PART VII

Case Studies

Perforated Caisson Breakwater at
Porto Torres, Sardinia

CHAPTER 248

Erosion of the Damietta Promontory, the Nile Delta

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Abstract

The Damietta sediment-formed promontory is located on the eastern half of the Nile Delta, about 40 km west of the Suez Canal breakwaters at Port Said. Following a long period of accretion, the promontory began to erode early this century with shoreline recession rates reaching a maximum of 38 m/yr. This paper documents the shoreline changes, the coastal processes responsible for those changes, and the protective measures that have been erected to control the erosion.

Introduction

During historical times, the Nile Delta shoreline was built out by sediments delivered to the coast through seven or more distributaries. Since the 9th century, most of the Nile River water and sediment delivered to the coast have passed through the Rosetta and Damietta branches, and these have built out the pronounced promontories apparent in the modern outline of the delta shoreline. The shapes of these promontories reflect the quantities of sediments delivered to the coast versus the effectiveness of the waves and nearshore currents in redistributing the beach sands along the delta shoreline.

About the turn of the century, the general accretion of the Rosetta and Damietta promontories reverted to erosion

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characterized by rapid rates of shoreline retreat. Inducement of this erosion is generally attributed to construction of barrages along the Nile River as part of water-control activities, and in particular to the construction of the Aswan Low Dam in 1902 and the Aswan High Dam in 1964 (Orlova and Zenkovitch, 1974; Inman and Jenkins, 1984; Frihy et al., 1991). Completion of the Aswan High Dam has cut off almost all water discharge from the river and the delivery of sediments to the delta coast.

The focus of this study is on the Damietta promontory which is located about 40 km west of the Suez Canal breakwaters at Port Said. The objectives of this paper are to: (1) illustrate the patterns of shoreline changes from analyses of old maps and recent surveys; (2) to summarize the measurements of waves, longshore currents and beach profiles; (3) to evaluate the longshore sediment transport rates through various techniques; and (4) to highlight the shoreline protective works that have been completed or are being proposed.

Patterns of Shoreline Changes

The shoreline changes, as revealed in old maps and recent surveys, are summarized in Figure 1. There was an overall accretion from the 1800 survey until about the beginning of the 20th century, the maximum seaward growth appearing in the 1912 mapped shoreline. After that date the successive surveys show a rapid retreat of the shoreline to the immediate east of the Damietta river mouth, that long-term maximum erosion averaging 38 m/yr between the 1912 and 1983 shorelines. Development in this erosion area to the east of the river was minimal, with the main impacts being the necessity of moving the coastal highway inland and the recent replacement of the light house which is in danger of being lost.

It is apparent in Figure 1 that the shoreline retreat and the rates of erosion have varied considerably along the length of the promontory shoreline, and actually revert to a zone of accretion to the east of a nodal area, reflected in the progressive seaward advance of the shorelines. Part of this accretion has been the development of a sand spit on the eastern flank of the Damietta promontory, seen in the 1973 and 1983 shorelines (Fig. 1).

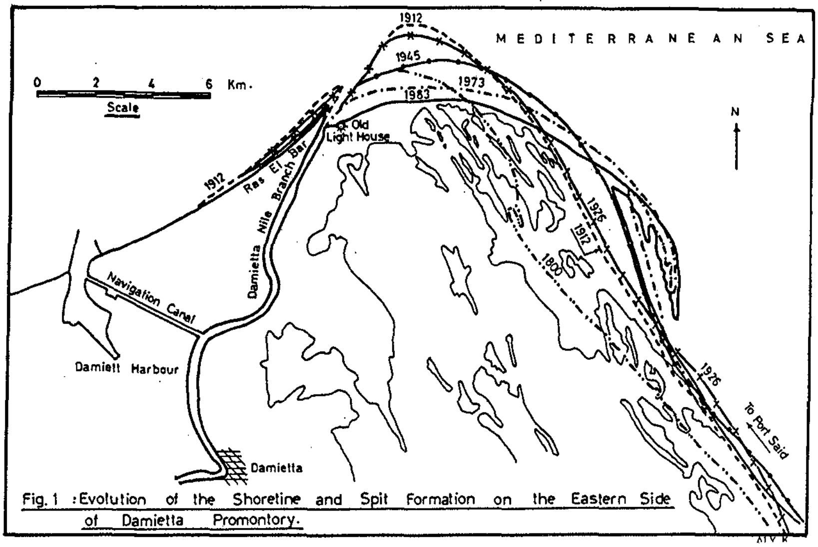

Fig. 1 : Evolution of the Shoreline and Spit Formation on the Eastern Side of Damietta Promontory.

The shoreline changes to the west of the river mouth have been particularly critical due to the erosion of the resort community of Ras El Bar. The study of old maps has shown that the Ras El Bar tongue of land grew in length to about 500 meters and widened during the period from 1800 to 1900, corresponding to the time of general growth of the Damietta promontory. Since the turn of the century, the pattern has been primarily one of erosion, during which the Ras El Bar tongue eroded back following the overall shoreline retreat of the promontory. The erosion has been partly stabilized by the placement of a series of groins and a seawall.

It is seen that there have been substantial changes in the shoreline positions along the Damietta promontory since about the turn of the century. The main impact has been one of erosion, with the point of the promontory having retreated by some 3 to 4 km and continuing at a rapid rate. However, beach accretion, partly in the form of a sand spit, has taken place along the eastern flank of the promontory. The inducement of these shoreline changes is undoubtedly a response to the cut-off of sand delivery to the coast through the Damietta branch of the Nile River. The continued action of waves, longshore currents and sediment transport has acted to displace sediments toward the east, resulting in the observed patterns of shoreline changes.

Processes Affecting the Damietta Promontory

The normal wind regime along the Mediterranean coast of Egypt is controlled by various atmospheric conditions which occur on a seasonal basis. The annual wind rose for the area offshore of Damietta indicates that the winds blow predominantly from the NW and WNW directions. These directions correspond to the maximum fetch distance along the length of the Mediterranean Sea, and account for the observed patterns of wave heights and directions along the Nile Delta coastline.

A program for collecting wave data in the study area began as early as 1964-1966 and has been continuous from 1972 onwards (Fanos et al., 1989; Nafaa et al., 1991). The earliest measurements were collected with pressure gauges termed the Offshore Pressure Operated Suspended System, installed in about 6 meters water depth directly seaward of the point of the Damietta promontory. Its records have been analyzed manually by the zero up-crossing method and/or the Tucker and Drapper method (Tucker, 1963; Drapper, 1966) to obtain significant wave heights and periods, while the wave direction was determined from wind data. In order to obtain a more complete description of the wave climate, a directional wave recording system termed the Cassette Acquisition System has been used since it became fully operational in 1985. It was installed in 7 meters water depth, about 1 km offshore from the Damietta Promontory. Measurements for 34 minutes every 6 hours are recorded on cassettes, and are computer analyzed to yield spectra, significant wave heights, periods, and wave directions (Lowe and Inman, 1984; Elwany et al., 1988; Nafaa et al., 1991).

Wave action on the Nile Delta is seasonal, with the intensity and direction following the seasonal patterns of winds. The maximum significant wave height recorded during 1985 to 1990 was 4.3 m. The predominant wave directions are from the WNW, NNW, N and W; a small portion of waves arrived from the NNE and NE, especially in March through April and possibly in November, due to easterly winds during those months. It is noticeable that wave characteristics vary from season to season and from year to year. These variations cause the changes in wave energy flux which are responsible for the nearshore coastal changes.

All of the wave records are from one point in shallow water, and in order to obtain the deep-water wave characteristics and to determine the wave climate along the length of the promontory shoreline, back and forward refraction calculations have been carried out. Figure 2 shows the back refracted rays of the recorded data (Elwany et al., 1989), and examples of forward refraction of waves from the NNW and WNW (CRI/UNESCO/UNDP, 1978). This figure illustrates the concentration of wave energy on the promontory, and in part explains the severe erosion that has occurred.

Longshore currents have been measured within the surf zone at three stations on each side of the mouth of the Damietta Nile branch. The collected data during 1990 and 1991 have been subjected to monthly, seasonal and yearly statistical analyses to determine the probability distributions of the longshore currents. The predominant current direction on both sides of the river mouth was found to be from west to east, except during the months of March, April, May and November when the current periodically reverses and its direction depends on the daily wind and wave directions.

The shift from erosion to accretion along the eastern flank of the Damietta promontory, Figure 1, reflects the longshore variations in the quantities of sand being transported. As one moves east from the river mouth, the erosion contributes more and more sand to the littoral transport toward the east, so that the total quantity must be progressively increasing. The maximum longshore sediment transport is positioned at the nodal point between the areas of erosion versus accretion. With the change to beach accretion, there is progressively less and less sand being carried as littoral drift. By this interpretation, the longshore sediment transport is everywhere to the east, but its varying quantities account for the shifts from erosion to

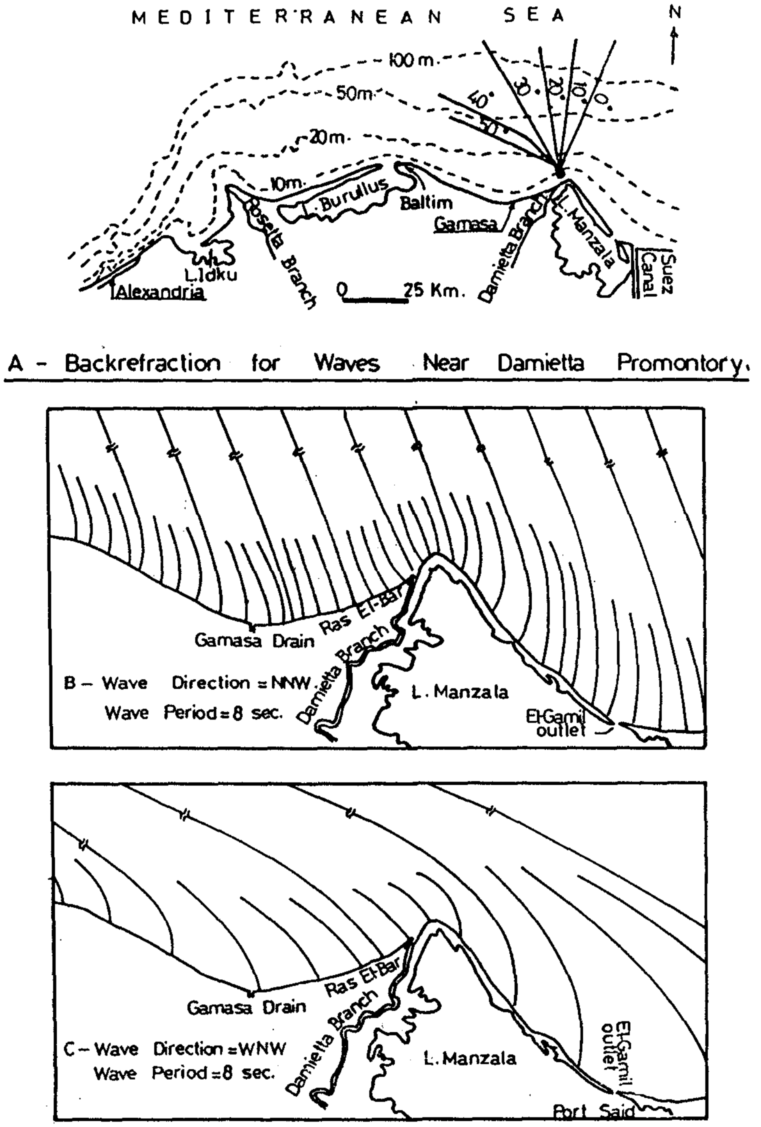

Fig. 2 : Backrefraction and Forward Refraction.

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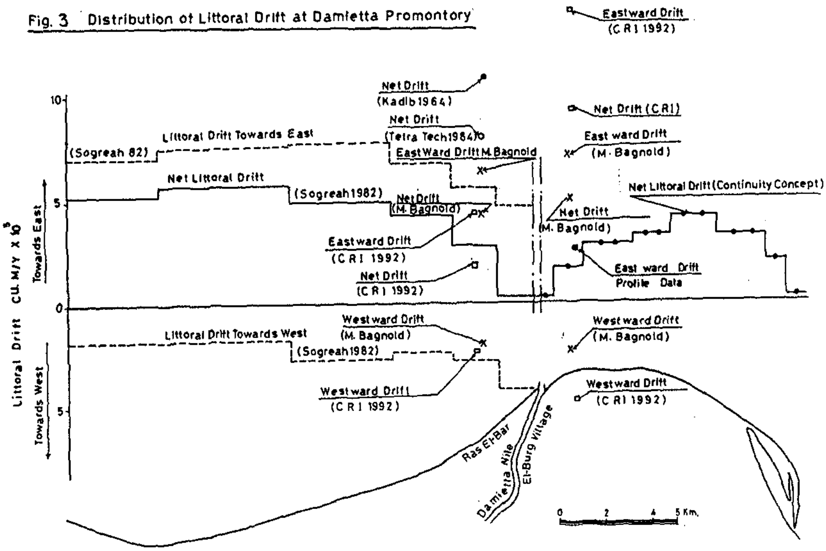
deposition.

This pattern of sediment transport has been quantitatively assessed for the stretch of shoreline east of the Damietta river mouth, similar to the analyses of Frihy et al. (1991) for the Rosetta promontory. The rate of shoreline retreat or advance is related to the longshore gradient of the sand transport rate, 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 = - signifies erosion, dy/dt = + represents accretion), then a consideration of sediment continuity yields $Z(dy/dt) = -dQ_S/dx$ where Q_S is the local sediment transport rate and x is in the longshore direction. Z is an elevation factor that converts the dy/dt shoreline change into a volume of sand eroded or deposited per unit shoreline length. According to beach profiles from the area, this elevation change is approximately Z = 4 meters. Therefore, there is a simple proportionality between dy/dt and dQ_S/dx.

The average rates of shoreline erosion or accretion (dy/dt) between the years 1912 and 1983 have been determined from Figure 1. The corresponding dQ_S/dx local gradients calculated from the continuity equation have been integrated in the longshore direction from west to east, to yield the graph of Q_S in Figure 3. It has been assumed that $Q_S = 0$ at the river mouth, that is, there is presently no exchange of sand with the area to the west, either with the river channel or with the western flank of the promontory. If there is in fact some net exchange, then the Q_S curve of Figure 3 would simply shift up or down by that amount, while retaining its overall shape. It is seen that Q_S progressively increases with longshore distance from the river, reaches a maximum of approximately 0.41×10^6 m^3/yr, and then decreases. According to the computations of Figure 3, the transport is reduced to essentially zero due to deposition on the sand spit along the eastern flank of the promontory, indicating that there is an approximate balance between the quantities of sand eroded and subsequently deposted. The varying quantities of longshore sediment transport rates found in this analysis are due to systematic changes in breaker angles and wave energies

Fig. 3 Distribution of Littoral Drift at Damietta Promontory



along this stretch of shore, in turn caused by the refraction of the predominant NW-NNW waves around the shallow offshore of the promontory.

Measurements and/or computations of the littoral drift have been carried out by various investigations along different stretches of the Damietta promontory. Kadib (1969) measured the transport at Ras El Bar using fluorescent tracers, and reported a value of 1.15 x 10^6 m^3/yr for the net transport toward the east. More recently, experiments by El Fishawi et al. (1992) have been carried out using tracers to determine sand transport rates at two locations, 0.80 km east and 3.0 km west of the Damietta mouth, every month during the period from January to December 1991. The results are graphed in Figure 3, labeled as CRI-1991. To the east of the river the evaluated net littoral drift is 0.8 x 10^6 m^3/yr, which is substantially greater than determined by the other techniques. To the west of the river along the Ras El Bar shoreline, the net littoral drift is evaluated to be 0.26 x 10^6 m^3/yr toward the east, a value that is smaller than obtained by the other techniques and studies.

Tetra Tech (1984) estimated the net littoral drift at Ras El Bar to be 0.8 x 10^6 m^3/yr to the east. Using the CERC equation, Sogreah (1982) evaluated the transport rates along an extended length of shoreline to the west of the river mouth, including the beach along Ras El Bar. The results are graphed in Figure 3. These calculations indicate that the net littoral drift is everywhere toward the east, progressively decreasing from 0.6 x 10^6 m^3/yr to essentially zero (0.03 x 10^6 m^3/yr) near the Ras El Bar jetty. The calculated values using the CERC equation are very approximate because they depend on the accuracy of measuring the shoreline orientations, the breaker angles, and breaker heights.

Longshore sediment transport rates can be computed from the daily measurements of wave heights (H_b) and longshore currents (v) with the modified Bagnold equation $Q_s = 0.026(H_b)^2v$ as established by Komar (1990). This formula is particularly applicable to analyses of sediment transport rates on the Nile Delta due to the accumulated long-term measurements of waves and longshore currents, and eliminates the requirement of accurate assessments of breaker angles needed in the CERC equation. Applying this relationship with the available wave and current measurements, the average annual eastward and westward littoral drifts on the western side of the river mouth were computed to be 0.64 x 10^6 m^3/yr and 0.2 x 10^6 m^3/yr respectively, the net to the east being 0.4 x 10^6 m^3/yr. These values are graphed in Figure 3 at the position corresponding to the location where the longshore currents were measured to the west of the Ras El Bar jetty. Similar calculations for a position to the east of the river mouth yielded eastward and westward transports of 0.72 x 10^6 m^3/yr and 0.23 x 10^6 m^3/yr, with a net 0.49 x 10^6 m^3/yr toward the east. This is approximately the maximum transport rate as evaluated above from shoreline changes and continuity considerations, but the measurement location is closer to the jetty where the calculated transport from continuity considerations is roughly half that value (Fig. 3). Therefore, the agreement is good only to a factor of 2.

Shoreline Protection Measures

The protective works on the Damietta promontory began in 1936 in order to defend the Ras El Bar summer resort from the erosion, and also to prevent siltation of the estuary. A 200-m long concrete jetty was constructed during the period 1936-41 at the NE extremity of Ras El Bar (Figure 4). In 1965 a concrete protective sea wall was built along the first 400 m of shoreline to the west of the jetty, fronted by riprap and doloes. Three 150-m long concrete groins were added in 1970 to protect the beach to the southwest of the sea wall, and in 1982 a basalt riprap revetment was constructed between the groins and to the west of the groin field. Presently, four detached breakwaters are under construction to the west of the groins, Figure 4, and the beach behind the breakwaters is being nourished. These combined projects will offer protection to nearly the full length of the Ras El Bar shoreline.

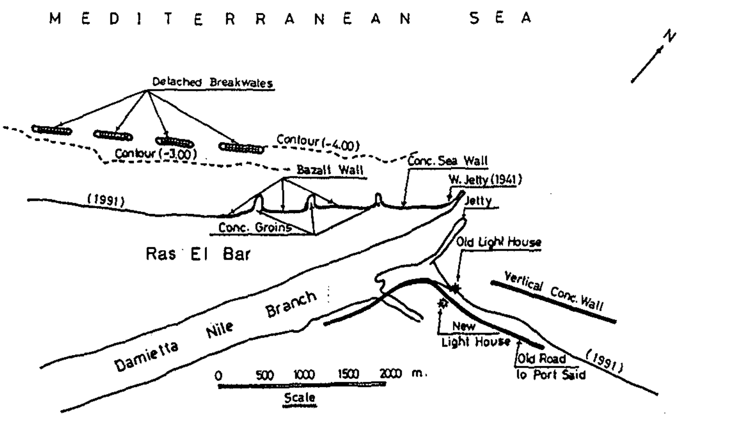


Fig. 4 :Protective Measures (1941 - 1991) on Western Side of Damietta Promontory.

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The jetty on the eastern bank of the river mouth was constructed in 1979. However, the earliest shoreline structure to the east of the river mouth was a seawall several kilometers in length, Figure 4, constructed in 1971 to protect the very old coastal road between Damietta and Port Said. Most of this wall has become submerged in the offshore during the continued retreat of the shoreline. Recent erosion has threatened the lighthouse to the immediate east of the river, and necessitated the placement of a protective riprap wall surrounding the structure and extending to the east. This old lighthouse has become unstable due to the erosion, and has been replaced by a new lighthouse in an inland position. Tetra Tech (1984) has suggested the construction of a revetment having a 6 km length along the coast, using the old road to Port Said as part of the structure. However, erosion would continue at its eastern end as the promontory shoreline continues to retreat. We have suggested that the revetment instead extend for about 1.5 km parallel to the old road, and then turn inland to the south to offer protection from the erosion that will continue further to the east.

Summary and Conclusions

Erosion of the Damietta promontory has been continuous since about the turn of the century, with very high rates of shoreline retreat. This erosion is confined to the central portion of the promontory closest to the river mouth. To the east of the river the rate of shoreline retreat progressively decreases along the flank of the promontory, and beyond a nodal area reverts to accretion and shoreline advance, in part involving the formation of a large sand spit. This reorientation of the shoreline is in response to the continued wave action and longshore sediment transport, while at the same time the sediment delivered to the coast has been cut off due largely to the construction of dams on the Nile River. A program of data collection, including the measurement of waves, beach profiles, longshore currents and sand transport rates, has documented the main processes responsible for the shoreline changes. The measurements of longshore currents and sand transport show a dominant movement toward the east, and this corresponds to the prevailing winds and waves arriving from the NW and WNW directions. Although the net longshore sediment transport is everywhere toward the east, the rates vary due to systematic longshore variations in wave breaker heights and breaker angles along the length of the promontory shoreline. This variation in rates of eastward transport is responsible for the patterns of shoreline erosion near the river mouth versus accretion at greater distances, the zone of erosion corresponding to the shoreline where the transport is progressively increasing while the accretion is in the zone of decreasing littoral drift.

The promontory erosion has threatened developed areas, in particular the resort community of Ras El Bar to the west of the river. The response to this erosion has been the construction of a jetty, followed by the placement of a seawall and series of groins along the eroding shoreline. Most recent is the placement of four detached breakwaters and nourishment of the sheltered beach. There is less development to the east of the river, but the erosion has destroyed the coastal road to Port Said, requiring its rerouting to a more landward position. The old lighthouse has been undermined by the erosion, necessitating its replacement. Riprap has recently been installed to protect the old lighthouse and extended eastward to offer some protection to the replacement Port Said highway. Plans are being formulated for the construction of a large seawall that will extend for several kilometers to offer additional protection to the eastern shore of the Damietta promontory.

Acknowledgements

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References

CRI/UNESCO/UNDP (1978) Coastal Protection Studies: Final Technical Report, Volumes I and II, Academy of Scientific Research and Technology.

Drapper, L. (1966) The analysis and presentation of wave data: A plea for uniformity: Proc. 10th Conf. on Coastal Engineering, Amer. Soc. Civil Engrs.

El Fishawi, N.M., A.M. Badr and A.A. Khafagy (1992) Fluorescent tracers at the eastern and western beaches of the Damietta mouth: Technical Report, Coastal Research Institute, Alexandria, Egypt.

Elwany, M.H.S., A.A. Khafagy, D.L. Inman, and A.M. Fanos (1988) Analysis of waves from arrays at Abu Quir and Ras El Bar, Egypt: Advances in Underwater Technology, Ocean Science and Offshore Engineering, v. 16: pp. 89-97.

Elwany, M.H.S., A.A. Khafagy, D.L. Inman, and A.M. Fanos (1989) Prediction of wave climate along the coast of Egypt: International Seminar on Climatic Fluctuations and Water Management, 11-14 December 1989, Cairo, Egypt.

Fanos, A.M. (1986) Statistical analysis of longshore current data along the Nile Delta coast: Water Science Journal, Water Res. Center, Cairo, v. 1, pp. 45-55.

Fanos, A.M., A.A. Khafagy and S.H. Sharaf El-Din (1989) Coastal changes along the Egyptian Mediterranean coast: International Seminar on Climatic Fluctuations and Water Management, 11-14 December 1989, Cairo, Egypt.

Frihy, O.E., A.M. Fanos, A.A. Khafagy and P.D. Komar (1991) Patterns of nearshore sediment transport along the Nile Delta, Egypt: Coastal Engineering, v. 15, p. 409-429.

Inman, D.L., and S.A. Jenkins (1984) The Nile littoral cell and man's impact on the coastal zone of the southern Mediterranean: Proc. Conf. on Coastal Engr., pp. 1600-1617.

Kadib, A. (1969) Rate of littoral drift at Ras El Bar using fluorescent tracers: Suez Canal Research Center, Technical Report No. 42.

Komar, P.D. (1990) Littoral sediment transport: Handbook of Coastal and Ocean Engineering, J.B. Herbich (editor), Vol. 2, Chapter 11, pp. 681-715.

Lowe, R.L., and D.L. Inman (1984) Wave parameters, Abu Quir array, Egypt: Scripps Institution of Oceanography, Univ. of Calfornia, SIO series 84/31.

Nafaa, M.G., A.M. Fanos and M.A. Elganainy (1991) Characteristics of waves off the Mediterranean coast of Egypt: Jour. of Coastal Research, v. 7, p. 665-676.

Orlova, G., and V. Zenkovitch (1974) Erosion of the shores of the

Nile Delta: Geoforum, v. 18, p. 68-72.
Songreah Consulting Eng. (1982) Effects of the construction of the Port of Damietta on the evolution of the littoral, Final report: Report No. 35/1201 R9, August 1982.
Tetra Tech (1984) Shoreline master plan for the Nile delta coast: Progress Report No. 1.
Tucker, M.J. (1963) Analysis of sea waves: Proceedings Institute of Civil Engineers, London, v. 26.