Beach and Nearshore Morphodynamics of the Central-bulge Of the Nile Delta Coast, Egypt

O. E. Frihy[*1] and E. A. Deabes[*]

[*] *Coastal Research Institute, 15 El Pharaana St., 21514, El Shallalat, Alexandria, Egypt.*

[1] Frihyomr@yahoo.com

Abstract- **Beach- nearshore profiles, annually surveyed between 1991 and 2010, combined with coastal processes are analyzed to assess changes in rate of shoreline position, seabed level, sediment volume and seabed grain sizes that developed after extensively protecting the central-bulge of the Nile delta coast with numerous engineering structures. This area including the Burullus-Baltim beach, 25 km long, is located on a very active littoral zone, which has experienced widespread erosion of -5 m/yr, originally before construction of a series of engineering structures to stabilize the shoreline. These structures built in stages and include 17 detached breakwaters, 9 groins, 3 jetties, seawall and basalt riprap. The shift from beach erosion prior to the construction of these engineering structures to accretionary tombolos (18.9 m/yr shoreline advance; 36 cm/yr seabed accretion) and salient has successfully stabilized the coastline. However, erosion appeared downcoast of the detached breakwater system up to the Kitchener drain has resulted in the construction of additional groins. It is expected that sediment producing to the east along Gamasa embayment by the eastwardly unidirectional current will subsequently diminish as a result of sand trapped by the constructed breakwaters, built early in 1993. Unexpectedly, the active accretionary channel-mouth sandbars developed at the Kitchener drain mouth followed the construction of the nine groins have contributed to the problem of periodic sedimentation of this drain. In general, the study coastline exhibits a wide range of beach dynamics resulted from interactions of waves and shoreline orientation, hard structures and sediment supply.**

Keywords- **coastal processes; beach erosion; protective structures; sediment transport; estuarine sedimentation; detached breakwaters; coastal dunes**

I. INTRODUCTION

Coastal structures such as jetties, groins, seawalls and shore-parallel breakwaters are probably the most dramatic cause of man-induced coastal changes. The fundamental problem associated with these structures is that they induce beach erosion on their lee or downdrift sides which may extend beyond the project area. In most cases erosion at this eroded sector might need for additional structures. This process may be repeated and continues to cover the entire coastline, referring to as the chain reaction [1]. In view of mitigation, beach erosion resulted from this situation cannot be stopped but it can be slowed, and loss of beach material can be compensated for.

The focus of this study is on erosion induced following protection of the central-bulge of the Nile delta coastline in the eastern Mediterranean Sea (Fig. 1A). It is almost 25 km long and extends from ~3 km west of the Burullus lagoon inlet to the Kitchener drain along. The coastline of this area including Burullus-Baltim sector forms a broad headland that was formed by the Sebennitic channel, a former third river tributary that dried up ~2000 B.P [2]. The mouth of the Sebennitic branch was located on what is now the inner to middle shelf off the north-central Nile Delta. Baltim beach is one of the most important public beaches fronting the central sector of the Nile Delta coast and is located about 11.5 km east of the Burullus lagoon inlet (Fig. 1A). Kitchener Drain, excavated between 1930 and 1940, lies in the eastern limit of the study area and flows south to north. This drain, ~70 km long and ~60 m width, receives an amount of 2.4 x 10^9 m3/yr drainage water via seven pumping stations from about 495 x 10^3 Fadden of agriculture land [3].

The study coastline is partially backed by a ~18 km long barchan dune system ranges from 500 to 800 m in width and is acting as a vital component of coastal and flood natural defenses (Figs. 1A and 2A, B,C). This system begins ~2.5 km east of the Burullus lagoon inlet and ends at the Kitchener Drain. The dunes are experiencing sea cut-off erosion that represents a significant source of sand to

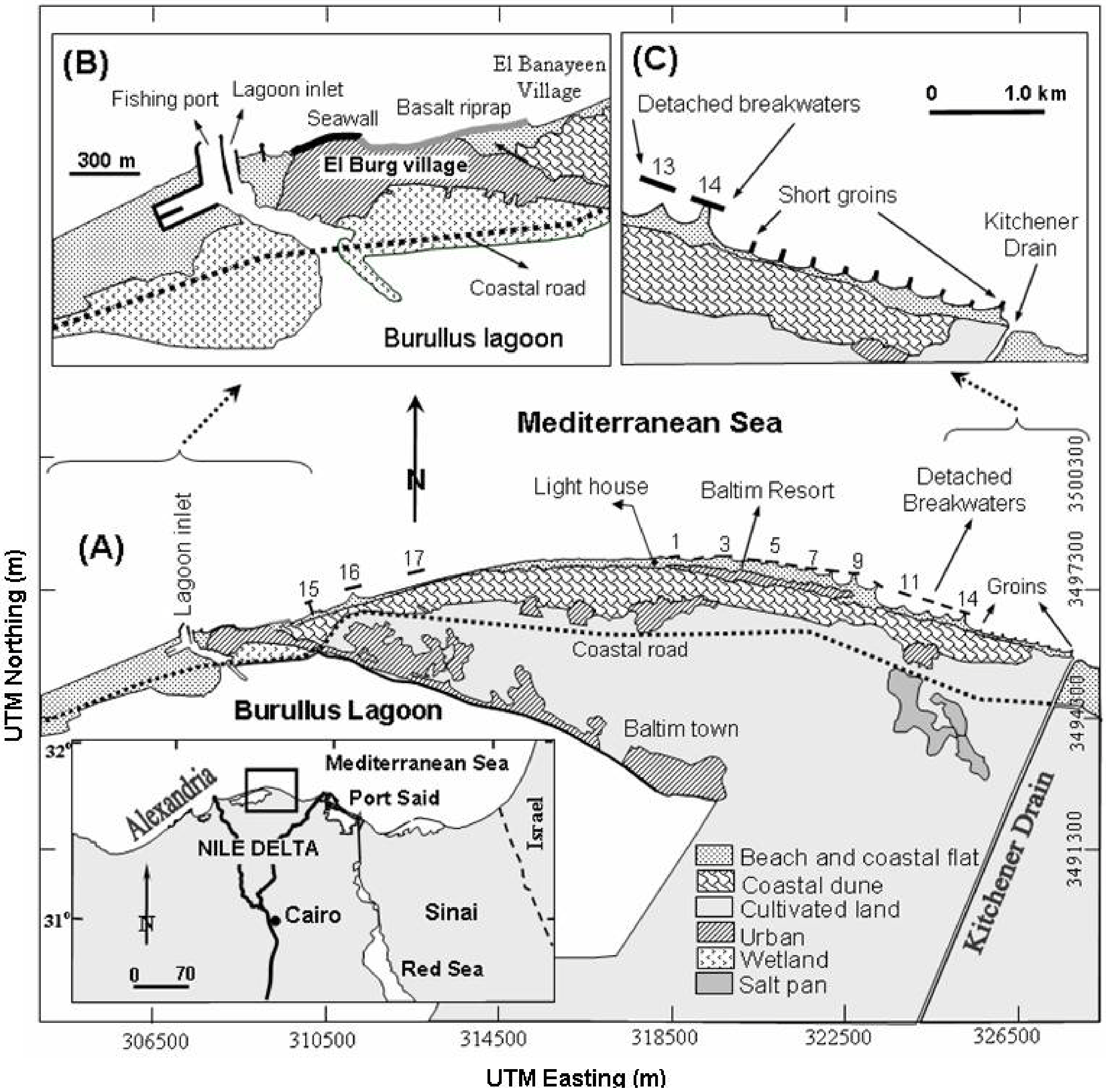

Fig. 1 (A) The study area at the Burullus-Baltim bulge sector on the north central-bulge of the Nile delta coast with the main geomorphologic units and the existed coastal structures (17 detached breakwaters, 9 short groins, 3 jetties, seawall and basalt riprap). Eventfully much of sediments moving to the east have trapped by the easterly longshore current forming tombolos in the lee side of the detached breakwaters (#1 to #17). (B) The Fishing port and the Burullus lagoon inlet. (C) The downdrift of the detached breakwater system at the Kitchener drain.

the adjacent beach and its contiguous littoral cell. The backshore flat between the beach and dunes is wide in places but absent in others (Fig. 2C, D). A large scale project is under consideration for industrial mining of heavy minerals in the Burullus and Baltim dunes. This project has been initiated on an evaluation and mineral processing study undertaken by Abu Halawa [4], confirmed the existence of approximately 5% total economic minerals in those dunes.

Erosion commenced along the Nile delta coastline when discharges from the river began to decrease in the late 19th century as a result of construction of river flow control structures, such as dams and barrages, on the upper and lower Nile River [5]. Following virtual cessation of sand delivery to the coast from the Nile, beside the action of wave-driven longshore currents continued to transport beach sand to the east, resulting in a major adjustment of the delta coastline (e.g. [5], [6] - [7]). Coastal erosion and sedimentation problems in channels (harbors, lagoon and estuarine inlets) still a major issue around the Nile Delta of Egypt.

Prior to protection, maximum erosion occurred adjacent to the delta promontories at, Rosetta, Burullus and Damietta. In general and under wave action, the eroded sand from these promontories is carried to the east, where it is deposited and results in beach accretion just to the east of the promontory saddles and also along the next embayments,

Fig. 2 Selected photographs showing prominent coastal features in the study area. (A) The western most part of the study area showing the Fishing port, lagoon inlet, concrete seawall and basalt riprap. (B) Morphological features formed by the detached breakwaters, #1 to #12, built at the Burullus and Baltim beach (2008 Ikonos satellite image). (C) The Burullus dune looking west where the basalt riprap fronting El Burg village. (D) The "T" shape groin recently constructed at ~2.5 km east of the Burullus inlet.

resulting in an overall smoothing of the coastline (Fig. 3), as in [8]. A portion of the eroded material has also accreted in the form of spits or shoals near the lagoon and river inlets that adversely impacted their navigation entrances [9]. The overall alongshore pattern, Fig. 3, has been extensively disrupted as a result of the beach intervention of hard protective engineering structures constructed along the eroded delta shores. With regard to the study area, and starting from the east, a fishing harbor was constructed between 2001 and 2009, immediately adjacent to the Burullus inlet (Figs. 1B, 2A). The inland harbor basin is protected by two jetties including one from the already jetties built on both sides of the Burullus lagoon inlet. These two inlet jetties (~300-180 m long) were originally built to control the navigation entrance of the Burullus lagoon inlet. Immediately east of the Burullus lagoon entrance, a concrete 600-m long seawall was built in 1982 to protect the eroded beach of El Burg village (Figs. 1B, 2A). To the east of this seawall a basalt riprap of ~1.0 km in length was constructed in 1984 to protect the eastern extension of that village. Further east of the basalt riprap, the Burullus-Baltim beach remained unprotected until 1992, at which time construction of protective breakwaters commenced. off this coastline, a total of 17 shore-parallel detached breakwaters have been constructed in four successive phases between 1993 and 2007 (Figs. 1A). The breakwaters were constructed parallel to the beach in the active surfzone at ~3 m water depth. The more recent detached breakwaters #15 to #17 have been constructed at ~ 3 km east of the Burullus inlet between 2001 and 2007. The length of breakwater #1 through #15 approximately 250 to 350m, whereas breakwaters #16 and #17 have a 500 m long each, as in [10]. Among these structures, breakwater #15 has taken a "T" shape (Figs. 1A and 2D). Three or two breakwaters are expected to be built eastward between breakwaters #17 and #1 to protect the large unprotected gap in this area, approximately 5.2 km long (Fig. 1A).

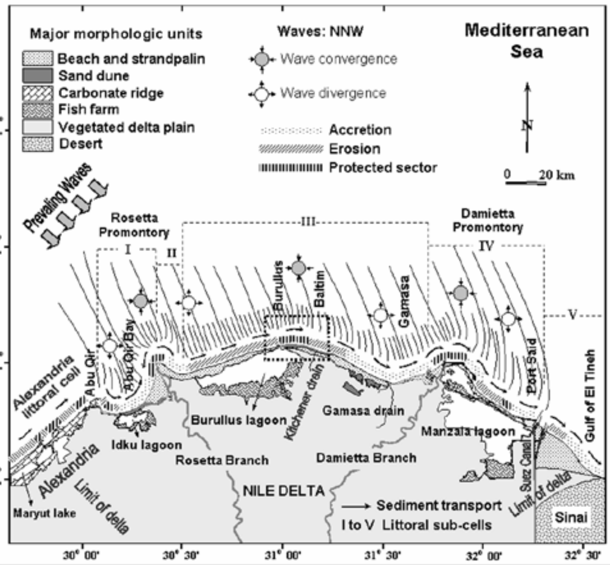

Fig. 3 Map of the Nile Delta east of Alexandria showing major geomorphologic units and the general alongshore pattern of erosion and accretion, and the protected shores (updated from [22]), and the boundaries of the five littoral sub-cells identified by [12]: I= Abu Quir sub-cell; II= Rosetta sub-cell; III= Burullus sub-cell; VI= Damietta sub-cell; and V= Port Said sub-cell. Wave orthogonals energy levels are indicated for the refraction of waves arriving from the NNW [30].

Previous studies of the shoreline position and sediment budget along the coastline of the Nile Delta show that coastal areas can be divided into a series of discrete sedimentation compartments called "littoral cells" (e.g. [11] and [12]). These sub-cells are generally located between the delta promontories and major engineering structures between them. The principal sources of sediment for each cell are the promontories that, through erosion, supply large quantities of sand to sink areas. These sinks occupy bays, embayments and saddles that generally lie to the east, exception of west Rosetta (Fig. 3). The area under investigation occupies a part of the Burullus littoral sub-cell, which extends from the Abu Khashaba east Rosetta promontory to a point between Damietta Harbor and Damietta River mouth (Fig. 3).

A series of studies on the morphology of the Nile Delta coast have been undertaken, ranging from local shoreline change patterns (e.g. [13], [14], [15], [16], [17], [18], [19], [20] - [10]) to a regional scale (e.g. [6], [8], [21] - [22]). With exception of the study of Frihy [23] on the seabed scour off the Rosetta promontory, these previous studies have tended to focus on shoreline change with relatively no emphasis on local seabed changes in the vicinity of engineering structures. Although these previous studies few of them has addressed the existence of accretional sand features (e.g. [24] and [25]). Accretionary formations in the form of spits and sand bars at the channel mouths of the Rosetta and Damietta Nile rivers have been identified along the coastline of the Nile delta, which has resulted in intermittent closure to shipping activities [9]. Therefore, the present study is completely different from other previous attempts in that it focuses on determining rate of shoreline and seabed changes estimated from updated ground survey and beach-nearshore profile measurements. Moreover, degree of disruption of the sedimentation pattern in response to the existing protection works, including those recently built is assessed. It also addresses accretional sand features responsible for sedimentation of the mouth of the Kitchener drain and factors contributed to their formation.

II. METHODS

Beach survey associated with beach profiling is used in this study to understand and quantify the variations in shoreline position and seabed levels which are undergoing continuous change in response to the marine processes. Shoreline and beach-nearshore profiles were surveyed between 1991 and 2010 along the 25 km long of the study area, covering a time span of 19 years. Morphodynamic changes are interpreted from consulted coastal processes prevail in the region, waves and currents in particular. Because of the missing profile data locally in stretch west of the Kitchener drain, 2.7 km long, shoreline positions of 2004, 2005, 2006, 2008, 2009 and 2010 were only used to calculate rate of shoreline and seafloor changes. Profiles were surveyed in the autumn (September/ October). The survey data were collected along 63 profile lines, numbered P1 through P63 in Fig. 4A, spaced between 90 and 1270 m intervals, and up to ~1.0 km offshore that correspond to the 6.0 meter water depth contour.

The profile surveys have been undertaken in three parts. The land survey was conducted using a Nikon Total Station POWER Set 3010 and graduated staff. The surfzone (the zone between the shoreline and water depth of ~1 m below MSL) was surveyed on foot during the land survey. The nearshore, from ~1.0 m to 6.0 m depth, was surveyed using a small surveying rubber boat equipped with a DGPS and an echo-sounder. Care was taken to ensure that there was a suitable overlap between each of theses surveys whenever possible. Depths along each profile were measured every 3 m using the Navi-Sound 205 echo-sounder with a vertical accuracy ±10 cm. Geographic coordinates of water depth stations were simultaneously measured using a Differential Global Positioning Instrument (DGP) with a relative accuracy of 1.0 m and horizontal accuracy ±5 m.

The survey elevation, land and water depth, are referenced to the Mean Sea Level (MSL) using local fixed benchmarks of known elevation and hourly water level measurements recorded at Burullus inlet (positions in Fig. 1). Data from each profile has been used to calculate the annual rates of shoreline and seabed changes (R) in m/yr, employing the least squares technique, the slope of the Y versus X plot. The width of the landward part of each beach-profile measured from a baseline of each beach-profile measured from a baseline is used to calculate the rate of shoreline changes. Among the examined 63 profiles, a total of 40 profile lines were selected to calculate the annual rate of shoreline change (erosion or accretion) between 1991 and 2010 using the least-squares regression (Table 1). The measured vertical distance of the water depth (H) between the seabed and the sea surface at MSL also used to calculate bottom changes over the time frame of profile collection periods

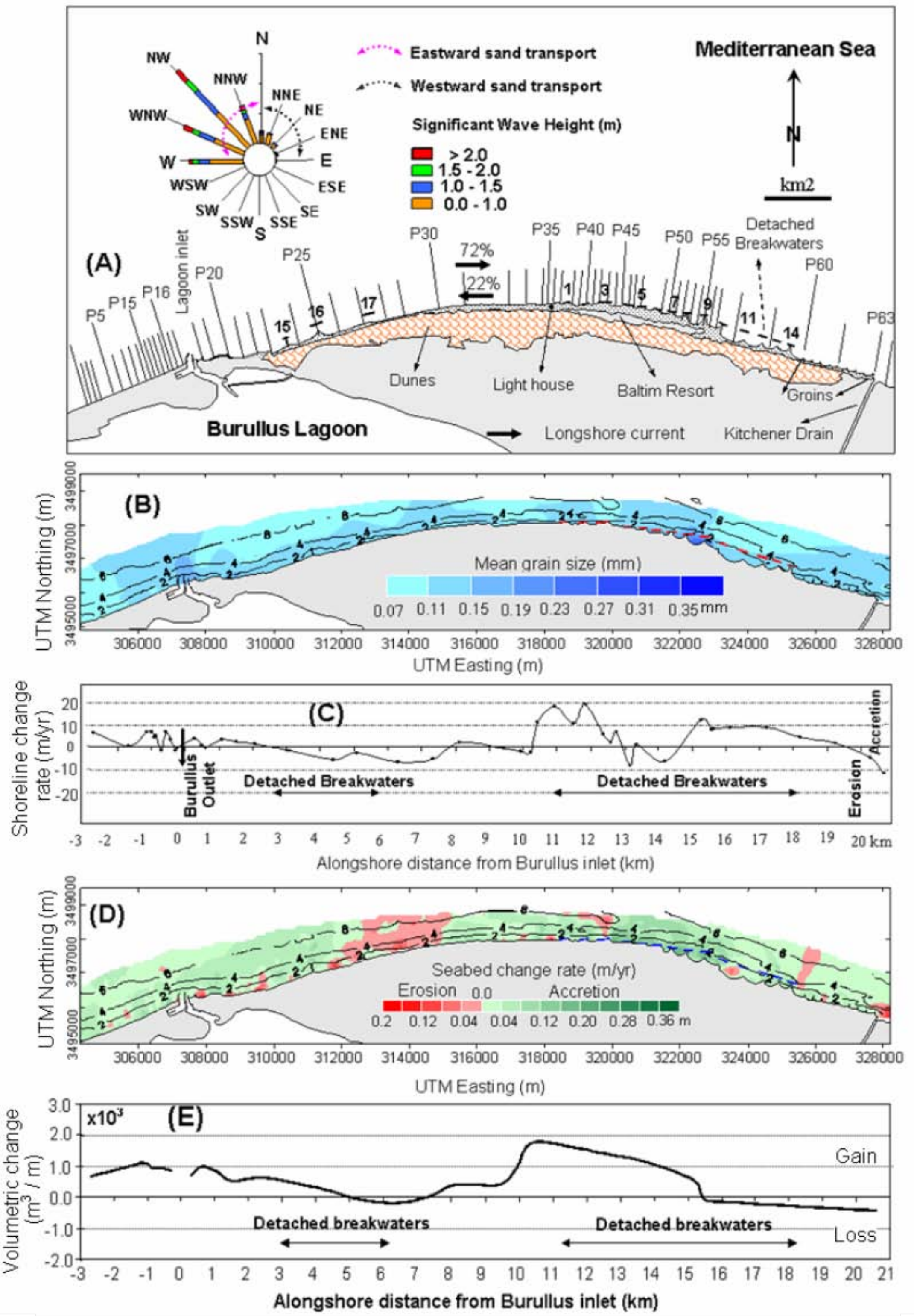

Fig. 4 (A) The study coastline showing positions of the surveyed beach profiles (labeled P1 to P63), and directional distribution of significant wave heights measured in Abu Qir Bay during 1985 and 1990 [31]. The predominant wave approaching from the NNW, NW, and WNW is responsible for generating the unidirectional net eastward-flowing transport. The opposing westerly longshore current is relatively small and is induced from waves occasionally approach from the NNW, N, NNE and NE sectors. Proportions of wave-induced longshore sediment transport pathways are indicated by arrows ([32). Breakwaters are numbered from #1 to #17 (B) Spatial distribution of mean grain

size (mm) of beach and surficial samples collected up to 6 m water depth. (C) Alongshore rate of shoreline change (m/yr). (D) Spatial distribution of rate of seabed changes (m/yr). (E) Alongshore distribution of sediment volume (m^3/yr).

following the same procedure used in calculating the annual rate of shoreline changes. Volumetric changes of the littoral sediments per linear meter (m3/m) were determined between successive surveys of profile data along the study area during the period between 1990 and 2010.

TABLE 1 RATE OF SHORELINE CHANGE CALCULATED FROM BEACH SURVEY AT SELECTED 40 PROFILE LINE. ANNUAL RATE SHORELIE (EROSION OR ACCRETION) IS CALCULATED BETWEEN 1991 AND 2010 USING THE LEAST-SQUARES REGRESSION. PROFILES WITH ASTERISK ARE SELECTED IN FIGURE 5 TO DEPICT CHANGE IN SHORELINE POSITION WITH TIME. PROFILE NUMBERS ARE DESIGNED ACCORDING TO THE NOMENCLATURE OF COASTAL RESEARCH INSTITUTE (CoRI) AND THE PRESENT STUDY. PROFILE LOCATION ALONG THE COASTLINE ARE SHOWN IN FIGURE 1A.

Profile Number		**Shoreline Change Rate (m/yr)**
CoRI	**Present Study**	
WBP 59.9	P1	6.45
WBP 60.6	P5	0.47
WBP 61.1	P8	6.68
WBP 61.3	P9	6.68
WBP 61.5	P10	4.45
WBP 61.7	P11	5.15
WBP 61.9	P12	-1.73
WBP 62.1*	P13*	6.55
WBP 62.3	P14	3.43
WBP 62.6	P15	-1.76
WBP 62.7	P16	-0.34
BRP 0.2	P17	3.73
BRP 0.5	P18	0.76
BRP 0.6	P19	-0.28
BRP 1.0	P20	3.35
BRP 1.5	P21	2.2
BRP 2.2	P23	1.35
BRP 3.0	P25	-1.62
BRP 4.0	P26	-5.63
BRP 5.0	P27	-2.5
BRP 6.0*	P28*	-6.81
BRP 7.0	P29	-5.31
BRP 8.0	P30	2.15
BRP 9.0	P31	-0.53
BRP 9.5	P32	-2.09
BRP 9.8	P33	-2.4
BRP 10.0*	P34*	10.92
BRP 10.5	P36	18.05
BRP 11.2	P39	10.18
BRP 11.4*	P40*	18.99
BRP 12.0	P43	5.61
BRP 12.2	P44	2.12
BRP 12.4	P45	6.83
BRP 12.8	P47	-8.47
BRP 13.0	P48	1.04
BRP 13.8	P50	-6.37
BRP 14.8	P55	11.98
BRP 15.4*	P56*	7.75
BRP 16.0	P57	7.87
BRP 16.5	P58	8.67
BRP 17.0	P59	8.73
BRP 18.0	P60	4.17
BRP 19.0	P61	1.61
BRP 19.5	P62	-4.71
BRP 20.0*	P63*	-11.5

A total of 290 bottom samples were collected in 2009 using a grab sampler every 100 m along the surveyed profile lines together with beach samples taken at the swash zone (see Fig. 4A for the profile location). Grain-size analysis was completed in the laboratory by dry sieving using standard ro-tap sieving at one-phi sieve intervals. The phi scale notation of Krumbein [26], where Ø equals minus the logarithm to the base two of the particle diameter in millimeters, is used as a size scale. The mean grain size (Mz) for each sample was calculated using the formula of Folk and Ward [27]. The resulting values of Mz in phi units were converted into millimeters according to the phi-mm transformation: (mm) = 1/2ϕ. Spatial interpolation of Mz and the seabed change pattern was performed using the "Kriging" interpolation method in the Golden Software SURFER 8.0 computer program.

III. RESULTS AND DISCUSSION

A. Coastal Processes

The Nile delta coast has a typical microtidal semi-diurnal tidal regime with an average range of 40 cm [5]. The delta coast is a typical wave-dominated or perhaps more accurately termed wave- and current-dominated ([28] and [29]).

Wave energy levels along the study area corresponds to the model developed by Quelennec and Manohar [30] for the refraction of waves arriving from the NNW indicates area of convergence orthogonals of high wave energy at Burullus-Baltim bulge followed by areas of divergence orthogonals of low wave energy along Gamasa embayment, location in Figure 3.

As the Nile delta is a wave-dominated coastline [29], wave induced-longshore currents is the main coastal process acting to cause morphologic changes. Such changes are interpreted in this study based on wave data (significant wave height, period and direction) reported by Deabes [31]. This wave data were measured at Abu Qir Bay between 1985 and 1990 at water depths of 18 m, see Figure 3 for location. (inset of Fig. 1) The wave rose constructed from this data has indicated that waves from the N-W sector dominate activity (80.5 %), with small components from the N-E (8.5 %) and the S-W (9 %) quadrants (Figure 4A). Maximum wave height in deep water (6.82m) corresponding to a period of 12.8 sec was documented at Abu Qir Bay. On average, the wave height and period are 1.2 m and 5.6 sec, respectively. According to Fanos [6] and Frihy [22], two main components are responsible for the longshore sediment transport along the delta: N-W and N-E components (Fig. 4A). These wave components are the predominant causes of morphological changes along the delta coastline (e.g. [29] and [22]).

In the present study, the relationship between the wave incident angles and the average shoreline orientation is evaluated to interpret longshore current responsible for the sediment transport along the coast. This relationship depends on longshore current generated in the surfzone when waves approach the coast at a certain angle [32]. In order to apply such relationship, the incoming wave components approaching the coastline is schematically diagramed versus average shoreline orientation (the W-E axis) in which the coast's normal line (the N axis) separates between wave components inducing the western and eastern longshore currents which are responsible for driving sand transport in the same direction (Fig. 4A). However, perpendicular wave approach parallel to this line represents an angle of incident close to zero, i.e. net zero transport. Accordingly, the predominant waves approach from the NNW, NW, and WNW sector (68% in total) are responsible for generating the eastward-flowing longshore currents, whereas the smaller portion of waves arriving from the NNE, NE, ENE (11% in total) produce the reversed longshore currents toward the west. Similar to the waves arrive from the north, those blown from the west and east directions are not effective in generating sand transport because they don't approach the coastline in an appreciable acute angle. Measured longshore current is predominated to the east (average = 72%) with a westward current reversal (average = 22%), with a maximum speed of 83 cm/sec [33] and [34] (Fig. 4A).

B. Sediment Characteristics and Morphodynamic Changes

Changes in rate of shoreline positions, seabed level, sediment grain size and volume are interpreted in this study in relation to coastal process to evaluate the morphological changes of the study coastline at its contiguous littoral zone. The spatial distribution of mean grain size of the beach and seabed sediment samples off the study area ranges between 0.07 to 0.35 mm (Fig. 4B). Generally, this distribution has no distinctive spatial pattern, suggesting lacking of grain sorting processes due to the disturbance effect resulted from numerous hard structures built in the study area. In other words, the spatial distribution of mean sediment grain size that originally resulted from erosion processes via cross-shore and longshore currents are locally disrupted by these hard structures. This is further confirmed from the statistical correlation between rates of seabed changes versus mean grain sizes for the samples collected from the study area (Fig. 5). The resulted weak correlation coefficient (R^2 = 0.0272), indicating that no apparent statistical trend exists between seabed changes and mean grain sizes of beach and seabed samples. Despite this relationship, the spatial pattern of mean grain in Figure 4B is locally directed spatially rather than in the alongshore direction. The locally seaward fining pattern indicates sediment transport caused by erosion of the beach face and surfzone and the transport of eroded sand toward offshore.

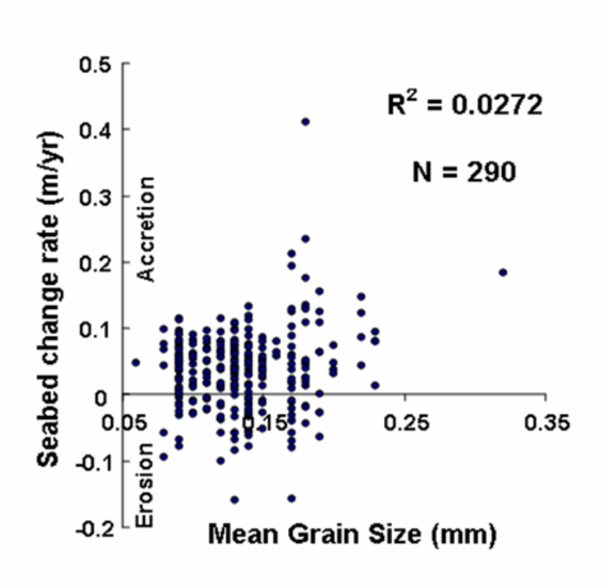

Fig. 5 Statistical correlation between seabed change rates versus mean grain size of the examined 290 seabed sediment samples showing no significant trends. R = correlation coefficient and N = number of seabed sediment samples.

Starting from the west, the jetty built at the Burullus inlet has trapped sand on its up drift side resulted from the eastward sediment transport current at a long-term rate of 6.7 m/year (Fig. 4C). This unidirectional net eastward-flowing current is generated from the predominant wave approach from a single quadrant (NNW, NW, and WNW) (Fig. 4A). Further seaward, this shoreline accretion is geographically associated with a seabed deposition (shoaling up) at a maximum rate of 12 cm/yr (Fig. 4D). In this respect, profile P13 is selected to depict such temporal accretion that shows an upward trend in the seabed level (Fig. 6G). The littoral accretion occurs along this local area is produced by the blockage of the N-W wave-induced eastward longshore sediment transport in particular by the western jetty of the Fishing port entrance, ~300 m long.

Further east of the Burullus inlet and its adjacent Fishing harbor, the shoreline is experienced state of stability with a general tendency toward accretion along the basalt riprap fronting El Bourg village (~1.3 km length). This accretion (3.4 m/year) is reverted to local erosion at the eastern end of this basalt riprap at El Banaeen village. This erosion continues along the 4 km-long unprotected sector and ranges between -2.5 and -6.3 m/yr (Fig. 4C). This beach erosion is associated with seabed erosion or deepening at a rate up to -20 cm/yr (Fig. 4D). Profile P28 (Fig. 6H) is selected as an example to confirm the downward erosional trend in this area. Presently, erosion in this area was mitigated by the construction of two detached breakwaters (0.5 km long) and a "T" groin structure (Figs. 1A, 2D). This erosion systematically diminishes alongshore to the east, and then reverses to broad accretion at a nodal point, positing 10.4 km from the Burullus inlet. This accretion fluctuates between 2.2 and 18.9 m/yr alongshore from 10.2 to 16.0 km east of the Burullus inlet where the detached breakwaters #1 to #14 are placed, i.e. spanning 5.8 km long. Following construction of these breakwaters, accretion has become the dominant process with the formation of tombolos on the leeward side of these structures. This accretion has filled the shadow area between the coastline and the breakwaters and also is associated with an offshore seabed deposition (shoaling) at a maximum rate of 36 cm/yr (Fig. 4D). The temporal accretion in the beach and seafloor changes at this area is documented at the selected profiles (P34, 40 and 56) as shown in Fig. 6C,D,E,I,J,K. The planform of the formed tombolo indicates that these accretionary features have been developed from the prevailing longshore current to the east, amounting 72 % (Fig. 4A).

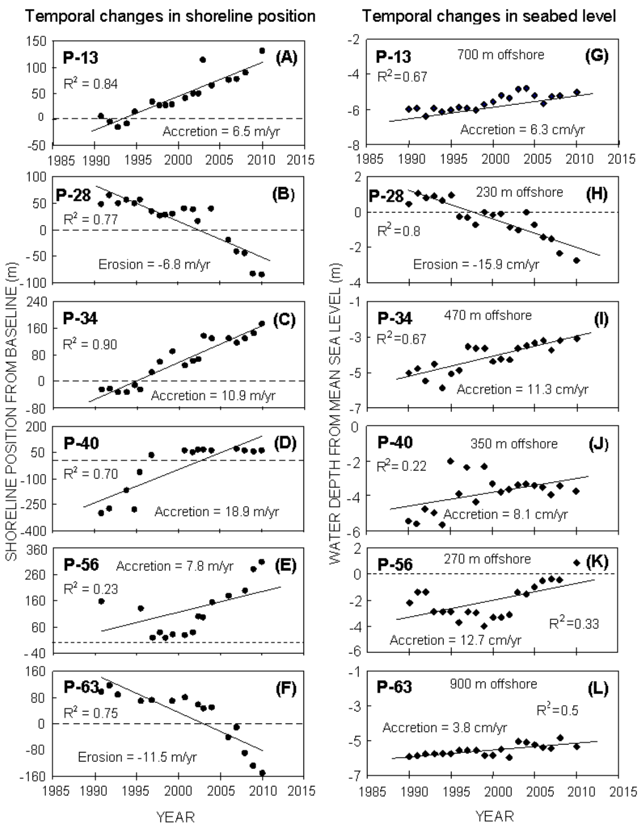

Fig. 6 Time series depicting temporal changes in the shoreline positions and seabed level at selected profiles. The annual rate of shoreline and seabed changes indicated in each graph is derived from the least-squares regression lines shown fitted to the measurements. Rates of beach changes (erosion or accretion), seabed level changes (deepening or shoaling) and R-squared value are indicated. Profile locations are in Figure 4A.

In other words, the bulge formation of the tombolo has eventually transformed the breakwater system to act as a shore-parallel seawall. This in turn have induced local erosion at a maximum rate of -11.5 /yr farther downcoast of the breakwater system particularly east of the Kitchener drain, approximately 5 km from breakwater #14. Local erosion of -6.37 m/yr is also occurred between breakwaters #10 and #11 (Figs. 4C and 6F). In order to mitigate the local erosion downdrift of the detached breakwater system, nine short groins of 40 m in length and 30 m apart were built in 2005 to stabilize the shoreline of this area. By the time, these groins have trapped much of sediments moving to the east by the easterly longshore current in the updrift side of these structures. Rate of shoreline change calculated between 2004 and 2010 along this sector indicates a maximum sand accretion rate of 8.7 m/yr (Fig. 4C).

The downcoast erosion east of the Kitchener drain was resulted from the interruption of the unidirectional easterly sediment transport by the breakwater system and their associated tombolo formations, thus increasing sand starvation of downcoast beaches of this area. The rapid erosion of -11.5 m/yr appeared downcoast of the Kitchener drain, as a result of sediment trapped by the massive engineering structures built along the central-bulge of the study area, is fronted by a seabed erosion (-20 cm/yr), followed by an offshore seabed accretion as indicated in profile P63, Figs. 4D and 6F, L.

In this study the change in the sediment volume per unit beach length in the littoral zone up to 6 m depth is calculated between 1990 and 2010 (Fig. 4E). As seen in this figure, variations in the sediment volume fluctuates between loss and gain of sediment in the alongshore direction. Sediment loss of -0.21 x 103 m3/m occurred along the unprotected sectors east of the basalt revetment and downcoast of the detached breakwater system (-0.44 x 103 m3/m). In contrast, substantial net sediment accretion of 1.85 x 103 m^3/m occurs in the vicinity of the detached breakwaters system and locally on the updrift side of the Fishing port (1.11 x 103 m^3/m). In comparison, the changes in the alongshore sediment volume are generally found to be correspond with the pattern obtained from the analyses of shoreline and seabed changes (Fig. 4C,D,E). This general correspondence indicates sediment paths, sources, and sinks, nodal points separating between erosion and accretion zones.

C. Sedimentation of the Kitchener Drain Mouth

Although the short groins built downcoast of the detached breakwater system have succeeded to stabilize the 2.7 km shoreline sector, the mouth of the adjacent Kitchener drain has experienced sedimentation problem (Fig. 1C). Change in the shoreline positions surveyed in 2004 to 2010 indicate the presence of intermittent sandy bars at the western side of the Kitchener drain mouth (Fig. 7). The configuration of these bars suggests that it was formed by the prevailing easterly movement of sediment, induced by the longshore current to the east at the drain mouth. As shown in Figure 7, these bars were subsequently eroded during the following decades. The bars are partially emerged and have a maximum relief of about 0.5 m above mean sea level. These accretionary features suggest the potential for continued shoaling and closing of the drain estuary until sediment sources are diminished. A ‘bottle neck’ is occasionally present in the channel entrance fluctuating in width between 25-45 m , and a very shallow water depth of less than 0.7 m was measured in the survey of May 2010. The sedimentation problem of the Kitchener drain can be resolved by seabed dredging to stabilize the entrance until sediment sources are stabilized. For calculations, approximately 0.3 x 10^6 m^3 in volume could be dredged from the drain estuary to remove the remnant sand body material. The dredged material can be bypassed as slurry via a pipeline to the eroded shores downcoast east of the Kitchener drain that experienced erosion rate of -11.5 m/yr.

IV. SUMMARY AND CONCLUSIONS

This paper evaluates temporal and spatial changes in the shoreline and nearshore seabed levels along the central-bulge sector of the Nile delta coastline and discussing dynamic processes, which have contributed to these changes. The study also incorporates assessing response of existing protective structures to the beach morphology and their impacts on grain sizes of the seabed sediments. Active accretional features responsible for the sedimentation of the Kitchener drain mouth are also mapped and assessed to propose appropriate mitigation measure.

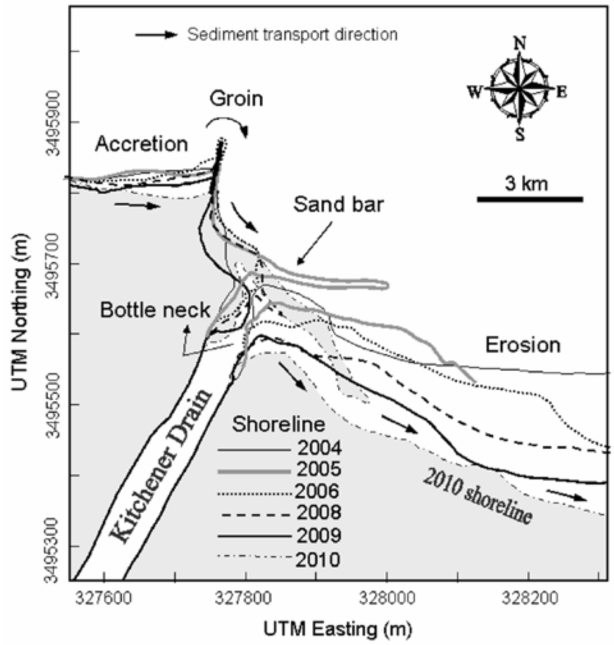

Fig. 7 Superimposed shoreline positions surveyed in 2004, 2005, 2006, 2008, 2009 and 2010, illustrating the presence of intermittent sandy bars and a channel bottleneck at the mouth of the Kitchener drain responsible for the periodic sedimentation of this drain.

Although the shore-parallel detached-breakwater system built along the central-bulge of the Burullus-Baltim stretch has succeeded in protecting the beach and dune belt by forming a series of accretionary tombolos and salients, it effectively disrupted the natural stability of the delta coastline. They have however blocked the natural movement of sediment eastward leading to accelerated erosion at the eastern end of the breakwater system including the eastern side of the Kitchener drain mouth. These structures together with their associated formations (tombolos and salients) have transformed this bulge area into an effective shore-parallel seawall or a littoral barrier, now experienced accretion instead of erosion which occurred prior to the building of the breakwaters in 1990, at a maximum rate of -6 m/yr. Eventually, the sedimentation pattern in the

Burullus sub-littoral cell has been disrupted due to the engineering structures and their sociated accretionary sand features.

As the study central-bulge was acting as sediment source for the downcoast beaches, we expect that sediment producing to the east along Gamasa embayment, immediate east of the Kitchener drain; will gradually deceasing as a result of the extensive engineering structures built along this sector. Presently, this embayment acts as a major sink for the Burullus sub-cell forming a self compartment littoral cell as termed by Frihy, as in [12]. In this sub-cell, sand eroded from the Burullus-Baltim bulge is transported to the east where it is trapped naturally along Gamasa embayment that results in shoreline accretion.

The sedimentation of the Kitchener drain is effectively influenced by the evolutionary changes of the mouth sand bars and bottleneck features. Shoreline change associated with continues formation of the sand bars acting to close the mouth of the Kitchener drain. Accretionary features developed at the mouth of this drain was subsequently formed from residual eroded sand resulted from the continued coastal retreat upcoast of the drain, and lately from continued sand-bypassed from sand trapped by the short groins built west of the drain mouth. Presently, sand bypassed by longshore current toward the drain mouth appears to have acted as a local sediment source for these accretionary sand features. Dredging of these accretionary features is most likely recommended to combat this sedimentation. The dredged material can be bypassed as slurry via a pipeline to the eroded downdrift beaches east of the Kitchener drain.

A general congruence has been observed between changes in the rates of shoreline and seabed change patterns and, to some extent, the mean grain size of sediments in the littoral zone. Accretion processes in the seabed is mostly dominate in the littoral zone off the study area and in particular associated with the accretionary salient and tombolo features formed in the lee side of the detached breakwaters.

The alternating pattern of erosion and accretion identified along the study coastline and it contiguous littoral zone are controlled by several diverse factors, including sediment availability, wave and longshore currents, and the construction of protective structures.

REFERENCES

[1] D. L. Inman, and B. Brush, "The coastal challenge fragile ribbons which border our land require more understanding new technology and resolute planning" Science; No. 181, pp. 20-31, 1973.

[2] D. Arbouille, and D.J. Stanley, "Late Quaternary evolution of the Burullus lagoon region, north-central Nile Delta, Egypt" Marine Geology, Vol. 99, pp. 45-66, 1991.

[3] A. I. El-Kolfat, "Effect of drainage water control measures on coastal morphology of El-Gharbia (Kitchener) drain and its outlet, Egypt" Second Regional Conference on Arab Water, Action plans for Integrated Development, paper # 80, 2004.

[4] A. H. Halawa, "Evaluation and mineral processing of some economic minerals in El Burullus Baltim sand dunes, Nile delta, Egypt" Ph.D., Mansoura University, Egypt, 205 pp, 2005.

[5] UNESCO/UNDP, "Coastal protection studies" Final Technical Report, Paris, Vol. 1, 155p, 1978.

[6] A. M. Fanos, O. E. Frihy, A. A. Khafagy and P. D. Komar, "Processes of shoreline change along the Nile Delta coast of Egypt" Coastal Sediments'91 conference, Seattle, Washington, Vol. 2, pp. 1547-1557, 1991.

[7] D. L. Inman, H. S. Elwany, A. A. Khafagy and A. Golik, "Nile Delta profiles and migration sand blankets" Proceeding at the 23rd International Conference on Coastal Engineering (American Society of Civil Engineering) Vol. 2, pp. 3273-3284, 1992.

[8] O. E. Frihy, and P. D. Komar, "Patterns of beach-sand sorting and shoreline erosion on the Nile Delta" Journal of Sedimentary Petrology, Vol. 61, pp. 544-550, 1991.

[9] O. E. Frihy, and D. Lawrence, "Evolution of the modern Nile delta promontories: development of accretional features during shoreline retreat" Environmental Geology, Vol. 46, pp. 914-931,2004.

[10] O. E. Frihy, M. M. El-Banna and A. I. El-Kolfat, "En-

vironmental impacts of Baltim and Ras El Bar shore-parallel breakwater systems on the Nile delta littoral zone, Egypt" Environmental Geology, Vol. 45, pp. 381-390,2004.

[11] G. Orlova, and V. Zenkovitch, "Erosion of the shores of the Nile delta" Geoforum, Vol. 18, pp. 68-72,1974.

[12] O. E. Frihy, M. A. Fanos, A.A. Khafagy and P. D. Komar, "Nearshore sediment transport patterns along the Nile Delta Egypt" J. Coastal Eng., Vol. 15, pp. 409-429,1991.

[13] V. Klemas, and A. M. Abdel Kader, "Remote sensing of coastal processes with emphasis on the Nile Delta" In International Symposium on Remote Sensing of Environments, Cairo, 27 pp,1982.

[14] O. E. Frihy, "Nile Delta shoreline changes: Aerial photographic study of a 28 year period" Journal of Coastal Research, Vol. 4, 1988, pp. 597-606.

[15] H. W. Blodget, P. T. Taylor, and J. H. Roark, "Shoreline changes along the Rosetta-Nile Promontory: Monitoring with satellite observations" Marine Geology, Vol. 99, pp. 67-77, 1991.

[16] O. E. Frihy, and Kh. M. Dewidar, "Influence of shoreline erosion and accretion on texture and heavy mineral compositions of beach sands of the Burullus coast, north-central Nile Delta, Egypt" Marine Geology, Vol. 114, pp. 91-104, 1993.

[17] O. E. Frihy, and M. F. Lotfy, "Mineralogic evidence for the Sebennitic promontory on the continental shelf off the central Nile delta" Mar. Geol., Vol. 117, pp. 187-194, 1994.

[18] M. A. El Sayed, N. A. Younan, A. M. Fanos and Kh. Baghdady, "Accretion and Erosion patterns along Rosetta promontory, Nile Delta coast" Journal of Coastal Research, Vol. 21, pp. 412-420, 2005.

[19] Kh. Dewidar, and O. E. Frihy, "Pre- and post-beach response to engineering hard structures using Landsat time-series at the northwestern part of the Nile delta, Egypt" Journal of Coastal Conservation: Planning and Management, Springer, Vol, 11, pp. 133-142, 2008.

[20] Kh.M. Dewidar, and O. E. Frihy, "Automated techniques for quantifications of beach change rates using Landsat series along the Northeastern Nile Delta, Egypt" Journal of Oceanography and Marine Science (JOMS), Vol. 1, pp. 28-039, 2010.

[21] K. White, and H. M. El-Asmar, "Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta" Geomorphology, Vol. 29, pp. 93-105, 1999.

[22] O. E. Frihy, E. A. Deabes and W. El-Sayed, "Processes reshaping the Nile delta promontories of Egypt: pre- and post protection" Geomorphology, Vol. 53, pp. 263-279, 2003.

[23] O. E. Frihy, S. Shereet and M. El-Banna, "Pattern of beach erosion and scour depth along the Rosetta Promontory and their effect on the existing protection works, Nile Delta, Egypt" Journal of Coastal Research, Vol. 24, pp.857–866, 2008.

[24] M. Manohar, "Undulated bottom profiles and onshore-offshore transport. Proceedings of the 16th Conference on Coastal Engineering" New York, pp. 1454-1474, 1979.

[25] M. Naffa, and O. E. Frihy, "Beach and nearshore features along the dissipative coastline of the Nile Delta, Egypt" Journal of Coastal Research, Vol. 9, pp. 423-433, 1993.

[26] W. C. Krumbein, "Application of logarithmic moments to size frequency distributions of sediments" Journal of Sedimentary Petrology, Vol. 6, pp. 35-47, 1963.

[27] R. L. Folk, and W. O. Ward, "Brazos River bar. A study in the significance of grain size parameters" J. Sediment. Petrol., Vol. 27, pp. 3-27, 1957.

[28] J. M. Coleman, H. H. Robert, S. P. Murray and M. Salama, "Morphology and dynamic sedimentology of the eastern Nile delta shelf" Marine Geology, Vol. 42, pp. 301–312, 1981.

[29] M. Manohar, "Coastal processes at the Nile Delta coast" Shore and Beach, Vol, 49, pp. 8-15, 1981.

[30] R. E. Quelennec, and M. Manohar, "Numerical wave refraction and computer estimation of littoral drift, application to the Nile Delta coast" Proceedings UNESCO Seminar on Nile Delta Coastal Processes, Academy of Scientific Research and Technology, Alexandria, pp. 404-433, 1977.

[31] E. A. Deabes, "The use of remote sensing and geographic information system (GIS) in building a decision support system (DSS) for coastline management of the Nile delta" Ph.D. Thesis, Oceanography Department, Alexandria University, 143 pp, 2007.

[32] CERC (Shore Protection Manual) "U.S. Army Corps of Engineering Research Center" Government Printing Office, Washington D.C., 214 pp, 1984.

[33] A. I. El-Kolfat, "Coastal protection by means of detached breakwaters" PhD Thesis, Faculty of Engineering, Alexandria University, Egypt, 111 pp, 1999.

[34] S. M. Shereet, “Coastal changes along the sides of Lake Burullus outlet” M.Sc. Thesis. Alexandria. Univers

[35] ity, Egypt, 170 pp, 1990.