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Research Article

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Abstract

*This study evaluates the effect of prevailing dynamic factors on the sedimentation process in Damietta Harbour along the Nile delta coast of Egypt. The monitoring program spanned the period between 1978 and 1999 and included measurements of waves, currents and bathymetric profiles. The evaluation was based on determination of erosion and accretion rates, current regime, sediment transport, wave characteristics and wave refraction. Results revealed that the predominant wave direction from N-NW sector (86 %) throughout the year is responsible for generation of a longshore eastward current. Less frequent waves from the N-NE sector generate an opposing longshore westward current. The refraction pattern for the prevailing wave direction indicates that the harbour and its navigation channel are located within a divergence of wave orthogonal and in an accretion sediment sink area. The annual net rate of littoral drift on the western side of the harbour is about 1.43 * 10^5 m^3 (accretion), while the annual net rate of littoral drift on the eastern side is about 2.54 * 10^5 m^3 (erosion). Currents fluctuate tremendously in speed and direction, especially during the winter months. Hence, sediment transport takes place in offshore, eastward, and onshore directions. Progressive vector diagrams show that the largest near bottom offshore, onshore and easterly net drift occurs during summer, spring and winter respectively. The onshore sediment transport generated during spring and summer plays an important role in the redistribution of eroded sediments during the winter. The overall study of dynamic factors indicated that the harbour site is characterized by eastern, western, offshore and onshore sediment movements. Therefore, the north-south orientation of the navigation channel, with its depth greater than the surrounding area, interrupts sediment drift from different directions and reduces the current speed. Consequently, the sediments sink within the navigation channel from different directions. The sources of sediments contributing to the siltation process of the harbour and its navigation channels are mainly derived from the Rosetta promontory, Burullus beaches, Damietta promontory and from offshore and the dumping area.*

Keywords: Erosion; Accretion; Waves; Wave Refraction; Currents; Damietta Harbour.

Introduction

Extreme long term erosion takes place along the Nile delta coast, and has significantly accelerated since the completion of the Aswan High Dam in 1964 (ORLOVA & ZENKOVITCH, 1974; SHARAF EL DIN 1974; ZAGHLOAL *et al.,* 1982; SMITH & ABDEL KADER, 1988 and FRIHY, 1988). Erosion causes a great impact on the national economy directly or indirectly: coastal roads, buildings and agriculture land are inundated. On the other hand shoaling and silting up of outlets of the Nile branches (Rosetta and Damietta) and outlets of the northern lakes are possible hazards. The study area lies between longitude 31° 34' & 31° 55' E and latitude 31° 27' & 31° 37' N. The area includes the Gamasa drain, the new Damietta Harbour and the Damietta promontory (Fig. 1).

The Damietta Harbour and its associated coastal structures were completed in November 1982 to serve trading vessels and ships of up to 250 m length and 12.5 m plunging depth. It is located about 9.7 km west of the Damietta Nile branch. Two jetties were constructed to prevent the limited SW – NE sediment transport from entering the channel and to protect the harbour entrance from siltation. The western jetty is about 1500 m in length, almost parallel to the navigation channel and extends to a 7.0 m depth contour. The eastern jetty is about 500 m in length, nearly perpendicular to the shore line and extends to about 3.0 m depth contour. The navigation channel was constructed in 1983 - 1984, with a total length of 20 km and water depth of 15 m (Fig. 1).

The navigation channel is loose silty fine sediment of D50, about 0.06 mm to 0.09 mm. The bed material in shallow depth is found to be fine sand of D50 about 0.08 mm to 0.09 mm, while in offshore depths (> 15 m) D50 is about 0.30 to 0.40 mm (SOGREAH, 1984). In the Damietta harbour area, the mean grain size tends to decrease gradually from beach to sea. For the beach sand, the mean grain size ranges between 0.14 mm and 0.58 mm with an overall average of

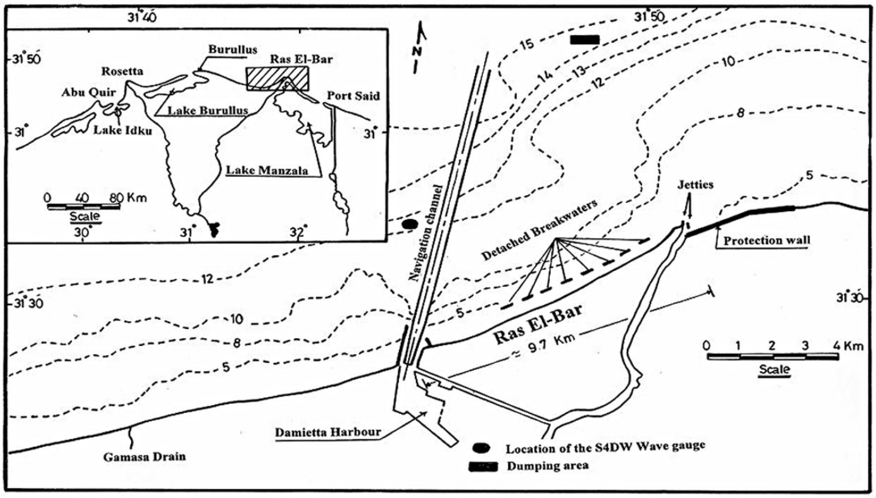

Fig. 1: Study area and location of Damietta Harbour and navigation channel.

0.25 mm, while it ranges between 0.08 mm and 0.22 mm with an overall average of 0.11 mm for the sea bottom sediments at up to 6 m water depth (CoRI 1998). The volume of annual dredged materials from the navigation canal during the period from 1986 to 1994 (Fig. 2, CoRI, 1998) was in general more than that estimated by the project consultant, of average 1.18 x 10^6 m^3/yr. Thus tremendous sedimentation took place in the navigation channel, creating hazards for vessels and cargo ships during their entrance to the harbour and perhaps preventing larger ones from entering the harbour. According to the Damietta Port Authority, the unit cost of maintenance dredging in 1988 were 0.23 Euro /m^3 (1.9 LE/m^3) and had reached 1.10 Euro/m^3 (9.25LE/m^3) in 2001. In 2004, the yearly cost of maintaining the access channel of Damietta harbour had reached 7.1 million Euro (60 million LE). Consequently, the cost of dredging is high due to the large quantities of sedimentation, and the high rate of increase in dredging costs affects the economy of the harbour. The dredged materials that are recovered by hoper dredger have been dumped at the eastern side of the navigation channel at about 11 km offshore (Fig. 1). Waves provide the necessary energy that forms beach configuration, sediment sorting on the shoreface, sediment transport crosshore and/or alongshore. They are responsible for most of the force acting on coastal and ocean structures (CERC, 1984). The main objectives of this paper are to study:

1. Erosion/accretion patterns and sediment volumetric changes within the study area from bathymetric profiles during two different periods: before (1978-1982) and after (1988-1997) the construction of Damietta Harbour.
2. Wave climate and refraction patterns in front of the study area, using wave data recorded in front of Damietta Harbour (1997-1999).
3. Current regimes in front of Damietta Harbour.
4. The impact of wave climate, current regime and sediment transport on the Damietta Harbour and its navigation channel.

Materials and Methods

The study area was assessed by 18 bathymetric profiles bathymetric profiles (Fig. 3). The profile lines were 0.5 to 8 km

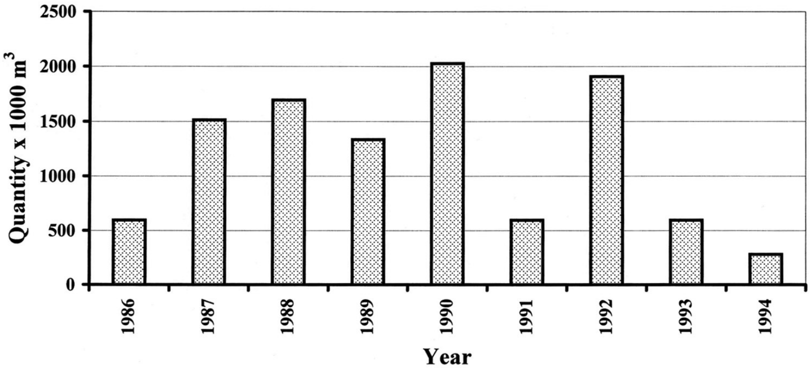

Fig. 2: Volume of dredged sediments from navigation channel (1986-1994).

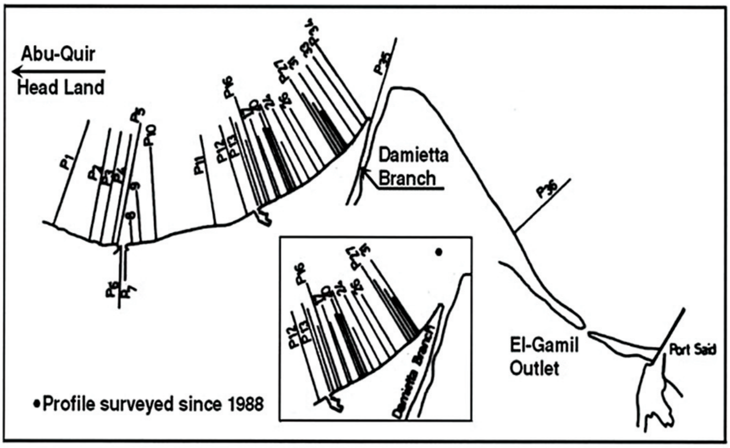

Fig. 3: Location of hydrographic profiles.

apart (except for the eastern side of Damietta mouth due to severe erosion) depending on the nature of the coastline and were selected to cover the whole area (Fig. 3). These profiles were surveyed during May (after the winter season) of the years 1978 and 1982. In 1988, a baseline was fixed to add 18 bathymetric profiles with space between any two adjacent profiles varying from 0.05 to 2.0 km to cover particularly the area on both sides of Damietta Harbour (approximately 2 km west of the harbour and 5 km to the east). A total of 36 beach profiles up to 6 m depth are included in this study and numbered consecutively from west to east in Figure 3.

The bathymetric profiles were surveyed nearly perpendicular to the shoreline and extending to 1 km distance from the shoreline (base line) or 6 m depth whichever was closer. Soundings were taken every 10 m from baseline up to a distance of 250 m seaward to trace the details of the surf zone, and then every 50 m up to 6 m depth. The sounding and inland leveling of the profiles were surveyed with the use of an echo-sounder, graded staff and rubber boat. Soundings were corrected with respect to the mean sea level. The 36 beach profiles were surveyed during May (after the winter season) of the years 1988 and 1997.

Wave and current data from August 1997 to July 1999 were recorded by a current/wave gauge S4DW deployed near the bottom (0.5 m above sea bottom) at the western side of the navigation channel of the harbour at a water depth of 12 m (Fig. 1). The study was maintained on a regular basis and programmed to work for a period of 20 minutes every 4 hours from August 1997 to January 1998, then every 2 hours from February 1998 to July 1999. It recorded the directional wave spectrum, current velocity and direction for 20 minutes (one record/sec) every 2 or 4 hours according to the program. The recorded data were transferred to the computer and analyzed using dedicated software to obtain a significant wave height, wave period, wave direction and maximum wave height for each burst of data. A computer program was developed to read the secondary current data (1 record each second for 20 minutes during each burst) and analyze it according to northerly and easterly direction and then compute the resultant current speed and direction for each burst of data.

Three seasons with respect to atmospheric circulation patterns (wind speed - wave climate - and air temperature) have been distinguished for the Egyptian coast by HAMMED 1983: winter (November to March), spring (April and May) and summer (June to September). Monthly and seasonally significant wave height and period as well as maximum wave height and period are presented in Figure 4. Wave refraction was performed for the main wave directions with predominant period, using Snell's law and assuming locally straight and parallel contours (DALRYMPLE, 1992). The wave and current data were subjected to statistical analysis on a monthly basis. The frequency distribution of each velocity group for the main 16 directions N, NNE, NE, ... etc. (each 22.5° interval) of the time series wave and current data were determined and depicted on a histogram. Daily mean current was determined and used to draw Progressive Vector Diagrams (PVDS) which show the pseudo-trajectory of particles in the sea. Volumetric changes of sediments were studied by analyzing the 36 beach profiles. The sounding of the successive surveys were compared to determine the volume changes in cubic meters. Volume changes (in m^3) based on erosion and accretion within the different profile depth zones (vertical depth differences) from 0 to -2, <-2 to -4, <-4 to -6, 0 to -6 and >0 to -6 m were calculated. Net volume changes were determined as the resultant of accretion (+ve) and erosion (-ve) changes within the different profile depth zones.

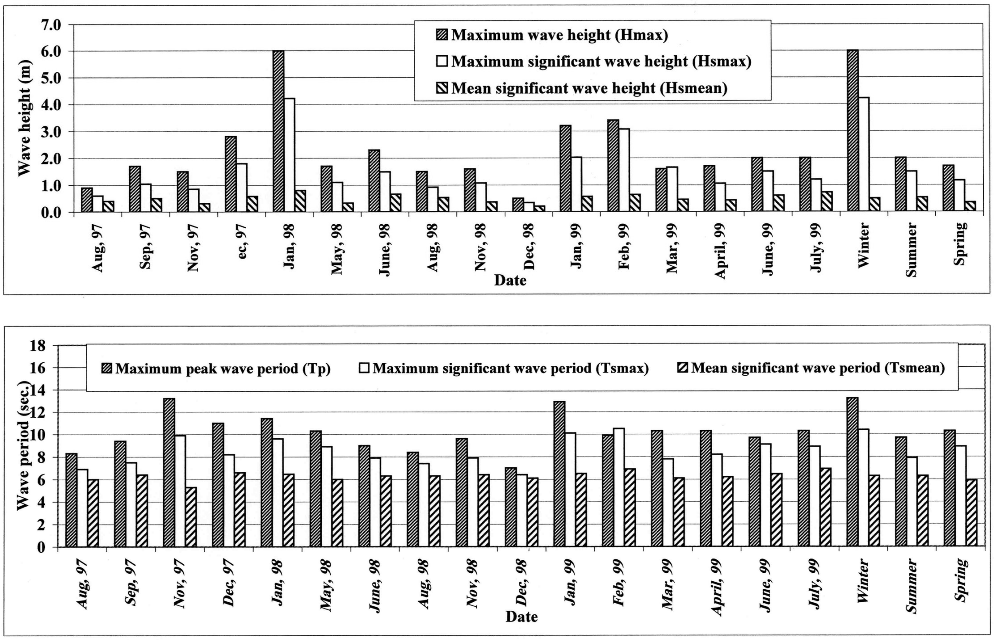

Fig. 4: Monthly and seasonally wave height (Hmax, Hsmax and Hsmean) and period (Tp, Tsmax and Tsmean)

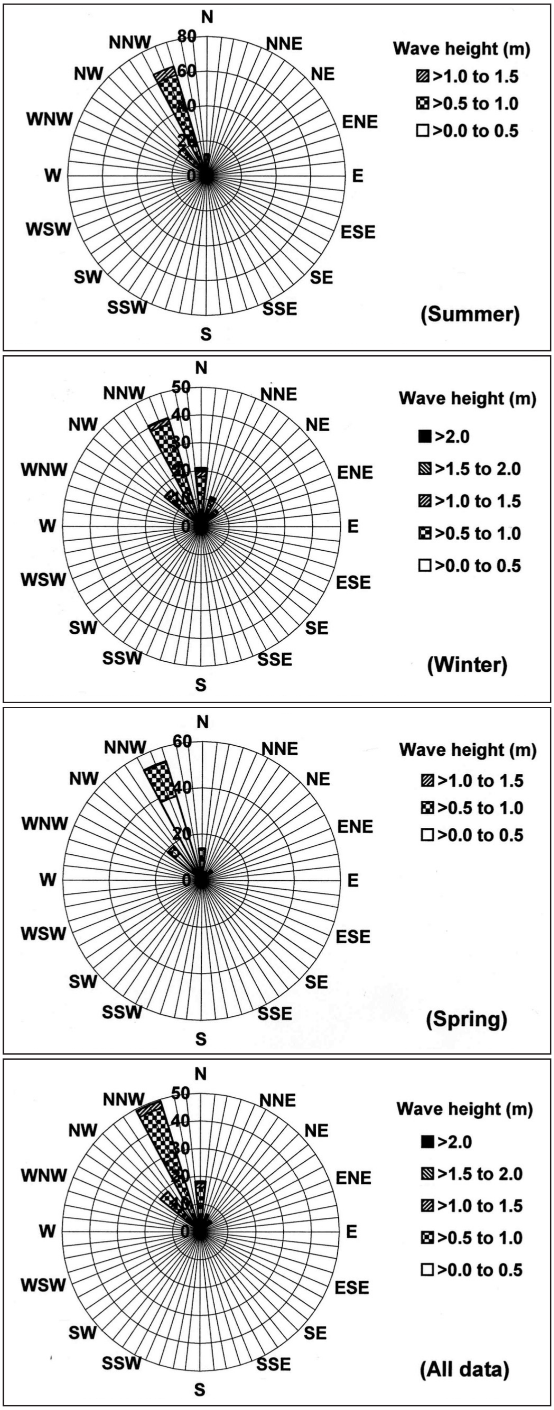

Fig. 5: Seasonally and all wave data rose at Damietta Harbour (August 1997 to July 1999).

Results

Proper understanding of hydrodynamic factors (waves and currents) and evaluation of the wave climate at a given site are necessary and essential for adequate design of engineering protective measures. Wave and current data recorded during the period from August 1997 to July 1999 are depicted in seasonal wave rise and histograms (Figs 5 and 7, respectively).

Waves

The maximum and mean wave heights are observed during winter months, and then they decrease in spring and increase gradually during summer (Figure 4). Maximum wave height during the strongest storms is in the order of 6.0 m, while maximum significant wave height is 4.2 m from N (January 1998 -Fig. 4). This in agreement with NAFFAA, 1995, who concluded that wave energy during the winter season is much more effective than in the summer and spring seasons. Wave period is ≤ 8 sec for 98.2 % of the time (60.4 % of the time between 7 and 8 seconds). The monthly maximum peak wave period fluctuates between 7.0 and 13.2 seconds. The predominant wave direction throughout is from the N-NW (86 %) sector for all months (mainly from NNW (49 %) direction), reflecting the eastward movement of fronts along the Mediterranean Sea, while a small percentage of waves from a NNE-NE direction were recorded during the winter and spring months (Fig. 5).

A refraction diagram (Fig. 6) illustrates a main concentration of wave energy at the tip area of the Damietta promontory for all wave directions. The distance between consecutive wave orthogonal increases gradually going to the western side of the Damietta mouth. It reaches a maximum distance (divergence of wave orthogonal), with significant spread of wave energy, in front of Damietta Harbour for WNW and NE wave directions. There is a slight spread of wave energy for NNW, NW and NNE wave directions in front of Damietta Harbour. The eastern side of the Damietta mouth is more exposed to incoming eastern waves than the western zone. A significant spread of wave energy occurs for western waves (NNW, NW and WNW) at about 25 to 35 km east of the mouth. It is obvious that the harbour area lies within convergent sediment drift area (sink area).

Currents

The major current is directed mainly eastward (NE-E sector) and westward (WSW-WNW sector) during different seasons (Fig. 7), depending on the angle between the north direction and shoreline orientation (65°). The seasonal current histogram indicated that the major current direction is eastward (45 %, 35 %, 20 %) and westward (37 %, 24 %, 48 %) during summer, winter and spring respectively. During the winter months (November to February), the currents are characterized by a wide fluctuation in speed and direction which may be attributed to the variability of the wind conditions. The maximum current speed was recorded during

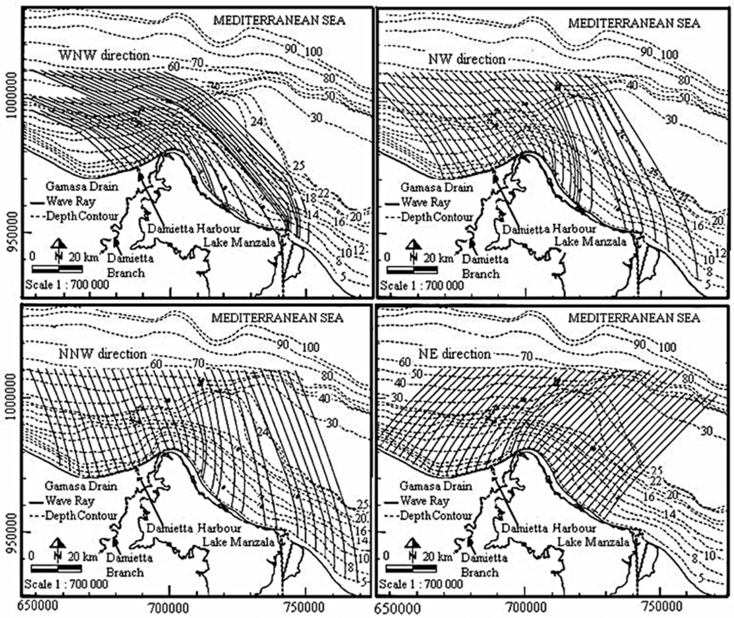

Fig. 6: Wave refraction pattern for the predominant wave direction and period = 8 sec (modified after, ABO ZED, 1996).

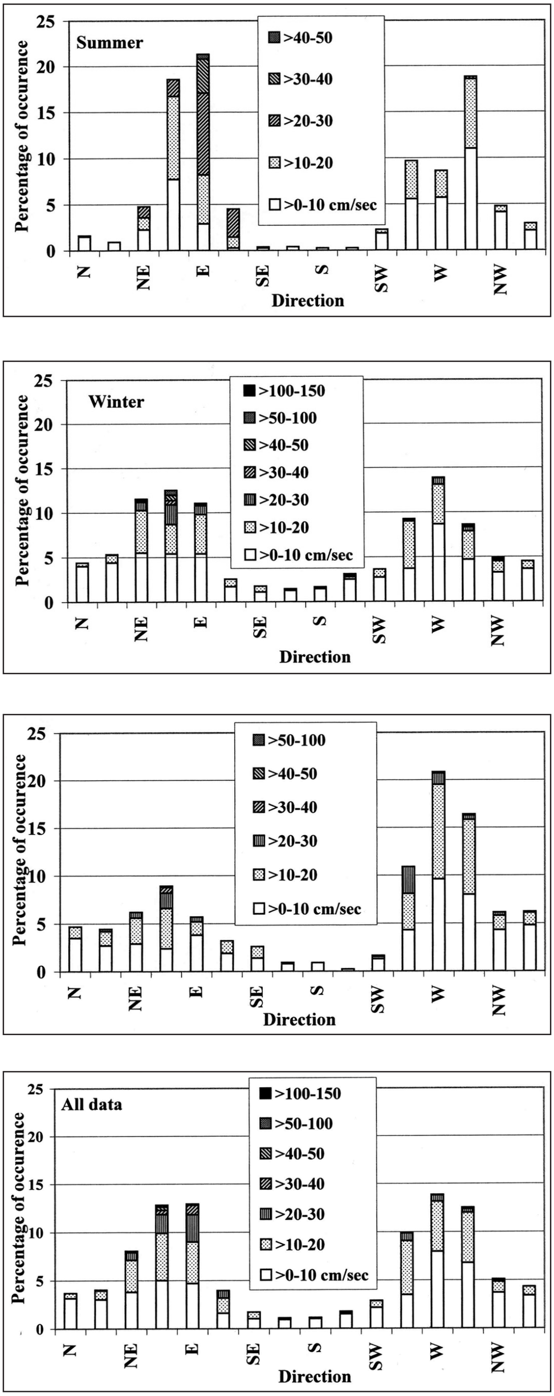

Fig. 7: Seasonally and all current data histograms at Damietta Harbour (August 1997 to July 1999).

January, 134 cm/sec towards SSW (onshore) which might bring part of the dredged materials back to the shore and navigation channel again (Fig. 1). During summer and spring, the maximum current velocity was 50 cm/sec towards the E and ENE respectively (Fig. 7). The tidal current had a periodicity of 12 hours and had some rotary effect (Fig. 8a and 8b). The tides are mainly semi diurnal with two unequal highs and lows daily. Progressive vector diagrams (PVDS) show steady offshore currents (NW to NNE direction), eastern currents (NE to E) and periods of onshore currents (SW to SE direction), Figures 8a and 8.b. Most important, however is the seasonal changing flow pattern.

During summer, the net near bottom currents were mostly between offshore (Fig. 8a.1) and onshore (Figs 8a.6 and 8b.5) through northeast direction. A near stagnant near bottom drift pattern occurs from 3rd June to 1st of July 1998 with a net drift only 50 km (Fig. 8a.5). The largest near bottom offshore net drift of 280 km was observed during the period 27th July to 17th of September 1997 (Fig. 8a.1), whereas the largest onshore net drift of 90 km was observed during the period of 7th June to 6th of July 1999 (Fig. 8b.5). Since the largest onshore net drift (90 km) is greater than the distance from the current/wave gauge to the shore line, water mass could not be moved further than the shoreline. It is suspected that onshore currents continue to transport sediments from offshore and the dumping area towards the navigation channel and the harbour site.

During winter, the net near bottom flow was eastwards through a northeasterly (Fig. 8a.2,3 and 8b.2,3) offshore direction (Fig. 8b.1). The largest easterly net near bottom drift of 140 km was observed during the period 6 January to 3 of February 1999 (Fig. 8b.2). Smaller net drift in an onshore direction was observed for a few days from 12 - 21 February 1999 (Fig. 8.b.5) and 1st of November to 16 of December 1997.

Spring is considered as a transitional period, when near-stagnant surface drift from 4th May to 1st June was observed with a net eastern drift of only 70 km. Figure 8b.4 shows onshore drift from 24th March to 21st of April 1999 with a net drift of 130 km.

The results of offshore current pattern (histograms and PVDS) coincide with the predominant wave direction for the different seasons. It is obvious that winter season,

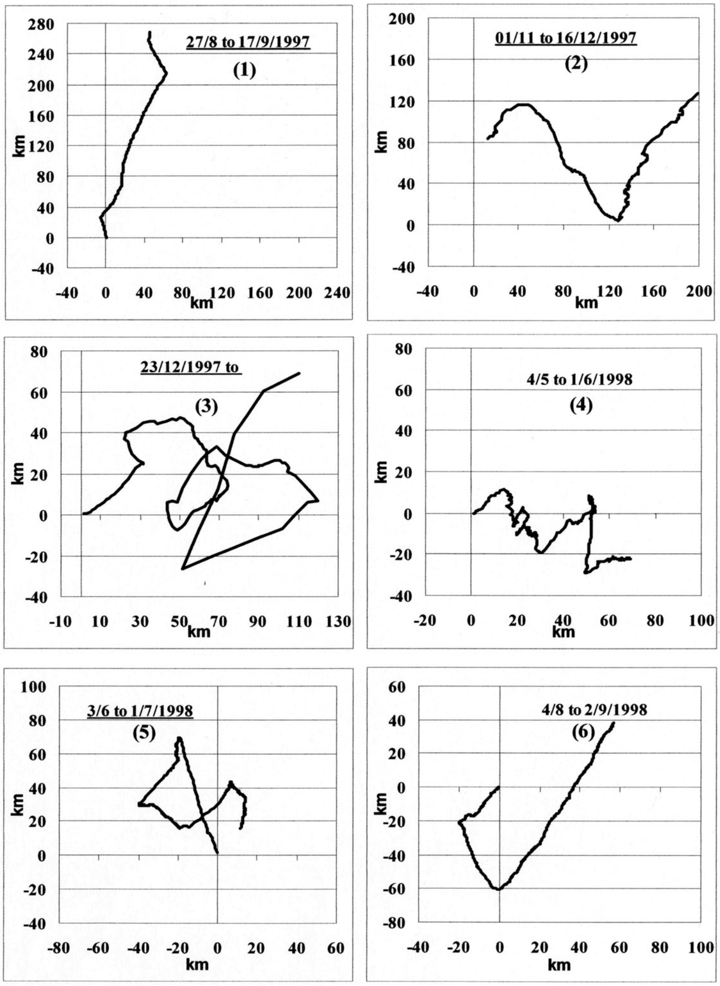

Fig. 8a: Progressive vector diagram for near bottom current for August 1997 to September 1998.

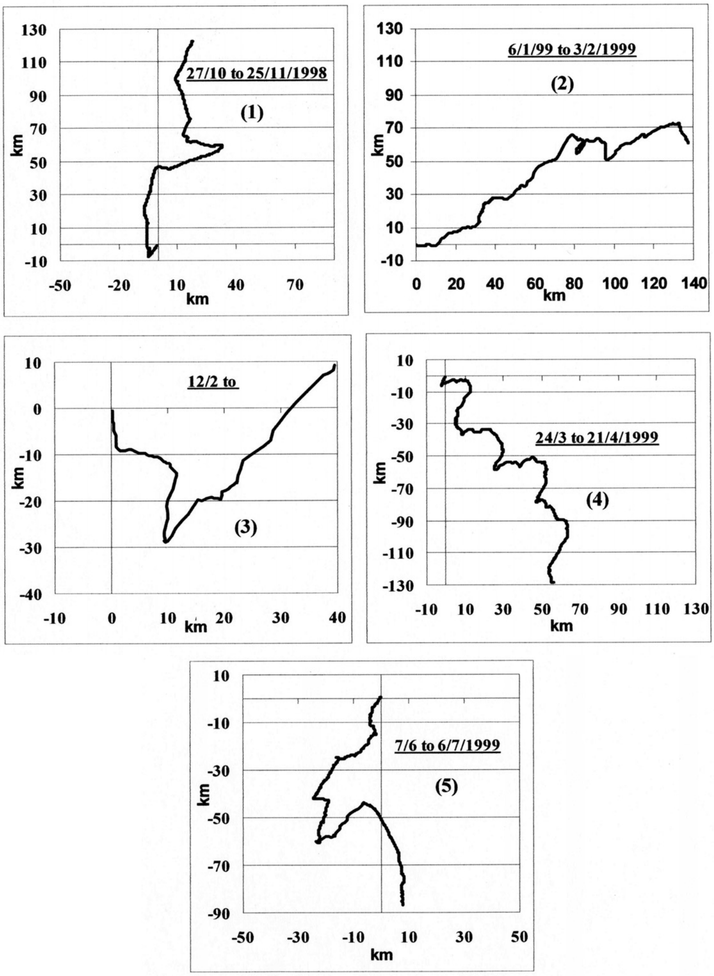

Fig. 8b: Progressive vector diagram for near bottom current for October 1998 to July 1999.

which is characterized by rough westerly sea waves, produces a maximum current speed with variable current direction, hence sediment transport from different directions were recorded (offshore, eastward and onshore direction). During spring and summer, the current speed is lower than the winter. The steady current in an onshore direction (SE and SW) was observed mostly during spring and summer. Thus, near bottom onshore current direction causes onshore sediment transport, which plays an important role in the redistribution of the eroded sediment during the winter season.

Erosion / Accretion Pattern

Volumetric changes during the study period were not constant. Before the construction of the harbour (1978-1982), the coastal stretch extended from the Gamasa drain to the Damietta mouth (Damietta Harbour lies in the middle) was marked by accretion for different depth zones (Fig. 9).

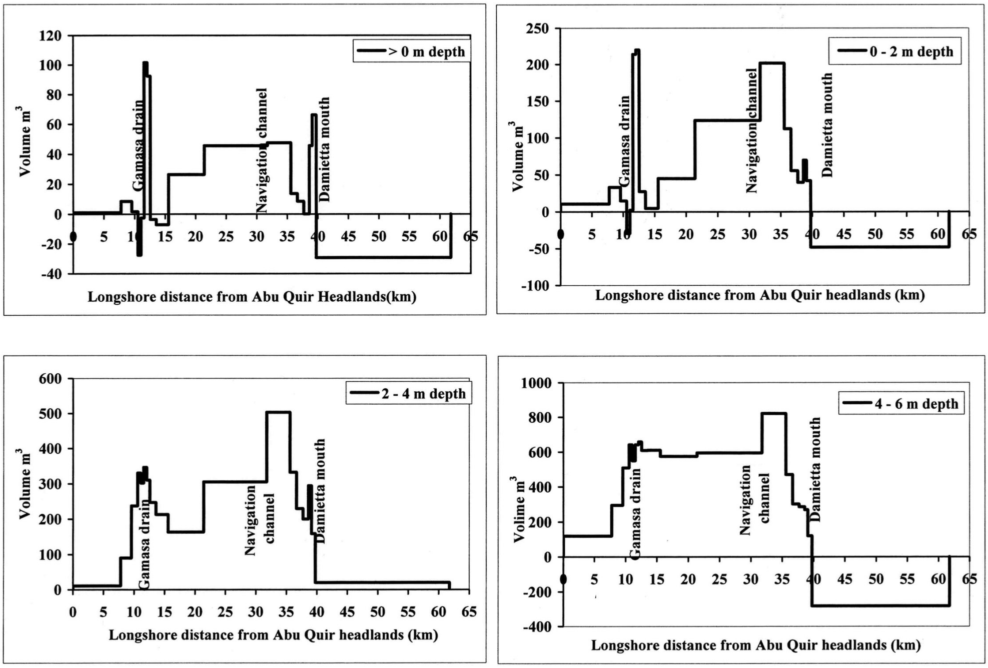

Fig. 9: Pattern of erosion and accretion (net volume) per meter, in different depth zone, along the study area between 1978 and 1982 (before construction of Damietta Harbour).

The area which extends from the Damietta mouth to about 22 km east is marked by erosion for different depth zones (>0, 0-2, 4-6 m depth) and except for at a 2-4 m depth there is a slight accretion. After the construction of Damietta Harbour (1988 to 1997), the western area of the harbour (2 km west) was marked by accretion, whereas the eastern area (5 km east) was marked by erosion for different depth zones (Fig. 10). This could be attributed to the fact that the western jetty (1.5 km long) interrupts the eastward sediment transport along the coast and blocks the eastern sediment transport. The annual net rate of littoral drift on the western side of the harbour is about $1.43 * 10^5$ m^3 (accretion), while the annual net rate of littoral drift on the eastern side is about $2.54 * 10^5$ m^3 (erosion) (Table 1).

Discussion

An intensive marine monitoring program was carried out to evaluate the effect of waves and currents on the sedimentation pattern of Damietta Harbour and its navigation channel. Beach profiles were used to define near shore changes (>0, 0-2, 2-4, 4-6 m depth) in terms of volume per meter before and after the construction of the harbour. Recorded waves and near bottom current data during the period from August 1997 to May 1999 were used to detect its effect on the sedimentation of Damietta Harbour. The study of waves, revealed that wave action along the study area is seasonally variable in intensity and direction. This coincides with NAFFA *et al.* 1991, who stated that wave intensity and direction is strongly related to the large-

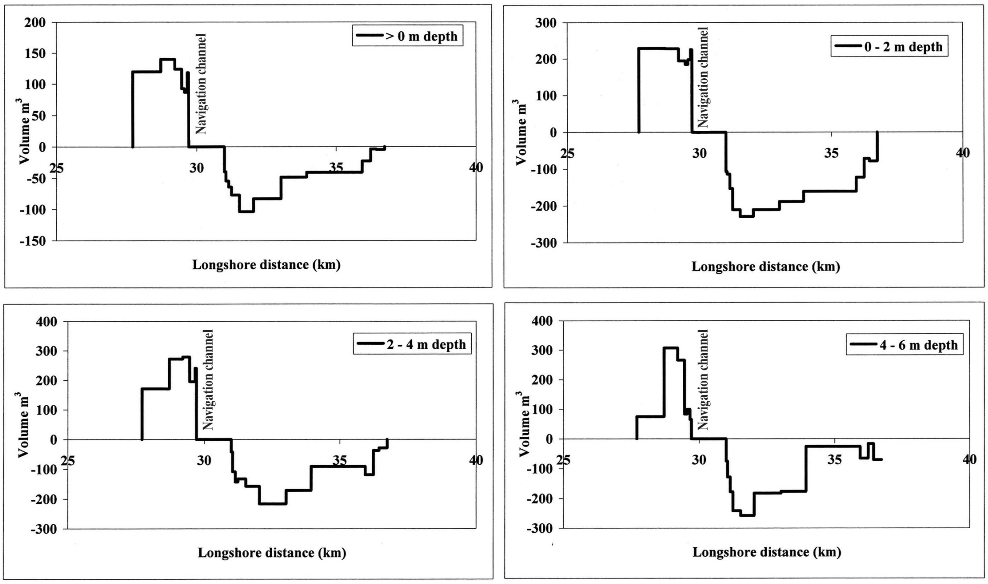

Fig. 10: Pattern of erosion, accretion and net volume per meter, in different depth zones, along coastal area of Damietta Harbour between 1988 and 1997 (after construction of Damietta Harbour).

Table 1
Accretion and erosion volume of sediment transport for different levels (1988-1997).

Water depth	Sediment volume x 105 m^3			
	East of Damietta Harbour		West of Damietta Harbour	
	Erosion	Accretion	Erosion	Accretion
> 0	3.23	0.20	0	2.51
0 – 2 m	9.24	0.11	0	4.22
2 – 4 m	7.63	0.20	0	4.44
4 – 6 m	6.53	0.48	0.48	3.64
0 – 6 m	23.40	0.99	0.48	12.30
> 0 – 6 m	26.63	1.19	0.48	14.81
Net volume	-25.44		+14.33	

scale pressure system moving over the Mediterranean Sea and the North Atlantic. The study shows that the predominant wave approach from NNW, NW and WNW is responsible for the generation of currents with an eastward direction (NE). The remaining portion of waves coming from N, NNE and NE directions produces reverse currents towards the west (SW). This is in accordance with the results of other studies along the Nile delta extensive coast (FANOS *et al.,* 1989, FRIHY & KHAFAGY, 1991, FANOS *et al.,* 1991 & ABO ZED, 1996). Near bottom currents were directed mainly in east (NE-E sector) and west (WSW-WNW sector) directions. The study clarified that the selection of the harbour site is characterized by a divergence of wave energy and a convergence of sediment drift (sink area). This agrees with SHARAF EL DIN and MAHAR 1997, who deduced that the area between Burullus and Ras El Bar is generally characterized by accretion. This confirms the results obtained by FRIHY *et al.,* 2002, who concluded that the harbour area lying within the eastern edge of Burullus embayment experiences sediment transport convergence. The largest near bottom offshore, onshore and easterly net drift was observed during summer, spring and winter, respectively. During winter, the easterly net near bottom drift is about 140 km (Figure 8b.2). This near bottom drift is greater than the distance between Rosetta (120 km), the Burullus headland (65 km) and Damietta Harbour. Hence the eroded sediments of the Rosetta promontory and the Burullus beaches contribute to the process of sedimentation of the harbour and its navigation channel. This coincides with FRIHY *et al.,* 1991 who stated that the sand transport eastward within the Burullus sub-cell is deposited to produce some shoreline accretion in the area of the New Damietta port. Our findings are also in agreement with FRIHY *et al.,* 2002, who manifested that the principal sources of sediment contributing to the processes of sedimentation of the harbour are the eroded Burullus and Ras El Bar beaches and submerged Damietta shoals. On the other hand, sediment eroded from the Damietta promontory is occasionally directed towards the west by current reversal, and some coming from offshore and the dumping area. The depth of the navigation channel is much greater than the whole surrounding area; therefore, the current velocity is reduced when crossing it, so the sediments will sink into it from different directions.

Conclusions

1. The overall study of dynamic factors (waves and near bottom currents) and erosion/accretion patterns manifest that the study area is a sinking area characterized by eastern, western, offshore and onshore sediment transport.
2. The onshore currents might bring back part of the dredged materials from the dumping area to the shore and to the navigation channel.
3. The orientation of the navigation channel (N-S) interrupts sediment movements from different directions. In addition, the existing harbour breakwaters are not long enough to stop sand bypassing from different directions. Also, bed load is moved along the sea bottom by currents and suspended sediment moves randomly due to heavy navigation in and out of the harbour.
4. The western jetty (1.5 km length) acts as a partial dam to littoral drift, blocking part of the sediment movement along the coast and erosion on the down drift side occurs (east of eastern jetty).
5. The selection of the harbour site is characterized by a divergence of wave energy and a convergence of sediment drift (sink area).
6. An impact assessment of the hydrodynamic factors and volumetric sediment changes is essential for any coastal construction plan to avoid future problems.

Recommendations

In order to mitigate the problem of sedimentation of the harbour and its navigation channel, a program should be carried out for one year with the following tasks:

- to perform bathymetric surveys to monitor the variation in the shoreline and offshore contours
- to determine sediment transport rates along different longitudinal regions of the navigation channel. These regions could be inside the harbour the section protected by the breakwaters, the f sector up to closer depth (maximum water depth for significant surface water effects on the sand bottom) and the offshore zone of the channel,
- to study spatial distribution of mean grain size, bed load and suspended load for coastal and offshore area
- to record near bottom current speed and direction on both sides of the channel to define current pattern throughout the year
- to develop a 2D- model to determine, wave and current distribution throughout the study area and to estimate the best and most economical solution, including the length of the breakwaters and the most suitable location for the dumping area
- to promote dumping of the dredged materials to selected areas outside the navigation channel at depths of more than 15 m and ensure that the Port Authorities are safeguarding such a regulation.

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