Natural and Human Impact on the Northeastern Nile Delta Coast of Egypt

Omran E. Frihy, Khalid M. Dewidar, and Mahmod M. El Banna

Coastal Research Institute
15 El Pharaana Street
21514 El Shallalat
Alexandria, Egypt

ABSTRACT


Beach profile data along the northeastern Nile delta, measured during the years 1971 to 1993, identify long-term seafloor and shoreline changes and sediment transport patterns. Two major zones of pronounced erosion occur in the vicinity of the Damietta Harbor and along the tip of the Damietta promontory. The erosion along the Damietta promontory is largely the result of cut off sediment supply to the coast. In the absence of sediment supply from the Nile river, waves and currents have strongly eroded the delta promontory close to the river mouth. Accretion continued further west in sediment sinks at the Gamasa embayment, east of the river mouth, and locally along Manzala lagoon barrier. Based on results of profile analyses the inferred directions of transport indicate that there has been a cross-shore component to the sediment movement, with erosion of the beach face and inner surf zone and the transport of the eroded sand toward the offshore as well as in the longshore direction. The spatial distributions of shoreline and bottom changes reflect the natural effect of interrupted sediment supply, sediment transport processes, shoreline configuration, seafloor gradient as well as impacts of the construction of protective structures.

ADDITIONAL INDEX WORDS: Nile delta, Egypt, beach erosion, bottom changes, sediment transport, profile analysis.

INTRODUCTION

Beach profile survey has been widely used to determine changes in coastline and sea bottom as well as sediment transport. In this study analyses of beach profile data were conducted in order to interpret the response of seabed and shoreline response to natural processes, such as waves, and currents. In addition, to determine the effects of coastal man-made structures placed in the path of the longshore movement in the area, both at the Damietta Harbor and at the entrance of the Damietta river mouth.

The study area (Figure 1) is located at the northeastern Nile delta coast, extending approximately 15 km east and west of the Nile mouth of the Damietta promontory. The Damietta branch is one of the two major distributaries of the Nile River. These branches have been the only source of sediments to form the delta promontories. The Damietta branch has developed the Damietta promontory. The most conspicuous features of the study area and the recent coastal changes are depicted on the aerial photograph (Figure 2). In this figure the shorelines of 1955 and 1983 are superimposed revealing a maximum shoreline retreat of about one kilometer over the last 28 years. The extensive erosion has modified the outer margin of the promontory and threatens developments within the resort community of Ras El Bar as well as the narrow sand barrier that separate the Mediterranean Sea from Manzala Lagoon. To the west of Ras El Bar is the new Damietta Harbor, Figure 1, which was developed in 1975–80 by excavation into the delta and the construction of jetties to control the navigation channel leading into the Mediterranean Sea. The navigation channel extends to a depth of 15m, so periodic dredging is required and the dredged sand is placed on the beach to the east of the harbor jetties. A number of structures have been constructed along the shores of the Damietta promontory to protect the coast from erosion, and also to reduce shoaling in navigation channels. These structures are described in detail by Fanos et al. (1995).

Little information is published on sea floor changes along the Nile delta beaches. To date, however, information on bottom changes obtained from beach profile analysis has not been used systematically in the Nile delta region. The investigations by Toma and Salama, 1980 and Frihy et al., 1991 were limited to determine bottom changes using historical hydrographic maps. However, several reports have been published on erosion of the delta coast (Manohar, 1976; UNDP/UNESCO, 1978; Klemas and Abdel Kader, 1982; Smith and Abdel Kader, 1988; Bloedget et al., 1991). Sediment transport patterns (Quennec and Manohar, 1977; Coleman et al., 1981; Fanos, 1986; Stanley, 1989; Frihy et al., 1991; Inman et al., 1992).

Earlier studies on coastal changes at the northeastern coast of the Nile delta using historical maps reveal that the promontory advanced seaward by about 2.8 km between 1800 to 1900 (Figure 4 in Frihy and Khafagy 1991). The reversal from general accretion to erosion began about 1900, with a subsequent shoreline retreat rate of 18 to 28 m/yr (Frihy and Khafagy, 1991). The extensive erosion has modified the out-

96042 received 6 May 1996; accepted in revision 5 October 1997.
er margin of the promontory and threatens the resort community of Ras El Bar. In addition, the channels of the Nile branch and the Damietta harbor are suffering from serious siltation problems resulting from human intervention and a reduction in the river flow. This problem has progressed so that shoaling of their entrances has created navigation hazards for fishing boats entering the Damietta branch and for the commercial shipping activities within the Damietta Harbor. As a result, these entrances are being dredged periodically to remove sediments accumulated in the navigation channel. The dredged materials are ordinarily placed in the nearshore area east of the harbor.

Previous studies of the northeastern Nile delta have concentrated on shoreline and bathymetric changes using historical hydrographic maps. Our study differs from these approaches in that we used direct profile measurements. The objective is to determine the long-term bottom and shoreline changes and thereby to determine sediment dispersal in the longshore and cross-shore directions in response to natural processes and the existence of coastal engineering structures. This information is needed to better plan and implement coastal protection structures along this important sector of the Nile delta.

**MEASUREMENT OF SHORE AND SEA FLOOR CHANGES**

This study is a part of a current program at the Egyptian Coastal Research Institute to document coastal changes...
along the northern Nile delta. More than 100 beach profiles have been surveyed since 1971 to monitor coastline changes. From these extensive survey 40 profiles have been selected to cover the northeastern coast of the Nile delta (Figure 1B).

The profile lines are perpendicular to the coastline, and extend seaward to about 6 m water depth or about 1,000 m from the fixed baseline. Distance between profiles ranges from 0.1 to 4.2 km. A high density of profile lines exists around areas of unstable beaches. Field surveys have been carried out annually or bi-annually using a rubber boat associated with a Standard Fathometer System during the calm conditions of September and October. When collecting profile data, onshore leveling and underwater soundings are adjusted to mean sea level (MSL), using fixed local bench marks of known elevation. Along the seaward segment of these profiles, station soundings were taken at 100 m intervals, i.e. 9 to 10 stations for each profile line. In the present study, data for 40 profile lines have been selected for analysis, extending from about 15 km east and west from the Damietta mouth (Figure 1B). The profile survey were carried out during the years 1971 to 1993. The time span of these data range from a minimum of 9 years to a maximum of 22 years. The short-time span profiles were surveyed later adjacent to the entrance of the Damietta harbor. The spatial distributions of the selected profiles comprise a grid map of 388 offshore stations. The profile analyses provide a data base to calculate four parameters (Figure 3).
(1) Change in the measured distance (y) between the baseline point fixed at the backshore and the shoreline position (dy).

(2) Change in the measured depth (h) between the seabed and the sea surface at each station relative to mean sea level (dh). This variable provides data on the bottom changes over the time of profile survey. The data for each profile are arranged in a three-dimensional array, where (h) is the water depth relative to mean sea level, (y) is the shoreline position relative to a bench mark, and (t) is the date of profile survey. These data permit the determination of the mean annual rates of bottom changes (cm/yr) and shoreline changes (m/yr). The data set was subjected to least squares regression analysis, the slope of the (h) or (y) versus (t) plot, to determine the mean annual shoreline retreat (dy/dt) and the rate of bottom changes (dh/dt), respectively.

(3) The average water depth for each station was also computed through the survey time (t), so as to provide a generalized bathymetric map for the littoral zone of the study area.

(4) The results of shoreline change rates (dy/dt) were used to calculate the local sediment, transport (dQ/dx) after Frihy et al. (1991).

**DISCUSSION**

Rates of Shoreline Change

Time series of shoreline positions for 4 representative sites are graphically presented in Figure 4A. The curves show marked variations in long-term mean rate of retreat and advance. A downward sloping line represents erosion while upward trends indicate bottom accretion. Most of the examined time series reveals linear and cyclic trends. Cycles of erosion and accretion peaks are repeated every 3 to 5 years. The alternating pattern of erosion and accretion may indicate cyclic change in waves and currents. Previous research has revealed that cyclic change in the position of shoreline and bottom level are common on sandy beaches and are associated with episodic events such as storms or water level rise. Such cycles of erosion and accretion have been documented by Inman et al. (1992) for various parts of the Nile delta.

The long-term average rates of shoreline erosion or accretion, determined from the analysis of the examined profiles, are plotted in Figure 5B. The alongshore distribution shows a considerable variability in shoreline changes. Starting from the west along the western flank of the promontory, it can be seen that west of the Damietta Harbor the rate of accretion (12.1 m/yr; profile no.2) declines toward the jetties, while erosion appears to the east of the jetties where it increases to a maximum at profile No.10 (~39 m/yr), further evidence that the construction has affected longshore sediment movement. Accretion to the west is part of the much larger-scale shoreline deposition that is naturally continuing along the Gamasa embayment between the Burullus and the Damietta promontories. Local accretion occurring at a rate of 6.8 m/yr at profile no.5 at the updrift side of the west harbor jetty and is caused by interrupting the transport of sand to the east.

The erosion to the east up to Ras El Bar is part of the overall erosion of the Damietta promontory. Part of this erosion, at profile No.13 about 3.3 km west of the Nile entrance, where erosion of ~10.3 m/yr might result from the construction of the five detached breakwaters. In 1993/94, five detached offshore breakwaters were constructed at about 3.3 km west of the Nile mouth to reduce the erosion impact at Ras El Bar beach. The breakwaters are oriented approximately parallel to the shore and extend over a distance of about 2 km. They serve as a littoral-sediment trap and thus provide protection by reducing wave energy across the nearshore area off Ras El Bar. The local beach erosion at the western terminal of these breakwaters that averaging ~10.3 m/yr is resulted from the interruption of the westward longshore transport by these structures, during seasonal reversal in wave climate, and thereby the amount of sediments is reduced in this locality. On contrary, significant beach sand has accumulated in the shadow zone in the form of tombolo in front of these structures.

Significant rates of erosion, ranging from ~0.22 to ~10 m/yr prevail along most of the area east of the harbor starting at profile No.10 to the entrance of the Nile adjacent to Ras El Bar beach (Figure 5B). Beach erosion rates along this stretch progressively decreased from ~10 m/yr east of the harbor to less than 1 m/yr west of the river mouth. Beach erosion in this area is least along Ras El Bar resort beach, just west of the Nile mouth, largely due to the presence of coastal protection structures such as seawall and groins. Along the resort of Ras El Bar, approximately 2 km long, 3 short groins were built during 1970. Subsequently a salt embankment was placed between these groins in 1982 (inset of Figure 1 B). To protect the Nile entrance from waves and currents, two jetties were built on both sides of the river mouth, the western jetty was constructed in 1941, and the eastern jetty was completed in 1979. However, shoaling of the Nile channel has caused navigation problem for the fishing boats entering the Damietta branch which is being used as a fishing harbor. Periodic dredging is undertaken to keep the channel safe for fishing fleet activities with a dredged sand being placed on the beach east of the river.

Erosion continues east of the Nile mouth along the promontory tip at a higher rate of ~9.8 m/yr. This eroding sector suddenly reverts to accretion at a nodal point at 7 km from the mouth at profile 38, beyond which significant accretion continued and then reverted to erosion again at profile 40. The pronounced accretion on the flank of the Damietta promontory forms the sand spit that has extended seaward from the promontory (Figure 5B). The local accretion (~1 m/yr) at profile 30 is produced by the blockage of the westward longshore sediment transport by the eastern jetty of the Nile mouth. The problem of beach erosion along the promontory tip was largely in response to a combination of cutoff River Nile sediment discharge from the construction of two dams at upper Egypt, prevailing coastal processes, and also by construction of jetties and groins. First the Aswan Low Dam in 1902, and in particular the Aswan High Dam in 1964, that cutoff all water discharge from the river and the delivery of sediment to the coast.

**RATES OF BOTTOM CHANGES**

Of the 40 profile lines, 6 have been selected as representative of sites in the study area. Time series of bottom
A. TRENDS OF SHORELINE CHANGES

Figure 4. A. Time series of changing shoreline positions for representative profile lines Nos. 3, 9, 36, and 39. B. Time series of changing positions of sea bottom for representative profile lines Nos. 2, 13, 23, 31, 35, and 38. Locations of the profile lines are shown in Figure 1B. The annual rates of shoreline change (dy/dt) and bottom change (dh/dt), R, indicated in each graph, are derived from least-square regression analysis of the profile data set.

changes along each selected profile are graphically shown in Figure 4B, each being a plot of the bottom position relative to the mean sea level through successive profiling years. As in the time series of shoreline changes, they show a downward trend (erosion or deepening) and upward trend of accretion (bottom shoaling). Also, most of them show marked variation of erosional and accretionary cycles superimposed on the average trend. This variation shows that there is a strong cyclicity in the bottom changes, with periods on the order of 3 to 8 years. This cyclicity could be related to the longshore and cross-shore movement of “sand blankets” as suggested by INMAN et al. (1992), at various locations along the delta shoreline.

Linear regressions have been undertaken for the 40 profile series at 388 stations, and the resulting long-term average seafloor variation (dh/dt) have been graphed in Figure 6B. The computer-generated spatial interpolation of these values across the nearshore zone shows considerable variations. The rates of mean erosion versus accretion vary substantially from site to site. Zones of erosion represent areas of sediment source, while zones of accretion act as sediment sinks. A maximum rate of bottom erosion of ~45 cm/yr exists in two main
regions. The first zone is situated in the nearshore area just east of the Damietta Harbor, whereas the second zone is located as a narrow zone off the promontory tip close to the river mouth including Ras El Bar (Figure 6B). These two zones are surrounded from the sea side by broad areas with small erosion rates (< - 15 cm/yr).

On the other hand, three zones of accretional sinks exist across the nearshore zone, consider as major sinks in the study area. One is located west of the study area within the Gamasa embayment, while the others are formed east of the river, positioned about 5 and 15 km from the Nile mouth, respectively. In comparison, the general distribution of bottom changes is in agreement with the erosion and accretion pattern along the shore as we observed it during this study (Figure 4 and 5). The accumulation of sediment off Gamasa embayment is a result of sand transported from material eroded from the central bulge of the Burullus promontory. Likewise, the accretion area in the vicinity of the Damietta spit is derived from sand eroded from the Damietta promontory east of the river. Further to the east, the offshore sand accumulation east of this promontory, 11 to 15 km from the mouth, is produced from the erosion of spit and beaches close to the river.

**Sediment Transport**

Sediment paths can be delineated if sediment sinks and sources are considered, and thereby the erosion/accretion patterns. In this study, the sediment transport regime can be inferred from the established erosion and accretion patterns
A. PROFILE POSITIONS

B. ANNUAL RATE OF BOTTOM CHANGES

C. WATER DEPTH (m) AND SEDIMENT TRANSPORT

Figure 6. A. Location of beach profiles along the northeastern Nile. B. The spatial variations of annual long-term average rate of bottom changes, showing areas of erosion (sources) and areas of accretion (sinks). The two sub-cells identified by FRITHY et al. (1991) are positioned on the bottom margin of this figure. C. The average bathymetry of the nearshore region, and the schematic sediment transport model generalizing sediment transport paths interpreted from the identified patterns of erosion and accretion in Figures 5B and 6B. The arrows depict the paths of longshore and cross-shore sediment transport. Seasonal reversal in sediment transport is shown by a dashed arrow.

in the alongshore and offshore direction and also from their corresponding sediment sources and sinks (Figures 5 and 6). The spatial patterns of erosion versus accretion in the study area indicate that sand is transported in two directions: an alongshore path with erosion of beach face and transport of sand by littoral current to the east; and a cross-shore component with erosion of the beach face and inner surf zone and the transport of the eroded sand toward the offshore. This
pattern of sediment movement is depicted by arrows in the
generalized map in Figure 6C. The onshore-offshore move-
ment only exists in the vicinity of the Damietta spit, in which
sand movement follows more or less the down slope contours
as well as the spit curvature. Across the nearshore zone, the
local accretion areas that is surrounded by areas of erosion
evidenced the inferred onshore-offshore transport.

Three main zones of accretion were recognized in the study
area; Gamasa embayment in the west, and Damietta spit and
Manzala barrier in the east. The entire quantity of the ac-
cumulated sand at Gamasa embayment is derived from the
eroded remnant Burullus headland midway between the two
Nile promontories. This embayment corresponds to the end
part of the Burullus sub-cell identified by Frihy et al. (1991)
who identified four discrete sedimentation compartment
called “littoral sub-cells”. Each sub-cell contains a complete
cycle of littoral transportation and sedimentation, including
sources and sinks of sediment and transport paths. Along the
coast of the Nile delta coast, the principal sources of sediment
for each littoral sub-cell are the eroded promontories which
supply large quantities of sand to the coast (Figure 6B). The
eroded sand is transported along the coast by waves and cur-
cents until it is intercepted and terminated in the downcoast
direction by adjacent sinks including promontory saddles,
embayments and long jetties (Figure 1A). According to their
analysis, the Burullus sub-cell contains the arcuate bulge of
the central-delta region to the Damietta Harbor. In this sub-
cell, sand eroded from the relict Burullus promontory and
coastal dunes is transported downcoast to the east and south-
west, resulting in shoreline and bottom accretion along Ga-
masa embayment (Figures 5B and 6B). This sand is wave-
driven by eastward littoral currents and currents generated
by the east Mediterranean gyre which sweep across the inner
shelf (Himan and Jenkins 1984). This general pattern ap-
pears to be consistent with net easterly littoral transport.

As previously noted, the western jetty of the Damietta Har-
bor has interrupted the easterly littoral currents causing sand accumulation on its updrift side, west of the harbor (Fig-
ures 5B and 6B). Substantial amounts of this sand bypass
the jetty and settle in the harbor entrance causing siltation.
In fact, the potential siltation induces by the interruption of
prevailing eastward coastal currents by the dredged naviga-
tion channel. This means that the canal act as a long jetty, it
has 15-km long and 15 to 16 meters water depth. This is
evidenced from the maximum siltation that taking place along
the offshore terminal of this canal along 3 to 5 km length offshore (personal communications with the harbor
authority). This confirms the idea that coastal currents in the
nearshore zone of the Damietta harbor is responsible for the
creating the siltation problems and not the cross-shore ones.

The coast between the Damietta Harbor and Ras El Bar is
subjected to sediment bypassing to the west during seasonal
reversal in wave climate that come from the NE direction.
This can be interpreted from 1983 aerial photographs which
show a small local accretion on the eastern sides of three
groins placed at Ras El Bar beach. Fluorescent-tracer exper-
iments by Kadib (1969) also suggest a net eastward drift
with seasonal reversal to the west along Ras El Bar beach.
Accordingly, on occasions sediments erode from the outer
margin of the promontory and move to the west and deposit
as a tombolo in the wave shadow of the five offshore break-
waters built west of the Nile mouth (Figure 1B, inset).

East of the river, the massive erosion along the outer mar-
gin of the promontory represents an area of divergence trans-
port, directing transport to the east and locally to the west,
and to some extent in the cross-shore direction in the vicinity
of the spit area (Figures 5 and 6C). The accumulation of sand
downcoast along the eastern flank of the Damietta promon-
tory results in both sand spit formation and additions to the
lagoon barrier. Offshore of the lagoon barrier the sediment
comes from the erosion of the promontory tip and partly from
the adjacent formed spit in this area. The spacial erosion/
accretion pattern in this area suggests an offshore transport
direction (Figure 6C). The offshore accretion zones indicate
sediment bypassing to the north as evidenced from the ero-
sion measured landward of these zones. This transport pat-
ttern is confirmed by study of Coleman et al. (1981) in which
they suggested that there may be an offshore movement of
sediment to the east producing sand shoals in this region.
According to their suggestion, these shoals may be an im-
portant element in accounting for the extensive shoreline ero-
sion that has occurred on the promontory. The dynamic pattern
along the eastern flank of the Damietta promontory corre-
sponds to the Damietta sub-cell defined by Frihy et al.
(1991). This sub-cell includes the entire length of Manzala
lagoon barrier starting from the river mouth and ending at
the 7.7 km jetty of Port Said (Figure 1).

In Figure 5B, the long-term average rate of shoreline
changes (dy/dt) is related to the longshore gradient of sand
transport rate (dQjdx), rather than to the absolute quantities
of that transport. If (y) is the shoreline position so that dy/dt
is its time-rate of change (dy/dt negative signifies erosion,
and dy/dt positive represents accretion). Therefore, there is
a simple proportionality between dy/dt and dQjdx, so that both
scales can be given in Figure 5B. Note that negative dy/dt
corresponds to the dQjdx, i.e. an increasing transport rate in
the longshore direction. The Q, values are plotted along the
shore in Figure 5C. It has been assumed that Q, = 0 at the
river mouth, that is, there is presently no exchange of sand
with the area close to the river mouth. It is seen that Q,
progressively increases with longshore distance to the east
and west from the river as sand is deposited in the areas of
accretion. The Q, reaches a maximum of approximately 9.5
× 10⁶ m³/year at Gamasa embayment. Areas of small Q,
being less than 1 × 10⁶ m³/year are noted close to the river
mouth and also close to the protective structures at Ras El
Bar and the Damietta Harbor. This is appeared from the
examined aerial photograph (Figure 2) and also from our field
observations that the three groins placed at Ras El Bar show
little accretion on both sides.

The alongshore variations in the shoreline changes indicate
a transport reversal from erosion to accretion or vis versa
exists at several points along the coast creating a set of di-
vergent longshore sediment transport “nodal points” (Figure
5B). These points of change from erosion to accretion resulted
from orientational changes of the shoreline along the Dami-
etta promontory and due to jetty construction.

The interpreted transport paths in the alongshore and
cross-shore directions are confirmed by studies of wave refraction and sediment transport (QueUennec and Mano­har, 1977), and current measurements (Coleman et al., 1981; Fanos, 1986; Inman et al., 1992). The established pattern of longshore transport shown in Figure 6C corresponds to the predominant wave direction from NW and NNW (Na­fAA et al., 1991). The predominant wave approach is responsible for the eastward-flowing longshore current. A smaller component of winds from the NNE produces the seasonal longshore currents toward the southwest (inset in Figure 1B).

**SUMMARY AND CONCLUSIONS**

Analyses of intensive beach profiling spanning 9 to 22 years (1971 to 1993) along the northeastern Nile Delta coast have contributed to the interpretations of shoreline and bottom erosional and accretionary changes in response to sediment transport processes. The profile analysis reveals that there is a strong cyclicity in the shoreline and bottom changes, with periods on the order of 3 to 8 years. This cyclicity is due to the longshore movement of “sand blankets” as noted by Inman et al. (1992) at various locations along the delta shoreline. Mapping of the annual rates of shoreline changes along the coast, together with the spatial distribution of changes in the seafloor, reveals distinct erosion and accretion patterns that result from, sediment input, shoreline orientation, transport processes, and coastal structures. The overall pattern of sediment transport paths is largely wave-driven, controlled by shoreline orientation relative to the dominant NW waves and the construction of protective structures. The pronounced changes in downcoast orientation along the outer margin of the promontory, produce erosion on both sides. The areas of highest rates of beach erosion and nearshore seabed deepening occur at the tip of the Damietta promontory and east of the Damietta Harbor. The coastal instability in the study area is due to the combined effects of interrupted sediment supply from the river, natural coastal processes and construction of coastal protective structures. The erosion at the Damietta mouth is induced by dam construction along the Nile which has eliminated sand delivery to the coast, and the prevailing longshore sand transport. On the other hand, the erosion east of the Damietta Harbor is mainly due to human intervention in constructing harbor jetties that blocked the longshore transport of sand resulting in erosion east of the harbor. Shoreline configuration and coastal sedimentation have been modified by artificial structures close to the inlet of Damietta river mouth and the two jetties placed at the Damietta Harbor. This study provides useful information for preparation and implementation of effective plans to help protect and remediate the northeastern Nile delta region by decision makers dealing with coastal zone management and planning.

**ACKNOWLEDGEMENT**

The authors wish to thank Dr. Aly Fanos, director of the Coastal Research Institute of Egypt, for providing data and general help in completing this study, and Dr. Shaleh M. El Kafay, Alexandria University, for assistance in developing a computer program for processing profile data used in this study.

**LITERATURE CITED**


Frihy, Dewidar and El Banna


