

Sediment Balance in the Nearshore Zone of the Nile Delta Coast, Egypt

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ABSTRACT

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Severe erosion of the Nile Delta coast began around the beginning of the present century in response to the construction of dams and barrages across the Nile. The erosion accelerated following the construction of the High Aswan Dam in 1964 which trapped all the flood sediments previously discharged to the delta shores. Volumetric change in the nearshore zone along the coast of the Nile Delta were determined from beach profile surveys at 62 sites covering a 12-year period (1978-1990) at 4-year intervals. The variations in sediment volume along the coast show severe erosion along the Nile promontories (Rosetta, Burullus and Damietta) where waves are more concentrated. The other parts of the shore at Abu Quir Bay, Abu Khashaba, Hanafi, Kitchener Drain, and behind Port Said breakwater receive the eroded material by eastward sediment transport resulting from the prevailing wave approach from the northwest. Greatest erosion is concentrated between Kitchener Drain and Gamasa ($-7 \times 10^6 \text{ m}^3$, for the period 1978-1981), while maximum accumulation of sediments occurs between Abu Khashaba and Burullus Inlet at Hanafi ($9.1 \times 10^6 \text{ m}^3$, for the period 1984-1987). The cross-shore volume changes in the nearshore zone indicate that sediment is moving offshore as well as alongshore as littoral drift.

ADDITIONAL INDEX WORDS: *Volume changes, erosion, accretion, beach profiles, shoreface.*

INTRODUCTION

The Nile Delta shore consists of sandy arcuate beaches, approximately 240 km in total length. The beaches of the Nile Delta are backed by coastal flats followed by coastal dunes and three lagoons (from west to east, Idku, Burullus and Manzala) (Figure 1). The arcuate coastline is characterized by three promontories. The present-day Nile estuaries (Rosetta and Damietta) are about 150 km apart, on either side of the broad remnant Burullus headland. The latter consists of sediment formed from the former Sebennitic branch which started during Holocene between 7500 to 3000 BP (ARBOUILLE and STANLEY, 1991), and was active until about 900 years ago (ORLOVA and ZENKOVITCH, 1974).

Earlier studies on coastal changes at the Nile promontories using historical maps reveal that they advanced seaward by about 3 to 4 km between 1800 to 1900. The reversal to an erosion phase began about 1900 due to the significant reduction in the Nile flow and sediment deposited at the Rosetta and Damietta mouths. This re-

duction resulted from the construction of dams and barrages across the Nile. The main Nile and its two branches are controlled by six barrages and three dams. Since closure of the High Aswan Dam in 1964, discharge of sediments at the mouth of the promontory has been reduced to near zero, and subsequently the coastline has been subjected to dramatic erosion (FRIHY and KHAFAGY, 1991; INMAN and JENKINS, 1984). The sediment deficiency is acting together with land subsidence, sea level rise, climatic oscillations, human intervention and sediment-transport processes causing erosion and accretion hazards. In response to this phenomenon, shoreline erosion has destroyed coastal roads and caused loss of buildings and valuable agricultural land as well as impacted recreational resort beaches. On the other hand, accretion has caused shoaling and subsequent navigation hazards at lagoon inlets and estuaries, besides harming the lake ecosystem.

Considerable interest has been paid over the last two decades to the marked coastal changes observed along the Nile Delta coast. This interest has yielded several reports: shoreline changes from historical maps (SESTINI, 1976; MISDORP, 1977; FRIHY and KHAFAGY, 1991); aerial photographic

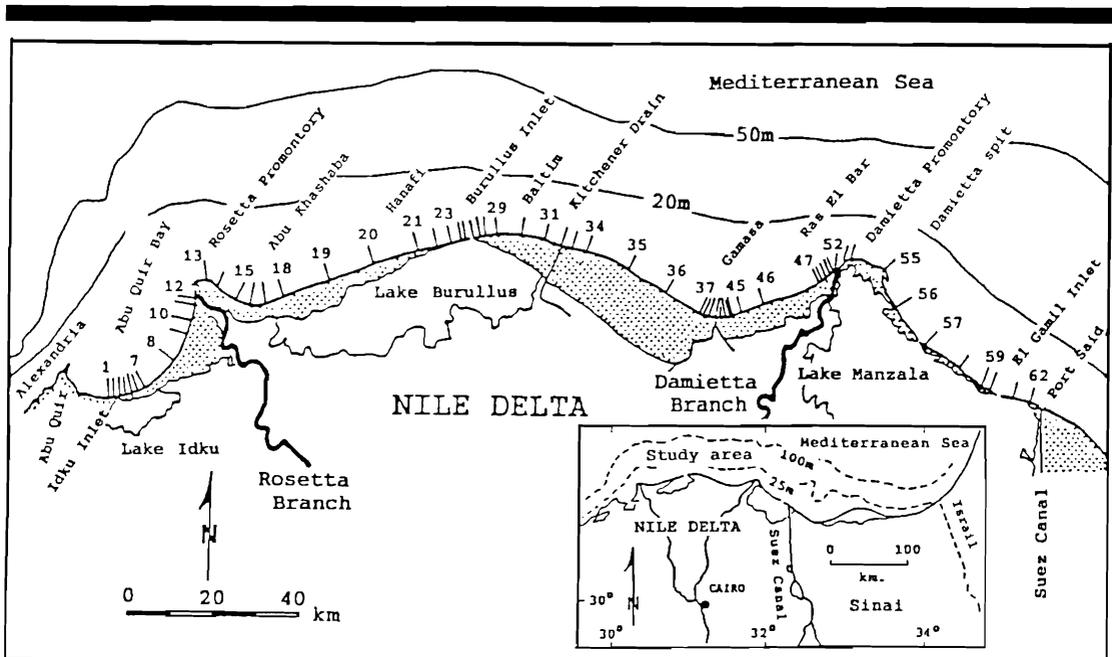


Figure 1. Sketch map of the Nile Delta coast showing the position of the 62 beach profile lines used in this study.

analysis (FRIHY, 1988); satellite images analysis (KLEMAS and ABDEL KADER, 1982; SMITH and ABDEL KADER, 1988; BLODGET *et al.*, 1991); bottom changes (MISDORP and SESTINI, 1976; TOMA and SALAMA, 1980); coastal dynamic processes (MANOHAR, 1981; KHAFAGY and MANOHAR, 1979; FANOS, 1986; ELWANY *et al.*, 1988, NAFAA *et al.*, 1991); sediment transport (INMAN and JENKINS, 1984; FRIHY *et al.*, 1991); and beach sediments (EL FISHAWI *et al.*, 1976; EL ASKARY and LOTFY, 1980). Earlier local and regional interpretations of short-term volumetric changes along the delta have been made by MANOHAR (1976) and EL FISHAWI and BADR (1989).

COASTAL PROCESSES

The grain size of the nearshore sediments decreases seaward. Medium and fine sand occur near the beach while very fine sand and silt exist up to 6 m water depth (MISDORP and SESTINI, 1976). Waves and currents associated with east Mediterranean gyre are the principal driving forces that transport sediments to the east (INMAN and JENKINS, 1984). The wave action on the Nile Delta is seasonal in nature. Waves reach the shoreline from NW–NNW, this being the direction of major

fetch along the delta coast. This in general produces a net longshore sand transport to the east (MANOHAR, 1981; NAFAA *et al.*, 1991). The wave action is seasonal, with high storm waves approaching from the NW–NNW during the winter (October to March). These are generating eastward-flowing longshore currents and a littoral sediment transport in that direction. Maximum measured current velocities range from 80 to 90 cm/sec (FANOS, 1986). Swells during the spring and summer are predominantly from NNW–WNW, with a small component from the NNE; this can cause either easterly or westerly sand transport, depending on the local shoreline orientation. The Mediterranean Sea at the Nile Delta is almost tideless (30–40 cm) and semidiurnal. Water level under storm surges is significant in coastal erosion and causes overtopping of the backshore and the coastal dunes. Usually, winter surges attack the coast with frequency of about 14 per year.

DATA BASE AND ANALYSIS

In 1971 the Coastal Research Institute (CRI) initiated a programme to monitor changes in the nearshore zone of the Nile Delta coast. A series

of annual beach profiles, extending from Abu Quir headland to Port Said, have been obtained extending to 6 m water depth or to 1,000 m distance from the baseline in the offshore. The profile lines are perpendicular to the coastline, spaced 0.5–10 km apart, with the closest spacing in areas characterized by frequent and rapid changes. The leveling and sounding data are adjusted to the MSL datum using fixed bench marks of known elevation, located behind the beach area. Leveling and soundings normal to the shore are taken at every 50 m. Leveling above MSL was measured using standard-surveying techniques using an EDM theodolite, while soundings below MSL were conducted using a rubber boat and a measuring chain. Distance and corresponding elevations and soundings along profiles were measured from a fixed point. The fixed point is an iron bar set in a concrete barrel connected alongshore with each others so as to form the survey baseline. These surveys provide an extensive data base on the volume changes of the nearshore zone over a 20-year period. A computer program was developed to analyze profile data to calculate quantities that were added to or removed from the nearshore zone. Volumetric changes within three separate depth intervals (0–2, 2–4, and 4–6 m) were calculated between successive profiles. Unit volume is defined as the cross-sectional area under the profile multiplied by a unit length of beach in the alongshore direction. Net volume changes as the sum of all positive and negative changes were also determined along and across the shore.

RESULTS AND DISCUSSION

Volumetric changes were determined at 62 beach profile lines surveyed out to 6 m water depth for each of five time periods (1978–1981, 1981–1984, 1984–1987, 1987–1990 and 1978–1990). The data plotted in Figure 2 (A to E) present the regional west-to-east variation in erosion and accretion from Abu Quir headland to Port Said.

Survey Period: 1978–1981

The distribution of volumetric changes along the delta coast from Abu Quir to Port Said revealed areas of erosion and accretion (Figure 2A). Erosion was formed along Rosetta promontory ($-4.1 \times 10^6 \text{ m}^3$), Burullus/Baltim ($-2.7 \times 10^6 \text{ m}^3$), the coastal zone between east of Kitchener drain and Gamasa ($-7 \times 10^6 \text{ m}^3$) as well as along the Damietta promontory up to 22 km to the east

($-5.5 \times 10^6 \text{ m}^3$). On the other hand, accretion occurred along the central ($4.8 \times 10^6 \text{ m}^3$) and the western part of Abu Quir Bay ($1.6 \times 10^6 \text{ m}^3$), midway between Abu Khashaba and 5 km west of Burullus Inlet ($4.3 \times 10^6 \text{ m}^3$), the coastal area of Kitchener Drain ($1.7 \times 10^6 \text{ m}^3$), west of Damietta promontory ($2.9 \times 10^6 \text{ m}^3$), west of El Gamil ($2.6 \times 10^6 \text{ m}^3$), and west of Port Said breakwater ($1.7 \times 10^6 \text{ m}^3$). The marked variability of erosion and accretion sediment volume along the delta coast is attributed to the longshore sediment transport to the east and partly to the west. Severe erosion is occurring along the promontory tips, with accretion taking place to the east or to the west. The eroded sediments from the tip of the promontory are deposited along both the western and eastern sides of the distributary mouth. The direction of sediment transport pattern along the Damietta promontory is somewhat similar to the Rosetta promontory. The outer margin of the promontory is subjected to intensive erosion, followed by marked deposition to the east along El Gamil-Port Said coast. The Gamasa sink has received sand from the continued erosion of the remnant Burullus-Baltim coast by the predominant littoral drift to the east.

The net sediment balance for the whole coast during this period was $-1.87 \times 10^6 \text{ m}^3$ (Table 1). This result is consistent with the total length of shoreline affected by erosion (50.3%) and accretion (49.7%).

Survey Period: 1981–1984

The alongshore variations in sediment volume during this period followed more or less the same erosion and accretion patterns as were recorded during the previous period, with some exceptions (Figure 2B). The coastal zone from the eastern side of the Rosetta promontory to Burullus Inlet, about 35 km long, which experienced accretion between 1978 and 1981, reverted to erosion ($-3.6 \times 10^6 \text{ m}^3$) during the following 3 years. Also the localized small erosion off Gamasa drain changed to accretion in this period ($0.8 \times 10^6 \text{ m}^3$). The net sediment balance of the coastal zone between 1981 and 1984 was $-7.41 \times 10^6 \text{ m}^3$. Based on the accreted and eroded coastal stretches, about 55% of the delta coast was retreated and 45% was prograded.

Survey Period: 1984–1987

The alongshore distribution of erosion and accretion during this period was more or less similar

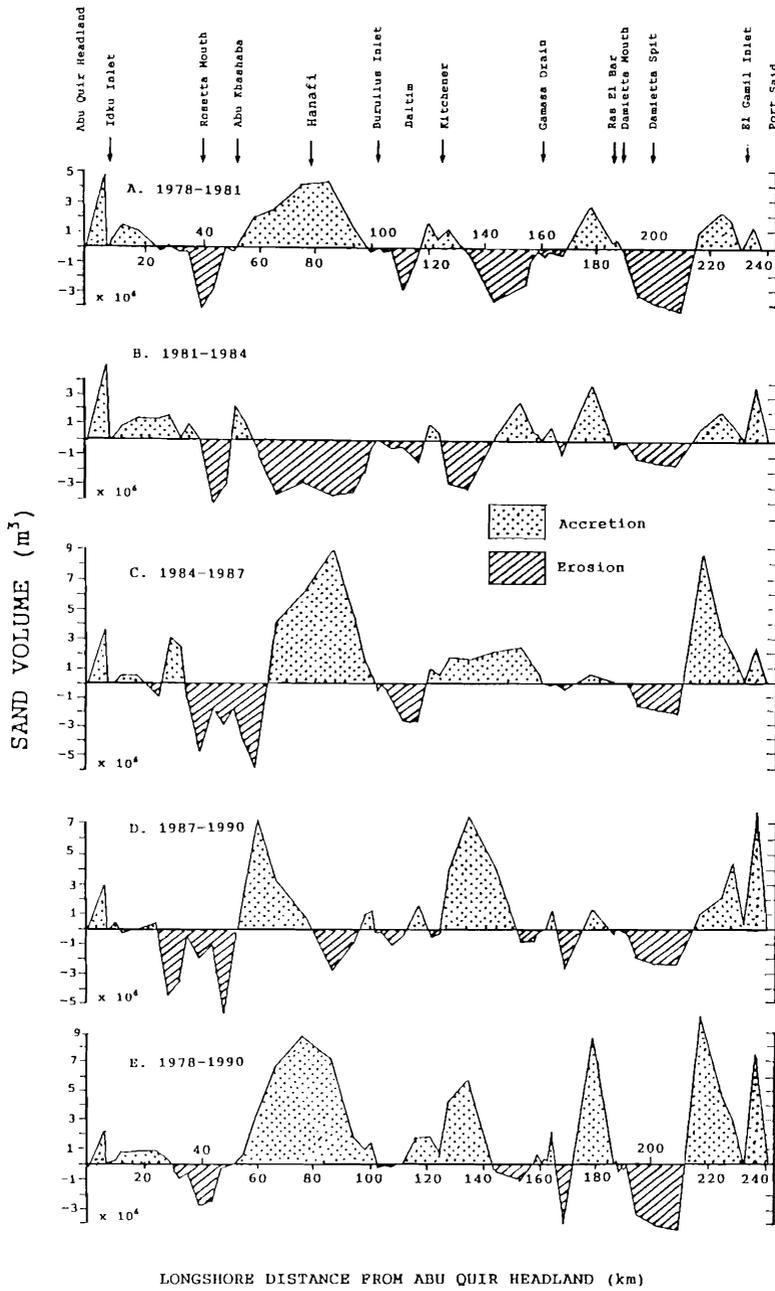


Figure 2. Changes in sediment volumes up to 6 m depth along the Nile Delta coast during the periods: (A) 1978-1981, (B) 1981-1984, (C) 1984-1987, (D) 1987-1990 and (E) 1978-1990.

Table 1. Sediment volumes of erosion and accretion ($m^3 \times 10^6$) across the different depth zones for the whole coast of the Nile Delta.

Year	Depth Zones (m)											
	0-2 m			2-4 m			4-6 m			0-6 m		
	E	A	Net	E	A	Net	E	A	Net	E	A	Net
1987-1981	7.67	5.23	-2.44	18.47	18.29	-1.8	19.07	19.82	+0.75	41.79	39.92	-1.87
1981-1984	7.10	2.45	-4.65	15.06	8.59	-6.47	19.91	23.62	+3.71	40.03	32.62	-7.41
1984-1987	8.06	6.14	-1.92	11.11	20.36	+9.25	19.09	40.68	+21.59	36.39	65.32	+28.93
1987-1990	11.11	6.17	-4.94	15.52	20.57	+5.05	14.80	39.82	+25.02	33.64	58.77	+25.13
1978-1990	10.48	6.11	-4.37	7.97	31.26	+23.29	16.31	60.70	+44.39	26.54	89.85	+63.31

*Note: A = Accretion, E = Erosion

to the previous two periods (Figure 2C). Erosion was observed along the eastern and western flanks of the Rosetta promontory ($-4.9 \times 10^6 m^3$), the coastal zone from Burullus to 10 km to the east ($-2.6 \times 10^6 m^3$) and east of the Damietta promontory ($-2.1 \times 10^6 m^3$). Accretion occurred along the coast from Abu Khashaba to west Burullus Inlet, between Kitchener and Gamasa drain ($2.5 \times 10^6 m^3$) and for 15 km west of El Gamil ($8.7 \times 10^6 m^3$) and west of Port Said breakwater ($2.4 \times 10^6 m^3$). Highest accretion sediment volume exists in the area between Abu Khashaba and west of Burullus Inlet ($9.1 \times 10^6 m^3$). The net sediment balance during this period differed from the previous six years showing an overall accretion of $28.93 \times 10^6 m^3$. During this period, 62% of the shore length was accreted, while 38% was eroded.

Survey Period: 1987-1990

The variations in sediment volume along the delta coast during this period were broadly similar to the pattern of 1984-1987 but with different magnitude, particularly between Abu Khashaba and Burullus Inlet as well as east of Damietta promontory (Figure 2D). Similar to the last period, the sediment balance out to 6.0 m water depth during this period yielded an accretionary value of $25.13 \times 10^6 m^3$. This accretion is also confirmed from the shore length that experienced accretion (58%) and erosion (42%).

Entire Period: 1978-1990

The net changes in sediment volumes for the entire 12-year period (1978 to 1990) are shown in Figure 2E. Erosion is apparent along the Rosetta ($-2.8 \times 10^6 m^3$) and east of the Damietta promontories ($-4.4 \times 10^6 m^3$), off Burullus Inlet ($-0.3 \times 10^6 m^3$), and adjacent to Gamasa Drain, while the rest of the coast shows net accretion. The

erosion accretion patterns indicate that the promontories are zones of erosion, while coastal zones such as promontory saddles, embayments and up drift sides of jetties are sinks.

On comparison, the net volumetric changes during this long period are not equal to the gross volume change for the four study periods. Therefore, the net volume change off the Nile Delta coast appears to be independent of time (*cf.* MANOHAR, 1976; EL FISHAWI and BADR, 1989). The sediment balance during this period (12-year interval) yields an accretion value of $63.31 \times 10^6 m^3$, *i.e.* giving a mean annual rate of accretion of $5.2 \times 10^6 m^3$. Based on the eroded and accreted shore length, about 69.5% was accreted, while 30.5% was eroded.

Sediment Transport

The cross-shore sediment transport in the near-shore zone of the Nile Delta can be inferred from the distribution of sediment volumes normal to the shore, established from analyzing annual beach profile surveys between 1978 and 1990 for the different depth zones (Figure 3). The results indicate that sediment eroded from the upper part of the beach profile (0-2 m) is deposited in the deeper part at 4 to 6 m water depth. However, in some coastal zones such as at Rosetta and Damietta promontories, erosion increase with increasing water depth. The lower parts of the profiles tend to maintain equilibrium through cross-shore (onshore-offshore) sediment movement. The alongshore sediment transport is also inferred from the resulting sand volume changes in the lower shoreface (4-6 m). Figure 4 summarized the relationship between volumetric changes and water depth for the whole coast for various surveys. It confirms the idea that volumes of accretion and erosion increase with increasing depth. The gross

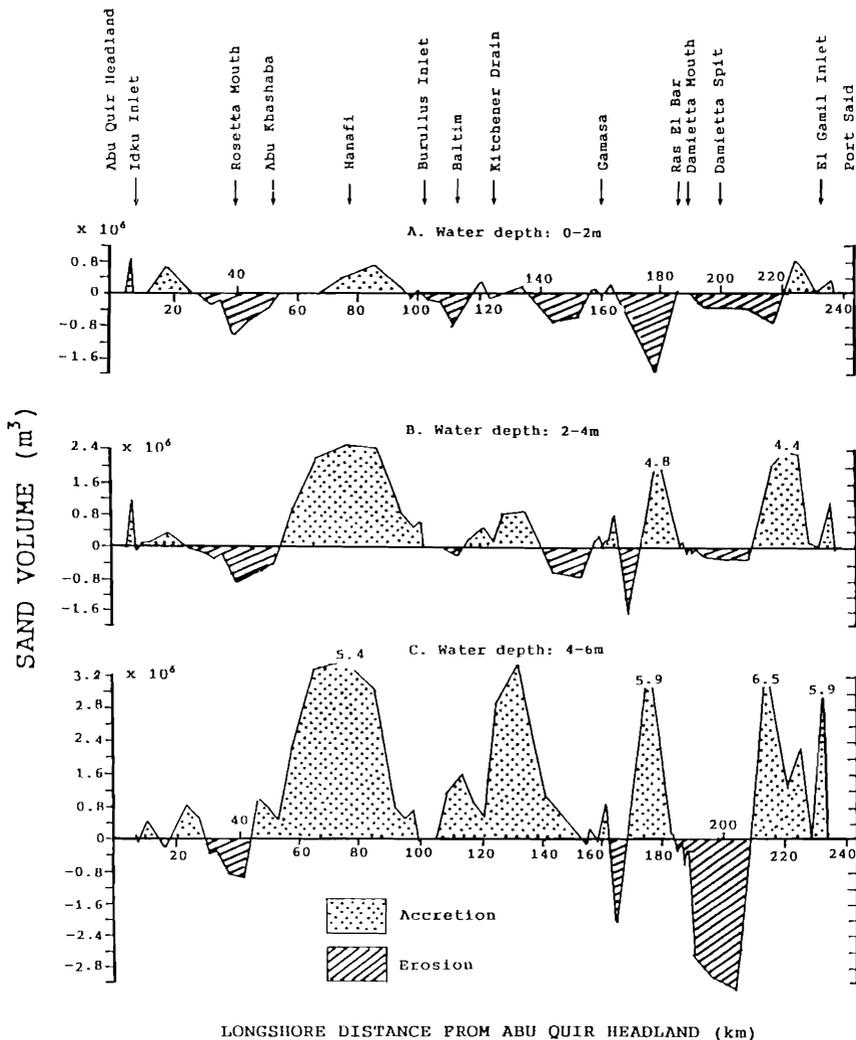


Figure 3. Changes in sediment volumes along the Nile Delta coast from 1978 to 1990 for water depth zones: (A) 0–2 m, (B) 2–4 m, and (C) 4–6 m.

volumes of accretion for the various years are much greater than that of erosion.

SUMMARY

A monitoring program was conducted by the Coastal Research Institute (CRI) to study the evolutionary changes along the Nile Delta coast since 1971. Quantitative identification of erosion/ac-

port in alongshore and cross-shore direction. The profile survey covers a 12-year period spanning from 1978 to 1990. The study is concentrated on accretional and erosional changes that took place between five successive periods (1978–1981, 1981–1984, 1984–1987, 1987–1990 and 1978–1990). The nearshore zone is characterized by great variability in sand volumes in alongshore and across-shore direction. The general volume changes along the Nile Delta shore show that zones of accretion occurred to the east of each erosion zone. The

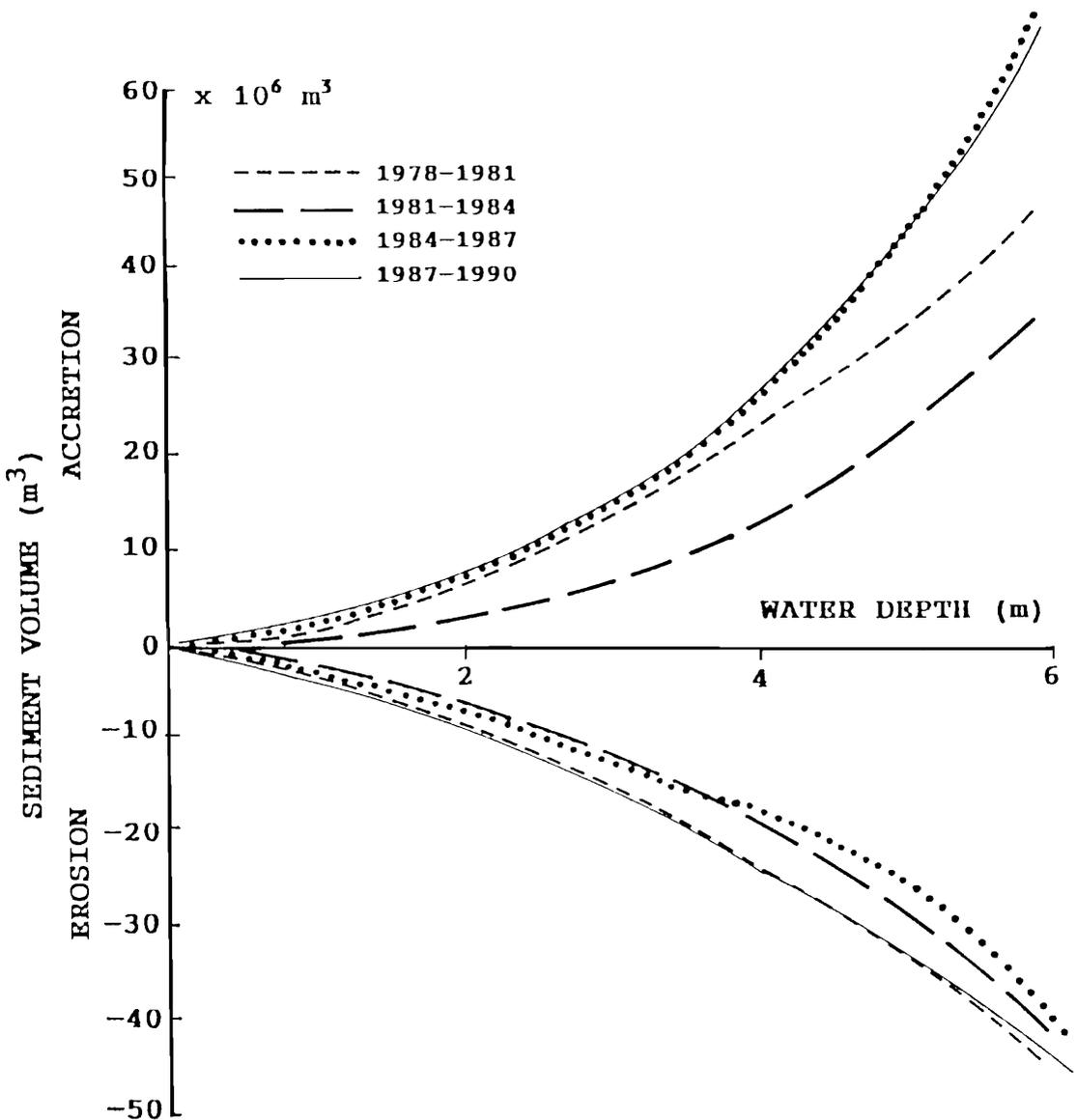


Figure 4. Cumulative volumes of erosion and accretion versus water depth for the whole Nile Delta coast.

Nile promontories act in a similar manner; much of the eroded sand comes from the outer tips of the promontories is transported eastward or locally westward by littoral drift and deposited in sinks. Based on profile analysis out to 6 m depth, the Nile Delta coastal zone can be divided into erosional and accretional stretches, with a few stretches showing negligible changes. Erosion

continues at Rosetta promontory, covering about 20 km from 8 km west of the Rosetta mouth to about 12 km to the east; Burullus-Baltim Inlet; about 12 km west and 12 km east of Gamasa Drain; and from Ras El Bar to 22 km east of Damietta promontory. Between these erosional stretches, accreted zones are present along the Abu Quir Bay, the coastal zone between 12 km east of the

Rosetta promontory at Abu Khashaba to the west of Burullus Inlet, Kitchener-Gamasa embayment as well as west of Port Said breakwater. The erosion/accretion pattern in sediment balance appears to remain stationary all over the Nile Delta coast except along the coastal zone between Abu Khashaba and east Burullus Inlet and along Gamasa embayment. The established erosion/accretion pattern along the shore has resulted from the continuous movement of sand from the eroded zones to the east or locally to the west. Studies on waves and currents along the Nile Delta coast (MANOHAR, 1981; FANOS, 1986; NAFAA *et al.*, 1991) reveal that for the most part, sand transport along the delta coast is directed toward the east due to the prevailing wave approach from the northwest, but there are local reversals and considerable variations in the magnitude of the otherwise eastward transport. The local reversal depends on the local shoreline orientation and wave climate.

The refraction patterns of the wave orthogonals for the Nile Delta coast from Abu Quir to Port Said have been constructed by QUELENNEC and MANOHAR (1977). The patterns show higher wave transport rates and wave convergence at the promontories and less transport at saddles and embayments. Similar transport rate (Q) and direction were estimated at the Nile promontories by FRIHY *et al.* (1991). Those patterns are generally consistent with the magnitude and direction of sediment volume changes presented in this study along the entire Nile Delta coast.

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□ RESUMEN □

Sobre la costa del Delta del Nilo, se inició, una fuerte erosión en respuesta a las construcciones de diques y presas que cruzan el Nilo. La erosión se aceleró en 1964 con la construcción de la Alta Presa de Aswan, que entrapa todo el volumen de sedimentos previamente descargado a las costas del delta. Los cambios volumétricos en la zona cercana a la costa del Delta del Nilo, fueron determinados por medio de perfiles de playa, medidos en 62 lugares, y durante un período de 12 años (1978–1990) a intervalos de 4 años. Las variaciones en el volumen de los sedimentos a lo largo de la costa mostraban un fuerte erosión en los promontorios del Nilo (Rosetta, Burullus y Damietta) lugares donde hay una importante concentración de las olas. En otras partes de la costa en Abu Quir Bay, Abu Khashaba, Hanafi, Kitchener Drain y detrás del rompeolas de Port Said se recibió el material erosionado por el transporte de los sedimentos que provienen del este. La máxima erosión se concentró entre Kitchener Drain y Gamasa ($-7 \times 10^6 \text{ m}^3$, para el período 1978–1981), y la máxima acumulación de los sedimentos se produjo entre Abu Khashaba y Burullus Inlet en Hanafi ($9.1 \times 10^6 \text{ m}^3$, para el período 1984–1987). Los cambios volumétricos, normales a la costa, indican que los sedimentos se han movido costa afuera y bajo la forma de deriva litoral a lo largo de la costa.—*Néstor W. Lanfredi, UNLP-CIC, La Plata, Argentina.*

□ ZUSAMMENFASSUNG □

Aufgrund von Dammbauten im oberen Nil setzte zu Beginn dieses Jahrhunderts an der Deltaküste eine einschneidende Erosion der Strände ein. Die Erosion wurde verstärkt nach Fertigstellung des Assuan-Hochdammes 1964, in dem alle Sedimente aufgefangen wurden. Die Volumenveränderungen an der Deltaküste wurden durch Profilvermessungen auf 62 Positionen in 4-Jahresperioden zwischen 1978 und 1990 bestimmt. Die Veränderungen zeigen sich in besonders starker Erosion an den Deltavorsprüngen (Rosetta, Burullus und Damietta), wo Wellenwirkung dominiert. Da die vorherrschenden Wellen aus Nordwesten kommen, empfangen die anderen Deltaabschnitte bei Abu Quir Bay, Abu Khashaba, Hanafi, am Kitchener-Kanal und hinter dem Wellenbrecher von Port Said die erodierten Sedimente durch longshore drift. Größte Erosionsbeträge finden sich zwischen Kitchener-Kanal und Gamasa mit 7 Mio. m^3 im Zeitraum 1978–1981, während die größte Akkumulation zwischen Abu Khashaba und Burullus bei Hanafi mit 9.1 Mio. m^3 im Zeitraum 1984–1987 zu beobachten ist. Aufgrund der Strandveränderungen kann man schließen, daß Sedimente sowohl küstenparallel wie auch meerwärts verdriftet werden.—*Dieter Kelleter, Essen, Germany.*