

Environmental impacts of Baltim and Ras El Bar shore-parallel breakwater systems on the Nile delta littoral zone, Egypt

O.E. Frihy · M.M. El Banna · A.I. El Kolfat

Abstract This study evaluates the impacts resulting from the construction of two large-scale detached breakwater systems on the Nile delta coast of Egypt at Baltim and Ras El Bar beaches (~18.3 km shoreline length). The two protective systems were installed in a water depth of between 3 and 4 m and consist of 17 units in total (each ~250 m long). A comprehensive monitoring program spanning the years 1990 to 2002 was implemented and included beach-nearshore profiles, grain size distribution of seabed sand and information related to the background coastal processes. Evaluation of these systems concentrates on the physical impacts on coastal morphodynamics, mitigation and their design implications. The beach and nearshore sedimentation (erosion/accretion patterns) and grain texture of seabed sediment in the study areas have been substantially disrupted due to the interruption of longshore transport by the shore-parallel detached breakwaters. Rate of shoreline and seabed changes as well as alongshore sediment volume have been substantially affected, resulting in accretion in the breakwater landward sides (tombolo or salient) followed by downdrift erosion. The preconstruction beach erosion at Baltim (−5 m/year) and at Ras El Bar (−6 m/year) has been replaced, respectively, by the formation of sand tombolo (35 m/year) and salient (9 m/year). On the other hand, beach erosion has been substantially increased in the downdrift sides of these protective systems, being −20 m/year at Baltim and −9 m/year at Ras El Bar. Further seaward, the two protective systems at Baltim and Ras El Bar have accumulated seabed sand at maximum rates of 30 and 20 cm/year

and associated with downdrift erosion of −45 and −20 cm/year, respectively. Strong gyres and eddies formed in the breakwater gabs have drastically affected swimmers and subsequently caused a significant number of drownings each summer, averaging 35 and 67 victims/year at Baltim and Ras El Bar beaches, respectively. This study provides baseline information needed to help implement mitigation measures for these breakwater systems.

Keywords Mediterranean Sea · Egypt · Nile delta Beach morphodynamics · Detached breakwaters Impacts · Impact mitigation

Introduction

Similar to other deltas worldwide, the Nile delta is presently subjected to significant shoreline changes due to a combination of natural and anthropogenic factors, including the reduction in the Nile discharge and sediment load to the Nile promontory mouths due to the construction of water control structures along the Nile, coastal processes and delta subsidence (Fig. 1) (UNESCO/UNDP 1978; Stanley and Warne 1998). In addition, changes to the local beaches have occurred from interfering of coastal protective structures with the natural net longshore sediment transport system, causing a sand deficit on the downdrift side of these structures. Previous discussions of beach erosion along the Nile delta are found in Orlova and Zenkovitch (1974), Inman and others (1976), Manohar (1976, 1981), Queleennec and Manohar (1977), UNESCO/UNDP (1978), Toma and Salama (1980), Manohar (1981), Klemas and Abdel Kader (1982), Fanos and others (1991) and Frihy and others (1998), among others. Previous studies on the effect of earlier protective structures on the Nile delta coast have been limited to shoreline changes (Fanos and others 1995; Frihy and others 2003). The dramatic erosion along some stretches in the delta has been mitigated by the construction of a series of coastal engineering structures which started extensively during the last decade, including jetties, groins, seawalls and detached breakwaters. Among these structures, two major

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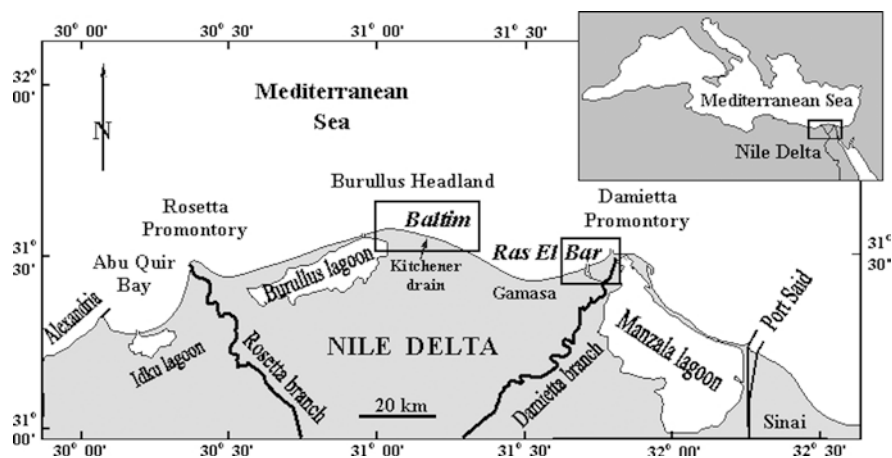


Fig. 1
Map of the Nile delta coast showing location of study areas at Baltim and Ras El Bar resort beaches

detached breakwater systems have been constructed to combat beach erosion along the Nile delta and span ~10 km long in total. These protective systems are the subject of this study and generally they are characterized by diverse environmental conditions (shoreline orientation versus incoming waves) and design dimensions which might be reflected in the nature and the magnitude of the induced impacts.

The study area, 18.3 km long, is located on a very active coastline consisting of a sandy beach. The beaches of these areas attract thousands of people from the adjacent delta region during the summer. The first system, Baltim resort, is located nearly in midway between Rosetta and Damietta promontories. It consists of nine emerged detached breakwaters constructed in the active surf zone at a water depth of between 3 and 4 m (Fig. 2A). These breakwaters were constructed in stages between 1993 and 2002 and front a shoreline of about 6.5 km long. Each individual breakwater extends between 250 and 350 m parallel to the beach and at a distance of 220 m from the shore, and the breakwaters are spaced 320 to 400 m apart (El Kolfat 1999). Another five breakwaters are expected to be built eastward up to the Kitchener Drain.

Further to the east, a second system of eight detached breakwaters, spanning ~3.5 km long, were installed between 1991 and 2002 to combat beach erosion at Ras El Bar resort on the western flank of the Damietta promontory (Fig. 2B). They were placed in approximately 4 m water depth at about 400 m from the shoreline with a 200-m gab width and 200 m length (El Kolfat 1999; Frihy and others 2003). Similar to the Baltim breakwaters, they are armored by 4- to 7-ton dolos units with a crest level of 2.5 m above mean sea level. The breakwater systems of Baltim were constructed from a land-based access and not from the sea. At each breakwater, a short groin was temporarily built to allow an access way for trucks carrying dolos units to the breakwater site (Fig. 2A). Ras El Bar breakwaters were built from the sea using a floating tag.

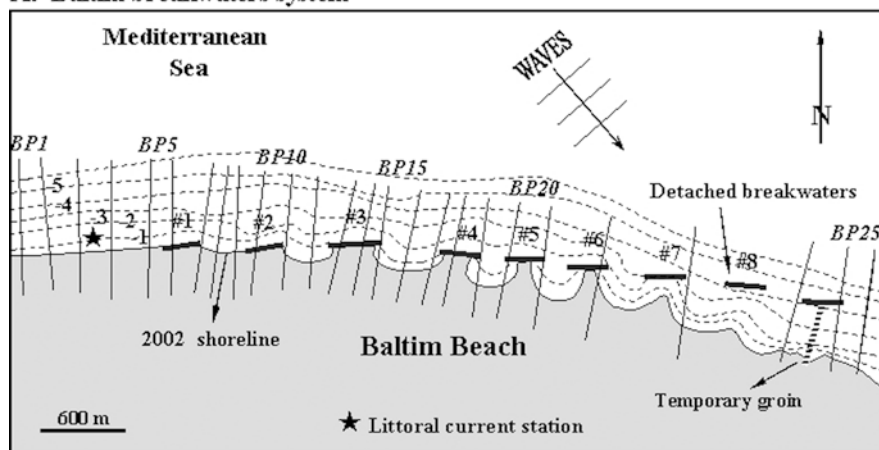
The main objective of this paper is to assess coastal impacts induced from constructing the two breakwater systems at Baltim and Ras El Bar beaches. This includes the effects of the breakwaters on nearshore morphodynamics, shoreline changes, nearshore sedimentation patterns, texture of sediments and swimming activities. Coastal pro-

cesses are incorporated in order to understand the hydrodynamic forces prevailing that could assist in the formulation of overcoming negative impacts at the two sites. This study differs from previous investigations in that we concentrate herein on the two recently built detached breakwater systems in relation to their physical and human impacts versus coastal processes and their design implications. Proper measures are proposed to mitigate the evaluated impacts.

Detached breakwater design parameters and beach changes

Detached breakwaters have been widely used as effective measures to combat beach erosion particularly along tideless coasts such as the Mediterranean. Along sandy coasts, the construction of detached breakwaters mostly affects the shoreline by creating either a salient or tombolo in its shadow area. However, in both cases erosion will take place at the downdrift side. A salient is defined as the growth of sediments from the shoreline as a result of their deposition and accumulation in the lee of the structure, while a tombolo is formed when the growth of sediments continues until they are connected to the structure (Fig. 3). The formation and development of salient or tombolo is a function of diverse mechanisms related to offshore breakwater design, including breakwater crest height (H), effect of the offshore distance of the breakwater (X), the length (B) and gab (G) of the breakwater (Wiggel 1964; Rosen and Vajda 1982; Herbich 1991; Dean and others 1997). According to Rosen and Vajda (1982), the ratio of X/B is the main parameter for controlling the geometry of the beach configuration in the sheltered area, resulting in the formation of either a tombolo or salient. Herbich (1991) concluded that the formation of a tombolo occurs if $X/B < 1$ (0.6 to 1.0), salient is formed when $X/B > 1$ (1.0 to 2.0), whereas detached breakwaters are considered ineffective for $X/B > 2.0$ (Fig. 3). In addition to the role of the offshore distance of the breakwater, Dean and others (1997) include breakwater crest height as an effective parameter in offshore breakwater design. In order to minimize formation of tombolo,

A. Baltim breakwaters system



B. Ras El Bar breakwaters system

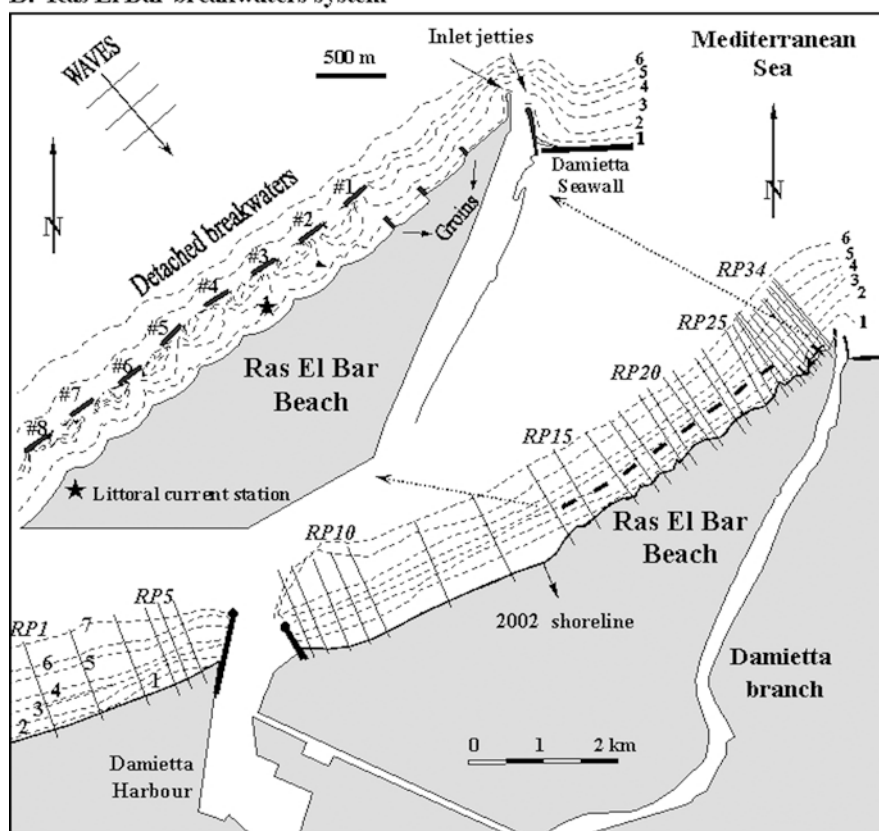


Fig. 2

The detached breakwater systems and examined beach profiles along Baltim beach (A) and Ras El Bar sector (B). Construction of these breakwaters follows their sequential numbers from west to east at Baltim (#1 to 9) and from east to west at Ras El Bar (#1 to 8). Locations of longshore current stations are also denoted. Depth contours in meters

the detached breakwaters should be constructed to a design that will allow waves to partially dissipate on the breakwater while at the same time allowing some wave energy to pass through to prevent the formation of the tombolo. This can be achieved by proposing reasonable submerging of the top of the breakwaters. With respect to alongshore spacing between breakwaters, it has been established that narrow gab (G) leads to much more accumulation of sand volume behind breakwaters than wider gab (Kraft and Herbich 1989). Accordingly, the formation of tombolos occurs if $G/B < 1$, while salient is formed when $G/B > 1$ (Fig. 3). The mechanisms described above are generally used to interpret beach changes behind the breakwater systems evaluated in this study. Re-

sponse of sandy beaches to detached breakwaters have been discussed worldwide by, among others, Toyoshima (1972), Noble (1978), Nir (1982), Walker and others (1982), Harris and Herbich (1986), Pope and Dean (1986), Suh and Dalrymple (1986), Hanson and Kraus (1990), Herbich (1991), Leont'yev (1999), Ming and Chiew (2000) and Zyserman and Johnson (2002).

Materials and methods

Annual profiles surveyed between 1990 and 2002 spanning the two study areas were analyzed in this study to

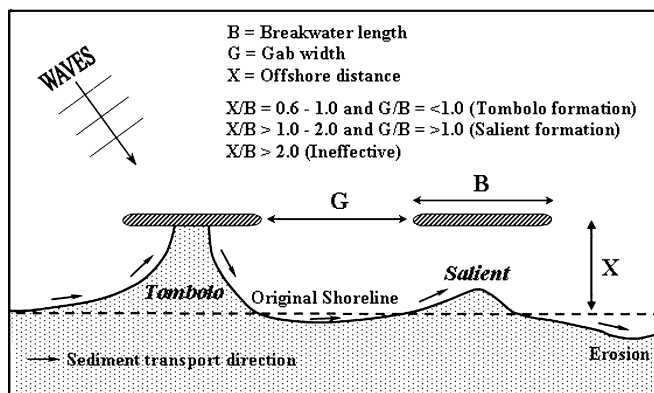


Fig. 3

Schematic diagram of detached breakwater parameters characterizing formation of accretionary beach features. Dimensionless ratios X/B and G/B are respectively defined by Herbich (1991) and Kraft and Herbich 1989

determine rate of seabed changes, sediment volume and grain size distribution of seabed samples in relation to the coastal processes. Twenty six and 34 profiles were surveyed to cover the Baltim (6.5 km long) and Ras El Bar (11.8 km long) coastal sectors, respectively (Fig. 2). The profile lines are perpendicular to the coastline, and extend to about 6 m water depth or to about 1.2 km seaward from the fixed baseline. Distance between profiles ranges from 0.1 to 1.2 km, with the closer spacing being in areas of rapid shoreline change. In the survey processes, the beach leveling and water soundings are adjusted to the mean sea level (MSL) datum using local fixed benchmarks of known elevation. Seaward of each profile, station soundings are taken at 100-m intervals along the profile line. Field surveys were carried out every year using a rubber boat during calm conditions in September and October.

The measured vertical distance of the water depth (H) between the seabed and the sea surface at MSL provides a reliable means of monitoring bottom changes over the time frame of profile collection periods. Bottom changes were determined every 100 m along each of the profile lines, measuring from the shoreline. The data from each profile are arranged in a 2-D graph, where H is the water depth relative to mean sea level and X is the date of survey. This permits the determination of the mean annual rate of bottom change (centimeters per year) employing least squares techniques, the slope of the H versus X plot. In the same manner, the measured shoreline displacement from the fixed baseline (Y) is used to monitor the shoreline changes over the time of profile collection. The data from each profile are arranged in a 2-D graph, where Y is the shoreline position relative to the fixed baseline, and X is the date of survey. This permits the determination of the mean annual rate of shoreline displacement (meters per year) employing a least squares technique.

Using a grab sampler, samples of bottom sediment were selected associated with the profile survey along the examined sites. Selected samples were recovered at every 100 to 200 m along each of the profile lines, yielding a total of 50 and 126 samples for Baltim and Ras El Bar sectors,

respectively. Grain size analyses were undertaken using standard sieving and pipette techniques, and size distribution data were obtained for each sample. Mean grain size was calculated from the sieving distributions using the formulae of Folk and Ward (1957).

As the Nile delta is a typical wave-dominated or perhaps more accurately termed wave- and current-dominated coast, daily longshore current speed and direction were measured at two main stations at Burullus and Ras El Bar beaches (Fig. 2). Longshore current measurements were obtained inside the surf zone, in water depths ranging from 1.2 to 1.5 m, by tracking the movement of a float (buoy), and measuring the time it takes to travel a distance of 20 m in the longshore direction. Measurements of current speed and direction were taken two times per day, once in the morning and once in the afternoon. Current is also measured occasionally in the gabs between the detached breakwaters using CM-2 direct current meter. Wave data measured at Abu Quir bay and at Damietta harbour have been taken from Frihy and others (2003).

Results and discussion

Impact assessment and mitigation

Each of the examined coastal sectors at Baltim and Ras El Bar is evaluated separately to determine the effect of their detached breakwaters on changing beach platform, sediment volume, seabed deformation, mean grain size of seabed sediment and human hazards. Possible mitigations are also incorporated to avoid or decrease the resulting impacts.

Baltim detached breakwaters

Changes in shoreline position prior to building the detached breakwaters of Baltim in 1990 and after construction in 2002 indicate that accretion in the form of tombolos has occurred in the leeward side of the first-built structures (Fig. 4A). This beach accretion is followed to the east by downdrift erosion between breakwaters #8 and 9. This pattern coincides with the alongshore rate of shoreline changes where a maximum rate of accretion of 35 m/year is documented behind the first-built breakwater following its construction (Fig. 4B). This accretion has filled the shadow area between the coastline and the breakwaters. As expected, local erosion is observed farther east of these breakwaters, approximately -20 m/year, backing breakwaters #8 and 9. This erosion is higher than that which occurred before construction of the breakwaters all along Baltim beach, which originally was -5 m/year (Frihy and others 2003). This local erosion has resulted from interruption of the prevailing eastward sediment transport by the tombolo formation and consequently increasing sand deficiency of down-coast beaches. The temporary groins built as an access way in order to construct these breakwaters might accelerate the downdrift erosion in this region (Fig. 2A).

Over the 12-year monitoring period during the full installation of breakwaters, the measured erosion in the lee

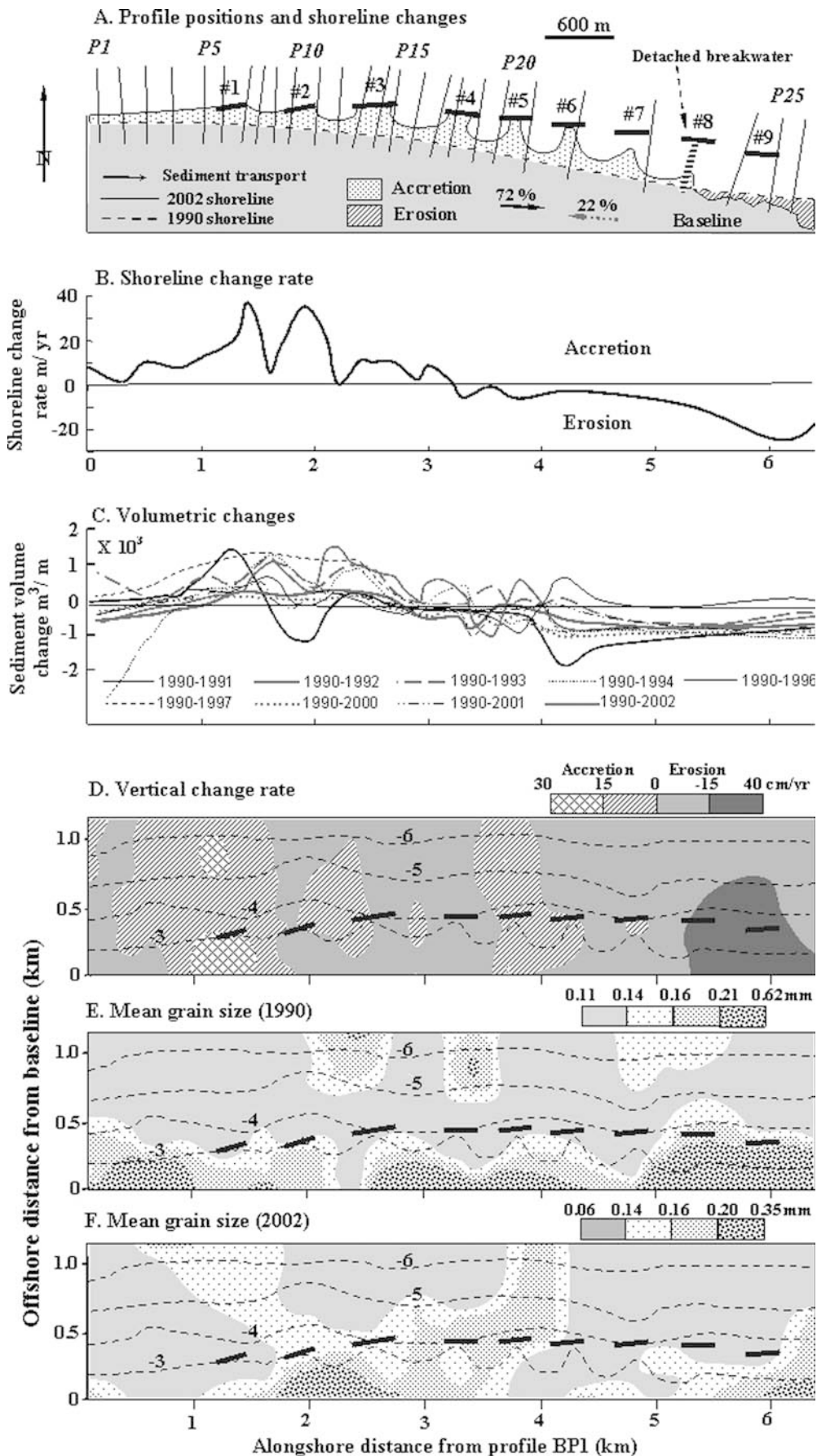


Fig. 4

A Shoreline of Baltim beach showing profile positions and the detached breakwater system. B Alongshore rate of shoreline changes between 1990 and 2002. C Alongshore sediment volume. D Spatial distribution of rate of seabed changes. E and F Spatial distributions of mean grain size in 1990 and 2002

of the breakwaters was about six times the background erosion. The downdrift erosion east of the breakwaters eventually resulted from the tombolo formed behind the first breakwater and subsequently the second one. The formation of the tombolo acts as a complete littoral barrier that traps all the littoral drift and thus interrupts the eastward longshore sediment transport. This erosion has adversely affected summer houses along the eastern part of the beach at breakwaters #8 and 9.

Net volumetric changes of sediments per linear meter (cubic meters per meter) were determined from beach profile data along the entire length of the Baltim study area during the period from 1990 to 2002 (Fig. 4C). Calculations are performed between successive surveys for the 26 profiles along the 6.5 km of monitored shoreline. These results are based on the volumetric changes occurring for each of the profile lines between monitoring surveys. The alongshore volumetric changes indicate that maximum net sediment accretion of 240 m³/m occurs in the vicinity of breakwaters #1 to 3. On the other hand, losses of sediments, with a maximum of -803 m³/m, are indicated down-coast of these structures, between breakwaters #6 and 9.

Rate of seafloor changes relative to MSL for the beach-nearshore profile survey calculated between 1990 and 2002 across the study area is shown in Fig. 4D. The computer-generated spatial interpolation of vertical change values reveals areas of erosion and accretion in the vicinity of the detached breakwater system. Nearshore areas adjacent to the earlier constructed breakwaters #1 to 5 show a tendency to seabed accretion down to 6 m water depth (0 to 30 cm/year) (Fig. 4D). Conversely, at the same depth zone, erosion exists down-coast east of breakwaters #6 to 9 (0.0 to -45 cm/year).

Logically, there is a closely geographic correspondence between changes in shoreline positions, sediment volume and the annual rate of seabed changes (Fig. 4A-D). The identified spatial distributions of erosion and accretion patterns reflect the longshore and offshore currents prevailing throughout the study area. During the entire period, measured longshore current showed that the predominant longshore current direction is to the east (average 72%) with a maximum current speed of 83 cm/s (average 44 cm/s) (Fig. 4A). Current reversal to the west is also measured (average 22%) with a maximum speed of 89 cm/s (average 48 cm/s). The remaining proportion (6%) records calm sea condition. According to Frihy and others (2003), the predominant wave approaches from NNW, NW, WNW, W and WWS are responsible for generating the eastward-flowing longshore currents along the entire Burullus coastline. The opposing westerly longshore current is induced from waves occasionally approaching from NNW, N, NNE and NE sectors. This directional distribution of waves is reflected in the net longshore transport rate which seems to be unidirectional all year long, being a maximum of 300×10³ m³/year (Frihy and others 2003).

The spatial distribution of mean grain size of sediment samples across the nearshore zone of the study area, derived from the surveys of 1990 (before breakwater construction) and 2002 (after breakwater construction),

reveals a distinctive pattern (Fig. 4E and F). In 1990, the mean grain size of bottom sediment tends to systematically decrease seaward. Markedly coarse-grained sand (Mz=0.23 to 0.31 mm) astride the shoreline down to 2 m water depth. This coarse-grained sand is followed seaward by parallel belts of finer sediments. In 2002, the sand tombolo formed in the leeside of the detached breakwaters disturbed the grain size distribution pattern prior to construction of the breakwaters in 1990. The coarse-grained belt close to the shoreline (Mz=0.23 to 0.31 mm) disappeared except near the area of the accreted sand formation, beyond breakwaters #2 and 3 (Fig. 4E). A small patch of this coarse-grained sand also exists in the downdrift area at breakwater #9.

Ras El Bar detached breakwaters

The alongshore change in shoreline positions between 1990 and 2002 indicates two main areas of accretion separated by an erosional zone (Fig. 5A). The alongshore rate of shoreline accretion in Fig. 5B indicates that areas of accretion exist beyond the detached breakwaters at Ras El Bar (maximum of 9 m/year) and on the updrift side of Damietta harbour (maximum of 15 m/year). Midway between them, maximum beaks of erosion, being -9 and -13 m/year respectively, exist between the eastern breakwater of Damietta harbour and the detached breakwater #8. Erosion of smaller rate (maximum of -1.3 m/year) is also documented at the eastern breakwater #1 close to the Damietta branch inlet between profiles RP27 and RP34 (Fig. 5A and B).

Figure 5C shows the distribution of sediment volumes (cubic meters per meter) in up to 6 m water depth (maximum of ~1.2 km offshore distance) along the 12 km of the monitored shoreline. As in Baltim, calculations are performed for each of the profile lines between successive surveys. The alongshore net of change is erosional, with a maximum of -540 m³/m in the nearshore area between Damietta harbour and the detached breakwater #8 (Fig. 5C). On the opposite sides of this area, this erosion is reversed to accretion to the west at the updrift side of Damietta harbour (maximum of 1,200 m³/m) and in the shadow area of the breakwater system (maximum of 605 m³/m).

Similar to Baltim beach, the alongshore distribution of annual rates of seafloor changes across the littoral zone is generally consistent with the shoreline change rate and volumetric change of sediment volume (Fig. 5B, C and D). Maximum erosion rates of between -10 and -20 cm/year occur in two main areas. The first area lies between east of Damietta harbour and the detached breakwater #8, whereas the second one is located further east along the downdrift coast of the breakwater system in the vicinity of breakwater #1. The erosion is turned to seabed accretion (0-20 cm/year) west of Damietta harbour and behind the breakwater system (Fig. 5D). The identified erosion/accretion pattern in this sector is due to the longshore blockage of littoral current by the two jetties of Damietta harbour and the offshore detached breakwater system (Fig. 5A).

Measured longshore current showed that the predominant longshore current direction is to the southwest (average

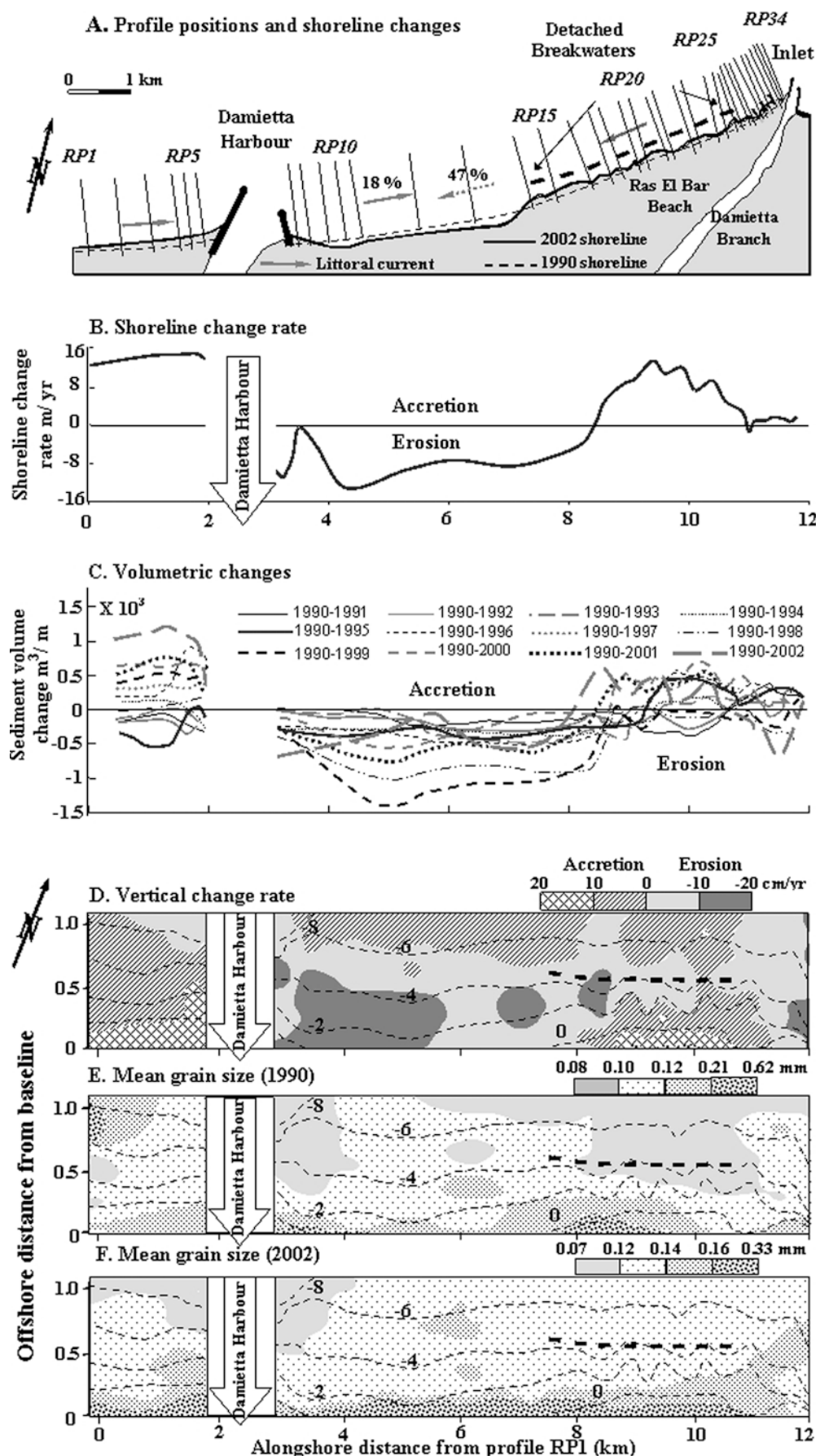


Fig. 5

A Shoreline of Ras El Bar sector showing profile positions and the detached breakwater system. B Alongshore rate of shoreline changes between 1990 and 2002. C Alongshore sediment volume. D Spatial distribution of rate of seabed changes. E and F Spatial distributions of mean grain size in 1990 and 2002

47%), with a maximum current speed of 44 cm/s (average 30 cm/s) (Fig. 5A). Percentage of occurrence of current reversal to the northeast is recorded (average 18%), with a maximum speed of 42 cm/s (average 30 cm/s). Ras El Bar coast is partially sheltered from NE waves and directly exposed to waves coming from the N and NW quadrant. The NW quadrant incorporating the N, NNW, NW and WNW waves is responsible for the generation of longshore current toward the SW and NE, respectively (Frihy and others 2003). This reversal of wave regime has produced three downdrift areas located just east of the eastern breakwater of Damietta harbour, and at the opposite terminals of the detached breakwaters #8 and 1. Maximum longshore transport rate is calculated in the eroding area between Damietta harbour and breakwater #8 ($449 \times 10^3 \text{ m}^3/\text{year}$) and decreases in accreting areas behind the breakwaters ($\sim 100 \times 10^3 \text{ m}^3/\text{year}$ maximum) (Frihy and others 2003).

Generally, the spatial distribution of mean grain size is more or less similar to that in the Baltim area, which is characterized by a seaward fining trend (Fig. 5E and F). Coarser sediments ($Mz=0.12$ to 0.62 mm) occur predominantly near the coast and become finer offshore ($Mz=0.08$ to 0.12 mm). The coarse-grained sediment near the coast ($Mz=0.14$ to 0.33 mm) predominates after breakwater construction in 2002 compared with that before construction in 1990. The offshore mean grain size trend down to 4 m depth in 2002 has been changed slightly by the construction of the detached breakwater system (Fig. 5E and F). The local sand zone ($Mz=0.08$ to 0.10 mm) was replaced by a relatively coarse sediment ($Mz=0.1$ to 0.14 mm).

The grain sorting processes of beach sediments of the Nile delta are documented in previous studies on relationships between mean grain size and rates of erosion and accretionary patterns (Frihy and Komar 1991, 1993). They have established that eroded areas are associated with finer-grained beach sands, and the greater the rate of erosion the finer the beach sand, while the areas of shoreline accretion are characterized by coarser sands. These relationships result from the processes of selective grain sorting as the waves and longshore currents first erode the sand from the beach face, transport the sand alongshore, and finally deposit it in areas of accretion (Frihy and Komar 1991). This concept is applicable in the grain size distribution of the nearshore area of the Ras El Bar stretch and to some extent in the Baltim zone where sediments of downdrift erosional areas are finer than those of accreted ones.

In addition to the physical impacts on the beach morphology discussed above, the formed sand tombolos at Baltim beach have obstructed swimming activities during summer holidays. If current practices continue, the progressive accumulation of tombolo sand could be transformed to a seawall instead of forming a secure swimming area behind the detached breakwaters. Currents and eddies generated in the gab areas between breakwaters have badly affected swimmers. The sharp curvatures of bottom contours in the gabs have enforced littoral currents to generate serious eddies of maximum speed of 51 cm/s (Fig. 2A). The number of drowning accidents is substan-

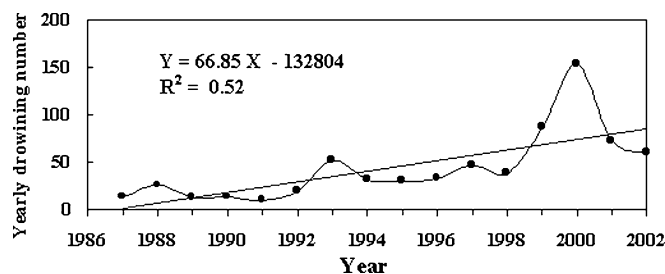


Fig. 6

Yearly rate of drownings (average 67 victims/year) in the bathing water zones recorded at Ras El Bar resort beach. (Data provided by the local hospital)

tially increased each summer, with about 35 victims/year on average (personal communication with the local Baltim hospital). The proposed temporary remedy involves removal of part of the formed tombolo in the shadow of breakwaters #1 and 6 to allow sand to bypass normally alongshore, thereby nourishing the unprotected areas in the downdrift side of the structures further to the east. The bypassing of sand resulting from removal of this tombolo would also create a safe area for swimming. Similarly, currents and gyres inside the shadow area of Ras El Bar breakwaters including the gap areas have seriously affected swimmers (Fig. 2B). Currents measured (up to 55 cm/s) drag swimmers downward to the bottom, causing drowning. As reported by the local hospital, the number of drowning accidents has noticeably increased since the construction of the breakwater system, averaging 67 victims/year (Fig. 6). As a temporary mitigation, nylon net is proposed to be placed vertically at approximately 2 m contour depth in the gab areas separating the safe and unsafe zones. This can be achieved in areas with no tombolo at Baltim, behind breakwaters #8 and 9, and along the entire coastline of Ras El Bar beach.

In view of design dimension, minimizing formation of tombolo at Baltim can be achieved by allowing waves to partially dissipate on the breakwater while at the same time allowing some wave energy to pass through to prevent the formation of the tombolo (Dean and others 1997). This can be achieved by proposing reasonable submerging of the top of the breakwaters. This will guarantee sand to be moved continuously along the shore. In addition, the dimensionless ratio X/B has to be >1 (1.0 to 2) to form salient instead of tombolo, as proposed by Wiggel (1964) and Rosen and Vajda (1982) (Fig. 3). In the Baltim case study, the X/B ratio is substantially smaller, ranging between 0.6 and 0.8, whereas the ratio G/B is valid to form salient, being 1.2 in average.

Of particular importance is the magnitude of erosion at Ras El Bar beach (as determined from shoreline and seabed changes and sediment volume), and its contiguous accretion features behind the breakwaters are relatively small compared with those in the Baltim area (Fig. 4B, C, D and Fig. 5B, C, D). This could be explained based on the breakwater dimensions such as breakwater length (B), their offshore distance from the shoreline (X) and the breakwater gab (G) which control

tombolo and salient formations. Although the breakwaters of Ras El Bar are emerged, ~2.5 m above MSL, the ratio X/B is >1.0 (being ~2.0), whereas it is <1.0 (being ~0.6 to 0.8) along Baltim beach.

Summary and conclusions

The present study was undertaken in order to determine whether the implemented detached breakwater systems that were built along Baltim and Ras El Bar resort beaches (18.3 km long) have affected the sedimentation patterns of the littoral cell and the swimmers using adjacent bathing water. Such determination is based on analyses of beach-nearshore profiles, current measurements and seabed sediment samples.

Herein, temporal and spatial changes in shoreline, seabed and alongshore volumetric changes incorporating texture of surficial sediment have been modified as a result of construction of the breakwaters in the study areas. Generally, the patterns and magnitudes of erosion/accretion indicate that the breakwaters have had a deleterious effect on the stability of the beach and nearshore profiles. As expected, results of profile analysis documented accretion behind the breakwaters associated with erosion in their downdrift sides. The formation of this erosion is due to the interruption of the longshore transport by the shore-parallel detached breakwaters and the two breakwaters at Damietta harbour. Comparison of the long-term background erosion rates with those determined in the last 12-year monitoring period suggests that the breakwaters caused an additional erosion rate above the background erosion by approximately 300 and 50% at Baltim and Ras El Bar beaches, respectively. In general terms, the problem of erosion in study areas has been shifted to downdrift areas but with higher rates.

Shoreline accretion due to tombolo formation at Baltim (35m/year) is followed by down drift erosion to the east (−20 m/year). These accretion and erosional rates are relatively less at Ras El Bar, being 13 and −9 m/year, respectively. These differences are attributed to the contrast diversity in the design parameters of the detached breakwaters of the study sites, including crest elevation, detached breakwater length, their offshore distance from the shoreline and the gab between breakwaters. At the two study areas, the detached structures are of higher relative crest elevations (emerged breakwaters) and were not sufficient to allow so much water to flow over the breakwaters and avoid tombolo formation. Because the Baltim breakwaters were built at a relatively shorter offshore distance than those of Ras El Bar (X/B ~0.6 to 0.8), tombolo has been well developed broadly where it is replaced by salient formation at Ras El Bar (X/B >~2.0). The bulge formation of tombolo at Baltim may eventually transform the breakwater system to act as a shore-parallel sea wall. In view of mitigation, the breakwaters of Baltim would have to be submerged rather than emerged and the X/B ratio would be >1 to 2. To allow sediment to transfer normally alongshore, sand

bypassing the seaward part of the tombolo formations might be considered as a proper corrective control work to nourish the downdrift eroded areas.

It is not surprising that the examined breakwaters have modified the spatial distribution of mean grain size of beach and surficial sediments. There are more differences than similarities between sediment grain size distribution before construction of the breakwaters (1990) and after construction (2002). There has been a general coarsening landward trend along the beach face backing the detached breakwaters. This pattern has resulted from grain sorting processes induced by erosion and accretion actions. Dramatically, water current fields have been modified landward of the breakwaters, causing strong eddies particularly in the gabs in water depth of <2.5 m. These eddies have resulted in serious drowning hazards. As a temporary mitigation, nylon net is proposed to be placed vertically behind the detached breakwater separating the safe and unsafe swimming zones, including the gab areas. Morphological and sedimentological related changes documented herein serve as baseline criteria needed by coastal managers to sustain these resort beaches protected as properly functioning breakwater systems. Moreover, the cases discussed here highlight the necessity for carrying out an environmental impact assessment study before implementing coastal projects.

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