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Economic evaluation of using marine dredged material for erosion control along the northeast coast of the Nile Delta, Egypt

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Abstract The present study is the first attempt in Egypt to assess feasibility of using of dredging material from Damietta Harbor in the northwestern Nile Delta for erosion control. The study also provides an economic evaluation for the shoreline management alternatives selected to mitigate for the effects of coastal erosion at two pilot eroding areas (namely, A and B) located near the Damietta Harbor. Results of compatibility analysis reveal that the dredging material is fairly compatible with the native sand of the nearby eroding beaches. In addition to soft nourishment by dredged sand, other types of coastal engineering measures which are often used in erosion management area were also evaluated as alternatives for erosion control and mitigation solution. Economic feasibility assessment by means of cost-benefit analysis of direct and indirect items has been carried out to facilitate comparison between these alternatives. Analysis of alternatives has been also supported by other criteria to select the cost-effective and environmentally acceptable option to protect the eroding pilot areas. These criteria include the high total cost paid for maintenance of the Damietta Harbor channel with no use, anticipated impacts on the littoral system, sustainability, future plans for protection of the existing coastlines, and lessons learned from previous shore protection works in the Nile Delta. The final selection of the best viable alternative indicates that the procedure of beach nourishment is the most appropriate form for protection area A, while a combination of groins and sand nourishment is more relevant for area B. In any case, material dredged from the navigation approach of the Damietta Harbor should be utilized as a borrow material in the nourishment schemes and excluding use of the terrestrial sources.

Keywords Dredged sediment · Compatibility analysis · Economic evaluation · Cost-benefit analysis · Sand nourishment · Erosion control

Introduction

The Nile Delta coastline (Fig. 1a) has a long history of erosion that has been aggravated due to the construction of the Aswan High Dam in 1964, which acts as a sediment trap in its reservoir south of Egypt. As early as 1964 (prior to the damming of the Nile River), an estimated 11.4 million m^3 of quartz-rich sand was discharged annually from the Nile, accounting for nourishment of the delta littoral cell (Hammad et al. 1979). In the absence of sediment supply to the Mediterranean coast off the Nile Delta, the continued action of coastal processes combined with the effect of accelerated sea level rise acts to induce beach erosion (UNDP 1978; Fanos et al. 1991; Deabes 2003; Frihy and El Sayed 2013). Erosion was more dramatic at the Nile Delta headlands and promontories at Rosetta, Burullus, and Damietta, ranged between 10 and 100 m/year, because they are more exposed to convergence wave patterns (high energy) and divergence longshore currents (Frihy and Komar 1993). A series of protective shore structures has been built at these headlands in an attempt to decrease the ongoing accelerated erosion. Following protection of these headlands, the general coast-wide patterns of erosion versus accretion

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Fig. 1 **a** Map of the northern Nile Delta showing main geomorphological features and location of the study area. **b** Enlarged map for the study area illustrating the approach channel of the Damietta Harbor and the eroding coasts A and B require protection. It also shows the geographic position of the offshore dumping site (*solid star*) and the sedimentation basin constructed west of the harbor to receive the expected slury matarial dredged from Damietta Harbor by hopper dredgers
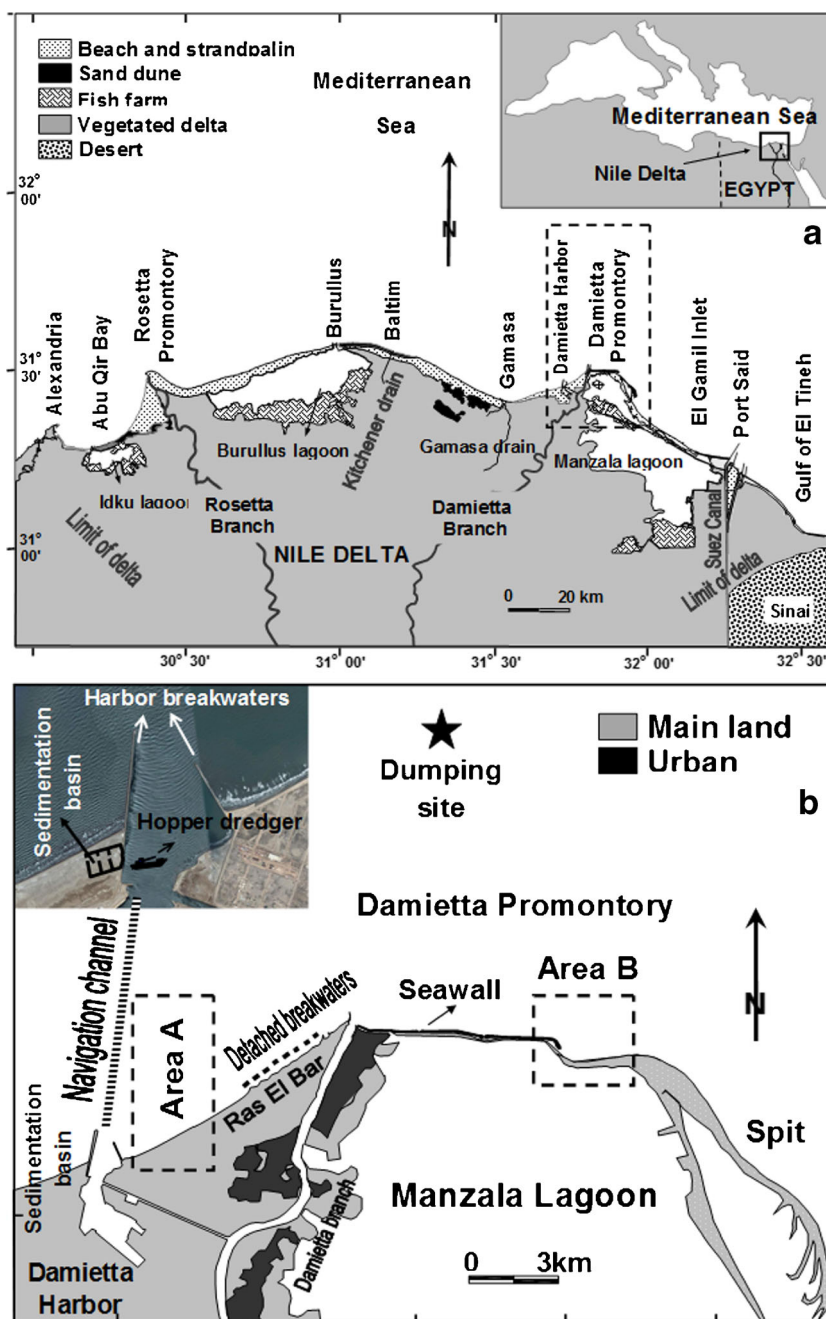
have totally re-shaped, in which the three promontory outer margins are now being armored by massive structures that include seawalls, detached breakwaters, groins, and harbor/estuary entrance jetties. Consequently, local down drift shoreline erosion and up drift accretion were initiated on both sides of these structures (Fanos et al. 1995; Frihy et al. 2003).

A greater portion of the updrift sediment accretion is associated with problematic sedimentation and shoaling in the approach channels of the delta harbors, lagoon inlets, and river estuaries. A huge quantity of marine sediments is being routinely dredged via hopper dredgers from the water pathways

and harbor's channels to maintain continuous water exchange and adequate shipping channel depth for safe navigation of vessels and fishing boats. Dredging activities include sediment removal from the seabed and transport from the dredging site to a disposal area or placement site, which is located either in an open-water or in upland locations. Specifically, most dredging activities exist at liquefied natural gas pier at Abu Qir Bay, Rosetta estuary, Burullus port inlet, Damietta Harbor, and El Gamil inlet near Port Said (Fig. 1a). Dredging of these waterways and harbors creates large volumes of dredged material. For instance, the inner part of the navigation channel of

Damietta Harbor is dredged at an average amount of sediment 1.19×10^6 m³ per year since 1986 to maintain safe navigation depth of −15 m and readily access to the harbor basin. Navigational channel sediments are routinely dredged via trailing suction hopper and disposed in an offshore site located about 11 km north of the Damietta Nile estuary, in water depth of ~20 m (Fig. 1b) without any recycling or beneficial use.

Until recently, sediments dredged worldwide from harbors were considered as a waste product of the dredging process and were a serious concern for the harbor managers. Today, they are seen as a valuable and natural resource that provides opportunities for a number of environmental, economic, and esthetic beneficial uses (Swafford and Gorini 1993; Pederson and Adams 2002; Harrington et al. 2004; Brandon and Price 2007). Several categories of beneficial uses have been reported worldwide. These include, among others, beach nourishment, landfill covers, creating bricks, building aggregate, road construction, agriculture, and even low-quality glass bottles manufacturing (EPA 1992, Demir et al. 2004; Parson and Swafford 2012).

Sand nourishment, which has been considered nowadays as widespread erosion mitigation (Charlier and De Meyer 1995; Wallingford 2005), refers to the artificial and repetitive sand dumping along the beach or nearshore areas from external sources. It is considered a "soft" response unlike "hard" breakwaters, groins, and jetties which can induce hazardous rip currents and gyres that may accelerate erosion of the Nile Delta shoreline and may also lead to unsafe situations for swimmers. It is beneficial as wave action spreads the material along the shoreline. Additionally, sand nourishment represents an effective sea-level rise adaption for vulnerable areas in low-lying coastal plains (Charlier and De Meyer 1995; Wallingford 2005). Coastal economies would also be revitalized during high touristic seasons as nourishment increases the recreational and esthetic values of the shoreline, and thereby increasing the economic values of beaches during summer holidays.

Unlike hard structures, soft beach nourishment can create a wider beach by artificially increasing the quantity of sediment on a beach experiencing sediment loss, improving the amenity and recreational value of the coast and replicating the way that natural beaches dissipate wave energy. This method requires regular maintenance by using more frequent re-nourishment with a constant source of sediment and is unlikely to be economical in severe wave climates or where sediment transport is rapid. It has been used in conjunction with hard structures to improve efficiency such as groins and submerged shore-parallel breakwaters.

Beach nourishment through placement of dredged material generally complies with the management approach known as "living with the sea" or "living shoreline". In that approach, attempts to optimally use natural marine resources and provide a good alternative to traditional shoreline hardening were done by introducing both hard and soft coastal engineering measures with lower construction costs and minimum impacts

on the surrounding environments. NOAA defines the term *living shoreline* as a more natural bank stabilization technique that uses sand fill, oyster shells bags, indigenous wetland vegetation, and limited use of rock to provide shoreline protection and maintain valuable habitat (http://www.habitat.noaa.gov/restoration/techniques/livingshorelines.html).

Taking this into consideration, use of dredged material of the Damietta Harbor in nourishment of the nearby eroding beaches can effectively be of help in combating accelerated erosion and management of the Nile Delta shoreline resources. The re-use of dredged sediments also would cost less than borrowing beach nourishment material from offshore sources that can also induce unfavorable environmental aspects, such as accelerating erosion rates along adjacent coasts.

The objective of the present paper is twofold. Firstly, it aims to assess the feasibility of the maintenance dredged material in Damietta Harbor for nourishment of nearby eroded beaches and remediation of accelerating erosion along the Nile Delta coast. Secondly, it presents an economic evaluation for the shoreline management alternatives selected to mitigate for the effects of erosion processes at two pilot sites, namely A and B identified in the northeastern Nile Delta (Fig. 1b).

Dredging operations in Damietta Harbor

The Damietta Harbor was constructed in 1982 and is located about 9.7 km west of the Damietta Nile branch (Fig. 1b). The harbor basin was constructed inland and its marine entrance was protected by two breakwaters (jetties) (Harris 1979). The western breakwater extends about 1600 m toward the north attaining the 6.5 m-depth contour. The eastern one is about 500 m long and extends to about the 3 m-water depth contour. The navigation channel is about 11.4 km long and 200–300 m width and a maximum water depth of about 15 m. Since 1986, the harbor has been experiencing sedimentation problems particularly in the 3-km inner approach channel and therefore requires frequent dredging to foster safe navigation depth and innocent passage of ships (Frihy et al. 2002). Currently, all dredged material is being destined for marine disposal and routinely dumped in offshore sites in ~20 m depth, corresponding to ~11 km north of the Damietta Nile estuary (Fig. 1b).

Dredging of Damietta Harbor navigation channel is very costly and represents an alarming problem for the port authority and Egypt's government. Present (1987–2015) and future estimates of sediment volumes and their corresponding cost are statistically extrapolated at 5-year interval (2016–2050), as shown in Fig. 2. The annual sediment volumes dredged from that channel and their corresponding cost are progressively increasing (Fig. 2a). As can be seen in this figure, volume of sediments dredged since the past 29 years (1987–2015) ranges from 0.225 to 1.964 million m³ with an average of 1.194 million m³ and a total volume of 32.23 million m³. Future

estimates of dredging cost are also extrapolated at 5-year intervals from 2016 up to 2050 using regression analysis, considering the local inflation rate of 11.06 %, and the resulted time series curve is graphically represented in Fig. 2b. The resulted trend line seems to be simple curvilinear due to the influence of inflation. Data of the actual and extrapolated time series indicates that during the past 29 years (1987–2015), a total amount of EGP 416.11 million (1 US\$ = 7.82 EGP) was paid to dredge a sediment volume of 32.23 million (Fig. 2a). Historically, the cost of dredging operations has risen from EGP 0.52 million in 1987 to over EGP 75.0 million in 2015 (Fig. 2b).

The higher expenditure cost together with the findings of the studies of Frihy et al. (2015, 2016) have encouraged the authority of Damietta Harbor to seek another solution for exploitation and management of maintenance of dredged material instead of their dumping them in offshore areas without any beneficial use or benefits.

To deal with the progressive increase of the cost of dredging, the two authorities responsible for management of these maintenance dredged material (Damietta Harbor Authority and the Shore Protection Authority) have recently signed a memorandum of understanding for transferring of the dredged material as slurry to a nearby disposal inland area west of Damietta harbor to be beneficially used for heavy mineral concentration and beach nourishment (Fig. 1b). Heavy

Fig. 2 Time series of cumulative annual past and future sediment volumes dredged from the Damietta Harbor (*upper*) and their corresponding dredging cost (*lower*). Past data from 1987 to 2015 (*solid dots*) were provided by the Damietta Harbor Authority. Future estimates of these data from 2016 to 2050 (circles) were statistically extrapolated at 5-year intervals using regression analysis. The local inflation rate (11.06 %) is considered in the interpolation process from 2016 up to 2050

mineral concentrates will be initially separated from the delivered slurry using industrial scale sets of spiral gravity separators with re-circulating loads. The mineral concentrate is a mixture of heavy mineral sand denser than quartz with a density generally greater than 2.8 g/cm^3, mostly magnetite, Ilmenite, leucoxene, garnet, ircon, rutile, and monazite. It is planned to finalize the processes of mineral separation in the black sand placer plant at Burullus (under construction), ~70 km west of the sedimentation basin.

The abandoned bare land west of the entrance of Damietta Harbor (a total surface area ~6 × 10^5 m^2; Fig. 1b) has been proposed to accommodate the pumped sediment/water mixture slurry traditionally using flexible pipelines of ~0.7–1.0 m diameter. Three sedimentation basins have been already constructed in that area to receive the expected slurry, with a maximum depth of 3 m and a total capacity of 750,000 m^3.

Hydrodynamic processes and erosion rates of the study shores

The two areas A and B (Fig. 1b) have been identified as two pilot eroding shores along the northeastern Nile Delta coast for studying feasibility of harbor dredged material for nourishment and other protective alternatives. These two sites are located within proximity of the Damietta Harbor and are being subjected to relative high rates of coastal erosion.

Area "A" lies in a central location between the Damietta Harbor to the west and Ras El Bar detached breakwaters to the east and extends for about 4 km alongshore. The beach sand has an average mean grain size of 0.128 mm and sorting of 0.823ϕ (or standard deviation). Standard deviation (σ) is a good measure of the degree of sorting (Folk 1974). The mainland hosts a various land use and coverage patterns, e.g., resort beaches, cultivated and bare land.

The second pilot area "B" tends to have a semi-concave shoreline and is located at the eastern end of the 6.2-km-long seawall on the eastern tip of the Damietta promontory (Fig. 1b). Like area A, the beach of this area and its contiguous backshore is still undeveloped. To the immediate east of area B, the shoreline is developed into long and narrow shore-parallel sand spit. Beach sand have an average mean grain size of 0.117ϕ and mean sorting of 0.643ϕ. The backshore spans the western part of the Manzala lagoon and composed of swamps and fish farms, the latter is characterized by linear and rectangular features.

Shoreline change rates along the identified eroding sites have been assessed using routine coastal surveys conducted in 2004 and 2014. Shoreline positions were measured using the Differential Geographic Positioning System (DGPS). Data obtained were processed to calculate the annual rate of beach changes applying the Digital Shoreline Analysis System (DSAS version 3.2), an ArcGIS tool developed by the US
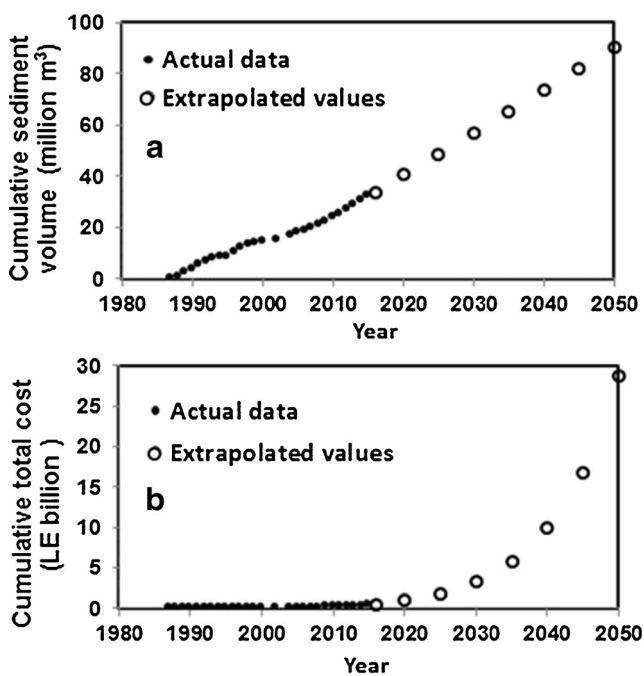
Geological Survey (Thieler et al. 2005). The system has been setup to calculate rates of beach change at a series of cross-shore transects at an interval of 100 m alongshore. The number of transects generated at areas A and B was 149 and 162, respectively.

The results of annual rates of shoreline changes are distributed alongshore of the study coastlines in Figs. 3a, b. These results indicate that rate of annual erosion versus accretion vary greatly along the study coastlines. Maximum erosion of −6 and −108 m/year exists at areas A and B, respectively. On the other hand, sand accretion is pronounced to the immediate east of these coastlines at a rate of 2.4 and 50 m/year, respectively. It is expected that this higher down coast erosion will progressively slow down once, the oblique wave angle to the shoreline orientation tends to be normal to the shore.

Erosion at the two study sites has been aggravated due to the adverse effect of the hard structures built in the region, including Damietta Harbor jetties, Ras El Bar detached breakwaters, and Damietta 6.2-km seawall. These structures resulted in blocking of sediment transport by waves leading to downdrift erosion. Area A is affected by the reversal of the longshore currents induced from the NE waves and the greater portion arriving from the NW direction (Fig. 3c). In contrast, the prevailing NW waves induce unidirectional longshore current which is responsible for creating erosion throughout area B. Sand eroded from this area is transported further to the east where it forms accreted spit (Fig. 3c). This coastline is now reshaped to a long concave beach, although originally it protruded seaward, forming the tip of the promontory (cf. Frihy and Lawrence 2004). This beach has eroded with time, acting as a sediment source for replenishing the downdrift accretionary spit. It is anticipated that the sedimentation pattern formed will change shortly due to the depletion of the sediment source, reverting to spit erosion and sediment migration downcoast along the lagoon barrier to Port Said (cf. Frihy and Lawrence 2004).

Current shore protection scheme

The Shore Protection Authority (SPA) which is responsible for managing the shorelines in Egypt dealt with installing a series of erosion control hard structures along the delta coast. Since 1984, SPA has designed and installed all massive engineering structures along the Mediterranean coast with a limited number of nourishment projects at Alexandria in which borrow sands were trucked from the desert some 150 km south of the city (Frihy and Dean 1992).

Major hard structures employed along the Nile Delta coast include seawalls west of Abu Qir Bay at El Tarh (1.2 km long), the outer margins of the Rosetta (5.0 km long), the Damietta promontories (6.2 km long), and revetments (east of the Burullus inlet). The latter was constructed in form of a basalt riprap of ~1.3 km in length at the downdrift of the

Burullus concrete wall (600 m long) to protect El Burg village. All of these structures negatively impacted the adjacent downdrift beaches by reducing the amount of sand available to them. For example, the two seawalls constructed at the outer margin of the Rosetta promontory have disrupted the eastward and westward wave-induced longshore sediment transport resulting in local downdrift erosion at the opposite ends of these walls (Fig. 4a). Latter, this erosion has been mitigated by constructions of a series of massive groins on both sides of the newly built seawalls (Frihy et al. 1991).

Two main formations of shore-parallel detached breakwaters made of dolos that were built during 1991–2002 at the central bulge of the delta along Baltim beach (17 units; Fig. 4b) and at Ras El Bar resort (8 units; Fig. 4c) have also induced adverse effect to the beach morphology. More specifically, the detached breakwaters at Baltim beach together with their associated tombolos and salient formation have transformed this sector into an effective shore parallel seawall or a littoral barrier (El Kolfat 1999; Frihy et al. 2004). The excessive accretionary tombolo sand formed in the lee side of these breakwaters has blocked bypassing more sediment resulting in local downcoast erosion to the east of these structures that has been eventually remediated by additional groins (Fig. 4b). Similarly, Ras El Bar detached breakwaters have disrupted the reversal westward wave-induced longshore sediment transport inducing local down drift beach erosion at area A examined in the present study (Fig. 4c). In all of these structure types built in the delta region, the locally formed downdrift erosion has been eventually protected by additional structures in areas where erosion was not previously expected. This process of protection has been repeated to cover the entire delta coastline, referred to as a chain reaction. Mechanism of erosional chain reaction that resulted from constructing engineering hard structures has been explained first by Inman and Brush (1973). In addition to these physical impacts, the rip and gyre currents formed in the lee side of Ras El Bar-detached breakwaters have caused disaster hazards for swimmers following building these structures (Fig. 4c). The shore-parallel seawalls constructed at the outer margin of the Rosetta and Damietta promontories have induced adverse erosion at their down coast sides (Fig. 4a, d).

Additionally, a number of shore-perpendicular structures such as jetties and groins were constructed in the Nile Delta for stabilizing and controlling the navigation depth of channels and inlets connected with the sea (at Rosetta and Damietta river mouths and coastal lagoon inlets). As a consequence, these structures disrupted the eastward wave-induced longshore sediment transport resulting in local down drift beach erosion and updrift accretion (Fanos et al. 1995).

Beach nourishment using dredged sediment

The compatibility or suitability of channel-dredging sand of Damietta Harbor for beach nourishment of native sand of sites

Fig. 3 Shoreline changes at pilot areas *A* and *B* (*upper figures*, **a** and **b**) estimated from shoreline positions, measured in 2004 and 2014, alternating between erosion and accretion. Lower figure (**c**) shows location of the pilot areas *A* and *B* and the directional distribution of total waves measured at Damietta Harbor (June 2001–June 2004) with relative proportion of wave direction corresponding to wave height. The *arrows* depict the general patterns of longshore sediment transport direction responsible for beach changes
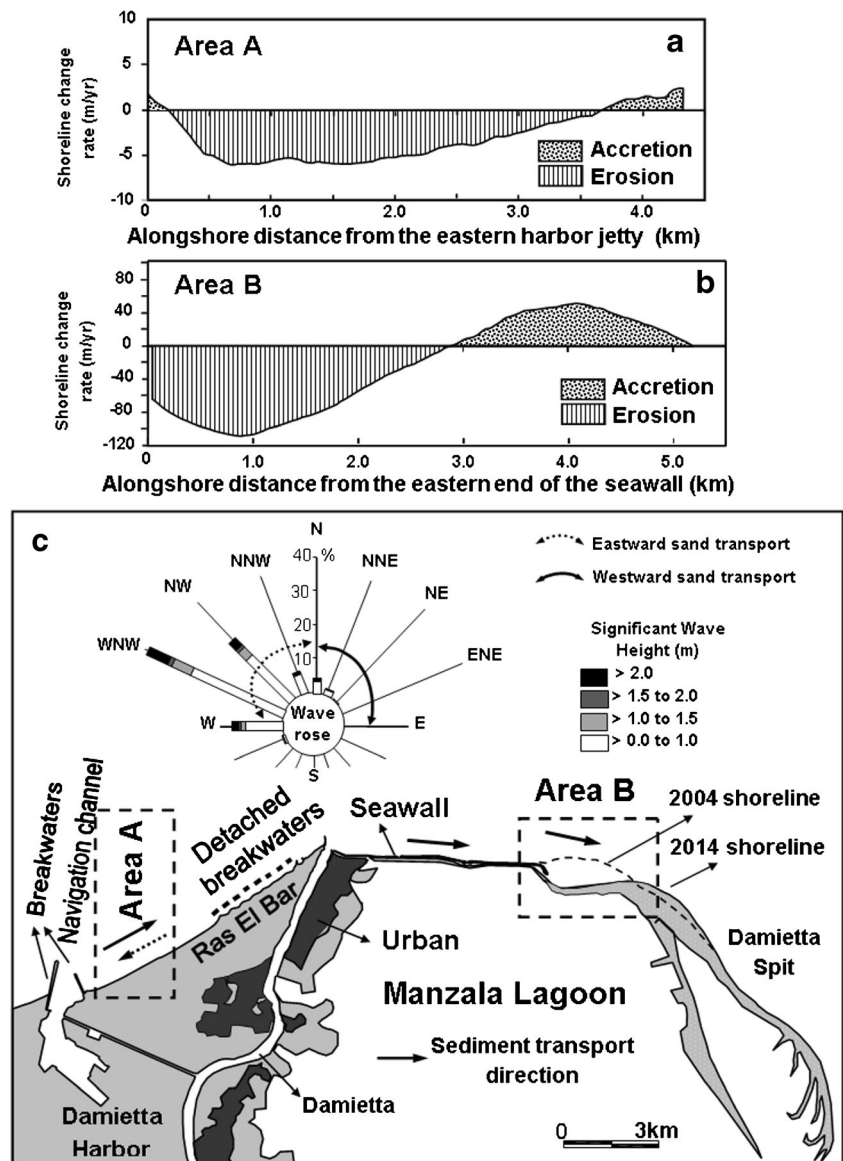
A and B has been assessed by Frihy et al. (2016) using standard evaluation approaches. Unlike the native sand (medium, fine, and very fine sand) of the eroding areas A and B, core samples collected from the dredged Damietta Harbor channel comprise admixture of sand-, silt-, and clay-sized particles. These textural differences are reflected on the compatibility analysis of dredged material with the native eroding beaches A and B.

The phi star (φ*) approach proposed by Dean (2000) has been the most practical method to quantify compatibility of dredged material to the eroding sites. In Fig. 5, the shaded areas between 2.76 and 10.0φ in the superimposed frequency curves produced in this method for the dredged material with the native eroding beaches represent similar grain size characteristics between dredged and native material. Obviously, the sand-sized fractions within the dredged material will remain

stable as bedload fractions on the seabed, whereas finer size suspended loads (mud) will be dispersed offshore by the active littoral processes. Accordingly, the volume of common sand-size fractions (fine and very fine sand) is expected to be 41.8 % (2.76–4.0φ) of the average weight fractions of borrow materials. Although this moderate compatibility, excessive volumes of these sediment can compensate for nourishing the eroding sites.

Volumes of borrow material required for nourishment and expected morphologic changes

The results of applying the morphodynamic numerical Delft3-D model version 4.01 by Bahgat and Ramadan (2015) is consulted in the present study to facilitate the most appropriate nourishment scheme and to simulate expected variations in
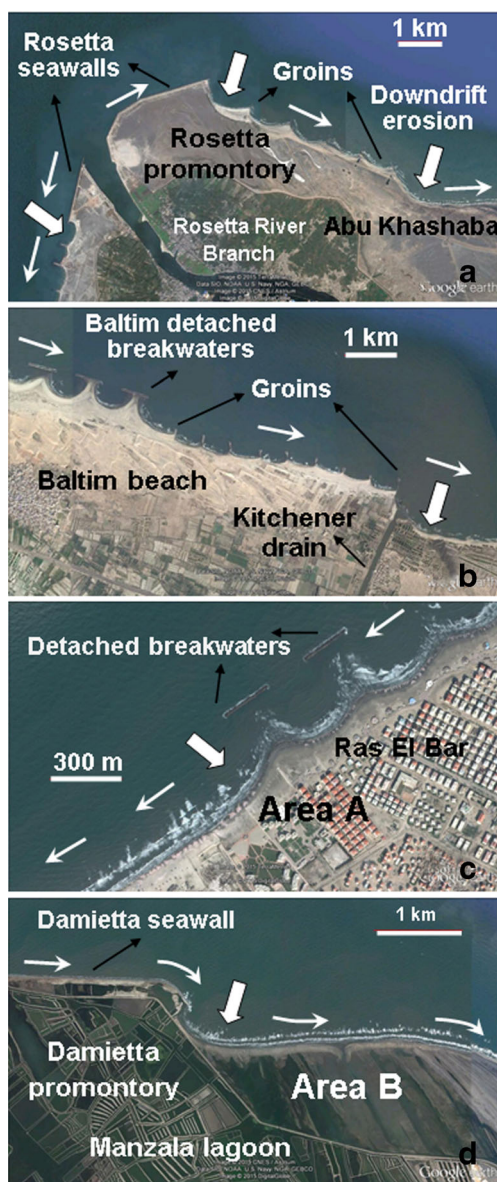
Fig. 4 Subimages from Google Earth showing representative examples for downdrift beach erosion resulted from construction of hard structures built at Rosetta promontory (**a**), Baltim beach (**b**), Ras El Bar resort beach (**c**), and east of Damietta promontory (**d**). Positions of these areas are indicated in Fig. 1a. The *thick white arrows* denote downdrift erosion, while the *shore-parallel white arrows* depict the broad patterns of longshore sediment transport direction as deduced by Frihy et al. (1991)

the seabed of the beach surf zones of the two study eroding areas A and B. The input data of the model included waves in 20 m water depth, tidal variations, bathymetry, shoreline position, grain size distribution of native, and borrow sediment. Principally, the modeling procedures allowed to compare between variations in seabed of the beach surf zones before and after placing the borrow material onto the eroding beaches A and B. Application of the model was also useful for estimation of the total volume of borrow sand required for applying

nourishment to these beaches. The modeling also allowed simulating the new beach areas expected to form after nourishment of the study eroding areas.

Of all nine scenarios examined by Bahgat and Ramadan (2015), only two scenarios (1 and 8) are selected to be applied as nourishment schemes that would effectively provide potential morphological benefits to the stability and viability of the eroding beaches with minimum adverse impacts to the surrounding environments. In scenario 1 and under assumption of 1 year running an amount of 300,000 and 500,000 m^3, dredged material can be directly placed onto the beaches of areas A and B, respectively. Assumptions of scenario 8 is the same as in scenario 1 except that the total dredged material will be increased to 450,000 and 750,000 m^3 at areas A and B, respectively. The running duration is 1 year in both scenarios. In these scenarios, the resulted spatial variations in the seabed and also in the cross-shore direction along a selected beach profile for each area are shown in Fig. 6 (Bahgat and Ramadan 2015). As can be seen from this figure, for scenario 1, the beach width at the two areas A and B would increase by about 0.102 and 0.297 km^2, respectively, with a shoreline advance of approximately 50 and 40 m after 1 year following nourishment, respectively, comparing to the original shore without applying nourishment. Following scenario 8, beaches of areas A and B will be widen by about 0.146 and 0.251 km, respectively (Fig. 6). Simultaneously, their contiguous shorelines advance to about 70 and 60 m, respectively, comparing with the pre-nourishment shores. In both scenarios, it is anticipated that the newly formed ~1.5 m berm will support combating inundation that may result from the expected sea level rise scenarios.

In addition to the formation of the new beaches, their profile slopes become milder due to the accumulation of sediments onto the breaker zone. Eventually, the newly formed gentle slopping seabed effectively dissipate the energy of deep water incident waves before reaching the shore, thereby acting as an additional submerged reef or as submerged wave breakers. Moreover, these new conditions would accelerate increasing natural sand accretion to the local shore-face within the receiving littoral systems of areas A and B. In other words, the budget of the littoral cell will shift from positive to negative balance.

Other possible protective and remediation alternatives

Four potential shoreline protection alternatives were selected for mitigation of erosion effects at areas A and B. These include conventional hard engineered structures and nourishment via borrow material from dredging activities (with or without heavy minerals separation) or from other terrestrial sources. The layouts of these alternatives are diagrammatically illustrated in Fig. 7. The selection procedure has taken into account the physical setting of the two study areas, learned

Fig. 5 Overlying frequency curves of average grain size distribution of dredged material and native eroding sand samples. The phi star value (φ*) in the frequency curves for areas *A* and *B* was estimated using Dean (2000) method. *Shaded areas* represent similar grain size characteristics between dredged and native sediment samples. Their corresponding mean grain sizes (Mz) are represented on the *vertical lines*
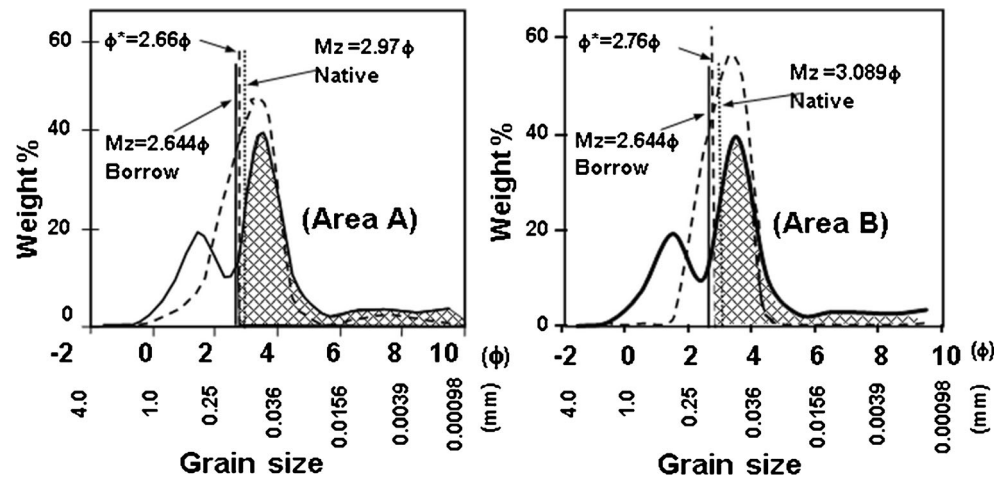
lessons from the previously constructed structures in the Nile Delta discussed in the preceding "Current shore protection scheme" section, and availability of borrow sand to create recreation beaches.

In addition to a "no action" alternative that was considered as a baseline, the conceptual alternatives selected include the following:

1. Hard structures (shoreline revetment, continuous submerged breakwater, emerged detached breakwaters, and groin system)
2. Nourishment using marine dredged material
3. Nourishment using other sediment sources
4. Nourishment with groin system (combined action)

No action

Following of the no action alternative would entail construction of possible measures for the eroding areas A and B. This alternative is used as basis to measure the effectiveness and economic benefits of the other alternatives. In other words, this alternative confirms necessity of implementing other protective alternatives which would safeguard landforms backing the study areas that are likely to be deteriorated without implementing other active alternatives. Consequently, the land-use/land-cover backing areas A and B will be inundated and flooded in the no action option.

Hard structures

A series of conventional hard structure alternatives are recommended herein to retard shoreline erosion at areas A and B, including shoreline revetment, continuous submerged breakwater, emerged detached breakwaters, and groin system (Fig. 7). Sand replenishment is often used in conjunction with

these alternatives when shorelines are being extended or restored.

In spite of the longer sustainability (25–50 years) of hard structures in protecting the shoreline from the ongoing erosion, a series of disadvantages or impacts on the adjacent coastal environment are commonly induced following constructions of these structures. Impacts on shoreline morphology vary depending on the type of structure, design dimensions, and coastal processes that prevail versus shoreline orientation. Impacts of the hard structures may include downdrift erosion, scour in front of seawalls, hazardous rip currents and gyres, endangering rocky and concrete sheltered beaches, destroy beach esthetics, and make beach access difficult. Unlike hard structures, nourishment improves the amenity and recreational value of the coast, replicating the way that natural beaches dissipate wave energy with minor down drift changes, adapting the effect of possible sea-level rise, and increasing "revenue factor" of formed beach. On the other hand, beach nourishment requires regular maintenance or re-nourishment and may cause traffic jam and road damages during trucking borrow sand delivered from inland sources.

Cost-benefit analysis

Vast literature reviews have been published on systematic steps that can routinely contribute to cost-benefit analysis (CBA) of specific environmental alternatives (Hanley and Clive 1993; Navrud and Mungatana 1994; Kasianov and Perelet 1996; Georgiou et al. 1997; Wise et al. 2004). These steps are systematically applied in this study to evaluate the cost and benefits of the possible protection measures to finally choose the most economically feasible one in terms of fewer costs and minor environmental impacts on the surrounding littoral system.

Fig. 6 Results of the numerical model scenarios 1 and 8 simulated for the study areas *A* and *B* showing spatial seabed changes and cross-shore variability in representative profiles 2 and 4 (after Bahgat and Ramadan 2015). In both scenarios, there has been an increase in the beach width associated with shoreline advance comparing to the original pre-nourishment shores. In addition, the profile slopes become gentler that will eventually dissipate the incident waves before reaching the coastline
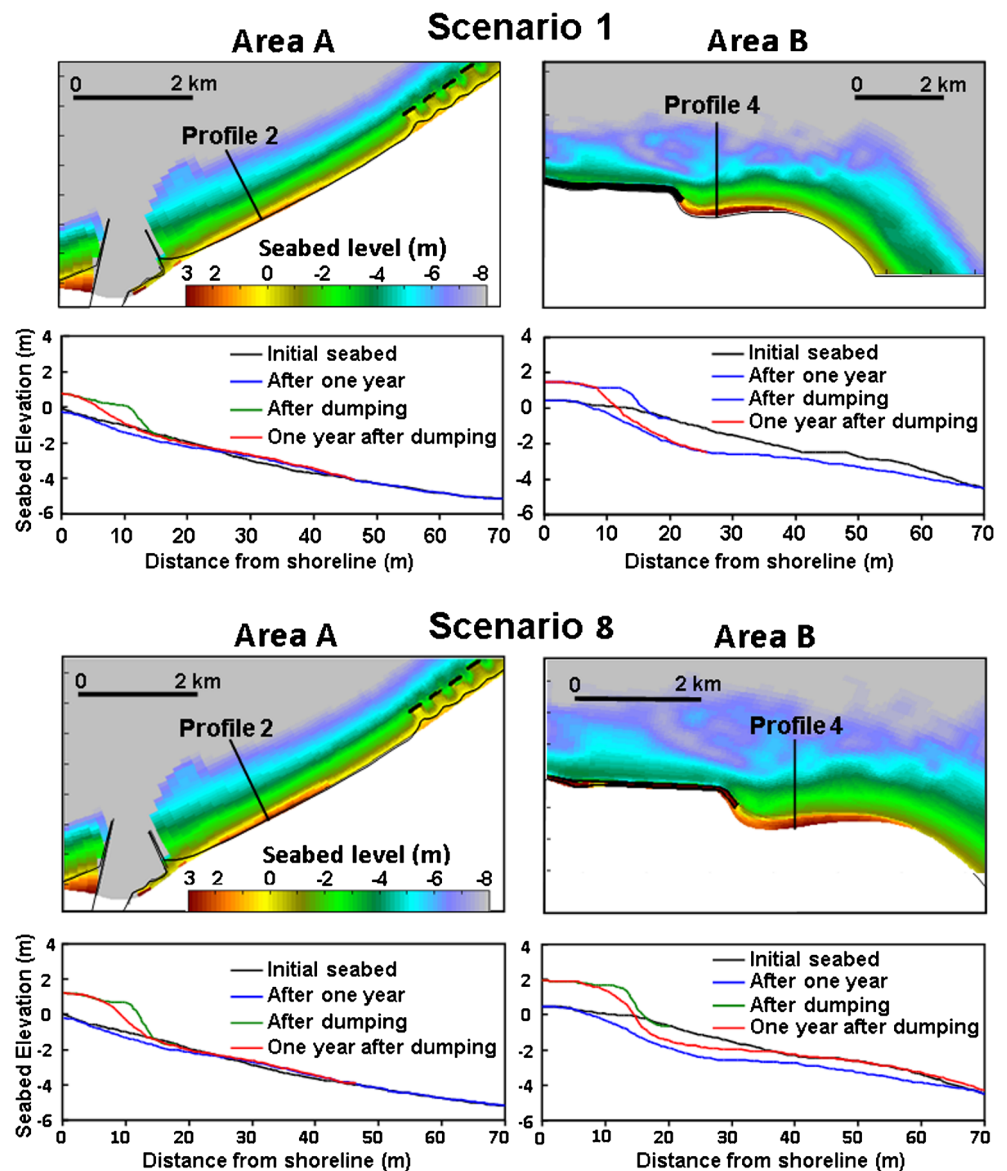
Valuation of costs and benefits

In order to be able to compare shoreline management alternatives, the costs and benefits gained after protection have to be determined to finally choose the most economic and environmentally sound one.

Detemination of costs

One of the key stages in CBA is to measure all the costs (**negative** values) and benefits (**positive** values) in monetary terms. Various cost-related protection works are consulted herein from authorities who are practically involved in the construction of erosion controll structures in the delta region. The SPA and Coastal Research Institute (CoRI) have kindly provided price list of the protection measures proposed in the present study. This list

includes the direct average prices of hard structures (EGP/m length) including materials, services, and maintenance. It also includes cost of trucking borrow sand (EGP/m^3) from the landbase sources to the eroding sites A and B. Table 1 summarizes the average unit price, the total cost of each alternative measure, and their general description.

Valuation of benefits

Benefits are mostly related to the monetary values of land-use/land-cover, a unit backing the coastline of the study areas A and B. Geomorphologically, this land coverage pattern differs in the study areas and includes beach and strandplain in areas A and B, as well as fishing resources in wildlife and aquacultures lagoon areas in area B. The present land-use/land-cover was identified using Google Earth images and eventually validated by

Fig. 7 Layout of alternative hard structures selected for protection of areas *A* and *B*. Depths are in meters
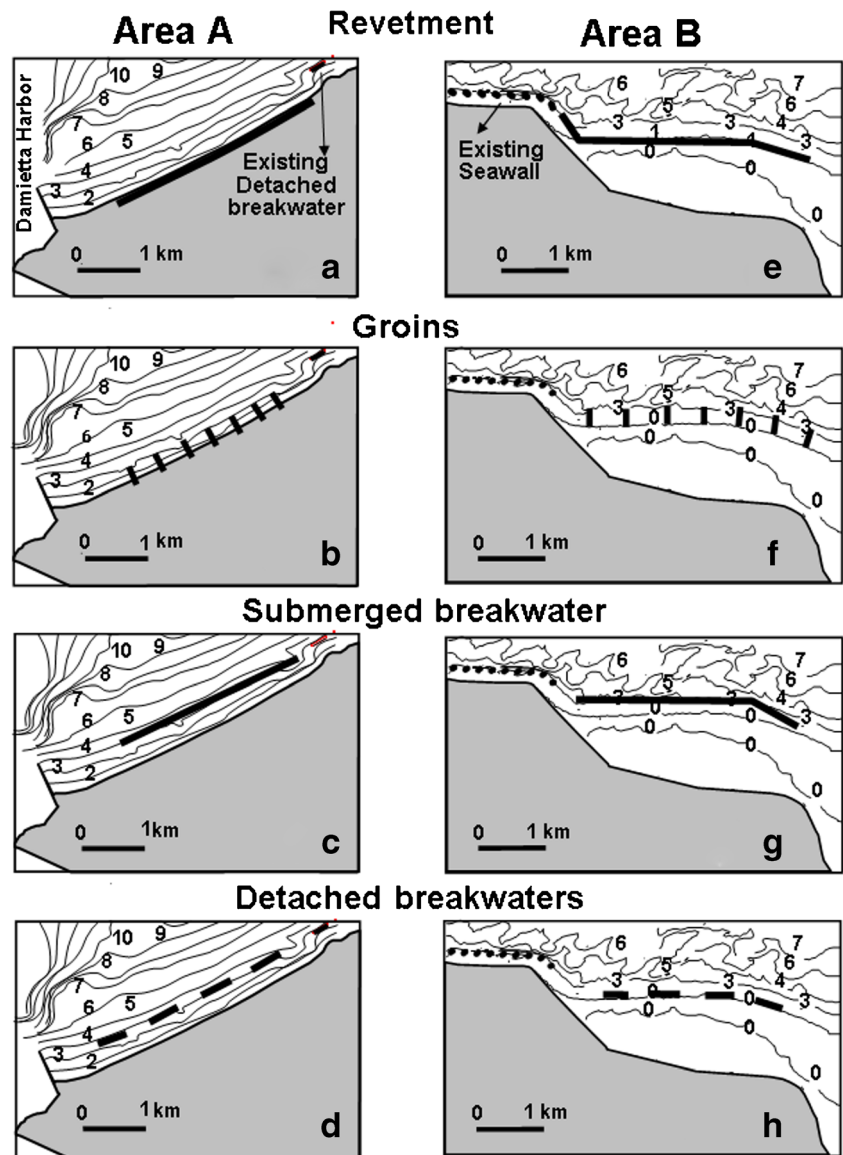
field observations. The identified land coverage pattern is measured herein using the GIS technique. Eventually, their valuations are estimated using the valuation contingent and benefit transfer methods. In contrast, valuation of some other indirect ecological items such as esthetic view, wildlife, biodiversity, and natural habitats cannot be priced because they are not sold in the markets (Georgiou et.al. 1997).

The southern limits of areas A and B, subjected to valuation process, are identified based on the positions of the 1-m contour in area A and the coastal road in area B. The selection of these topographic key features is based on the worst-case sea-level rise scenario (A1F1) of the Intergovernmental Panel on Climate Change (IPCC 2007). According to the this scenario, sea level will likely rise by 0.73 m by 2100, if higher mean surface temperature increased by 4.0 °C.

The width of strandplain differs significantly from one site to another (Fig. 8). Strandplain is defined as a broad belt of sand along a shoreline with a surface exhibiting well-defined parallel or semi-parallel sand ridges. In area A, the strandplain is well developed, whereas it is very narrow in area B. Strandplains typically are created by the effect of wave-induced longshore currents along the deltaic coastlines (McCubbin 1982; Fitzgerald et al. 2007).

The seawall and the strandplain in area B are backed by Manzala lagoon which is occupied by swamps, wildlife, and fish farm covers (Fig. 8). As the strandplain in area A seems not economically uniform in land-use revenue, it has been divided into two parallel zones, the seaside resort beach (50 m wide) and its contiguous backshore up to 1-m contour (Fig. 8).

Table 1 Estimated total cost of the proposed shore protection alternatives for the eroding areas A and B

Alternative		Description	Model	Area A					Area B				
				Structure length (m)	Sediment volume required (m³)	Unit cost Hard (length) (EGP/m)	Unit cost Soft (volume) (EGP/m³)	Total cost (EGP million)	Structure length (m)	Sediment volume required (m³)	Unit cost Hard (length) (EGP/m)	Unit cost Soft (volume) (EGP/m³)	Total cost (EGP million)
Hard Measure	Revetment	Armor stone revetment		3000	–	5000	–	15	3500	–	6000	–	21
	Submerged breakwater	Continuous submerged BW at 4-m water depth		3000	–	35,000	–	105	3500	–	40,000	–	140
	Detached breakwater	Four detached BW at –4 m water depth		1600	–	30,000	–	48	1600	–	36,000	–	57.6
	Groin system	Seven groins up to 3-m water depth		1400	–	15,000	–	21	2300	–	18,000	–	41.4
Soft Measure	Nourishment dredged source	Using dredged material from Damietta Harbor	Model scenario 1	–	300,000	–	20[a]	6.75	–	500,000	–	35[a]	18.75
			Model scenario 8	–	450,000	–		9.75	–	750,000	–		27.5
	Nourishment outer source	Using quality desert sand	Model scenario 1	–	300,000	–	70[a]	21	–	500,000	–	85[a]	42.5
			Model scenario 8	–	450,000	–		31.5	–	750,000	–		63.75
Combined	Nourishment with groin system	Nourishment in the vicinity of stone groin system	Model scenario 1	1400	100,000	15,000	20[a]	23	2300	150,000	18,000	35[a]	46.65
			Model scenario 8	1400	100,000	15,000	70[a]	28	2300	150,000	18,000	85[a]	54.15

BW breakwater

[a] Unit cost of trucking borrow material

Fig. 8 The lower map showing main land-use/land-cover classes in the study areas *A* and *B*, while the *upper panels* further illustrate location of these classes in relation to shoreline
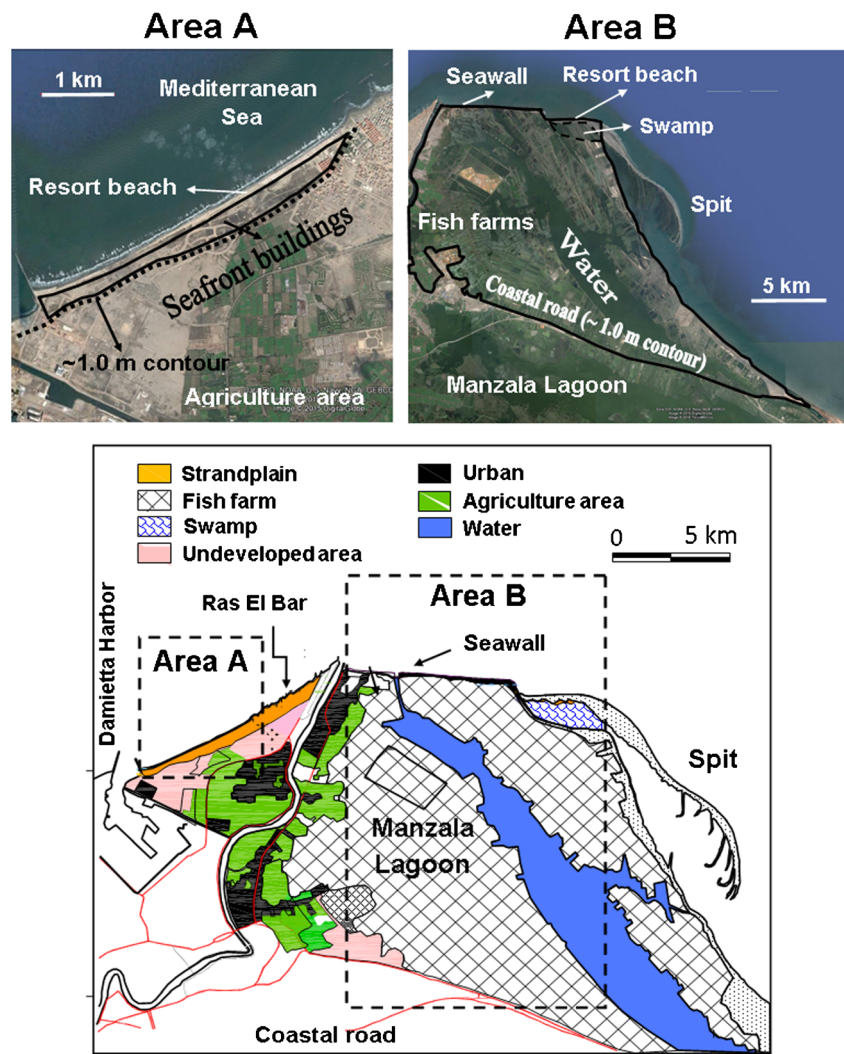
The land-use/land-cover of the two backing areas (A and B) are converted into monetary benefits by application of the contingent valuation method. The contingent valuation is used to estimate the total economic value of the identified land-use/land-cover backing the study areas. This popular method is mainly based on prices obtained from on-site ground survey undertaken by the report team in the study areas. The measured areas of land-use/land-cover, unit price, and the corresponding total benefits are listed in Table 2. The estimated total values have dual use, as "benefits" in case of applying the shore defense alternatives or losses and as costs if the no action is adopted. The cost values also include the expected impacts to the surrounding coastal system that may result from applying the proposed alternative measures and the maintenance of the proposed structure or nourishment to keep the shoreline stable. The maintenance cost is approximately 5 % of the hard structure cost as estimated by the Shore Protection Authority in Egypt.

The strandplain of areas A and B has been valuated using the method of benefit transfer (BT). This method is an economic valuation tool that uses valuation estimates from other

areas and applies them to a similar location (Brouwer 2000). Therefore, the economic value of Ras Bar resort beach located about 4 km east of area A has been utilized for valuing the study beaches A and B applying the method of Hansona et al. (2002). In this method, the annual revenue at Ras El Bar is valuated based on number of visitors and their average amount of money spend per year for a unit beach area, as simply given by:

$$\text{Annual beach revenue } \left(\text{EGP/m}^2\right) \tag{1}$$
$$= (\text{number of visitors} \times \text{person spends EGP per year})$$
$$/\text{total beach area } \left(\text{m}^2\right)$$

Applying this simple relationship at Ras El Bar, where the number of visitors is about 2 million persons, the total money spending per year equal 500 EGP and the total beach area is 0.528 km², yielding a revenue of 1900 EGP/m². The results

Table 2 Economic valuation of land-use/land-cover for areas A and B

Area A

Alternative		Identified landforms or Description	Area of land (km²)			Economic values benefits without HM separation			Economic benefits of HM separation process		Total gross benefits (EGP million)
			Added new beach	Existing beach	Strandplain	per unit		Gross benefits (EGP million)	Per unit	Gross benefits (EGP million)	
						Beach (EGP/m²)	Strandplain (EGP/m²)		Revenue of HM Separation (EGP/m³)		
Hard measure	Revetment	Stabilize the area behind, limiting flooding of the land	–	–	1.05	1900	4500	4716	–	–	4716
	Submerged breakwater	Control erosion and widen beaches	–	0.2	1.05	1900	4500	5090	–	–	5090
	Detached breakwaters	Control erosion and widen beaches	–	0.2	1.05	1900	4500	5090	–	–	5090
	Groin system	Control erosion and widen beaches	–	0.2	1.05	1900	4500	5090	–	–	5090
Soft measure	Nourishment dredged source	New beach formed	0.10	0.2	1.05	1900	4500	5284	7.5	2.25	5286
		Model scenario 1									
		Model scenario 8	0.15	0.2	1.05	1900	4500	5366	7.5	3.4	5369
	Nourishment outer source	New beach formed	0.10	0.2	1.05	1900	4500	5284	–	–	5284
		Using quality desert sand									
		Using quality desert sand	0.15	0.2	1.05	1900	4500	5366	–	–	5366
Combined	Nourishment with groin system	New beach formed	0.07	0.2	1.05	1900	4500	5223	7.5	0.8	5224
		Using groin and nourishment (dredging sand)									
		Using groin and nourishment (desert sand)	0.07	0.2	1.05	1900	4500	5223	–	–	5223

Area B

Alternative	Area of land (km²)					Economic values benefits without HM separation				Economic benefits of HM separation process		Total gross benefits (EGP million)
	Added new beach	Strandplain	Swamp	Fish farm	Lake	per unit			Ross benefits (EGP million)	Per unit	Gross benefits (EGP million)	
						Beach or strandplain (EGP/m²)	Swamp (EGP/m²)	Fish farm (EGP/m²)		Revenue of HM separation (EGP/m³)		
Hard measure	–	0.76	2.3	103	40.6	1000	200	12	2495	–	–	2495
	–	0.76	2.3	103	40.6	1000	200	12	2495	–	–	2495
	–	0.76	2.3	103	40.6	1000	200	12	2495	–	–	2495
	–	0.76	2.3	103	40.6	1000	200	12	2495	–	–	2495
	0.3	0.76	2.3	103	40.6	1000	200	12	2792	7.5	3.75	2796

Table 2 (continued)

Alternative	Area of land (km²)				Lake	Economic values benefits without HM separation				Economic benefits of HM separation process		Total gross benefits (EGP million)
	Added new beach	Strandplain	Swamp	Fish farm		per unit			Ross benefits (EGP million)	Per unit	Gross benefits (EGP million)	
						Beach or strandplain (EGP/m²)	Swamp (EGP/m²)	Fish farm (EGP/m²)		Revenue of HM separation (EGP/m³)		
Area B												
Soft measure	0.25	0.76	2.3	103	40.6	1000	200	12	2745	7.5	5.63	2751
	0.3	0.76	2.3	103	40.6	1000	200	12	2792	–	–	2792
	0.25	0.76	2.3	103	40.6	1000	200	12	2745	–	–	2745
Combined	0.17	0.76	2.3	103	40.6	1000	200	12	2660	7.5	1.13	2661
	0.17	0.76	2.3	103	40.6	1000	200	12	2660	–	–	2560

Volume of sand in scenario (1) 300,000 m³ (area A) and 450,000m³ (area B), while in scenario (8) 500,000m³ (area A) and 750,000 m³ (area B)

HM = heavy mineral

estimated at Ras El Bar are then used as a guide to price the annual revenue of the study beaches A and B (Table 2).

It is worth noting that adding dredged sediments in the littoral system of areas A and B will also maximize the environmental benefits of the nourished beaches, such as esthetic view and beach quality (surf zone wideness) and increasing the "beach revenue" of the new beach. Use of marine dredged sand in nourishment of eroded beached also is advantageous over protective hard structures and borrow inland or desert sand. For example, trucking beach quality sand from inland sources would induce environmental problems pertaining to traffic jam and damage of paved road. In addition to induced negative environmental impacts, using of borrow sand from inland sources is not recommended because of its incurred high total cost.

Similarly, the southern portion of the strandplain backing the seaside beach of Ras El Bar valuated above is priced based on average prices of sea-front buildings, recreation assets, and facilities that accommodate summer visitors, including apartment motels, hotels, restaurants, entertainment, etc. More or less similar to the Eq. 1, valuation of these areas is valuated using this relationship:

$$\text{Annual strandplain revenue}\ (\text{EGP}/\text{m}^2)$$
$$= (\text{average price of beach front-building}) \qquad (2)$$
$$/\text{total surface area}\ (\text{m}^2)$$

Application and solution of Eq. 2 on the study area, would yield an annual strandplain revenue of 4500 EGP/m². Same as above, the results estimated at Ras El Bar are transferred to the study area A and not in B. Unlike area A, area B is under planning and is expected to be reclaimed for industrial and commercial project. Accordingly, the total benefits of the swamp are approximately 2.264 km², as the unit swamp area is monetized by 1000 EGP/m². Results of total benefits relative to costs for the study areas are listed in Table 3.

Valuation of the net present value and benefit-cost ratio

Comparison between the proposed alternatives with varying costs or benefits necessitates calculation of two parameters as follows:

Net present value

The net present value (NPV) is the difference between the present value of cash inflows (total benefits) and the present value of cash outflows (total costs). NPV is used in capital budgeting to analyze the profitability of a projected investment or project. NPV values greater than zero imply that the

proposed project seems to be a good candidate for implementation.

The NPV is given by the following formula:

$$\text{NPV}(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

where R_t is the net cash flow during the period t (total benefits/total costs), N is the total period of time (e.g., hard structures life, $\approx$25 years), and i is the rate of interest.

For the proposed alternatives, the cash inflow for each alternative includes the total costs and the maintenance expenses of hard structures (about 5 % of the structure cost) or additional costs for nourishment to maintain beach stability. The cash outflow, however, is the total benefits (revenues) due to the protection of areas A and B; this flow contains revenues of new and existing beach, strandplain, swamp, fish farm, and lake.

Benefit-cost ratio

The benefit-cost ratio (BCR) is calculated as the total benefits divided by the total costs (total benefits/total costs). If the BCR exceeds 1.0, the project alternative should be accepted.

Results of the total costs and benefits together with the calculated parameters (NPV and B/C ratio) are listed in Table 3.

Extraction of black sand from dredging material

Potential benefits from management of dredged material can be also maximized through extraction of economic heavy minerals. The Nile Delta beaches and nearshore environments have been known as loci of deposition and concentration of heavy minerals which originally was derived from weathering of the Ethiopian high plateau and transportation by Nile River during summer flood seasons to the receiving basin and the southeastern Mediterranean shores (Hassan 1976; Said 1981).

Frihy et al. (2015) indicated that sediments dredged from the Damietta Harbor and some other navigation waterways along the Nile Delta coast are relatively rich in black sand and therefore, can be exploited as a promising source for valuable economic heavy minerals. The average total heavy mineral concentrations in sediments dredged from the Damietta Harbor channel was found to be 2.9 %, with predominant higher concentrations (weight per kilogram) of magnetite (1.298 %), ilmenite (1.266 %), hematite (0.005 %), leucoxene (0.030 %), garnet (0.031 %), zircon (0.133 %), and rutile (0.103 %). Dredged sediments collected from different areas within the same harbor channel have been recently analyzed for heavy mineral determination by the NMA (2016). Results

indicate higher concentrations relative to the study of Frihy et al. (2015), in which the total heavy mineral content is 6.5 % and consists of magnetite (0.38 %), ilmenite (0.57 %), rutile (0.16 %), leucoxene (0.13 %), garnet (0.13 %), zircon (0.21 %), and monazite (0.007 %).

Economically, using harbor and channel maintenance dredged sediments beneficially as a source for valuable economic minerals can significantly contribute to reduction of the cost of periodical dredging operation. Most of the heavy minerals have a very high economic value and are readily required for many industries. Current prices for heavy minerals in US$ are as follows: ilmenite ($110/ton), magnetite ($125/ton), leucoxene ($400/ton), garnet ($200/ton), zircon ($800/ton), rutile ($500/ton), monazite ($20–55/kg), and green silicates.

The study of Frihy et al. (2015) also concluded that separation of heavy mineral concentrates from the slurry of dredged material can be conducted using industrial-scale sets of spiral gravity separators with re-circulating loads. The spiral sets can be mounted onboard marine hopper dredger in situ during deepening the navigation channel or on the floating platform in the sedimentation basin west of the harbor (Fig. 1b). The first choice is practically difficult because it requires a particular hopper dredger equipped with onboard spiral sets. In comparison, the second choice is much appropriate and cost-effective. Gravity spirals are being commonly used worldwide for concentration of low-grade ores and heavy mineral placers (with up to 80 % recovery) from the quartz sand (tailings) in terrestrial and offshore slurry material (Abu Halawa 2005).

Comparison of erosion control alternatives

Results of cost-benefit analysis, summarized in Table 3, are used herein to facilitate comparison among the study alternatives and eventually the final selection of the least cost option. Also considered in this evaluation is the expected potential impact in view of lessons learned from the behavior of shore protection works on the surrounding littoral system of the Nile Delta in Fig. 4. Other criteria for such evaluation include sustainability of the proposed defense alternatives and future development plans in the study area.

Results of the economic analysis of the evaluated alternatives indicate potential positive average annual net economic benefits (NPV) between EGP 2354.7 million and EGP 4861.7 million as well as a B/C ratio of average annual benefits to costs between 17.82 and 783.1, depending on 2015 price (Table 3). Range of these values also depends largely on whatever the alternative could create new beach behind or not. The net present value (NPV) of the proposed alternatives during the hard structure lifetime (25 years; $t = 25$) was calculated for areas A and B (Table 3), revealing an NPV value between EGP 5631.7 million and EGP 46478.7 million.

Table 3 Results of cost/benefit analysis for areas A and B, including estimated costs, benefits, and CBA parameters (NPV and B/C ratio)

Alternative for protecting eroding sites		Description		Area (A)							Area (B)						
				t = 1				t = 25			t = 1				t = 25		
				Total cost C (EGP million)	Total benefit B (EGP million)	Ratio (B/C)	The NPV (EGP million)	Total cost C (EGP million)	Total benefit B (EGP million)	The NPV (EGP million)	Total cost C (EGP million)	Total benefit B (EGP million)	Ratio (B/C)	The NPV (EGP million)	Total cost C (EGP million)	Total benefit B (EGP million)	The NPV (EGP million)
Hard measure	Revetment	Armor stone revetment		15	4716.3	314.4	4264.2	31.8	5663.5	5631.7	21	2494.7	118.8	2473.7	44.5	37,993.7	37,949.2
	Submerged breakwater	Continuous submerged BW at −4 m water depth		105	5089.8	48.5	4521.4	222.7	14,410.4	14,187.7	140	2494.7	17.82	2354.7	297.0	37,993.7	37,696.7
	Detached breakwaters	Four detached BW at −4 m water depth		48	5089.8	106.0	4573.1	101.8	14,410.4	14,308.6	57.6	2494.7	43.31	2437.1	122.2	37,993.7	37,871.5
	Groin system	Seven groins up to −3 m water depth		21	5089.8	242.4	4597.5	44.5	14,410.4	14,365.9	41.4	2494.7	60.26	2453.3	87.8	37,993.7	37,905.9
Soft measure	Nourishment dredged source	Using dredged material from Damietta Harbor	Model scenario 1	6.75	5286.2	783.1	4788.7	32.7	21,925.0	21,892.3	18.75	2795.3	149.1	2776.6	94.4	46,573.1	46,478.7
			Model scenario 8	9.75	5369.8	550.7	4861.7	48.7	24,308.5	24,259.8	27.5	2750.9	100.0	2723.5	141.0	45,307.8	45,166.8
	Nourishment outer source	Using quality desert sand	Area A (300,000 m²), Area B (500,000 m²)	21	5284.0	251.6	4773.7	111.8	21,860.0	21,748.2	42.5	2791.6	65.68	2749.1	226.2	46,465.3	46,239.1
			area A (450,000 m²), area B (750,000 m²)	31.5	5266.4	167.2	4748.2	167.7	24,211.4	24,043.7	63.75	2745.3	43.06	2681.6	339.4	45,146.6	44,807.2
Combined measure	Nourishment with groin system	Nourishment in the vicinity of stone groin system	Using dredged material	23	5223.5	227.1	4717.0	40.7	20,135.6	20,094.9	46.65	2660.8	57.04	2614.1	103.5	42,733.9	42,630.4
			Using quality desert sand	28	5222.8	186.5	4711.8	61.7	20,114.2	20,052.5	54.15	2659.7	49.12	2605.5	143.4	42,701.8	42,558.4

The analysis process was applied starting from 2015 for 1 and 25 years that denotes hard structure lifetime. The non-priced values (e.g., esthetic view, wildlife, biodiversity, habitats, traffic jam, and road damage) are not included in the table

End results indicate that the procedure of beach nourishment is the most appropriate form for protection area A, whereas a combination of groins and sand nourishment is more relevant for area B. In both options, material dredged from the navigation approach of the Damietta Harbor should be utilized as a borrow material in the nourishment operations. Although the dredged sediments are not typically compatible (only 41.8 %), excessive volumes of these sediment can compensate for nourishing the eroding sites according to the results of the mathematical model.

Results of CBA also indicate that the continuation of dumping the dredging material in offshore areas without any beneficial use will result in cumulative loss of EGP 12.4 billion by 2050. This comprises loss of EGP 8.4 billion due to un-exploitation of the dredging material for economic heavy minerals and additional EGP 4.0 billion due to cost of dredging and dumping of potential nourishment sand in offshore areas.

Based on all of aforementioned results, the present study strongly recommends exploitation of the dredging material as source of nourishment sand for combating ongoing erosion in areas A and B. Use of borrow sand from inland sources should be avoided because of its negative environmental impacts and incurred high total cost. From the relationship between erosion control alternatives and environmental and economic criteria (Table 4), it is very clear that alternatives 5 and 6 are very viable for protection and erosion control of areas A and B, respectively.

Conclusions and recommendations

Results of compatibility analysis indicate that sediment dredged from the Damietta Harbor in the northwestern Nile Delta is technically feasible for beach nourishment of both eroding areas A and B and for separation of economic heavy minerals. Nourishment using other desert sand sources would be very costly, not environmentally sound, with regard to roadways damage and traffic jam.

The present study suggests a nourishment scheme by means of subaerial placement of borrow material directly onto the beach according to hypothetical scenarios 1 and 8 resulted in application of mathematical modeling. In scenario 1, an amount of 300,000 and 500,000 m^3 have to be dumped onto the eroding beaches A and B, while in scenario 8, this amount is increased to 450 and 750 m^3 in areas A and B, respectively. Although the dredged sediments are not typically compatible (only 41.8 %), excessive volumes of these sediment can compensate for nourishing the eroding sites.

An economic feasibility assessment of erosion control alternatives has been also undertaken to compare between alternatives with varying costs and benefits for protecting two eroding coastlines at the Nile Delta. These alternatives include the following: (1) shoreline revetment (riprap), (2) groin system, (3) submerged breakwater, (4) emerged detached breakwaters, (5) nourishment (sub-aerial placement onto the beach) using dredged or outer source, and (6) nourishment with groin system.

Among the alternative protection measures selected, the option of beach nourishment was found to be the most appropriate form for protection area A and a combination of groins and sand nourishment for area B, both are cost-effective and environmentally sound measures. In both options, material dredged from the navigation approach of the Damietta Harbor should be utilized as a borrow material in the nourishment operations and exploited for nourishment sand and economic heavy minerals. Dredged material from the Damietta Harbor is relatively rich in heavy minerals with a grade of 2.9 −6.5 % by weight. This proportion could yield total revenue of $14.33/$m^3$ if extracted from dredging material for local industrial uses and applications. The shore protection that relies on hard stabilization structures should be avoided or minimized wherever possible, if dredged material is available.

In any case, governmental institutions in Egypt such as SPA and Damietta Port Authority should seriously take

Table 4 Comparison of erosion control alternatives versus evaluation criteria

Alternatives	Does it meets purpose and need	Technically feasible	Economically feasible	Environmentally acceptable
1. Shoreline revetment (riprap)	No	Yes	Yes	No
2. continuous submerged BW	Maybe	Yes	Maybe	No
3. Emerged detached BWs	No	Maybe	No	No
4. Groin system	No	Yes	Yes	No
5. Nourishment	Yes	Yes	Yes	Yes
6. Nourishment with groin system	Maybe	Yes	Yes	Maybe

Beach nourishment is appropriate for area A, while the combination of groins with sand nourishment is relevant for area B

serious actions toward exploiting the dredging material for environmental and economic uses instead of their dumping without any recycling or exploitation. Therefore, we urge governmental authorities and legislative bodies in Egypt for issuing appropriate legislations for banning of dumping of dredging marine material without recycling or beneficial use.

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