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MATHEMATICAL MODEL FOR COASTAL SEDIMENT TRANSPORT FOR THE DAMIETTA PROMONTORY

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ABSTRACT

The Damietta Promontory was constructed by sediment delivered to the coast by the Damietta branch of the Nile River. Following a long period of accretion the promontory began to erode early this century. This present study deals with the coastal processes. A 2-D mathematical model has been developed to study the coastal processes over the coastal area. This model is capable to calculate the wave characteristics, current distribution, sediment moving, and the corresponding bed level changes. The main objective of this study is to take one stations at north coast of Egypt (Damietta) to estimate the amount of erosion and accretion quantity, and to have a better understanding of beach stability in the attendance of existing protected structure, also predict the shore line after 10 years. This study also documented the rate of sediment transport, shore-line change and prediction of its position along Damietta promontory, which clarify an equilibrium case for the shoreline where it is oscillated between sea word and land word due to the exist of the detached break water.

1. INTRODUCTION

Two thirds of the Earth's surface is covered by water, one third is land, and the transition between them is a small strip, the coastal zone. Although the coastal zone covers less than 15% of the Earth's land surface, this is where the majority of the world's population live and work.

The coast is where land, water and air meet. This triple conjunction is further complicated by the fact that the water may be fresh or salt. The coast is best viewed as a zone of mixing or adjustment.

The coastal zone is that space in which terrestrial environments influence the marine environments and vice versa. The coastal zone is of variable width and may also change in time. Delimitation of zonal boundaries is not normally possible, more often such limits are marked by an environmental gradient transition. At any one locality the coastal zone may be characterized according to physical, biological or cultural criteria.

Many coastal problems are now being encountered worldwide have resulted from the unrestricted development of coastal areas and resources. These problems include the accumulation of contaminants in coastal areas, erosion, and the rapidly increasing decline of habitats and natural resources.

Beach erosion is one of the largest world problems from the perspective of land preservation. To control beach erosion, first of all, the reason why such an unfavorable phenomenon has occurred must be defined. To eliminate the cause is the best way to solve the problem, but this can not always be accomplished.

The shore can be protected against erosion through the use of coastal structures, a nonstructural procedure, such as beach fills, or a combination of structures and nonstructural method.

The Nile Delta is the only delta existing along the south-eastern part of the Mediterranean sea. It is considered one of the most interesting natural laboratories not only because of its coastal processes and evolution (erosion accretion), but also because of its economic importance related to Egyptian natural sources and land management.

So, it is important now to study the Nile Delta coast in the attendance of the existing protected structure to have a better understanding of the shoreline in the future which could help the protected structure studies to reach the equilibrium state of the coast.

2. MATERIAL AND METHODS

2.1. Data collection and processing technique:

- The data Collection about the Nile Delta Coast at the area of study include:
  - Shoreline position.
  - Water level.
  - Water level.
  - Wave Data.
  - Long-shore current data
  - Structures and other engineering activities.

Mainly for;

- Assemble and analyze the relevant data.
- Apply Numerical Modeling to get the Required output.
- Predict the shore position after 10 years.

The study area known by Damietta promontory is located in the eastern part of the Nile Delta at about 40 km to the west of Suez canal break-water at Port Said. It lies between longitudes 31^0 42\ E & 32^0 E, and latitudes 31^0 20\ 50\\ N & 31^0 21\ 30\\ N, Fig. 1.

The shoreline under consideration covers a distance of 25 km as follows:

- 22km to the west side of Damietta Nile branch.
- 3 km to its east side.

This promontory came into existence during the 10th century AD when 33% of the water and sediments of the Sebennetic branch were diverted to Damietta Nile branch and the rest to Rosetta branch (CoRI/UNESCO/UNDP 1978). The sediments supplied to the sea were directed to the west and east sides under the combined action of waves and currents and thus forming the present promontory.

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 1936-1941, at the NE extremity of Ras El Bar. In 1965 a concrete protective sea wall was built along the first 400 m of shoreline to the west of the Jetty, fronted by rip-rap and dolos. Three 150 m long concrete groins were added in -1970 to protect the beach to the southwest of the Seawall- and in 1982 a basalt rip-rap revetment was constructed between the groins and to the west of the groin field.

Presently eight detached breakwaters have been constructed to the west of the groins 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.

This study is to understand and to estimate the erosion and deposition processes using Numerical Modeling along the Damietta promontory, by using the following techniques:

1. Application of Genesis model to Study erosion/accretion patterns and volumetric changes along, eastern and western side of studied area.
2. Evaluate the correction factor for shore line estimation.
3. Prediction of the erosion/accretion volumetric changes, along the areas of study

of Damietta promontory.

Field data have a significant role where these data enable the investigators to know the factors affecting the Damietta area and to have a qualitative picture on the study areas.

The present data consists of wave measurement, long-shore current, and water level variation.

All these data have been collected by the Coastal Research Institute (CoRI) during 1997 & 1998. Fig. 2 gives the locations where these data are collected, while Table (1) shows a brief summary of them for Damietta.

The wave data collected by S4DW instrument were used in this study to predict wave properties (height, direction, and period) in deep water then at breaking along the Damietta coast. The sediment transport rates, computed by using Genesis model. Genesis model have been tested with the existing shore line from the profile at the study period May 1997- May 1998.

2.1.1. Sea Level Data:

Recording tide guage is installed and fixed near the exit of Damietta harbor figure (2). The level of records is adjusted to the mean sea level, which is zero survey authority. Normal checks of the level were carried out at regular intervals. The records began in 1 May 1997 until 31 May 1998. The hourly – recorded sea level data are gathered for thirteen months, then monthly mean sea level, the highest water level, the mean high, the mean low, and the lowest water level for the study period are obtained. For the mean sea level study, the mean values for the whole data set have been computed by averaging the value over the appropriate periods of a day, month or year respectively.

Table (1): Inventory of data collection (Damietta)

Time of the record	Continuous record	6 times per day for the whole period.	Almost two lines per day
Period of the record	1/5/1997 to 31/5/1998	27/8/97 to 5/12/1998	1/1/97 to 8/98
Instrument used	Automatic recording water level (Marigraph)	S4DW wave recorder	Submerged conical type of floats
Location	At one point in western side of Damietta promontory	In the western side of the study area in water depth 11.5 M.	Three stations at west, middle, and east
Type of data	1- Water level change	2- waves measurement (direction wave spectrum at one point)	3- Littoral Current

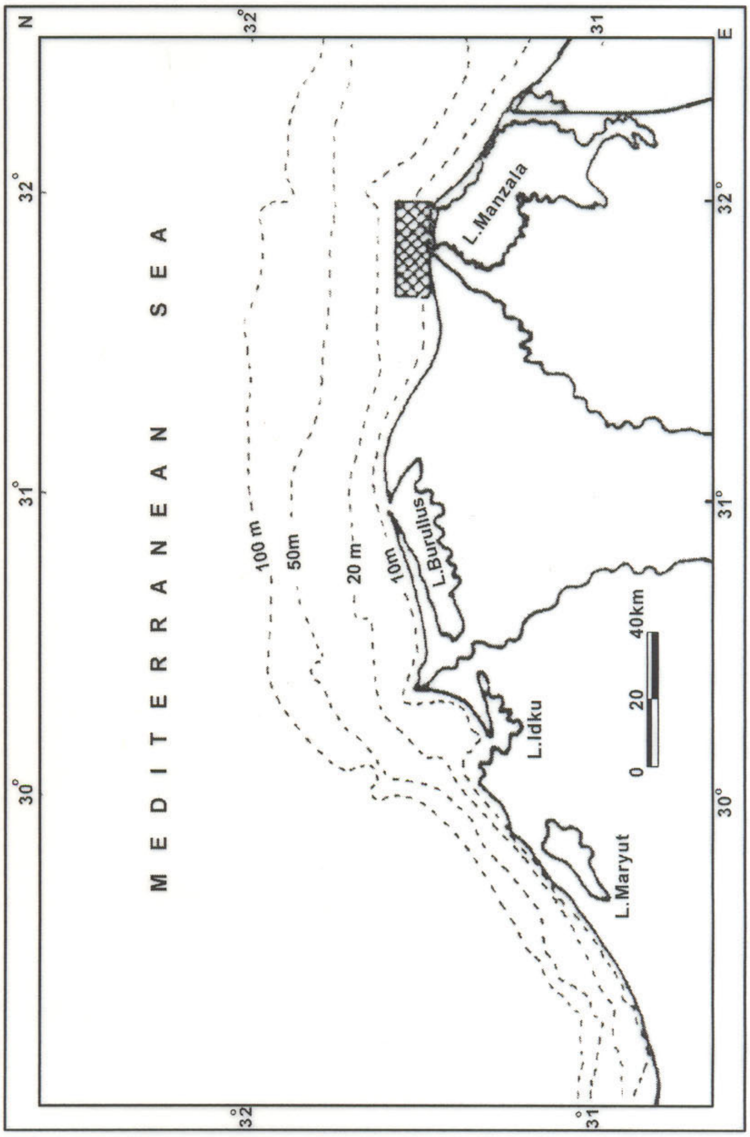

Fig. (1): Chart of the Mediterranean Egyptian Coast Showing the Area of Investigation

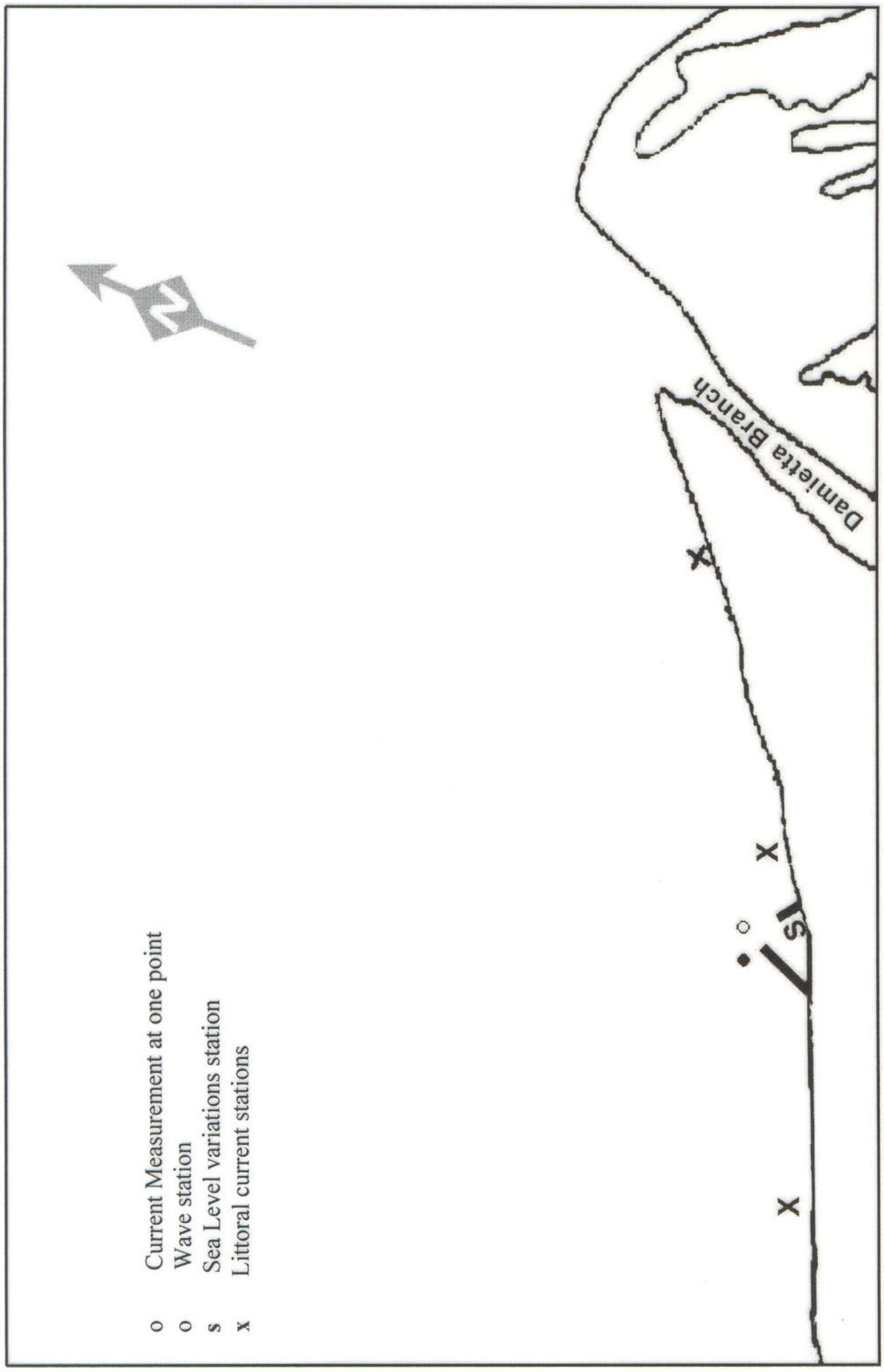

Fig.(2) Diagram Showing the Collected Places – Damietta

2.1.2. Wave Analysis:

Directional wave measurements were made using the S4DW, which was installed in a water depth of about 11.5 m.

Wave direction is derived from the two components of the current direction, i.e. north and east components. It is programmed in this study to work for a period of 20 min. every 4 hours.

Table (2) represents the available wave data during the study period it is clear that there are many gaps in the data.

Calculation have been prepared to calculate monthly and seasonally (for the whole wave data), maximum and mean wave period & wave height and percentage of occurrence for different wave height classes (0-50,>50- 100- >100-150 cm … etc) in the main sixteen directions (N, NNE, NE,... NNW). Also the cumulative percent of wave period have been calculated for different months and seasons, as well as, for the whole wave data.

Table (2) Number of valid wave data Damietta Through the different months and its data ranges

Months	Number of data	Date range	Number of days
August 97	27	27-31	5
September 97	98	1-17	17
October 97	110	13-31	19
November 97	181	1-30	30
December 97	147	1-31	31
January 98	83	1-14	14
February 98			
March 98			
April 98			
May 98	325	4-31	28
June 98	346	1-30	30
July 98	15	1-2	2
August 98	330	4-31	28
September 98	110	1.2&1 5-23	11
October 98	36	27-30	4
November 98			
December 98	21	3-5	3
Total	**1829**		**222**

2.1.3. Distribution of Wave Height and Direction:

There are many factors affecting the waves propagate from deep water to shallow water till they break. These factors are (Fanos 1979, Weigel 1964, SPM 1973), the shoaling which is the effect of the changes of the depth, the refraction which depend on the bottom contours shape, and then the breaking at the breaker line.

In order to be able to get the distribution of the waves on an area, these factors should be taken into consideration.

Generally, there are two basic techniques for refraction analysis namely: graphical method and numerical one. The numerical solution can be simplified for parallel contours, and Snell's low of the light can be applied.

So, for parallel contours and neglecting the effect of the current, the refraction coefficient K_R can be computed using Snell's low (SPM 1973), which is given by:

$$K_R = (\cos \alpha_o/\cos\alpha)^{1/2} \quad (1)$$

$$\alpha = \sin^{-1} (C/C_o \times \sin\alpha_o) \quad (2)$$

where,

α = is the angle between the wave crest and the shoreline.

α_o = is the angle between the deep water wave crest and shoreline.

C = wave celerity.

C_o = wave celerity in deep water.

The wave period is constant in deep and shallow water (SPM 1973).

The other factor affecting the wave height is the shoaling coefficient K_s which gives the effect of depth itself on the waves and this can be given by:

$$K_s = [(1/2)(1/n)(C_o/C)]^{1/2} \quad (3)$$

2.1.4 Wave breaking:

When the wave in the deep water move towards a shore until the water depth becomes shallow enough to initiate breaking. This depth is known by breaking depth D_b, and the wave height at this point is denoted by H_b.

The breaker height (H_b),the breaking depth (D_b), the unrefracted deep water wave height (H_o), the deep water wave length (L_o), is as follows:

$$H_b/H_o = 1/[3.3 \times (H_o/L_o)^{1/3}] \quad (4)$$

And

$$D_b/H_b = 1.28 \quad (5)$$

The last expression (D_b/H_b) can be computed by the use of beach slope.

The following expression was derived by SPM 1973:

$$D_b/H_b = 1/[b-(aH_b/gT^2)] \quad (6)$$

$$a = 1.36\, g\, (1-e^{-19m}) \quad (7)$$

$$b = 1.56 / (1+ e^{-19.5m}) \quad (8)$$

Where,

T = wave period

g = acceleration of gravity.

$n = 1/2[1+(4\pi d/L) \sinh(4\pi d/L)]$

2.2. Applying Gensis: Generalized Model for simulating shoreline change:

Mathematical shoreline models are tools which are widely used now a days to study the effect of hydrographic parameters on coastal processes and calculate the sediment transport rates and consequently the shoreline changes.

The SMS (Shoreline Modeling System) program was developed at the Coastal Engineering Research Center (CERC),US Army Engineer Waterways Experiment Station. (Genesis Manual)

The SMS program contains numerical simulation model, Genesis (GENEralized model for Simulating shoreline change), Genesis model, Generalized model for simulating shoreline changes. This model predicts shoreline changes due to spatial and temporal differences in wave forcing.

The spatial long-shore extend of the modeled area covers from less than one Kilometer to hundred Kilometers, and simulation interval ranges from a month to hundred months. The shoreline evolution portion of the numerical model is based on one - line theory which assumes that beach profile shape remains unchanged, allowing shoreline change to be described uniquely in terms of the translation of a single point on the profile.

The standard assumptions of shoreline change modeling are:

a- The beach profile shape is constant.

b- The shoreward and seaward limit of the profile are constant.

c- Sand is transported along-shore by the action of breaking waves.

d- The detailed structure of the near-shore circulation is ignored.

e- There is a long-term trend in shoreline evolution.

The equation governing shoreline change is formulated by conservation of sand volume. Consider a right-handed Cartesian coordinate system in which the Y-axis point offshore and the X-axis is oriented parallel to the trend of the coast (Fig. 3).

The equation for rate of change of shoreline position is:

$$\partial y/\partial t + 1/(D_b + D_c)\{\partial Q/\partial x - q\} = 0$$

∂ y : the change shoreline position.

∂ X : the length of the shoreline segment.

∂ T : time interval.

D_b: the Bern elevation.

D_c: closure depth.

∂Q : the change in the long-shore sand transport rate.

q : the-volume of sand which add or removes per unit width of beach (which arise from a line source or ink).

In order to solve the Equation, the initial shoreline position over the full reach to be modeled, boundary conditions on each end of the beach and values for Q, q, D_b, and D_c must be given.

And the empirical predictive formula for the long shore sand transport rate used in Genesis is:

$$Q = (H^2 C_g)_b, \{a_1 \sin 2\theta_{bs} - a_2 \cos\theta_{bs} \times \partial H/\partial X\}_b$$

Where

H = Wave height

C_g = Wave group speed given by linear theory.

B = Subscript denoting wave breaking condition.

θ_{bs}= Angle of breaking waves to the local shoreline.

The non-dimensional parameters a1 and a2 are given by:

$$a1 = k_1/16(p_s/p\text{-}l)(1\text{-}P)(1.416)^{5/2}$$

$$\text{And } a2 = k_2/8(p_s/p\text{-}l)(1\text{-}P)\tan\beta\ (1.416)^{7/2}$$

Where

K_1, k_2= empirical coefficient, treated as calibration parameter.

p_s= density of sand (taken to be 2.65×10^3 kg/m^3 for quartz sand).

ρ= density of water (1.03 10^3 kg/m^3 for seawater).

P= porosity of sand on the bed (taken to be 0.4).

Tan β= average bottom slope from the shoreline to the depth of active long-shore sand transport.

For Genesis, three types of plots can be created:

1- The net transport rate option, displays the average annual net long-shore sand transport rate, computed over the simulation period.

2-The shoreline changes option, allows the user to display the computed shoreline change between the initial shoreline position and the final shoreline positions.

3-The shoreline position option, enable the user to plot the initial and calculated shoreline together with the specified coastal structures simulated, including beach fills, seawall, Groins and detached breakwaters.

The developed model was calibrated using the available data from Damietta area, which obtained from field measurements. After getting all the required constant and parameters, the model has to be applied.

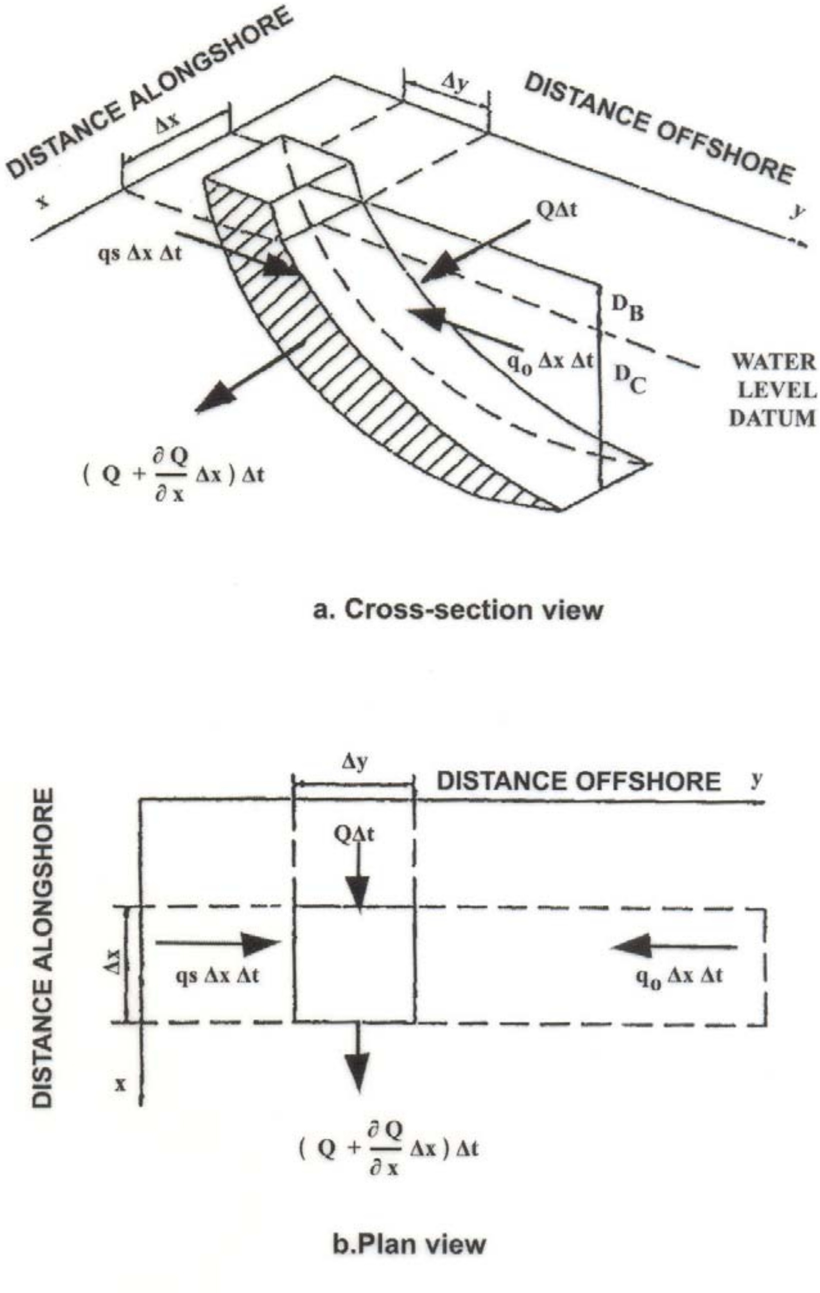

Fig. (3) Definition Sketch for Shoreline Change Calculation

The input data and their resources are as follows:
1- Directional wave spectrum data recorded by S4DW, installed at depth 11.5 m, during the period from 1/1/1998 to 31/12/1998.
2- The shoreline orientation and near-shore water depth are taken from CoRI (Coastal Research Institute) survey in 1998.
From the map of scale 1:10000 for study area, the grid system were applied as the shoreline grid. The shoreline was divided into 98 cells, the cell unit is 100 m in length along the shore.

Operation of the Genesis Model requires:
(i) The initial shoreline at the beginning of all simulation.
(ii) Input of a measured shoreline position corresponding to the end of the simulation, which is used to compute a calibration verification error.
(iii) Input the location and position of structures.

3. RESULTS AND DISCUSSION

3.1 Rate of sediment transport:

Genesis model showed the distribution of sediment transport rate along the study area for year 1998 (Fig. 4). This figure shows that the maximum rate is at the eastern side of the east break water of Damietta harbor (1001.1 $\times 10^3$ m^3/year). While the lower value (2.0055 $\times$ 10^3 m^3/year) is taken place on the western side of the west break water for Damietta harbor. Generally the average of sediment transport in the study area is 523.4 $\times$ 10^3 m^3/year.

3.2. Shoreline change:

Figure (5) show the shoreline change during 1998 along the study area (according to Genesis model). From this figure we can deduce the following:
1- At western side of the study area, shore line oscillated between back and fore-ward direction with a maximum distance 42.5 m, and 40.02 m, respectively.
2- Behind the western breakwater for Damietta harbor, shoreline moves fore-ward (due to littoral Current direction, and exist of western breakwater).
3- Infront the eastern side of Damietta harbor, shoreline moves fore-ward with a maximum value (93.4 m), which explain the sedimentation of harbor channel.
4- The middle part of the study area is oscillated between seaward and landward with a few distance, due to the exist of the detached breakwater and current circulation pattern.
5- At the western side of Damietta mouth the shoreline moved landward with maximum value (52.5 m).
6- Around the Damietta mouth shoreline move seaward, with maximum distance (26.5 m), this explain more sedimentation in the mouth.

3.3 Shoreline position:

Fig. (6) shows the shoreline position after one year (from 1/1/98 to 31/12/1998) as a result from applied Genesis model.

From this shore, we can deduce the following:
1- At eastern side of Damietta harbor, shoreline shifted seaward.
2- Outside the eastern breakwater, shoreline shifted more seaward i.e. around the eastern breakwater there is a too much accretion.
3- In front of the detached breakwater, the shoreline oscillated between landward and seaward.
4- At the western and eastern side of Damietta Mouth shoreline shifted landward but in-front the mouth is shifted seaward i.e. there is much erosion around the mouth with too much sedimentation in the mouth itself, (due to effect the current circulation, and protective constructions in this area).

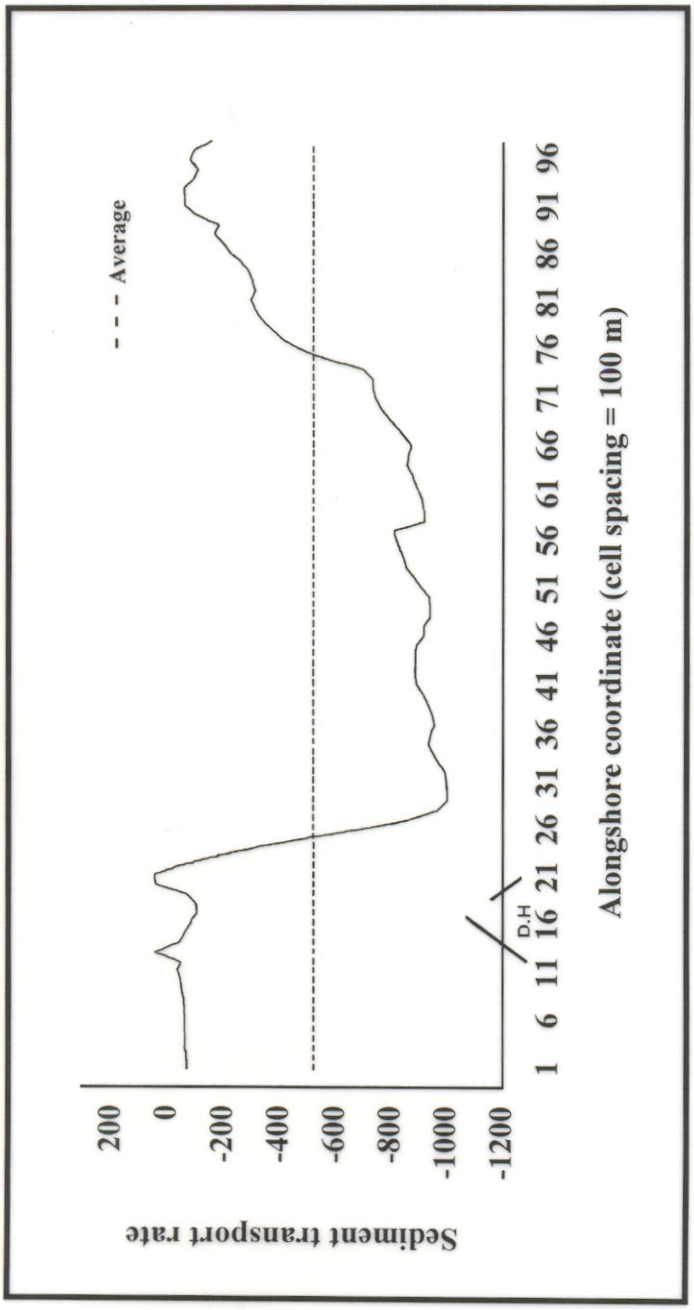

Fig. (4) : Rate of Sediment Transport Along Damietta Area During 1998 ($\times 10^3$ m^3)

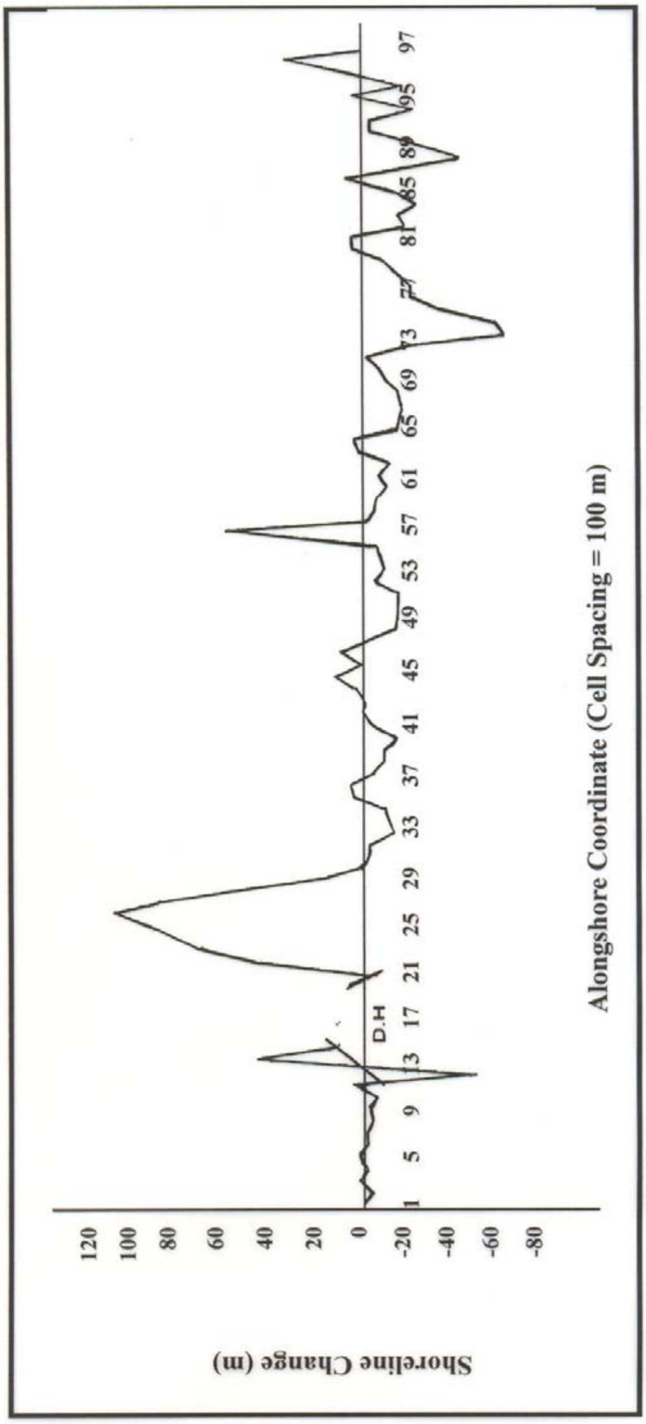

Fig.(5) Shoreline Change From Initial

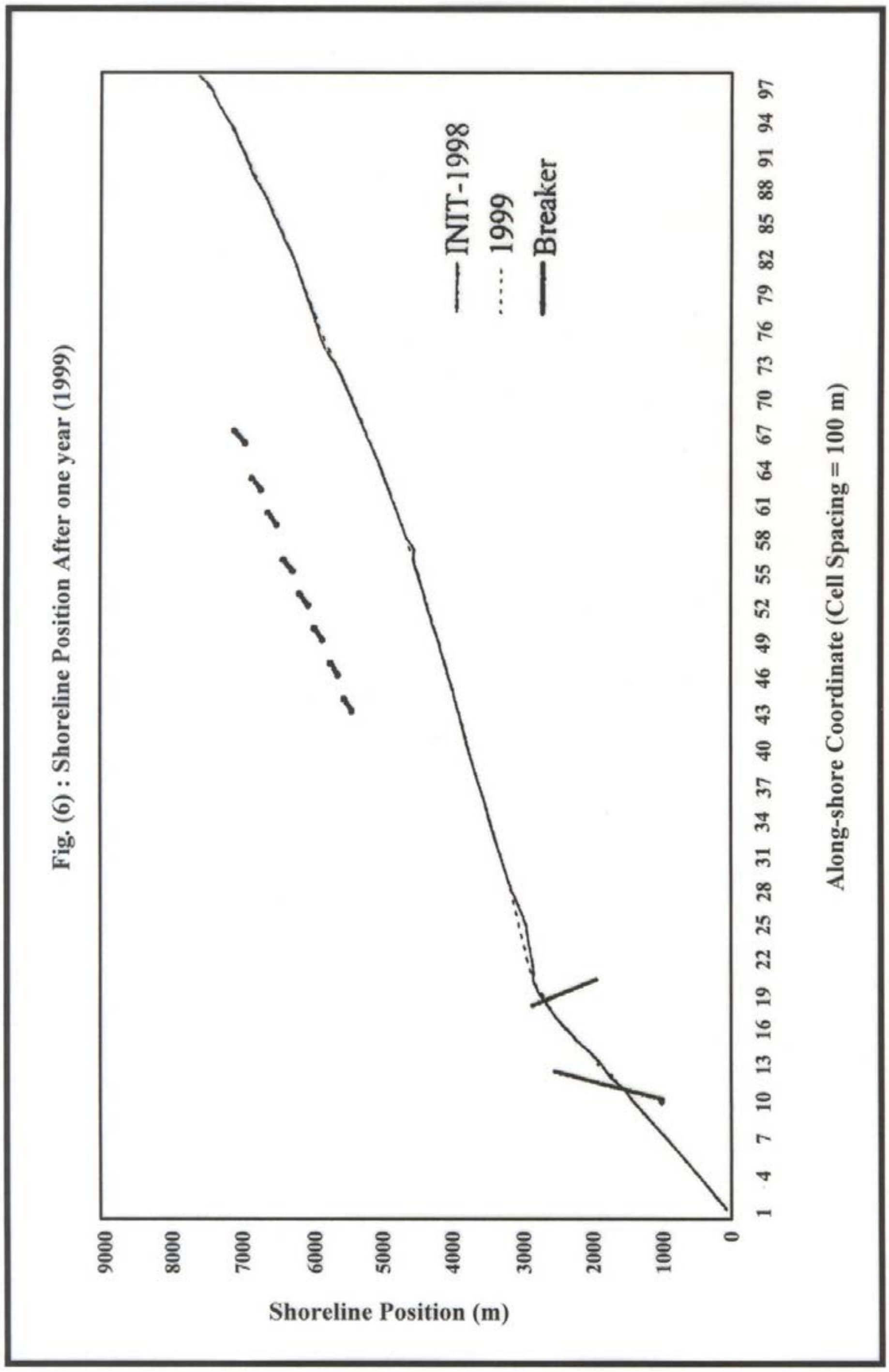

Fig. (6) : Shoreline Position After one year (1999)

3.4 Prediction of shoreline position:

The shoreline position has been predicted after ten years from a study period using SMS Model. The results are shown in Fig. (7). From this figures it is seen that:

1- At the western part of study area behind the western harbor breakwater, shoreline retreated landward with a maximum value 208m closed to breakwater.

2- Around the eastern breakwater the shoreline oscillated between shifted landward and seaward with higher value 178 & 258 m. respectively.

3- From eastern breakwater of Damietta harbor and until a distance about 3 km, to east, the shoreline shifted seaward (accretion) with a higher distance 438 m.

4- In central region of the study area there is a neutral and equilibrium of shoreline where it oscillated seaward and landward and shifted with a very few meters, (due to the existence of the detached breakwater).

5- In the area behind the western side of Damietta mouth, shoreline shifted landward with a higher value 230 meters (erosion case).

6- Around Damietta mouth shoreline shifted seaward with a higher value equal to 58 m (more sedimentation for Damietta mouth).

Thus the general predominant direction of sediment transport is towards east on both side of Damietta harbor and west side of Damietta mouth due to the predominant wave direction. Also the values by Genesis and the direction of sediment transport results is in agreement with other studies done before.

Also the rate of sediment transport of the eastern side of Damietta harbor is more than on western side (agreement with other methods).

4. CONCLUSIONS

The present study was undertaken in an effort to better understanding the prevailing dynamic forces affecting coastal changes along Damietta promontory.

Moreover, this study would likely provide practical insights information that could assist in solving the problem of siltation of the Damietta harbor channel and coastal change along Damietta promontory. For Damietta the study area lies on the northeastern Nile delta Coast of Egypt and extend about 25 km long.

The sediment transport rate was calculated using Genesis model. The average of sediment transport rate in the study area is 523.4 x 10^3 m^3/year, while the maximum and the minimum values are (1001.7 x 10^3 m^3/year) & (2.006 x 10^3 m^3/year), at the eastern side of east Break water, and the western side of west break water for Damietta area, respectively.

The middle part of the study area is oscillated between seaward and landward with a few distance, due to the exist of the detached breakwater and current circulation pattern.

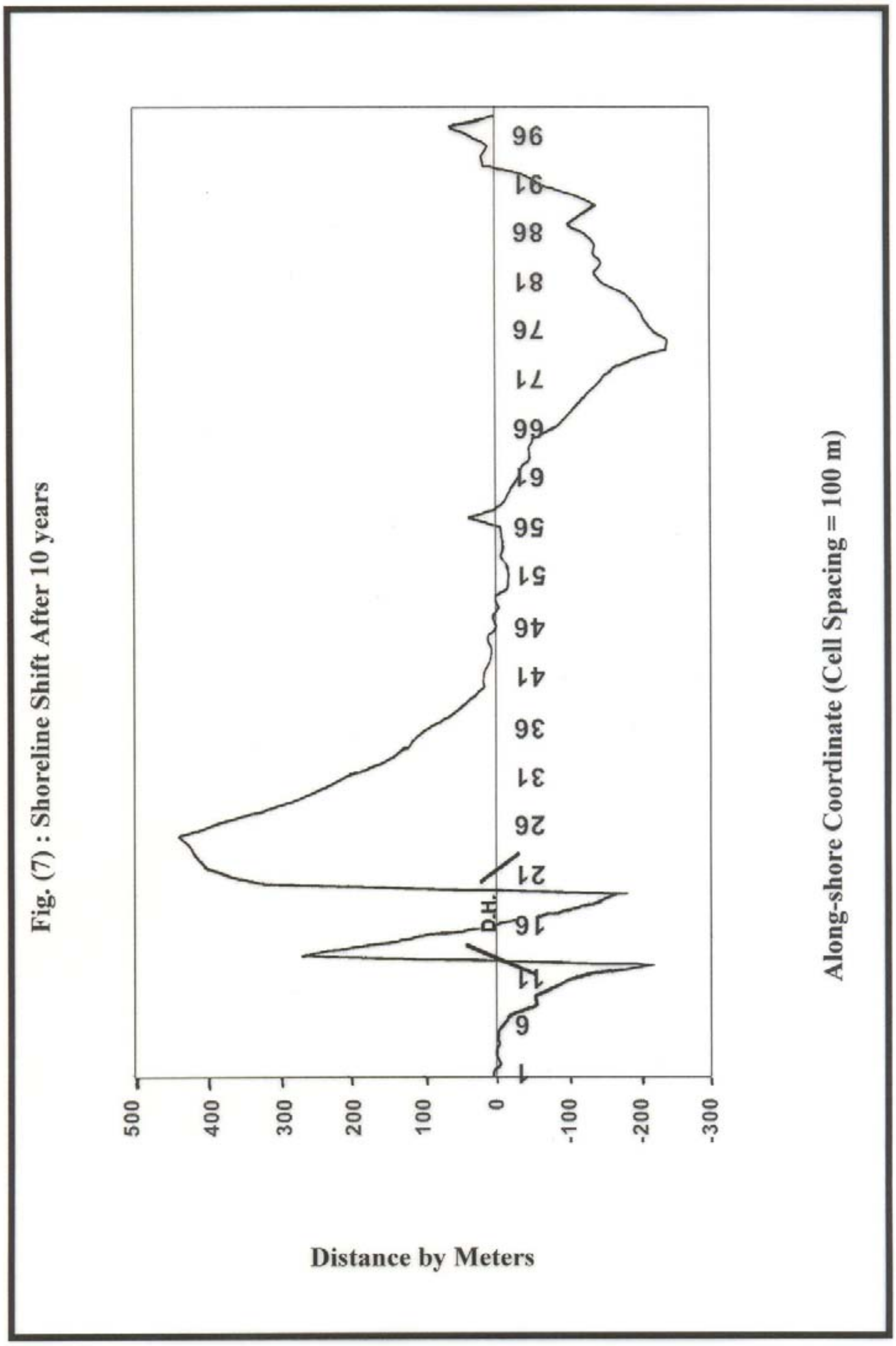

Fig. (7) : Shoreline Shift After 10 years

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