CHAPTER EIGHTY SEVEN

TRANSPORT OF NILE SAND ALONG THE SOUTHEASTERN MEDITERRANEAN COAST

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ABSTRACT

The potential for longshore sediment transport (LST) is estimated from a three-year set of directional wave data measured off Haifa, Israel. The resulting annual cycle of LST, together with an analysis of the wave and shore characteristics, suggests a wave-induced sediment transport mechanism with a uni-directional annual transport that gradually decreases along the transport path from the source (Nile delta) to sink (Haifa Bay). Existing estimates of the rates of transport of Nile sediment are in good agreement with this result.

Introduction

Mineralogical studies of coastal sediments from Alexandria eastward to the Sinai and Israel show that the Nile River has been the source of sediment for beaches and coastal dunes as far north as Akko, a shoreline length of about 700 km (Shukri, 1950; Emery and Neev, 1960; Shukri and Philip, 1960; Nachmias, 1969).

This suggests the coastline from the Nile delta through Akko (Fig. 1) to be a classical "littoral cell," i.e., a complete sedimentary compartment that includes the sediments' sources, transport paths and sinks (e.g. Imman and Brush, 1973). The Nile littoral cell thus begins with the Nile River as the original sonrce of fine quartzitic sand whose path leads along the coasts of Sinai and Israel. The cell terminates near Akko, in the Haifa Bay sink (Emery and Neev, 1960; Nir, 1973; Imman et al., 1976; Goldsmith and Golik, 1980; Nir, 1982a). Since the construction of the High Aswan Dam, the Nile no longer brings sediment to the coast, and erosion of the Nile delta now constitutes the sediment source for the Nile littoral cell (Imman et al., 1976; Imman, 1984).

At source, the Nile material may be carried eastward by either the prevailing westerly waves, or the counterclockwise Mediterranean gyre, or both (Inman et al., 1976). Here, the large angle of wave attack (westerly waves on an east-west beach), coupled with the existence of rather high waves (Lowe and Inman, 1983), snggests a very high rate of wave-induced transport. Also, the existence of eastward currents outside of the breaker zone (Manohar et al., 1974; Inman, 1984) indicates the existence of a steady current (the east Mediterannean gyre). This current may also be instrumental in the eastward transport of the Nile material.

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Farther east, toward the Sinai and especially along the Israeli coast, the rate of wave-induced transport must obviously he reduced due to the change in shore orientation vis-a-vis the approach directions of deep-water waves (Fig. 1a). It is unclear whether a wave-induced transport ("longshore sediment transport" or LST) or a current-induced transport ("shelf transport") is the main mechanism for moving the Nile sand along the cell.

In this paper we consider the mechanism of sediment transport along the Nile cell, making use of some recent results from a directional wave measuring system off Haifa.

Previous Studies of Sediment Transport Along the Israeli Coast

The study of Emery and Neev (1960) is a pioneer work, and classical paper. The observed presence of quartzitic sand with a distinctive suite of heavy minerals, and the gradnal decrease in sand size, led these authors to conclude that the heach sands of Israel are derived mainly from the Nile River. This sand is transported, they claim, hy hoth the wave-induced longshore current and hy the fringe of the offshore Mediterranean circulation current. During a three-day snrvey Emery and Neev measured the wave-induced current and found that it is northward directed and decreases in size as one moves along the coast from Sinai through Bat Yam (sonth of Tel Aviv), hnt reverses direction and gradually increases north of this nodal point.

Using some theoretical arguments on the heach orientation relative to an assumed dominant direction of wave approach, and the above experiment as an example, Emery and Neev generalize the above findings into the following conclusion. A snpposed change in the net LST direction occnrs near Tel Aviv, hence a significant amount of current-induced transport must he present to account for the abundance of Nile sediments north of Tel Aviv.

Although the Emery-Neev study deserves much credit for many of its pioneer findings, we feel that it errs in the above general conclusion. In particular, the three-day survey - conducted in the summer - is prohahly indicative of the summer LST trend, hut certainly not of the winter and net annual trends (see later).

Using wave refraction diagrams for various combinations of wave period and direction, Goldsmith and Golik (1980) proposed a slightly different pattern for the LST along the Israeli coastline. According to their study the gross LST is equal or very close to the net transport and is directed eastward along the Sinai coast as far east as Rafa. From Rafa to Haifa sand is transported both northward and southward according to wave direction. Generally, the northward component is larger than the southward in the southern part of the coast, decreases as one goes northward along the coast, and is smaller than the southward component in the northern part of Israel. Again, as with the Emery-Neev study, Goldsmith-Golik invoke a nodal point of zero net-LST in the center of Israel and, consequently, require a large amount of currentinduced transport. Like the preceding Emery-Neev stndy, the Goldsmith-Golik study lacks adequate ground-truth wave data for proper evaluation. With the recent deployment of directional wave systems off the Israeli coast, we are now in a better position to understand the mechanism and rates of sediment transport along this coast.

An LST cycle at Haifa

A directional wave station at Haifa, Israel, provides long-term measurements of both wave energy and direction. It offers an opportunity for estimating the direction and rate of sediment transport within the eastern portion of the Nile littoral cell. Moreover, conclusions can be drawn regarding the sediment transport along the cell.

The following results are based on three years of twice daily wave measurements. Details on the measnring system, procedures, and analysis techniques are given in Carmel et al., 1984a, b.

The monthly-average significant wave height is shown in Fig. 2a. It indicates a bi-modal climate, with a primary (winter) cycle whose monthly average wave height peaks around December-January at about 1.1m, and a secondary (summer) cycle that peaks around July-August at abont 0.8m. Further investigations reveal that the winter peak is caused by westerlies (eastward-moving low fronts) which move over southern Europe or northern Africa and generate big storm waves over the eastern Mediterranean (Carmel et al., 1984a). On the other hand, the summer peak consists of rather steady waves which are generated over the eastern basin of the Mediterranean by the seasonal trongh of low pressure (Carmel, 1984).

The directional wave data may be used for estimating the potential for longshore sediment transport. This is done through the use of equation (1) (e.g., Inman and Bagnold, 1963; Komar and Inman, 1970; Inman et al., 1976):

$$Q_{1=\frac{K}{(\rho_{s}-\rho)gN_{0}}(EC_{n}cos\thetasin\theta)_{b}}$$
(1)

where Q_1 is the volume sediment transport rate, K = 0.77 is a dimensionless constant (Komar and Inman, 1970), $\rho_s = 2.65$ and $\rho \approx 1$ gm/cm² are the densities of the quartzitic grains and water, respectively, $N_0 \approx 0.6$ is the "at rest" volume concentration of grains, E is the wave energy density, C_n is the group velocity, Θ is the angle between the wave crest and the beach, and the subscript b indicates the breaker point.

We use the bi-monthly accumulative wave data to estimate the bimonthly LST rates from equation (1). The resulting net average LST rates are shown in Figure 2b. The net monthly transport shows an annual cycle with a northward peak of 75 x 10^3 m³/month in mid-winter and a southward steady rate of approximately -25 x 10^3 m³/month in summer. Thus, the high winter waves generate a large northbound transport, while the smaller summer waves cause a smaller flow of sediments in the gpposite direction. The net annual transport rate is $110 \pm 100 \times 10^3$ m³/yr.



Figure 2. The monthly average significant wave height at Haifa (a); the bi-monthly average sediment transport rates at Haifa, computed from the directional wave data (b).

Projections on the Longshore Transport Rates along the Nile Cell

The winter westerlies and the summer seasonal trough are the dominant meteorological phenomena to govern the wind and wave generation in the Eastern Mediterranean. One thus expects the wave climate along the entire Nile littoral cell to be highly correlative and basically similar. The deep water waves arrive at Haifa from three windows of deep water wave approach (Fig. 1a). While the stormy winter waves arrive solely from the central and sonthern windows (Carmel et al., 1984a), the summer waves arrive only from the central and northern windows (Carmel, 1984).

Now, compare for instance the localities of Haifa, Hadera, Ashkelon and Rafa, arbitrarily picked along the Israeli coast (Fig. 1b). The beach normal is denoted by arrows, the wave approach windows, determined as in Fig. 1a by the protruding headlands of Egypt, Libya, Crete and Turkey, are shown by the open and hatched sectors. It is clear from Fig. 1b that the net transport must remain northbound and gradnally increase with the southward distance from Haifa. This is a result of the gradual change in beach orientation.

The above presents a consistent picture, where the sediment transport is wave-induced, and the net annual transport is unidirectional and gradually diminishing along the sediment path, thus allowing for the buildup and maintenance of the abundant Nile-sand beaches and coastal sand dunes.

Estimates of LST at various locations along the Nile cell

Inman et al. (1976) use a 10-year data set of marine wave observations to compute the LST rate at varions locations along the Nile delta. Because of the wide angle of wave attack, this method is considered reliable here. The computed results are "higher" than 860 x 10^3 m³/yr for the net (eastward) transport at the Rosetta and Damietta promontories. Only the main wave component was considered here. Quelennec and Manohar (1977), taking all wave components into account, indeed obtained higher rates; 0-1.5 x 10^6 m³/yr in between the two promontories, up to 3 x 10^6 m³/yr immediately on their eastern sides.

Inman et al. (1970; 1976) also estimate from the entrapment of sand at the entrances of the Bardawil Lagoon, that the net LST rate is about 500×10^{3} m³/yr and eastward at this location in Sinai.

The huge breakwater of the Ashdod harbour in southern Israel has yielded diversified estimates of the LST rate there. Dornhelm (1972) studied the annual bathymetric maps and concluded that the breakwater has interrupted some 80% of the northward sand transport, yielding a rather low estimate of $50,000 \text{ m}^3/\text{yr}$ northbound net transport. On the other hand, Finkelstein (1981), reanalyzing the same maps, found a large offshore sand accumulation and thereby arrived at a rather large estimate of $560,000 \text{ m}^3/\text{yr}$ northbound net transport.

An excellent survey of the various estimates of LST along the Israeli coast is given by Nir (1982b), from which the following paragraph is quoted:

"On the basis of theoretical studies Migniot (1974), Sauzay et al. (1974) and Manoujian and Migniot (1975) show that the annual resultant sediment transport is always directed to the north and reaches about 400,000 m³ at Gaza, 215,000 m³ at Ashdod, 100-150,000 m³ at Hadera and only 80,000 m³ at Atlit."



A summary of the above estimates, including that given by us for Haifa (110 x 10^3 m³/yr), is given by the direction and length of the solid arrows in Figure 3.

Several features are evident in Figure 3:

1. All estimates yield a counter-clockwise direction for the net transport, i.e., unidirectional along the way from source to sink.

2. Big discrepancies occur between the three estimates made at Ashdod, probably a result of the complicated path and entrapment of sediments around the harbour's breakwater. We take the average of these three estimates $(275 \times 10^3 \text{ m}^3/\text{yr})$ to represent the true transport rate at this locality.

3. The LST estimates begin with a maximum at the Nile source (860 x 10^3 m³/yr), are gradually diminishing along the sediment pathway, and reach a final low near the Haifa sink (80-110 x 10^3 m³/yr at Atlit and Haifa, respectively).

Hence, all existing estimates are in good agreement with our result on a wave-induced sediment transport, with a unidirectional and gradually decreasing rate from source to sink.

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