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NEARSHORE COASTAL CHANGES ALONG THE NILE DELTA SHORES

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ABSTRACT

The Nile Delta coast is a dynamic system formed by the Nile River sediments discharged into the Mediterranean Sea through the historic seven branches of the Nile. The central headland at Burullus began to erode around the 10th century upon abandonment of the old Nile branch which had been providing sediment to this area. Commencing in the early 20th century the nine barrages along the main river were constructed which initiated a general erosional trend along the Nile Delta with concentrations around the Rosetta and Damietta promontories. This alarming erosion has been aggravated since the erection of the Aswan High Dam in 1964, which trapped essentially all of the flood sediments in its storage basin.

Eighty beach profiles, covering the Delta coast, have been surveyed twice per year since 1976 and surveying is continuing to the present. A computer program was developed to analyze the collected profile data. This program calculates the accretion/erosion quantities and the movement of various contour lines up to 6 meters depth. The results have shown that the changes do not follow a clear pattern except at the Rosetta and Damietta promontories and around the El Burullus area where consistent erosion is evident.

INTRODUCTION

The Nile Delta coast consists of sandy beaches approximately 240 km in length (Figure 1). This coastline has two promontories at Rosetta and Damietta and one "bulge" at Burullus with concave shorelines in between. Six outlets exist in this coastal segment, listed from west to east as: Idku Lake Outlet, Rosetta Exit, Burullus Outlet, Gamasa Drain Outlet, Damietta Exit, and El Gamil Outlet. The

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Figure 1. General Layout of Main Profiles along the Nile Delta Coast.

instability of the Nile Delta coastal zone in terms of erosion and accretion has been documented since the beginning of the present century. Local severe erosion has destroyed roads and caused losses of buildings and resort beaches while shoaling due to siltation in lake outlets and estuaries has resulted in navigation hazards and reductions in fish productivity. There has been considerable interest over the last two decades in the marked coastal changes observed along the Nile Delta coast, leading to studies of: coastal geomorphology (Sestini, 1976; Frihy et al., 1988); analysis of beach profiles up to the 6 m depth (Manohar, 1976 a & b); aerial photography analysis (Frihy, 1988); satellite image analysis (Klemas and Abdel Kader, 1982; Smith and Abdel Kader, 1988; Blodge et al., 1991); shoreline changes (Sestini, 1976; Misdorp, 1977); dynamic factors (Khafagy and Manohar, 1979; Manohar, 1981: Fanos, 1986: Elwany et al., 1988; Naffaa et al., 1991) sediment transport (Inman and Jenkins, 1984; Frihy et al., 1991) and sediments (El Askary and Lotfy, 1980).

The erosion and accretion patterns along the Nile Delta coast in general are a result of: 1) a decrease of sediment supply after the construction of the Aswan High Dam and other impoundment structures built on the Nile which have reduced the sediment supply from more than 120 million tons per year to almost zero at present (Orlova and Zenkovitch, 1974; Sharaf El Din, 1974: Smith and Abdel Kader, 1988; Frihy, 1988), 2) rise of sea level in the Mediterranean over the last 40 years at an average rate of about 1.63 mm/yr (Sharaf El Din et al., 1989), 3) subsidence of the land at a rate of 3.5 to 5.0 mm/yr in the northern part of the Delta based on carbon-dated core sections (Stanley, 1988), and 4) dynamic factors including waves and currents which are the principal driving forces for the transport of sediments and hence the chief agent in beach erosion. Wave action along the Nile Delta coast is seasonal in nature. The energy supplied by severe Winter storms contributes significantly to the total annual energy budget. The maximum wave height recorded is 4.0 m in Winter at Abu Quir Bay. The predominant direction of the waves is WNW-NW with less wave energy from the NNE-NE sector (Naffaa et al., 1991). The predominant littoral current is toward the east with velocities ranging from 20 to 50 cm/sec (Fanos, 1986).

This paper describes the nearshore coastal changes, including the sediment quantities, shoreline changes, bar formation and physiographic nearshore units from the profile data collected during the last ten years, i.e., from 1981 to 1990.

DATA COLLECTION

The data base for this study has been established from repeated surveys of 80 hydrographic profiles along the Nile Delta coast and simultaneous collection of sediment samples. The most westerly profile is located 6 km west of Maadia Outlet and the most easterly profile 5 km east of El-Gamil Outlet (about 7 km west of Port Said western breakwater). The spacing between adjacent profiles depends on the nature of the coastline and varies from 0.5 km to 10 km with the exception of one 17 km spacing between two profiles west of Rosetta (Figure 1). More detail is provided in Khafagy, Fanos and Naffaa (1992).

The profiles are referred to a permanent baseline which extends, more or less, parallel to the local shoreline. The monument for each profile is a steel angle iron imbedded in a barrel filled with concrete. The hydrographic survey of the coastal profiles extends from the monument to the closer distance of a 6 meter water depth or 1000 m offshore. The surveys have been conducted twice per year since 1976; once during September/October termed "Autumn profiles" which represent the results of the Summer season swell waves and the other during April/May termed "Spring profiles" representing the results of the Winter season storm waves.

The surveys along the profiles are carried out by taking a measurement every 10 meters along the first 250 m from the baseline (surf zone) and then every 50 meters. A surface bottom sediment sample is taken every 100 meters with a grab sampler. The measurements are corrected to the zero Survey Authority datum.

ANALYSIS OF PROFILE DATA

The profile data have been analyzed in terms of their spatial and temporal variations (Khafagy, Fanos and Naffaa, 1992). Samples are given in Figure 2. Two methods have been used in the analysis of the beach profiles namely: the Eigenfunction method (Winant et al., 1975) and the erosion/accretion method (CRI/UNESCO/UNDP, 1978). The first considers the spatial and temporal characteristics of the profiles by computing the first three eigen-functions, representing the mean,



Figure 2. Typical Accretional, Erosional and Equilibrium Profiles.

bar/berm and terrace functions, respectively. The results from this method are beyond the scope of the present paper. Some results for the Burullus area are presented in Khafagy and Fanos (1981). The accretion/erosion method was used to interpret the nearshore changes and the coastal processes of the Nile Delta coast. This method seeks to calculate the nearshore morphology characteristics of the profiles such as the position of the shoreline, depth contours, underwater bars, bed slopes and the volumetric transport rates of the sediments by erosional and/or accretion processes.

A computer program was developed to calculate the accretion/erosion quantities between adjacent profiles. Also computed are the bed slope, bar characteristics and the distances of the 0, 2, 4 and 6 m contours from the original baseline. The surface bottom samples were analyzed mechanically and the mean grain size (D_{50}) was computed for each sample.

RESULTS AND DISCUSSIONS

Nearshore Profiles

Based on examination of the 80 profiles along the Egyptian coast, over the period 1981 to 1990, three profile types were identified:

i. Undernourished profiles characterized by a rapid recession of the beach. These profiles act as sediment sources; the Rosetta Promontory profiles (Figure 2) provide examples.

- Overnourished profiles which are generally accreting and act as sediment sinks, e.g. profiles at Abu Khashaba about 10 km east of Rosetta Branch, and in Abu Quir Bay from Maadia Outlet to 6 km south of Rosetta Exit (Figure 2).
- iii. Dynamically stable profiles which keep their forms at a maximum steepness, and unlike the undernourished profiles which erode continuously, they alter between erosion and accretion. Profiles of this type exist between Kitchener Drain and New Damietta Harbor and west of the Burullus Outlet (Figure 2). Figure 3 gives the seasonal changes for each profile type.

Shoreline and Bed Contour Changes

Measured shoreline and depth contour changes, i.e. 0 m, 2 m, 4 m and 6 m contours during the 10 year period (1981 to 1990) are shown in Figure 4. It is clear that the shoreline is retreating along almost the entire coast except in some short regions between Maadia and west of Rosetta, at Abu-Khasaba, between Kitchener Drain and west of New Damietta Harbor and to the west of Port Said breakwater. Maximum retreat of the shoreline is documented at Rosetta Promontory to be about 70 m/y, while it is about 5 m/y at both of Burullus Headland and Ras El Bar sea resort and about 8 m/y to the east of Damietta branch. There are three regions which are subject to erosion from the shoreline to the 6 m contour. They are Rosetta and Damietta promontories and Baltim Sea resort area which is located about 10 km to the east of Burullus Outlet. This is due to the wave and current action and the absence of the sediment supply from the Nile itself which was balancing some of these losses before the completion of the High Aswan Dam. Also Figure 4 shows that there is accretion for the contours 2, 4 and 6 m along some other areas of the Delta.



Figure 3. Seasonal Shoreline Variations.

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Figure 4. Changes of Contour Lines along the Nile Delta Coast.

Bed Slope Changes

Based on the profile data it is evident that the Nile coastal beaches have two or three ranges of gradients, with the steeper gradients located in the surf or breaker zone (ranging from 1:76 to 1:140); followed by a seaward transitional milder slope ranging from 1:35 to 1:350 and a still flatter seaward slope ranging from 1:90 to 1:435. The slopes steepen just west of the outlets within and beyond the breaker zone. This is true for all the outlets except those which are provided with protective structures (Maadia, Burullus and El-Gamil) such as jetties where they are flatter in the breaker zone only due to sedimentation processes. However, for the Damietta Outlet, the slopes are steeper due to the formation of a large eddy west of the jetty which prevents any sediment deposition. East of the outlets, the slopes are steeper than those on the west side, especially in the breaker zone. They gradually flatten for some distance to the east and then steepen again both in and beyond the breaker zone. The very steep slopes (1:5) at the eastern part of the Damietta Promontory are the result of active scour in front of the vertical wall existing in the area and not due to natural causes. The changes in bed slopes during the 1981-1990 period were relatively small.

Grain Size Changes

The size characteristics of the surface bottom samples along the Nile Delta coast during the 1982 to 1989 period show insignificant changes. Some decrease in sediment size was evident from 1982 to 1989, primarily in the zone of maximum wave energy and strong longshore current, namely the breaker zone; from the shoreline to a distance of 300 m offshore. The data showed a clear trend of size reduction in the seaward direction. Coarser sands were also found near Maadia, near Burullus and at Damietta Outlet. These may be a "lag" product resulting from erosion concentrated at the old Nile branches.

Relation between median grain size and bottom slope

It is well known that grain size is an important parameter in determining the profile slopes under water or above water. Figure 5 shows the variation in slope as a function of median grain size D_{50} , for the beach face and beyond the breaker zone for the entire coast. It is clear that: (i) the slope increases as grain size increases, (ii) the effect of grain size on slopes is greater in the beach zone area than beyond the breaker zone, and (iii) exposure to different wave conditions such as breaking waves modifies the slopes and grain sizes.



Figure 5. Bottom Slope Versus Medium Grain Size.

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NILE DELTA COASTAL CHANGES

Underwater bars

One characteristic feature of a beach in a relatively enclosed sea with small tidal range such as the Mediterranean Sea is a series of submarine bars (Manohar, 1979). Along most of the Nile Delta coast there are three underwater bars, one in the breaker zone in depths of 0-2 m (summer bar) formed by the short waves and swells, one or two storm bars in water depth ranging from 3-4 m and/or from 5-6 m formed by the largest storm waves. The convex shape of the bars has been interpreted as an index of the existence of more than one predominant wave direction, i.e. waves from NE and NW directions (Khafagy, Fanos, Naffaa, 1992). The bar heights range from 0.30 m to 1.00 m and in some cases are very flat and low in height. Their heights increase in areas of accretion and flatter slopes, whereas in erosional areas their base is large and their heights low. The formation and migration of these bars is a complex phenomenon which is difficult to study in a natural environment.

Volumetric Changes and Trends in Erosion and Accretion

Coastal processes can be interpreted in terms of changes of profiles and volumes. These types of results were developed from the 1981-1990 profile data and are presented in Figure 6. Figure 6b presents the mass curve (cumulative volume along the baseline). In the mass curve, a steeper upward slope indicates accelerated accretion and a flatter slope means the accretion is less than in the previous zone. A downward slope signifies erosion. Figure 6c presents the total volume of sediments moving on the Nile Delta coast within the zone between the baseline and the 6 meter contour. These figures indicate the following:

- 1. Volumetric change rates appear to depend on time, for example the volume change during a particular period is not equal to volume change per year multiplied by the number of years.
- 2. The gross volume change (accretion + erosion) which amounted to 235×10^6 cu.m. in the ten year period is by far larger than the net volume change (accretion erosion) which amounted to 13×10^6 cu.m. in the same period.
- 3. In the breaker zone, erosion predominates over accretion, with a few areas of accretion such as Abu Khashaba east of Rosetta Exit, to the west of Gamasa Drain and near Port Said. The accretion in the Baltim Sea resort area is due in part to the artificial nourishment of the beach.
- 4. The net volume change over the full length of the coast is sometimes accretion (up to 6 m depth) and sometimes it is erosion. This means that sediments are coming from or lost to depths beyond 6 m. This stresses the importance of extending the profile surveys offshore beyond 6 m to the closure depth.
- 5. The changes of the profiles do not follow a certain pattern except at Rosetta and Damietta promontories and to the east of Burullus Outlet where they erode progressively.



Figure 6. Mass Curve of Total Sediment Volume Determined from Profile Data Along the Nile Delta Coast during the Period from 1981 to 1990.

6. The analysis of the spring profiles shows recession along the coast due to the high waves of the winter season while autumn profiles show redistribution of the sediments and shoreline advancement due to the lower swells of the summer season.

Physiographic Nearshore Units

According to the seasonal analysis of the beach profiles many independent physiographic units could be proposed as described below and shown in Figure 7:

- 1. Abu Quir Bay from Madiaa Outlet to 6 km south of Rosetta Exit is an independent unit although its northern end acts as a sink for the erosional products from the Rosetta Promontory.
- 2. The Rosetta Promontory, for about 15 km on both sides of the Rosetta Exit behaves as a separate unit acting as sources for adjacent areas.
- 3. Abu Khashaba zone acts as a sink for erosional material from the Rosetta Promontory.
- 4. The 40 km east of Abu Khashaba to Burullus Outlet appears to be a unit by itself where the shore is shifting back and forth.
- 5. The reach from Burullus Outlet to Kitchener Drain is an erosion area with cusp formation at Baltim sea resort.
- 6. From Kitchener Drain to the western breakwater of New Damietta Harbor is almost stable area with some accretional and erosional pockets.
- 7. Damietta Promontory on both sides of the Nile estuary is a separate unit similar to the Rosetta unit.
- 8. The reach from the beginning of the spit and up to 15 km to the east acts as a sink for the promontory erosion and to some extent as a source for the 10 km stretch located immediately eastwards.
- 9. The remaining stretch appears to be an independent unit and acts as the major source for the Port Said breakwater and its entrance channel.

SUMMARY AND CONCLUSIONS

The coastal processes and changes along the Nile Delta shoreline are a result of the dominantly westerly wave incidence, the historic changes in location of the Nile tributaries (\approx 1000 years before present) and the more recent (this century) dramatic reduction in sediment supply due to barrage construction along the Nile River. An effective means of studying the current processes is through analysis of repetitive beach profiles extending a sufficient distance seaward to encompass the active profile.

This study has identified the dominant erosional areas as those characterized by convex outward shorelines as a result of historical sediment supply by the Nile River tributaries. These erosional zones serve as sources of sediment for the accretional areas which are dominantly concave in planform. Consistent with theory



Figure 7. Physiographic Units Identified.

of planform change, it is expected that the erosional zones will broaden with time. The profile and sediment characteristics are qualitatively in agreement with the findings of previous investigators, namely that there is a correlation between local slope and local sediment size. The profile analysis indicates a complex pattern of erosion/accretion both in the longshore and cross-shore directions.

Continued profile measurements will provide a valuable data base which will provide additional understanding of the complex and dynamic coastal processes along the Nile River Delta and will assist in the critical future management decisions relating to this resource.

REFERENCES

- Blodge, H.W., Taylor, P.T. and Roark, J.H., 1991. Shoreline Changes along the Rosetta, Nile Promontory: Monitoring with Satellite Observations. Marine Geology, 99.
- CRI/UNESCO/UNDP, 1978. Coastal Protection Studies. Final Tech. Rep., Paris, France, 155 p.
- El Askary and Lotfy, 1980. Coastal Erosion and Accretion at the East of Damietta, Egypt. Bulletin of the Faculty of Science, Jeddah, 4, 257-264.

- Elwany, M.H., Khafagy, A.A., Inman, D.L., and Fanos, A.M., 1988. Analysis of Waves from Arrays at Abu Quir and Ras el Bar, Egypt. Adv. Underwater Technol., Ocean Sci., Offshore Eng. Soc., Underwater Technol., 16: 89-97.
- Fanos, A.M., 1986. Statistical analysis of Longshore Current Data along the Nile Delta Coast. Water Sci., J., Cairo, 1:45-55.
- Frihy, O.E., 1988. Nile Delta Shoreline Changes: Aerial Photographic Study of a 28-Year Period. J. Coastal Research, 4: 597-606.
- Frihy, O.E., El Fishawi, N.M. and El Askary, M.A., 1988. Geomorphological Features of the Nile Delta Coastal Plain: A Review. Acta Adriatica (Yugoslavia), 29, 51-65.
- Frihy, O.E., Fanos, A.M., Khafagy, A.A. and Komar, P.D., 1991. Patterns of Nearshore Sediment Transport along the Nile Delta, Egypt. Coastal Engineering, 15, 405-429.
- Inman, D.L. and Jenkins, S.A., 1984. The Nile Littoral Cell and Man's Impact on the Coastal Zone of the South Eastern Mediterranean. Scripps Institution of Oceanography Ref. Series 84-31, University of California, La Jolla, 43 p.
- Khafagy, A.A. and Manohar, M., 1979. Coastal Protection of the Nile Delta. Nat. Resour., 15: 7-13.
- Khafagy, A.A. and Fanos, A.M., 1981. Eigen Function Analysis of Beach Profiles at Burullus Coastal Site. Internal Technical Report, Coastal Research Institute. Alexandria.
- Khafagy, A.A., Fanos, A.M. and Naffaa, M.G., 1992. Beach Profile Analysis During the Period from 1981 to 1990. Internal Technical Report, Coastal Research Institute, Alexandria, Egypt.
- Klemas, V. and Abel Kader, A.M., 1982. Remote Sensing of Coastal Processes with Emphasis on the Nile Delta. In: International Symposium on Remote Sensing of Environments. Egypt, 27 p.
- Manohar, M., 1976a. Beach Profiles. Proceedings of UNESCO Seminar on Nile Delta Sedimentology, Alexandria, 95-99.
- Manohar, M., 1976b. Dynamic Factors Affecting the Nile Delta Coast. Proceedings UNESCO Seminar on Nile Delta Sedimentology, Alexandria, 104-129.
- Manohar, M., 1979. Undulated Bottom Profiles and Onshore-Offshore Transport. Proceedings of the 16th Conference on Coastal Engineering, N.Y., 1454-1474.
- Manohar, M., 1981. Coastal Processes at the Nile Delta Coast. Shore and Beach, 49, 8-15.
- Misdorp, R., 1977. The Nile Promontories and the Nile Continental Shelf. Proceedings UNESCO Seminar on Nile Delta Coastal Processes, Alexandria, 456-551.
- Naffaa, M.G., Fanos, A.M. and el Ganainy, M.A., 1991. Characteristics of Waves Off the Mediterranean Coast of Egypt. Journal of Coastal Research, Vol 7, No. 3.
- Orlova, O. and Zenkovitch, V., 1974. Erosion of the Shores of the Nile Delta. Geoforum, 18, 68-72.
- Sestini, G., 1976. Geomorphology of the Nile Delta. Proceedings UNESCO Seminar on Nile Delta Sedimentology, Alexandria, 12-24.

- Sharaf El Din, S.H., 1974. Longshore Sand Transport in the Surf Zone Along the Mediterranean Egyptian Coast. Limnol. Oceanogr., 19: 182-189.
- Sharaf El Din, S.H., Ahmed, K.A., Khafagy, A.A., Fanos, A.M. and Ibrahim, A.M., 1989. Extreme Sea Level Values on the Egyptian Mediterranean Coast for the 50 years. International Seminar on Climatic Fluctuations and Water Management. Cairo, Egypt.
- Smith, E.S. and Abdel Kader, A., 1988. Coastal Erosion Along the Egyptian Delta, Journal of Coastal Research, 2, 245-255.
- Stanley, D.J., 1988. Subsidence in the Northeastern Nile Delta: Rapid Rates, Possible Causes, and Consequences. Science, 240, 497-500.
- Winant, C.D., Inman, D.L., and Nordstrom, C.E., 1975. Description of Seasonal Changes Using Empirical Eigenfunctions. Journal of Geophysical Research, Vol. 80, No. 15.