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Testing a Combination of Hard and Soft Measures to Enhance the Stability of Rosetta Outlet

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Abstract

This paper is an extension of the different tested alternatives of coastal protection measures aims to reach a stability condition around Rosetta promontory, Egypt. Rosetta inlet suffers from coastal problems represented in shoreline erosion, and siltation inside the inlet.

Rosetta Promontory was created by sediment transported along the Nile River and delivered to the coast by the Rosetta branch. Following a long period of accretion, the promontory began to erode in the mid-1900's, particularly, after building the Aswan high Dam in 1964 that detained the sediments and the water behind resulting in such problems.

This study investigates different alternatives of hard and soft measures attempting to find an optimal solution for these problems (erosion, and accretion) to enhance the stability of the promontory.

The simulation of the study area was carried out using a 2D dimensional model (Coastal modeling system). This model was calibrated and validated using different data collected from: Coastal Research Institute (CoRI), Coastal protection authority, Hydraulic Research Institute (HRI), and Nile Research Institute (NRI). The different scenarios have been simulated, and compared based on the morphological changes, wave characteristics, construction cost, and environmental effect.

Introduction

Many coastal problems all over the world have resulted from the unsustainable of the coastal zone resources. Among the various problems in this vulnerable area arises the accumulation of the inlets, problems include the accumulation of shoreline erosion, deteriorating of the ecosystem.

One of the most vulnerable areas along the Nile Delta coastal area is Rosetta promontory. It lies on the northwestern Nile Delta coast as shown in Figure 1. Rosetta promontory is an example of many outlets suffers from erosion along the coastline. It is due to low water and sediment discharges resources of the Nile River since constructing the water control structures, mainly AHD along the River Nile [1,2]. In addition, it is considered as a sink for the eroded sediments transported offshore from the Abu Kir Bay and Rosetta [3]. These sediments result in hindering the navigation process as it accumulates at the river outlet. Moreover, it threatens the lives of habitat in this area and also threatens the nearby areas with inundation in flood conditions (the maximum flood event occurred in 1998≈83 MCM/day, HRI) as it reduces the capacity of the waterway cross section. Moreover, frequent dredging was carried out to overcome the siltation problem inside the outlet, but the situation is still unstable [2,4].

Although protection works (two revetments of 5 km long and 14 groins east and west of the promontory) have been constructed to mitigate the erosion problem at the Rosetta outlet [5], the shoreline along Rosetta promontory is still unstable and the protection works have not been efficient enough to stop erosion [6]. These coastal structures decreased the shoreline erosion within the construction area, but shifted the problem to the adjacent beaches.

The main target of this paper is to reach an integrated practical solution achieving the sustainable stability for Rosetta promontory. This can be implemented through a testing combination of soft measure (sand nourishment), and hard measures (jetties and groins). This paper is considered an extension to the previous work implemented by [7-9].

Material and Method

The simulation has been carried out by using different field data. The field data (bathymetry, wave, tide, and Rosetta discharges) were obtained from the Coastal Research Institute, Hydraulics Research Institute, and Coastal Protection Authority. In addition, geometric data include; land boundary, land elevations, groins elevations, and Rosetta branch position which was used in determining the closed, open boundaries of the model and creating the grids.

Hydrodynamic model setup

An accurate bathymetric grid is essential because wave propagation is strongly influenced by nearshore bathymetry. In addition, high spatial resolution is necessary to adequately resolve the inlet. The nearshore, off shore, the inlet, Rosetta branch, and adjacent beaches were surveyed between 2005 and 2006 by Coastal Research Institute. The CMS grid was constructed based on the above mentioned bathymetric data. A variable sized rectangular-cell grid system, with a spatial resolution ranging from 20*20 m in the vicinity of the inlet, and the nearshore zone, navigation channel to 70 × 120 m near the ocean boundary was generated with a number of ocean cells=24613. Having the fine grid spacing at and around the estuary enabled capturing the sediment transport and morphologic change processes where they mainly occurred. Larger the offshore grid spacing, the speeder the

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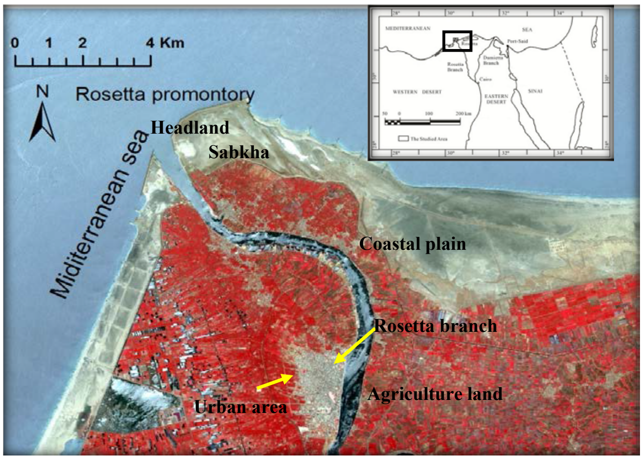

Figure 1: Rosetta promontory at the terminal of Rosetta branch, SPOT image 2012, [10].

computational process is. A CMS-Wave was also generated that had the same dimensions as flow. To simulate the flow field, CMS-Flow was driven by the measured tide along the open boundaries from October 2005 to May 2006. After examining 5 years (1986-1990) records, wave during 1986 was judged to be representative and used in the modeling effort. The half-plane model of CMS-Wave was selected for this study. Figure 2, shows both CMS-FLOW and CMS-WAVE grids.

Model calibration and validation

To calibrate the model, bathymetry evolution maps (October 2005, and May2006) were used. Input data for the wave, and flow mode were prescribed and the model was executed to predict the bottom evolution after six months starting from October 2005 to May 2006.

Several profiles were considered at western and eastern sides of the outlet as shown in Figure 3, to perform sensitivity analysis and model calibration. The important parameters used in calibration hydrodynamic time step (300, 450 and 600 sec), Manning coefficient (0.009, 0.125, 0.025, 0.04 and 0.05), different transport formulas (Van Rijn, Land-Cirp and Watanabe), scaling factor (0.5, 0.7, 0.9, 1.0, 1.3 and 2.0) for bed load and suspended load, total adaptation length (1, 5, 10, 20, 50 and 100), and also the effect of smoothing the bathymetric contour.

The squared correlation coefficient according to bed change, bed depth, Brier skill score(BSS) and Normalized root mean square error (NRMSE) was calculated for all profiles. The results show that our model is qualified to predict the coastal morphodynamic processes as shown in Table 1 with 0.025 of Manning coefficient, 450 sec time step, scaling factor of 2.0 and adaptation length of 10 m. Moreover, the model was validated through comparing model results with the previous published studies and Google earth image as shown in Figure 4 [4]. From these figures, it is clear that the model results as shown in Figure 5 succeed to present the nature in a good way represented in the exact location of the nodal point (divergence point, where the current flow diverge to the east and west) and the sedimentation inside the inlet.

The output of CMS like, wave transformation, flow circulation, water levels, sediment transport, will be used as inputs for PTM model. In addition, native sediment data, source file, and boundary cell strings were created, then CMS-PTM parameters could be specified in order to simulate the spatial distribution of nourishment material in the open water after releasing from the source in terms of identifying the suitable locations for the placement sites, the proper grain size of the used sediments, and describing the qualitative behavior of the particle state (suspended, and deposited) during, and after nourishment process.

The validation of PTM was conducted through comparing its results with a fluorescent tracer study performed by Abo zed and Shereet [10,11] along Rosetta coast to predict the direction of sediment movement and to estimate the sediment dispersion at the western side of the promontory and near Rosetta outlet shown in Figure 6. The results of PTM simulation gives a good correlation with the experimental one as it gives almost the same grain size distribution.

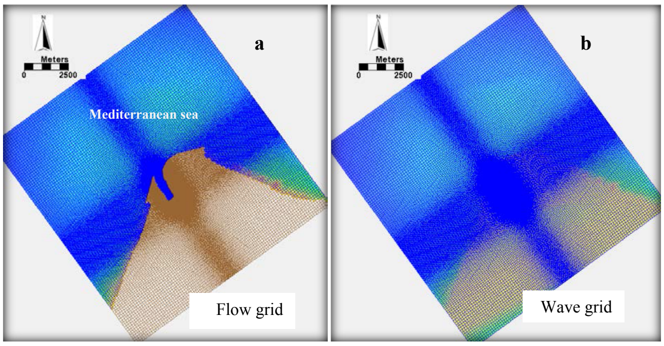

Figure 2: Model grids with boundary condition for Rosetta Promontory, resolution increases at the vicinity of the throat and the surf zone, (a) CMS-Flow grid, and (b) CMS-Wave grid.

Figure 3: Location of the selected profiles along eastern and western sides of Rosetta outlet used in calibration and sensitivity analysis.

Section name	R^2 (bed depth)	R^2 (bed change)	BSS (bed change)	RMSE (bed depth)
RHP30	0.98	0.60	0.612	0.061
RHP29	0.99	0.50	0.483	0.052
RHP24.8	0.97	0.70	0.683	0.083
WBP4.6	0.95	0.36	0.320	0.091
WBP8.8	0.97	0.34	0.316	0.078
WBP9.6	0.94	0.38	0.351	0.132

Table 1: Correlation coff. and Brier skill score of profiles due to bed depth and bed change.

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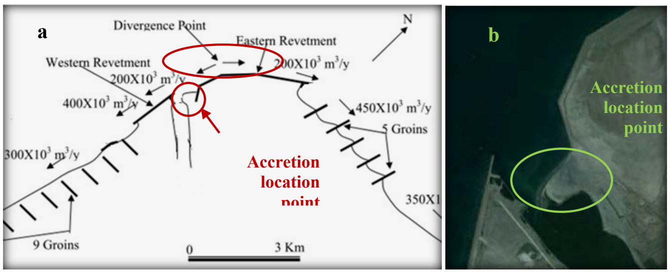

Figure 4: (a) location of the divergence (nodal point) [4],(b) location of the sedimentation inside the outlet, Google earth, 2003.

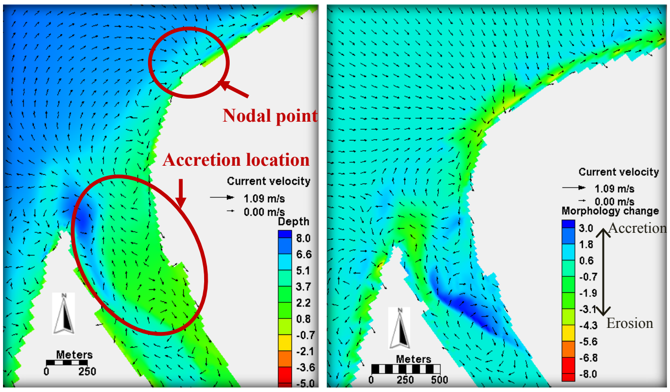

Figure 5: (a) Location of the divergence (nodal point) and sedimentation inside the outlet for the simulation results based on: a) water depth, (b) morphology change.

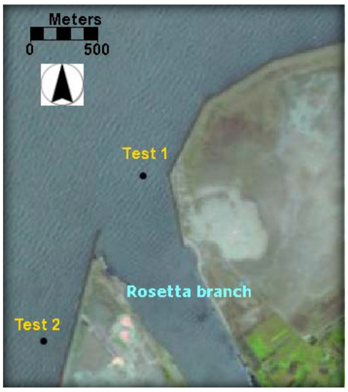

Figure 6: Location map of fluorescent sand tracer experiments[11] and PTM sediment release points.

Tested scenarios

Different scenarios, including beach nourishment and hard structures have been tested using CMS. After that, a comparison was implemented between the previous results published by [9] and the recent scenarios in this paper to obtain the optimal scenario capable of restoring the stability of Rosetta promontory taking into consideration the construction cost and the environmental effect. To compare between different scenarios, the hot spot area was divided into three subareas; the eastern, middle and western as shown in Figure 7.

Nourishment and hard structures alternatives

According to particle tracking model simulation results [12], the nourishment locations were selected among different tested locations based on the sites of severe erosion (in front of seawalls) at both sides of the promontory. In addition, the different available sediments sizes around the study area were tested to select the suitable size for nourishment process. On the other hand, the hard structures alternatives were selected in the positions at the boundary of the inlet to ensure trapping longshore sediments, and restoring the beach in the study area. These scenarios are considered an extension to the work published by [9].

Results and Analysis

Beach nourishment (second scenario with sand volume 300000 m^3).

Three scenarios are tested as shown in Figure 8. The first one includes beach nourishment with a volume 300000 m^3 (the placement site is at western side) with an eastern jetty of 360 m length at the tip of the eastern revetment. The second scenario is the same as the first one; the only difference is on the eastern part of the promontory which includes three inclined groins. The third scenario is the same as the two previous scenarios, the difference is on the eastern part which include an eastern jetty of 360 m length beside the near-shore nourishment (centered on the nodal point for sand volume 300 000 m^3).

Figures 9 and 10 show the morphological change and sediment volume after one year for the three scenarios. Generally, it is concluded

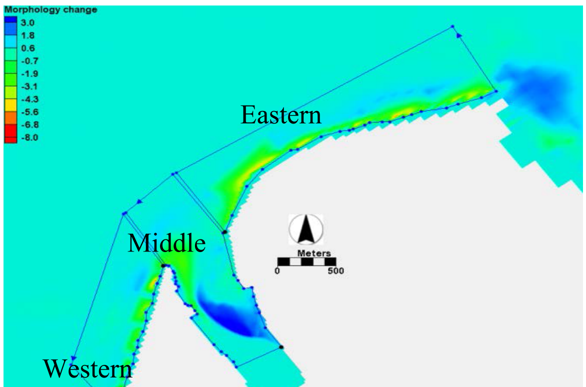

Figure 7: Three subareas used to estimate sediment volume (accretion erosion and net volume).

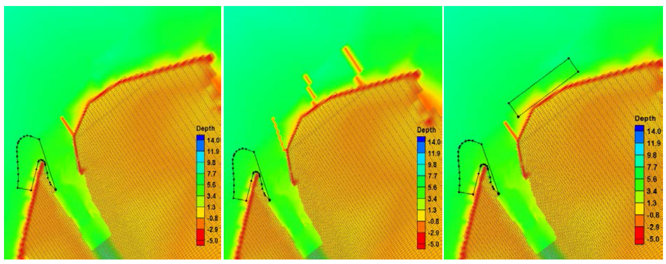

Figure 8: The three tested scenarios (combination between the best scenarios in beach nourishment group with hard structures).

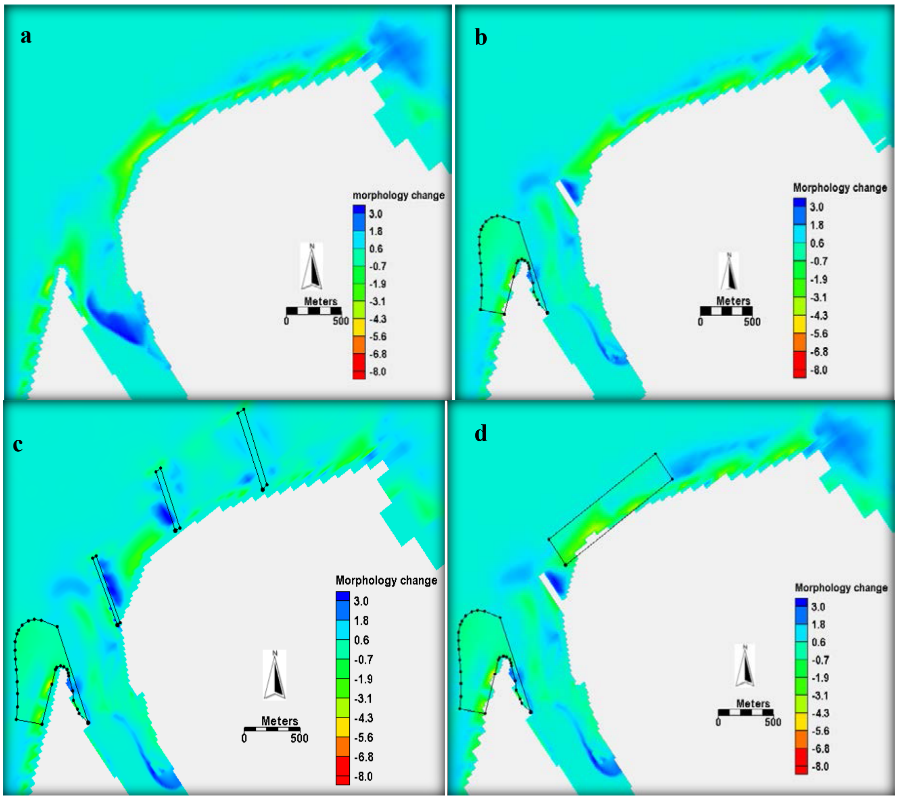

Figure 9: Model results of the morphological changes for different nourishment scenarios (a) no action, (b) first scenario, (c) second scenario, and (d) third scenario.

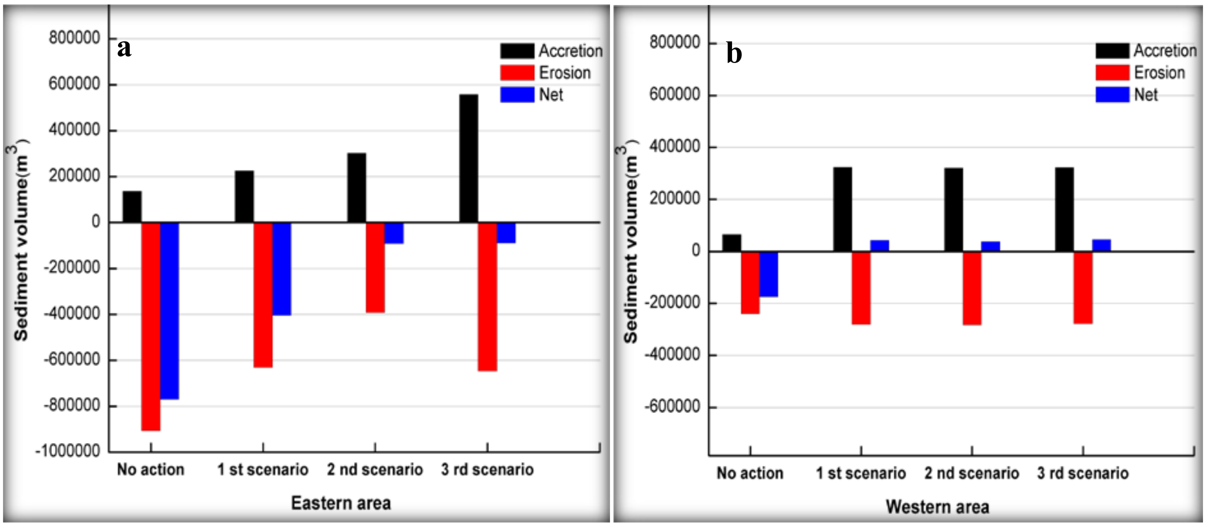

Figure 10: Annual sediment volume of the three scenarios at; (a) eastern area and (b) western area.

that the second, and third scenario are better than the other, as they decrease the erosion rate, especially in front of the eastern revetment in addition to decreasing the accumulation of the sediments inside the inlet. Figure 11 shows the sediment concentration, and the total sediment transport, it is clear from these figures that the total sediment transport and the sediment concentrated have the smallest value at the second scenario.

Construction cost

The cost of second scenario=(580+540+730)* 7000+(300 000*9)=12,950,000 $.

The cost of third scenario=(360)* 7000+(600 000*9)=7,920,000 $.

So, according to the construction cost, the third scenario is the best one.

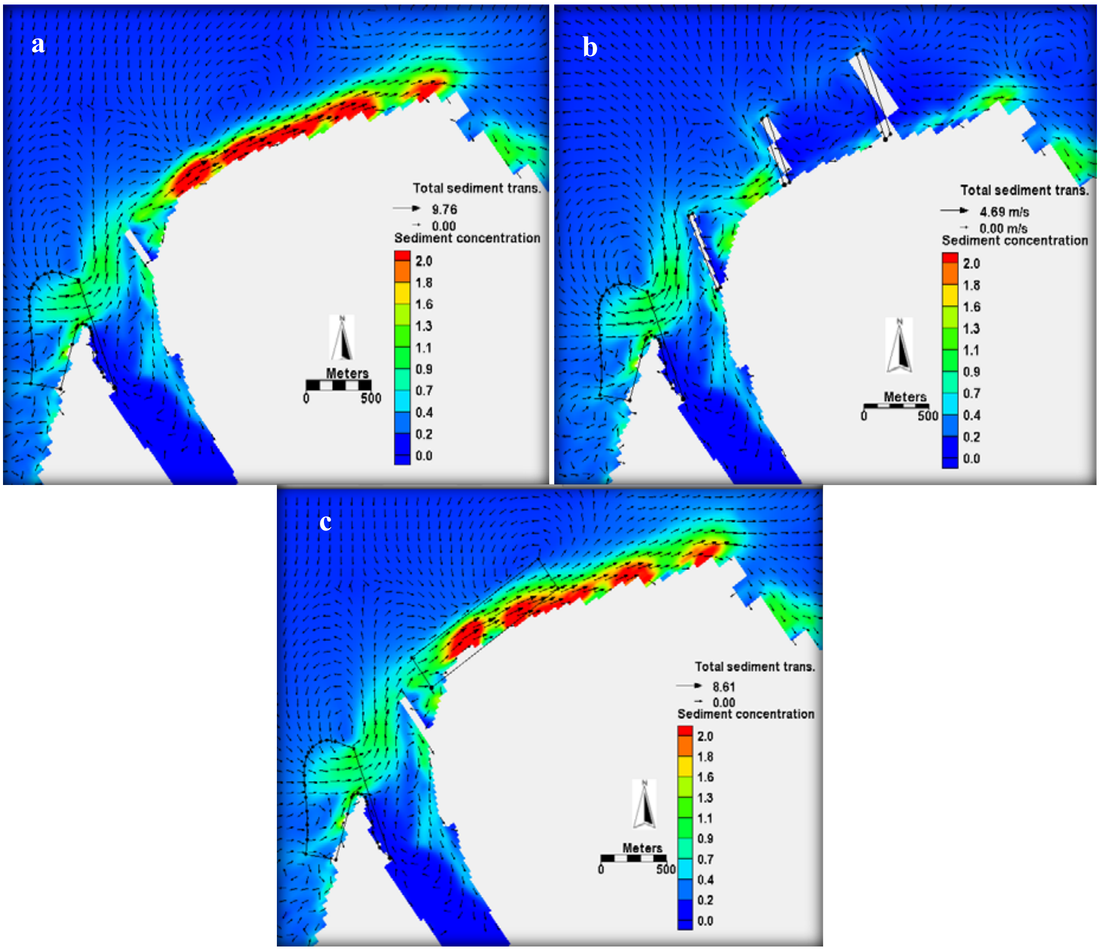

Figure 11: Sediment concentration map combined with total sediment transport vectors for the three scenarios.

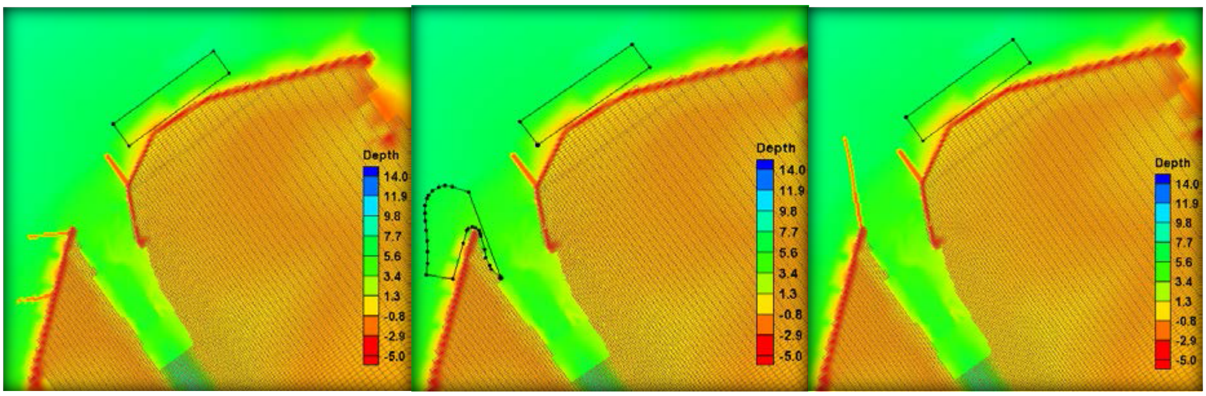

Figure 12: The best three scenarios.

Optimum scenario within the tested groups

In this section, a comparison between the best option in the last three groups as shown in Figure 12 was performed to obtain the optimum solution that ensures a sustainable stability for the promontory entirely.

It is clear from the morphological results as shown in Figure 13, that the third scenario succeeded to decrease the sedimentation inside the inlet to its minimal rate.

It is concluded that the third scenario is the best solution as it reduces the accretion inside the outlet to its minimum levels besides reducing the erosion rate in front of the eastern and western revetment. But in order to maintain entire stability, the western area has to be protected from erosion. Accordingly, different volumes of beach

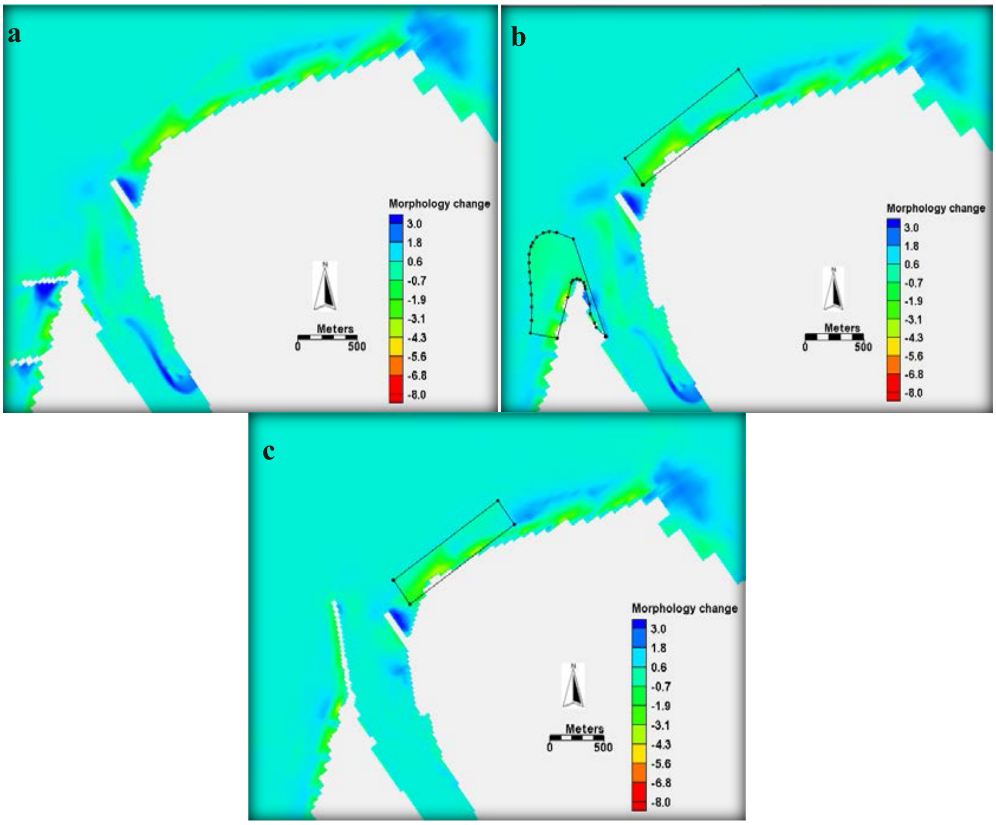

Figure 13: Model results of the morphological changes of different three nourishment scenarios.

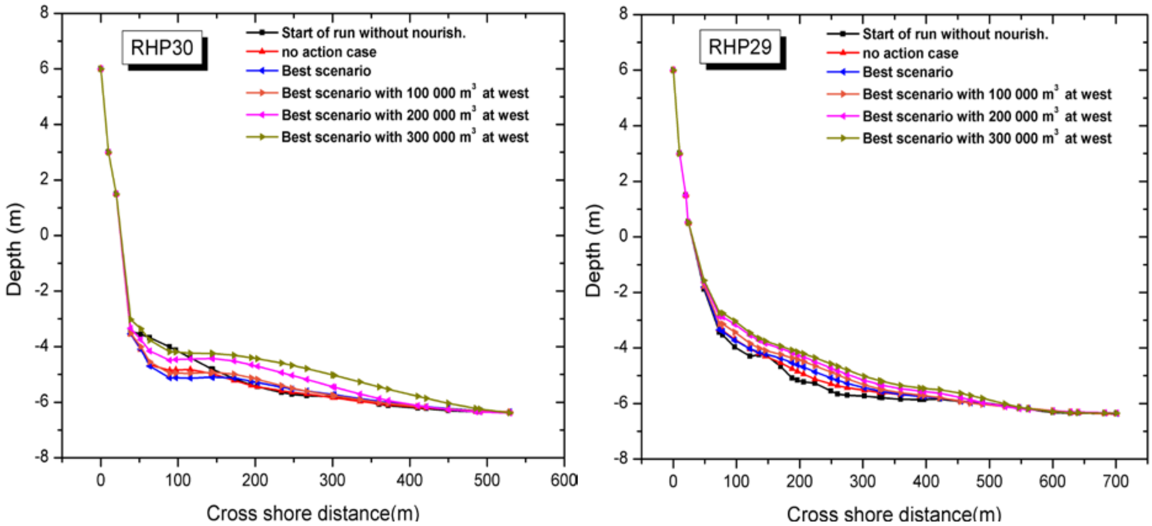

Figure 14: Sea bed profile results of the optimum scenario with different beach nourishment scenarios.

nourishment (100000, 200000, and 300000 m^3) will be tested with the optimal scenario. The results of seabed profiles in the western side of the promontory are extracted as shown in Figure 14. It is clear that the volume 200000 m^3 at the west is enough to stabilize the western area.

Moreover to estimate the periodic time to nourish the western and eastern part, five years simulation was performed. The results of the bed evolution outside and inside the outlet as shown in Figure 15 show that, it is better to nourish annually in front of the eastern and western areas with volumes 300000 and 200000 m^3 respectively. In addition, the accumulated sediments behind the eastern jetty were calculated as 36000 m^3. This amount should be dredged also every year to prevent bypassing sediments inside the outlet and bypassed to the nourishment sites.

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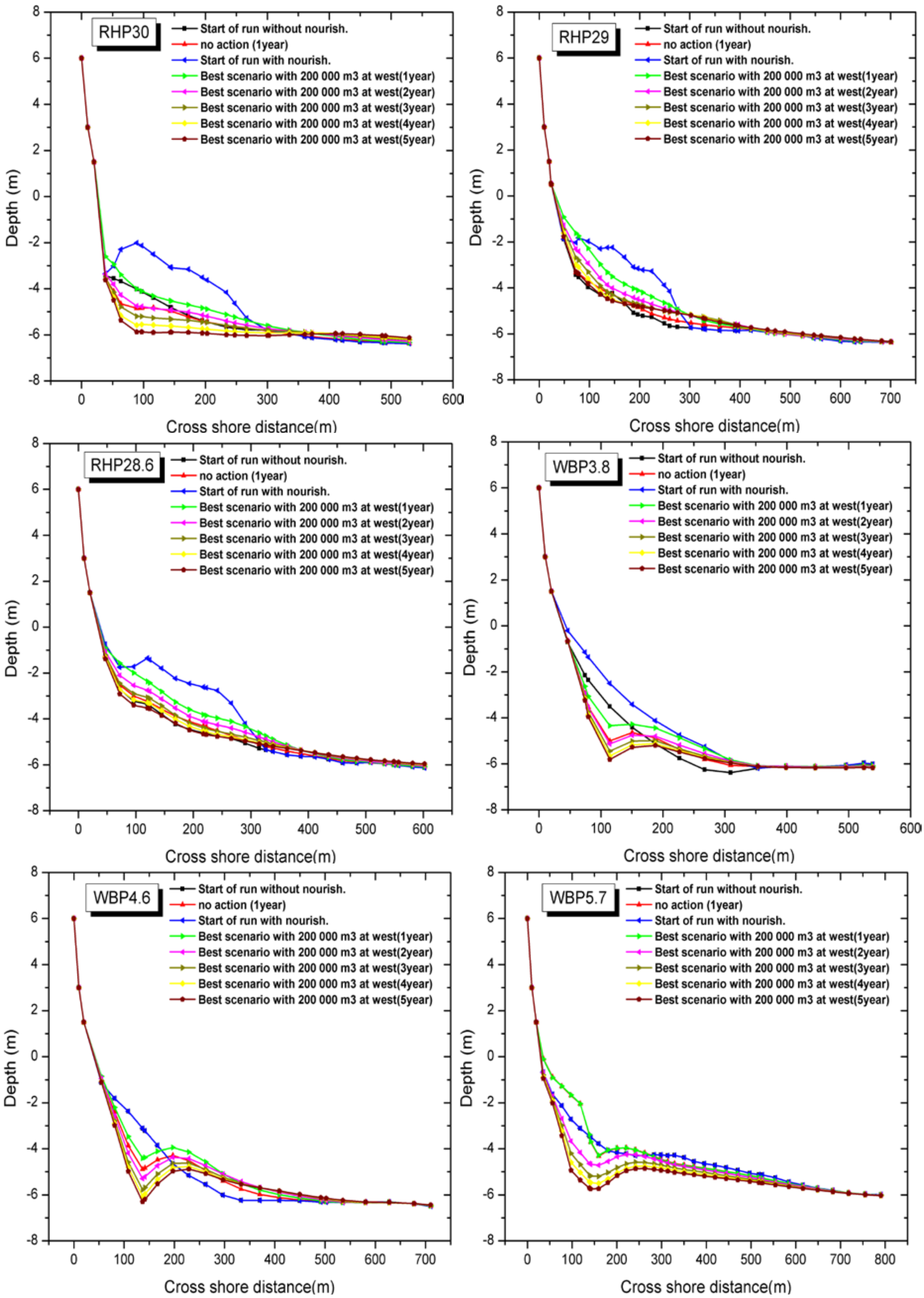

Figure 15: Sea bed profile results of the optimum scenario with nourishment volume 200000 m3 at the west.

Generally, it is concluded that this optimal solution maintains the navigation process in addition to mitigating the erosion problem in front of the revetments.

Environmental Impact of Optimum Scenario

Morphodynamic aspect: Figures 16-18 show a comparison between the optimum solution of the recent study with the no action case. It is clear that the optimum solution has improved the stability of the outlet represented in: a) decreasing the siltation inside the outlet which satisfies the navigation conditions, and overcomes the erosion problem in front of the seawalls that threatens its stability as shown in Figure 16. On the other hand it has decreased the wave height at the outlet compared to the no action case as shown in Figure 17, which in turn leads to decreasing the wave energy at the outlet. Moreover, the total sediment transport at the outlet, especially in front of the eastern seawall has been decreased as shown in Figure 18. This decrease is due to the hindering of the littoral drift by the boundary jetties.

Environmental aspect: The deterioration of Nile water quality is most pronounced in the Rosetta branch due to the disposal of municipal and industrial effluents, in combination with agricultural drainage and decreasing flow as the water arrives at the Nile estuary [13]. In addition to nutrient-enriched waters, other pollutants such as trace metals and hydrocarbons of industrial origin are reaching the Nile estuarine environment. All of these pollutants have severely affected Rosetta outlet. There are numerous reports of high concentrations of contaminants such as aluminum, iron, copper, zinc, cadmium, and lead, dissolved and in particulate forms, inside waters contributing to the estuarine environment of Rosetta area. The particulate form is mostly associated with suspended matter (both organic and inorganic), which afterwards is deposited as sediments [14,15].

The release of oil wastes into the Nile estuary is inevitable, and oil products are harmful pollutants adversely affecting the biota of the Nile estuary ecosystem. The varying levels of pollutant concentrations in the Nile estuary environment are related to the river discharging capacity, the distribution of land-sourced effluents along the Nile delta region, and temporal variations in these factors. The eastward flowing Mediterranean currents along the Egyptian coast carry pollutants from the western effluents (Rosetta branch and coastal lakes) to the eastern side of the delta.

In conclusion, the obtained scenario in the present will not

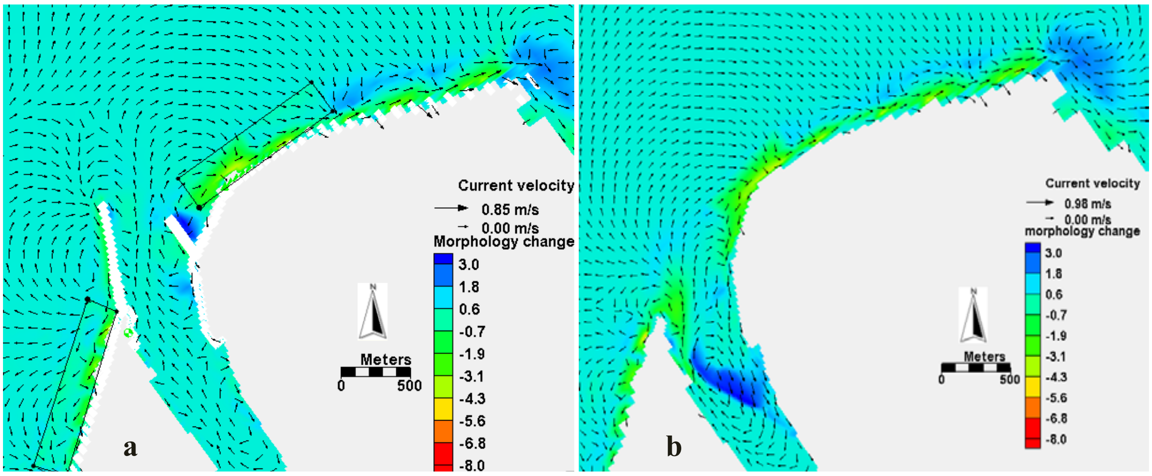

Figure 16: Model results of the morphological changes of the (a) optimum, and (b) no action scenarios.

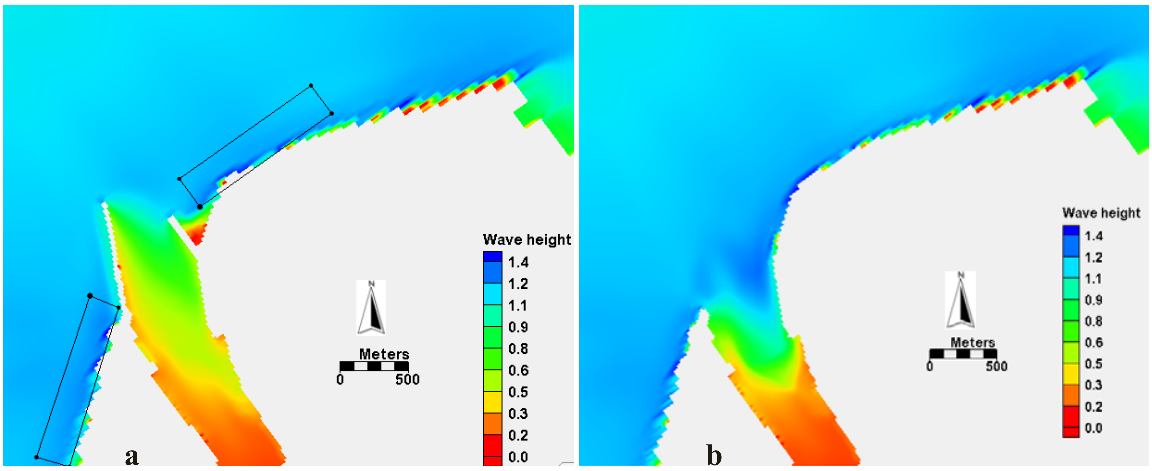

Figure 17: Model results of the wave height distribution of the (a) optimum, and (b) no action scenarios.

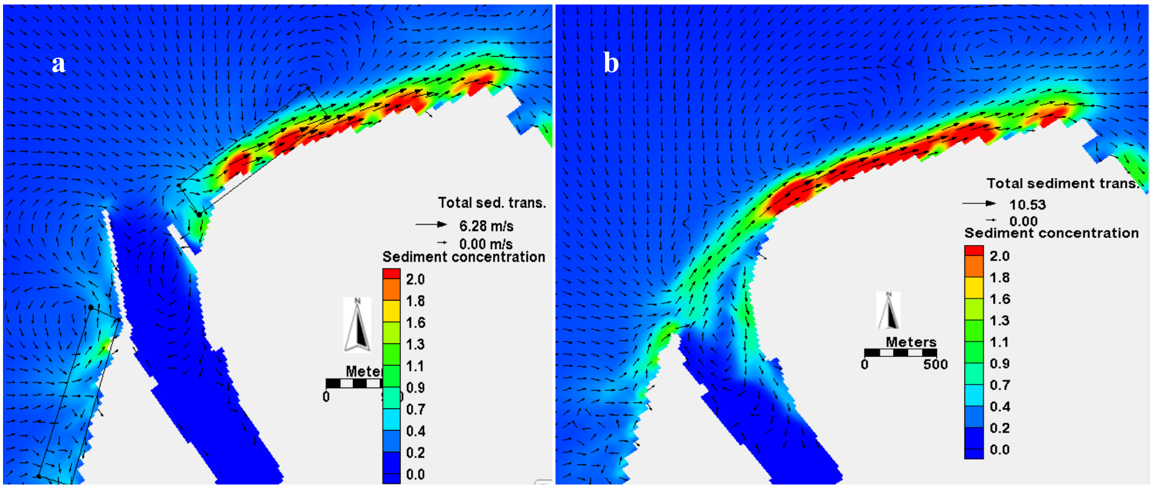

Figure 18: Model results of the total sediment transport of the (a) optimum, and (b) no action scenarios.

affect the water quality nor the fish catch as the deterioration in both categories parallels the decrease in the discharged fresh water and fertile sediments after the construction of AHD.

Conclusion

The hydrodynamic modeling using CMS has been applied at Rosetta promontory to check different alternatives to reach an integrated solution for ensuring the sustainable stability. Different alternatives, including a combination between sand nourishment and hard measures are presented to investigate the effect of each one on the Rosetta promontory stability.

It is concluded that the optimum solution is to use a combination between soft measures (nourishment) and hard measures (jetties). This solution includes an eastern jetty of length 360 m and western jetty of length 800 m, in addition to sand nourishment of (300,000, 200,000 m^3) in front of the eastern and western revetment respectively. Within the tested scenarios, the optimum one has the following merits:

- The periodic sand nourishment will be every two years for the western part and one year in the eastern one.
- Moreover, a dredging work will be required behind the eastern jetty with (36000 m^3) annually.
- The construction cost of this solution is estimated to be 12,620,000 $.
- The annual maintenance cost will be (2,700,000 $) every year for the eastern part of the promontory, while the western part will be maintained every two years with 1,800,000 $. This cost includes sand nourishment only.

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