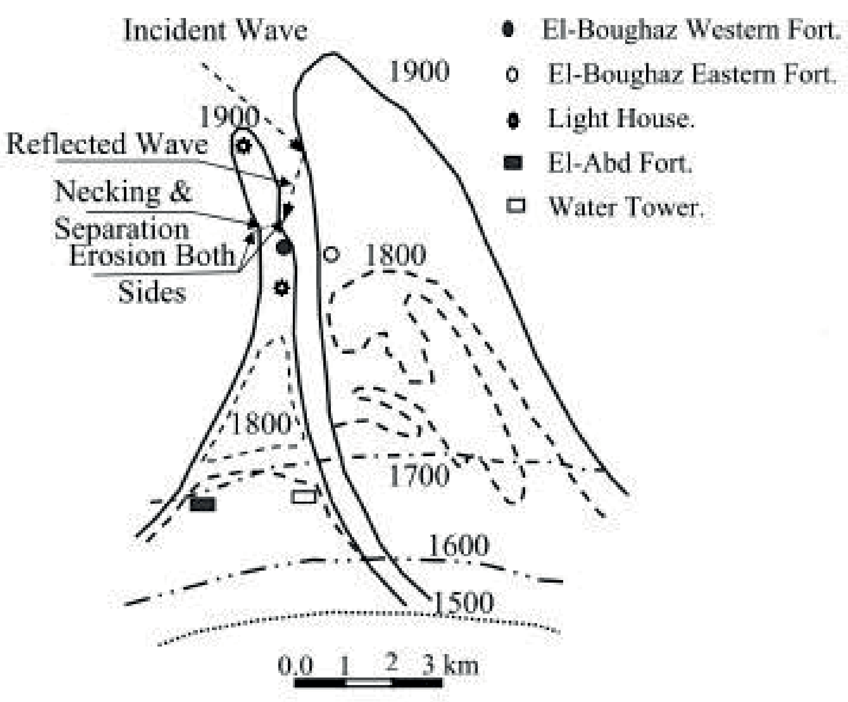

Figure 16: Shoreline Advance along Rosetta Promontory, (1500-1900), (El Sayed et al., 2007).

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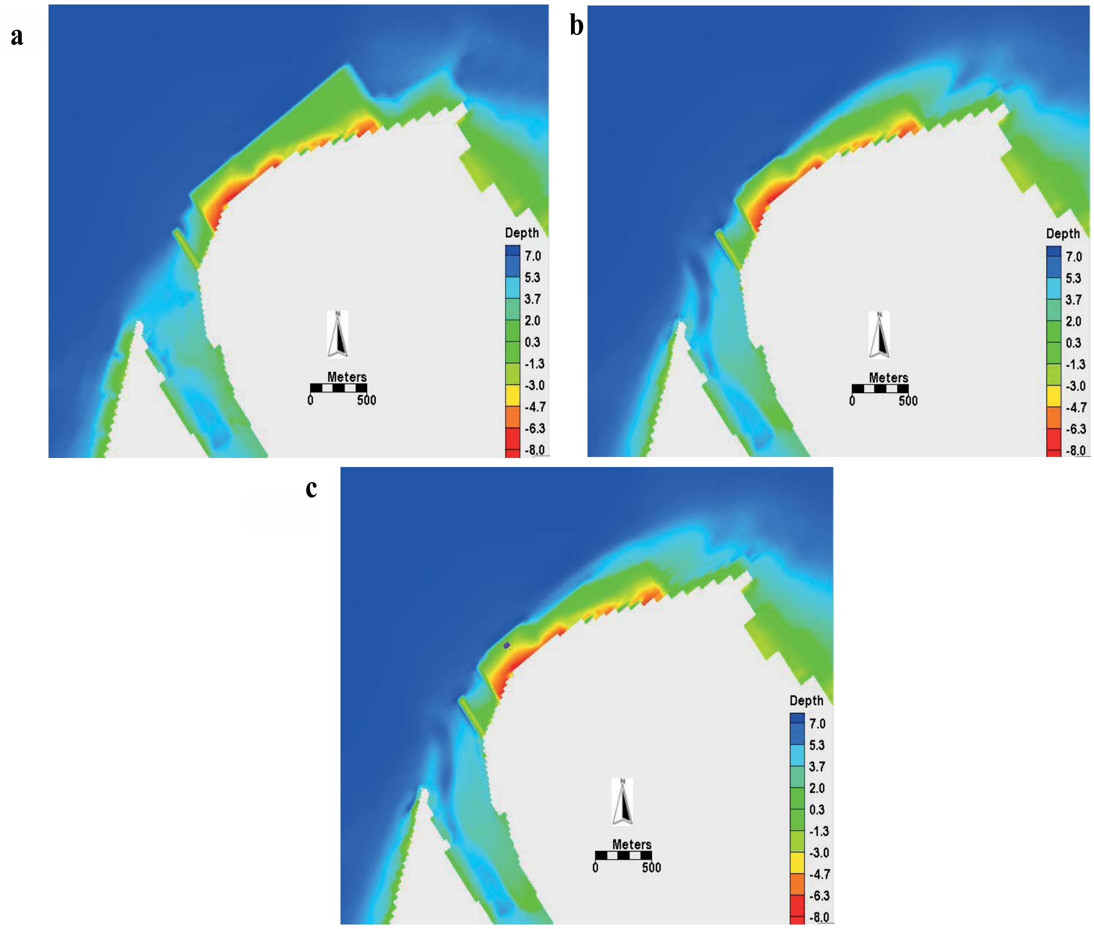

Figure 17: Successive Snapshot for the water depths due to the sand engine method at Rosetta promontory. a) At the beginning of the run, b) 3.5 months later, and c) after one year.

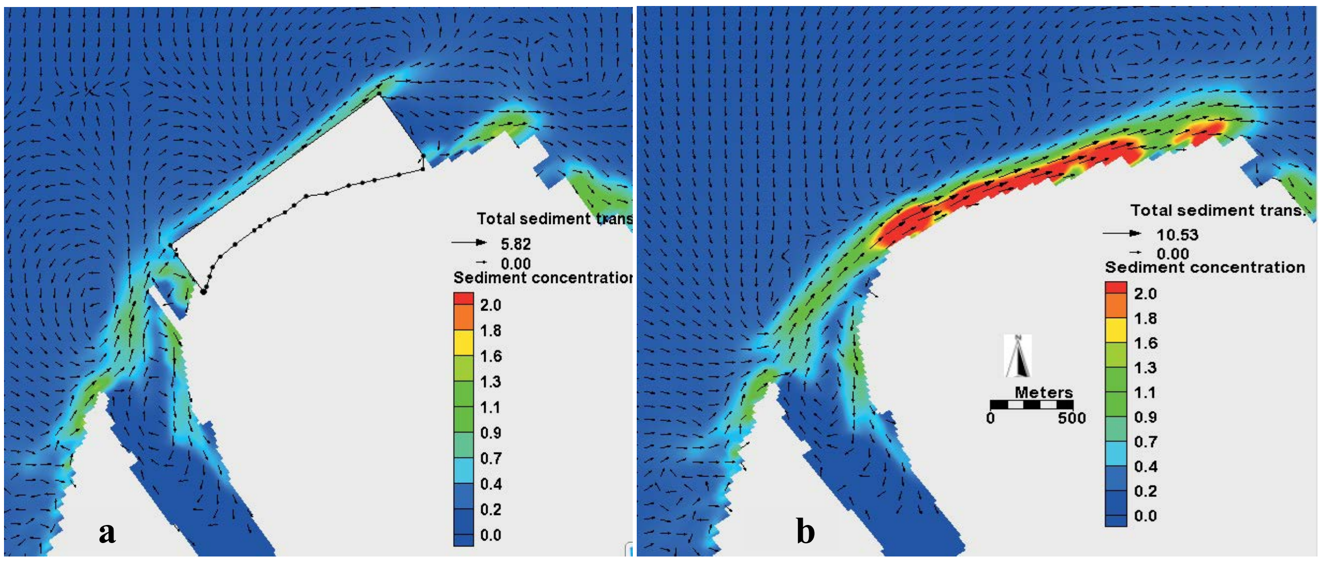

Figure 18: Model results of the total sediment transport of the (a) sand engine method, and (b) no action scenarios.

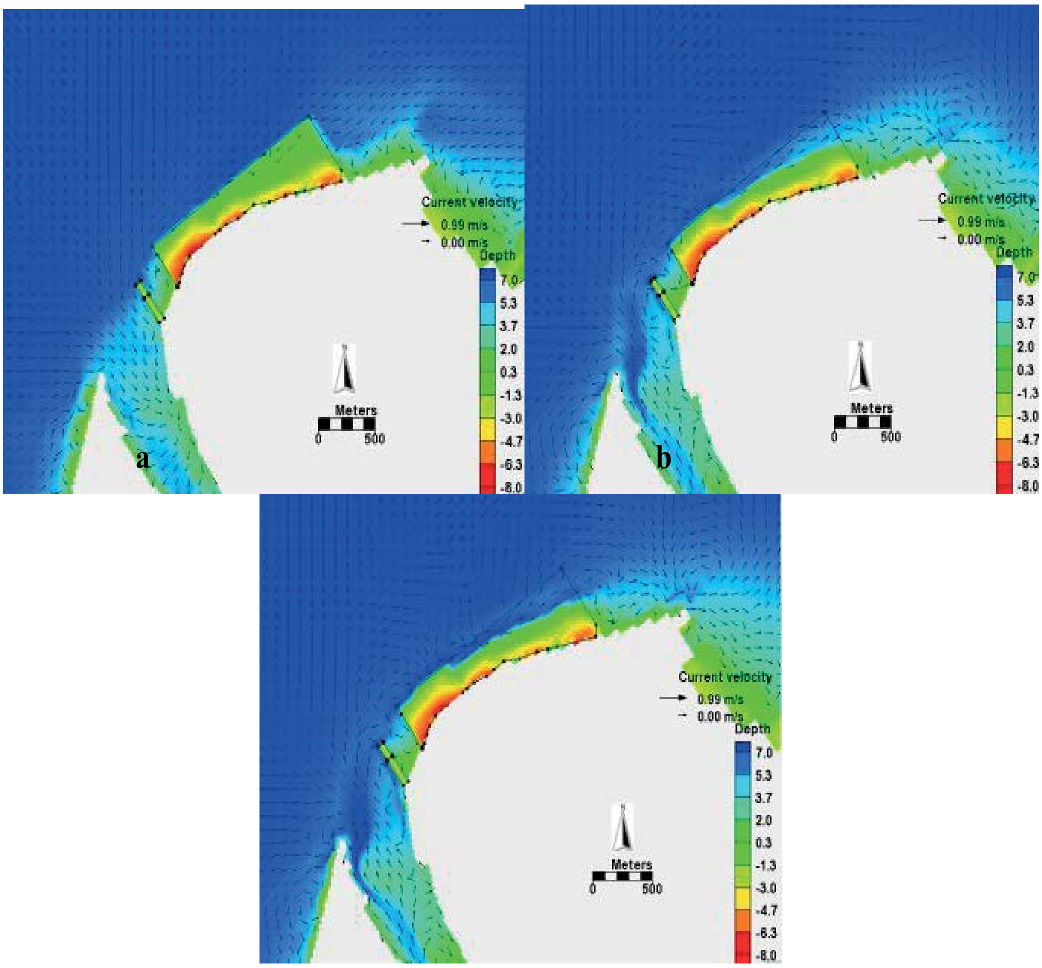

Figure 19: Model results of the water depths and current velocities: a) at the beginning of the run, b) after two years, and, c) after five years.

motor technique is predicted to be more effective, economical, besides being environmentally friendly for the long term than traditional nourishments especially at (beach and shoreface) presently being used to mitigate the coastal recession. Moreover, it rehabilitates a wide range of the coastline around under the effect of coastal processes at the nourished area.

Conclusion

The coastal inlets are of great economic and environmental significance. Although many hard measures have been implemented to mitigate the shoreline against recession and siltation inside the inlets, it still has negative effects on the environment. So, developing new techniques that are environmentally friendly to save the coastal environment become an urgent need to achieve the coastal zone management. In Egypt, Rosetta outlet suffers the same problems. Different hard and soft measures were constructed to mitigate these problems, but the situation is still unstable.

Two different alternatives that build with nature and have minimum ecological effect have been proposed. The first scenario is to divert channels from sea to the river to provide water discharges to the river after the lack of water discharges occurred since1964 due to AHD construction in order to retrieve the hydraulic stability for the cross section of Rosetta outlet. The other one is to investigate the effect of sand motor technique. A calibrated 2D morphodynamic model (CMS) was used to conduct the simulation of both scenarios.

The simulation results showed that diverted channel enhances the situation locally, particularly the left channel, but with a limited effect on the sedimentation inside the inlet and this is due to the angle of the prevailing wave that govern the siltation in front of the channels at the seaside [34]. The sand motor techniques expected to be more innovative one for the long term rather than traditional shoreface nourishments, and the other hard measures. that are being used to treat coastal erosion The great benefit from this solution is to build with nature, and preserve the ecological situation. So, it is recommended to investigate sand motor technique at a regional scale to precisely study this innovative method.

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