— *In* : Transformations and evolution of the Mediterranean coastline —

Dynamics and management of sand along the Israeli coastline

by

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ABSTRACT

The drastic increase in the population density of the Israeli coastal plain since the beginning of this century caused intervention in the natural coastal processes, and a deficit in the sand budget of that coast. It is estimated that some 20 million m^3 of sand were removed from the coastal sand system by sand mining from the beach and as a result of sand entrapment by coastal structures. Indications of coastal erosion which resulted from this deficit already exist. The estimated income of sand, by the natural Longshore Sediment Transport (LST) of 170,000-540,000 m^3/year, will not suffice to remedy the damage which has already occurred, and certainly not the demand for sand, in view of the extensive coastal developments in Israel, which is forecast for the next two decades. Two possible sources for sand should be explored: sand which may be present under a mud layer on the middle and outer continental shelf and import of sand from the vast dune fields in northern Sinai, Egypt.

RÉSUMÉ

L'augmentation considérable de la densité de population dans la plaine côtière d'Israël depuis le début du siècle a modifié les processus naturels, entraînant un déficit en sable de cette côte. On estime à quelque 20 millions de m^3 le sable "disparu" du système côtier en raison de l'extraction sur les plages et des retenues provoquées par les structures immergées. On possède

déjà des indications sur le degré d'érosion côtière qui résulte de ce déficit. Le volume de sable naturellement déposé par le transport littoral de sédiment est estimé à 170 000-540 000 m^3 par an; cet apport ne suffira pas à réparer les dommages déjà occasionnés et encore moins à répondre à la demande entraînée par le développement important des infrastructures sur le littoral israélien, prévu pour les deux prochaines décennies. Deux sources d'approvisionnement en sable pourraient être explorées : un gisement éventuel sous une couche de boue au centre et aux marges du plateau continental ainsi que des importations en provenance des vastes dunes du nord du Sinaï, en Egypte.

INTRODUCTION

It is estimated that during this century the population inhabiting the Israeli coastal plain has increased from less than 100,000 to 3-4 million people as a result of the massive immigration to the country. As shown in Figure 1, Israel finds itself in a unique situation among the developed countries, having both the highest population density and the highest rate of population growth. As it is the case all over the world, in Israel population moves to the coastal plain resulting in a high population density, which exerts multiple and continually increasing demands on the coastal zone. This region is used for bathing and recreation, ports and boat anchorages, oil and coal terminals, stilling water basins of power plants, sewer outlets, marine farming and, until 30 years ago, for sand mining. All these, combined with predictions for sea-level rise, cause changes to the coast, changes which are already noticeable.

One of the coastal elements which has been affected by these developments is the sand. Most of the sand on the Israeli coast is not indigenous. Since the formation of the Nile Delta, sand has been driven by waves and currents from the Nile Delta eastward along the coast of Sinai to the Israeli coast. Construction of the low Aswan Dam in 1902, and later of the high Aswan Dam in 1964, reduced and then stopped sand input into this system. In Israel, massive amounts of sand were mined from the beaches since the beginning of this century until the practice was stopped by the government in 1964. This and the intensive construction of coastal structures have reduced the natural sand reservoir and intervened in its natural flow.

Recent archaeological findings on the sea bed indicate that the sand budget along the coast is in deficit. The remnants of a neolithic village that existed some 8,000-10,000 years ago on the sea shore near Atlit, some 15 km south of Haifa, were recently discovered at a water depth of 8.5 m (HERSHKOVITZ and GALILI, 1990; GALILI *et al.*, 1993). On that site, burial grounds with human skeletons exposed on the sea bed were found. It is quite clear that fragile objects such as human skeletons would not have survived many winter storms had they not been protected by a layer of sand. Now these skeletons are exposed : the sand which protected them for more than 8,000 years has disappeared and has not been replaced.

In a similar way, a 2,000 year-old merchant boat was noticed "popping up" from the sandy bottom on the beach of Ma'agan Michael, some 40 km south of Haifa (LINDER, 1992). When it was unearthed, the boat with all its merchandise and utensils was still intact. Again, this boat could not have

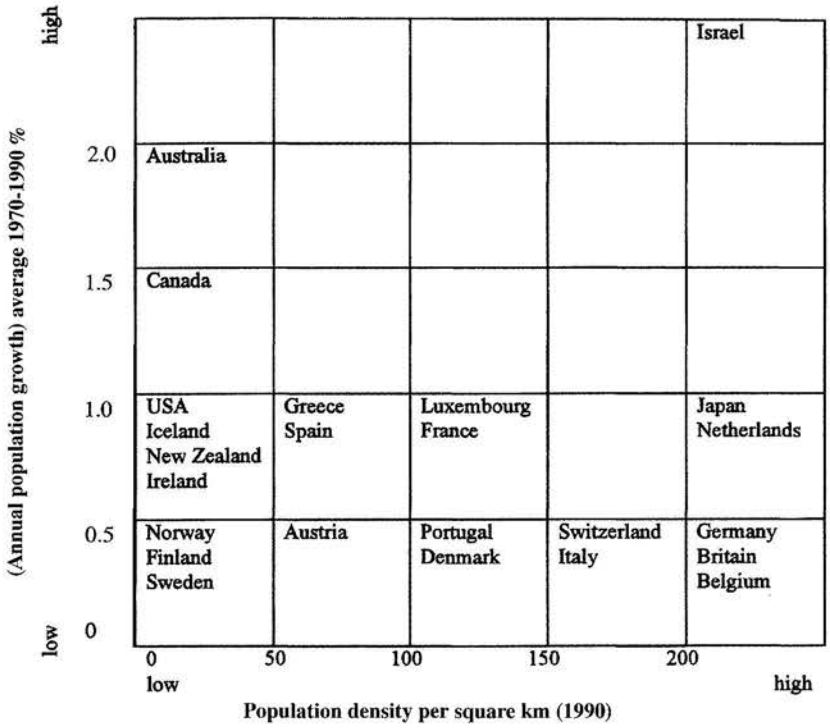

Figure 1 – OECD countries and Israel, population density and growth. From MAZOR (1993).

survived for 2,000 years had it not been protected by a layer of sand which is now disappearing. These archeological findings clearly indicate that the Israeli coastline suffers from a deficit in its sand budget, a deficit coming about at a time when huge quantities of sand are being sought for urgent engineering projects.

This paper will describe the natural processes which affect sand drift along the Israeli coast, human interference in these processes in the past and future, its impact on the sand system, and will propose means to cope with the problem of sand shortage.

THE ISRAELI COASTLINE

The Mediterranean coast of Israel extends along some 180 km from Gaza in the south, to the Lebanese border in the north (see Figure 2). With the exception of Haifa Bay, it is a smooth coastline which gradually changes its orientation from NE-SW in the south to almost N-S in the north. The coast may be divided into five geomorphological units: from the southern border to the vicinity of Tel Aviv the beach is 30-50 m wide and backed by a low (5-7 m) bluff and wide (up to 10 km) dune fields; from Tel Aviv to the vicinity of Hadera the beach is narrower (0-30 m) and backed by a high (up to 40 m) cliff; from Hadera to Haifa the coast is of low profile with no bluff or cliff and, at times, with small embayments; Haifa Bay, from Haifa to Akko,

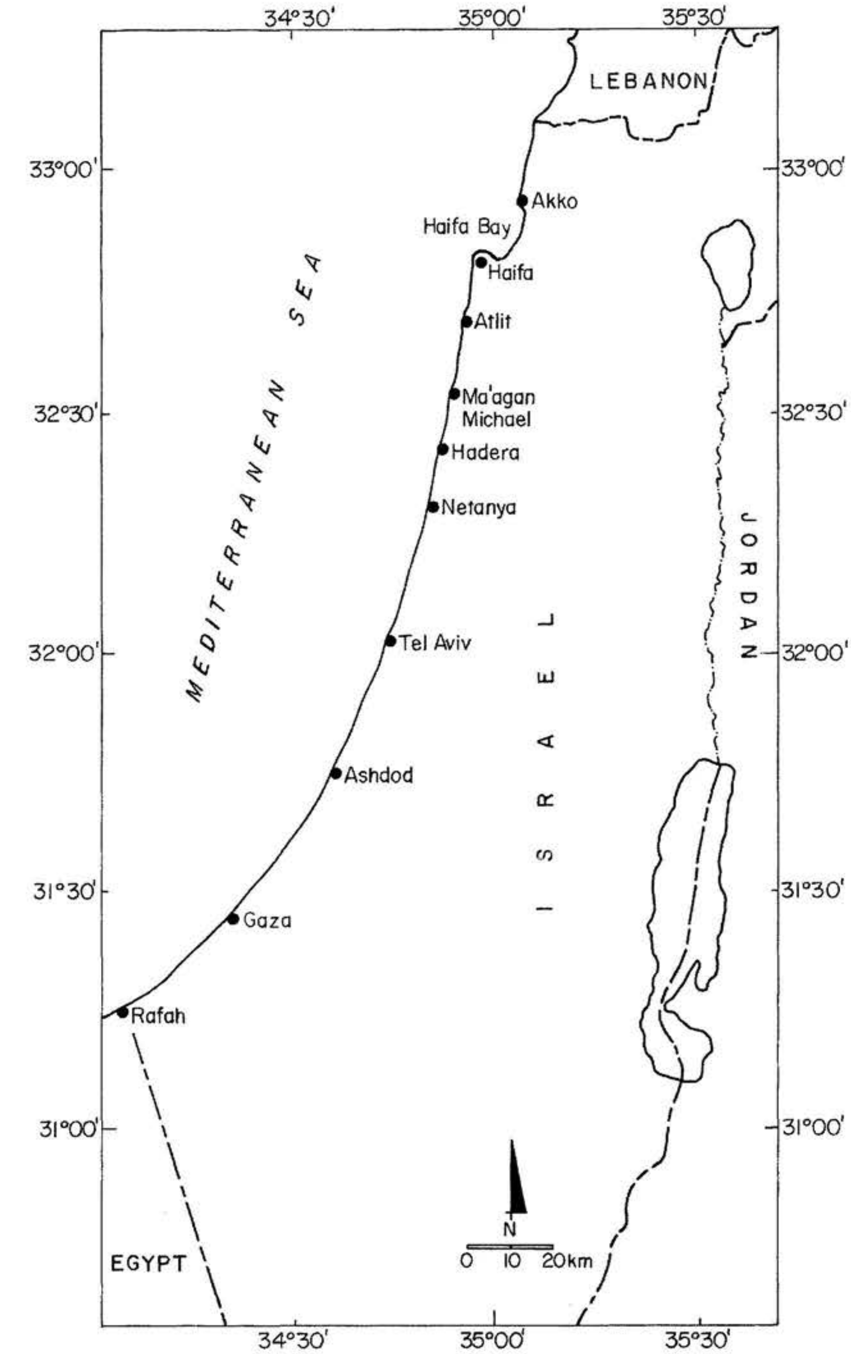

Figure 2 – Location map.

where the beach is backed by dunes and from Akko to the Lebanese border where the beach is mostly rocky with pocket beaches backed by a low cliff.

Most of the coastline, from the south to Akko, some 150 km, is part of the Nile littoral cell (INMAN and JENKINS, 1984). This cell, which extends from the Nile delta in Egypt to Akko (Israel) consists of input of quartz sand from the Nile river, transport of sand by the action of waves and currents eastward along the Sinai coast to Israel, wind-blown sand from the beach landward and a sediment sink in Haifa Bay (Israel). North of Akko, the sand is meager in its quantity and biogenic in its origin, consisting mostly of crushed shells, carbonaceous algae, carbonate pebbles and granules and very little quantity of quartz grains.

DYNAMICS OF SAND

Sand sources

The watershed area of the Mediterranean coast in Israel is made of carbonate rocks and cannot therefore supply quartz sand to the beach. All of the quartz sand which is found on the beach and the continental shelf of Israel was brought there from the Nile river and delta. Indeed, the assemblage of heavy minerals found in the sand shows similarity to that found in sediments of the Nile river (POMERANCBLUM, 1966). The only rock unit found in the watershed area which could contribute quartz sand to the beach is eolianite sandstone which is locally called "Kurkar". Kurkar is found as elongated ridges running parallel to the beach on the coastal plain and the continental shelf. However, Kurkar is built of nilotic sand brought in previous cycles of sea level stand and cannot be distinguished from the present day sand.

Longshore Sediment Transport (LST)

The first to propose a model which describes the pattern of the sand transport along the Israeli coastline were EMERY and NEEV (1960). They took into consideration two facts:

a) The longest fetch that the Israeli coast is facing is a narrow window of about 12° with an azimuth of 282° (Figure 3). This fetch extends to a dis-

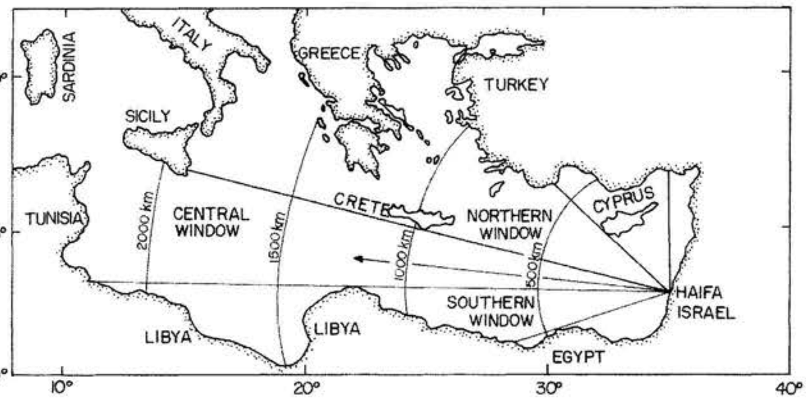

Figure 3 – The fetch facing the coast of Israel. Notice that the central window reaches the straits of Sicily, a distance of some 2,400 km. From CARMEL *et al.* 1985.

tance of about 2,400 km (as far as the straits of Sicily), and therefore the highest and longest waves approach the coast from that direction.
b) The gradual change in the orientation of the Israeli coast.

The combination of these two factors implies that most of the wave-induced longshore currents should be from south northward along the southern part of the coast and vice versa, along its northern part with a nodal point, according to EMERY and NEEV (1960), near Tel Aviv (Figure 4). Accordingly, this should also be in the direction of the LST.

This model raises a problem as to the source of quartz sand which is present on beaches north of Tel Aviv, as there is no input of such sand from land to these beaches. EMERY and NEEV were aware of this difficulty and proposed the existence of an additional mechanism for sand transport: the margin of the Mediterranean Current which drives the sand on the inner continental shelf northward. On its way this sand feeds the beaches, including the northern ones (see Figure 4).

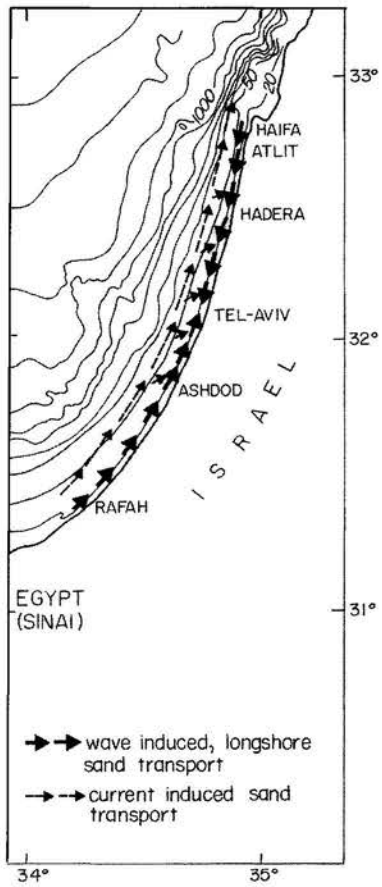

Figure 4 – Sediment transport pattern along the Israeli coastline according to EMERY and NEEV (1960).

GOLDSMITH and GOLIK (1980) made use of a detailed bathymetric survey of the Israeli continental shelf which was carried out in 1969-1970, to prepare a refraction pattern of the waves as they move across the continental shelf towards the beach. As measured data on wave characteristics (height, frequency and direction) were not available, GOLDSMITH and GOLIK computed the refraction pattern of hypothetical, monochromatic deep water waves, approaching the shore from various directions. These computations provided the wave height, direction and rate of LST in the breaker zone, for each of the waves which was treated. The analysis of the results of all the selected waves yielded a model of the LST sand transport which distinguishes four section of the southeastern Mediterranean coastline (Figure 5):

a) Along the Sinai coastline, net transport equals gross transport and is directed from west eastwards.

b) Between Rafah and Haifa, the transport direction depends on the wave direction, and therefore may be from south northward and vice versa. However, in the southern part of this section most of the LST is directed northward, and it decreases

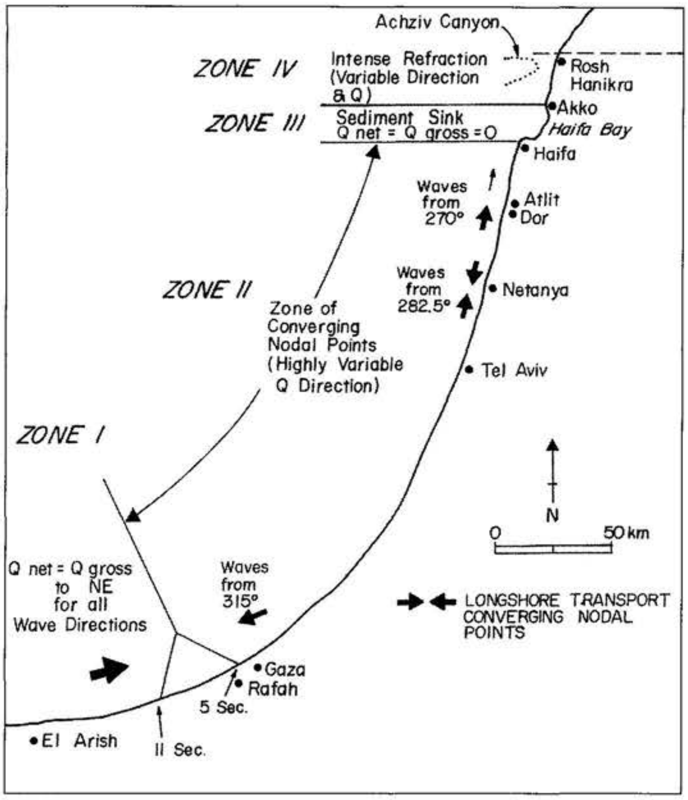

Figure 5 – LST model for the southeastern Mediterranean coastline after GOLDSMITH and GOLIK (1980).

in quantity, and may even reverse direction to the south, as one goes northward along the coast.
c) In Haifa Bay, the waves undergo divergence as they approach the beach, resulting in small wave height with low energy and small LST. Haifa Bay may therefore be considered a sedimentological sink.
d) North of Akko, to the Lebanese border, the pattern of wave direction is complicated due to the irregular bathymetry of the continental shelf. No nilotic sand is found along that part of the coast; the sediment is rather sparse and, consequently, the LST there is small and insignificant.

The two models described above are qualitative in the sense that they provide the direction of the sand transport but not the rate of transport. CARMEL *et al.* (1984, 1985) conducted directional wave measurements in shallow (6.5 m) water in Haifa and computed the net LST there, which they estimated at 110,000 ± 100,000 m^3 northward. CARMEL *et al.* (1984) suggested that since the orientation of the Israeli coastline gradually changes from almost N-S near Haifa to NE-SW near Rafah and then E-W along the Sinai coast, the LST along the entire Israeli coast south of Haifa is directed northward and is progressively decreasing from the south northward as described in Figure 6.

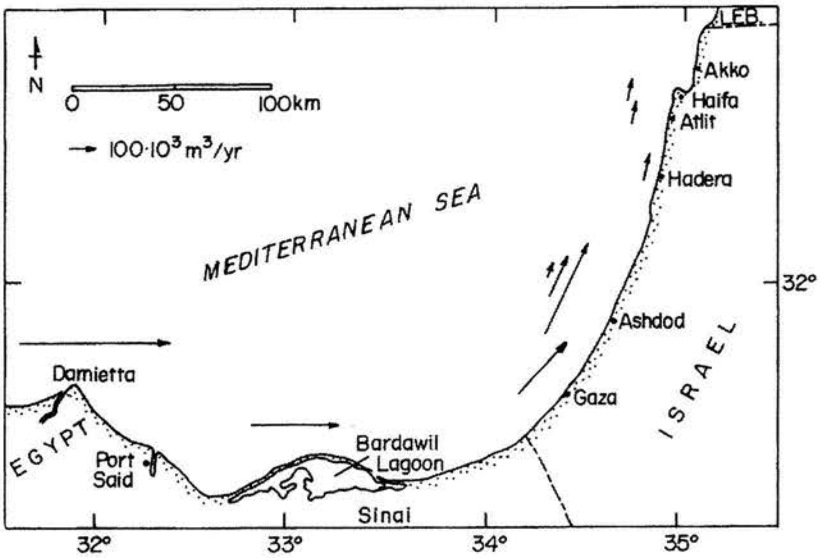

Figure 6 – LST along the southeastern Mediterranean according to CARMEL *et al.* (1984).

GOLIK (1993) brought field evidence which supports the model proposed by EMERY and NEEV (1960). This consists of: a) beach accretion on the northern side of coastal structures in Haifa and Hadera on the northern part of the coast *vs.* beach accretion on the southern side of coastal structures on the southern part of the coast, indicating convergence of the LST in the middle of the coast as proposed by EMERY and NEEV (1960); b) bedforms on the continental shelf off Ashdod and Haifa show a northward flow of sediment. Furthermore, monitoring of coal particles falling during unloading of coal from ships to the coal terminal at Hadera at a water depth of 23 m showed that these migrate northward. Although the hydrodynamic properties of coal differ from those of sand, it is difficult to visualize how the coal particles would move northward while sand migrates in the opposite direction. The northward transport of sediment on the continental shelf, beyond the surf zone, is one of the elements of the EMERY and NEEV model.

SHOSHANY *et al.* (1996) analyzed aerial photographs which were taken between 1955 and 1990 of the shoreline of Netanya. Two tombolos were formed there as a result of two detached, shore parallel, breakwaters built there in 1969-1970. Comparison of the shoreline position, to a distance of 1,400 m north and south of the tombolos, prior and after the formation of the tombolos shows that beach accretion of about 20 m occurred north of the tombolos, whereas beach erosion took place south of them. This change indicates that the tombolos cause interference with the LST and that the direction of the LST along that coast is from north to south.

In summary, there is no question that the sand on the Israeli coast originates in the Nile River, that it migrates along the Sinai coast eastward and then northward along the Israeli coast as far north as Akko. The pattern of sand movement along the northern section of the coast between Tel Aviv and Haifa is still not clear. The reason for this ambiguity is the fact that along this part of the coast, the wave direction is very close to the beach normal. The net sand transport, therefore, may be either northward or southward, probably fluctuating between these directions.

Wind-blown sand

The southern part of the Israeli coastal plain as far north as Tel Aviv consists of extensive dune fields which penetrate from the shore inland to a distance of up to 10 km. North of Tel Aviv, sand dunes are found only where gaps in the coastal cliff exist such as near Netanya and Hadera. These dunes were formed by sand blown from the beach inland. Using eolian sediment traps, GOLDSMITH *et al.* (1990) measured the rate of eolian transport at a few stations along the coast. They found that the net transport is landward and that its rate is small relative to the gross transport, 0.1-0.2 *vs* 39-49 $m^3m^{-1}y^{-1}$ respectively. The rate is higher on the southern part of the coast than on the northern one and this is due to vegetation which is more abundant in the north. According to their estimate the sand contribution from the beach landward is about 20-30% of the LST.

SAND RESERVOIR ON THE SEA BED

At the end of the last glacial period, some 18,000 years ago, sea level was lower by about 120 m than its present level, the continental shelf was exposed and covered by sand which was blown from the shore inland. Processes of solution and redeposition of carbonates solidified this sand into a sandstone locally called "Kurkar". The gradual rise of sea level since the beginning of the Holocene caused migration of the shoreline eastward and deposition of new sediment on top of the Kurkar. The nature of this sediment was determined according to the physical conditions which governed the site of deposition. Near the shoreline, where wave energy is high, only sand could be deposited, but with increasing distance from the shore, the sediment gradually gets finer from medium sand to fine sand, silt and clay. NIR (1973) reports that 2-3 km offshore, at a water depth greater than 30 m sand is not present any more. Figure 7 presents a schematic geological section which resulted from this development.

In an effort to determine the sand reservoir which is found on the continental shelf, GOLIK *et al.* (1993) used shallow seismic profiles which were taken from all over the Israeli continental shelf. The hard, irregular Kurkar layer is a good reflector and may easily be noticed on the record. GOLIK *et*

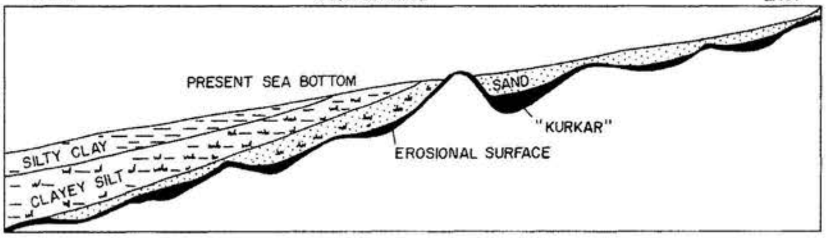

Figure 7 – A schematic cross section of the sea bottom and sub bottom of the Israeli continental shelf. From NIR (1973).

al. (1993) computed the volume of the unconsolidated sediment which overlies the Kurkar between 15 to 30 m water depth. This is the depth range in which sand may still be exploited under certain conditions. They estimated at 3.8-4.9 x 10^9 m^3 the volume of unconsolidated sediment found on the inner continental shelf. The volume of this sediment is gradually decreasing from an average of 46,000 m^3 per frontal meter of beach between Rafah and Ashdod to negligible values south of Haifa. It should be emphasized, however, that this is not clean sand but sand mixed with various quantities of silt and clay.

MAN'S IMPACT ON THE SAND SYSTEM

Man's impact on the coastal sand in Israel is due to two types of activities: mining of sand from the beach for building purposes and the construction of various coastal structures which intervene with natural sand transport causing beach accretion and erosion.

Sand mining from the beach

The use of beach sand for building purposes in significant quantities started at the beginning of the century with the massive immigration to the country and the buildup of new towns and cities along the coastal plain. According to written records, close to one million m^3 of sand was mined from the beach in 1963 only. Between 1949 and 1964, 5 million m^3 of sand were mined from the Palmakhim-Nitzanim beaches (Zifzif Committee, 1964). Examination of aerial photographs taken in the late 50's and early 60's clearly show scars, which were caused to the beach by mining along many kilometers of coastline (see Figure 8). Although quantitative information on the beach mining activity is meager, it is very reasonable to assume that from the beginning of the 20^{th} century until 1964, when beach mining was stopped by governmental decree, the amount of sand mined from the beach was in the order of 10 million m^3.

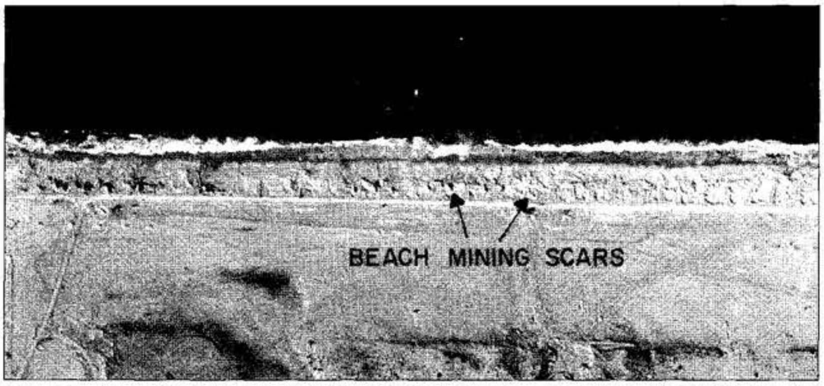

Figure 8 – An aerial photograph taken in 1958 from a beach in the vicinity of Ashdod, showing sand mining scars.

Effect of coastal structures

Modern construction of coastal structures in Israel began in 1932 with the construction of Haifa Port. But it was not until the late 1960s that a momentum of building coastal structures took place, a momentum that will continue into the future. Various types of coastal structures were built along the coast: ports, boat anchorages, stilling water basins for power plants, groins, detached shore parallel breakwaters, sea walls, jetties, and pipe lines for oil and domestic and industrial sewer. The number of structures on the Israeli coast is not known but is estimated at approximately 50 which interfere with, and affect coastal processes.

NIR (1976, 1982) investigated the effect of coastal structures on the nearby beach, paying special attention to detached breakwaters. He found that the tombolo which is formed behind a detached breakwater reaches half its size between 1-3 years after construction of the breakwater, and matures within less than 6 years. The size of the tombolo, in terms of area and volume, depends on the ratio between the distance of the breakwater from the shoreline and its length. If this ratio is 2 or more, sand accretion is negligible. He estimated at 600,000 m^3 the volume of sand which was trapped next to nine detached breakwaters and groins during their first five years of existence.

Using aerial photographs and bathymetric maps, GOLIK *et al.* (1996 a,b) studied the effect of Ashdod Port on the shoreline and the sea bottom. They found that during its 35 years of existence, the port caused beach accretion of a magnitude greater than 100 m near the port's main breakwater. During that period, the port trapped more than 4.5 million m^3 of sediment on the sea bed in its vicinity.

If one extrapolates these measured volumes to other coastal structures on the Israeli coast, it may be estimated that the total volume of sand trapped by coastal structures is close to 10 million m^3. Added to the sand mined from the beach, it brings to some 20 million m^3 the total volume of sand removed from the coastal system due to human activity, and hence the deficit in the sand budget.

Future demands for sand

Israel is facing a severe shortage of sand within the near future. The annual demand for sand for the building industry is 8 million m^3. In the coming decade, both Haifa and Ashdod Ports must undergo expansion which will require an estimated quantity of 10-12 million m^3. In addition, the demand for development of various beaches for recreational activities is continually increasing and this again will require an unknown quantity of sand. Serious studies and discussions concerning the building of artificial islands offshore are now underway. In view of the increasing demands for real estate in the coastal zone, there is a high likelihood that the idea of building artificial islands for purposes such as airports, power plants, office buildings, hotels and even housing, will materialize. One island alone will require between 20 to 25 million m^3 of filling material, and sand will be one of the materials sought for this purpose.

Possible solutions to the sand shortage

According to various estimates (Delft Hydraulics, 1994), the annual net LST into the Israeli coast is between 170,000 to 540,000 m^3. It is clear that this quantity cannot solve the present problem. A shortage of sand in Israel is bound to happen unless other sources of sand are sought. Two possible sources to meet the future demand for sand may be considered: offshore sand mining from the sea bottom and/or the import of sand from a foreign source.

It is well known that sand migrates seasonally in the on-off direction: during the stormy winter from the beach to the offshore, where it forms a bar, and from the bar to the beach during the summer. When recurrent surveys of bathymetric profiles are carried out along a certain range for a long period of time, the envelope of the profiles closes at a certain depth which is called the "closure depth" (see Figure 9). A conservative estimate of the closure depth along the Israeli coastline is between 10 and 15 m. As sand migrates in the on-offshore direction at depths shallower than the closure depth, mining there should not be permitted: it is as harmful to the beach as is extracting sand from the beach itself.

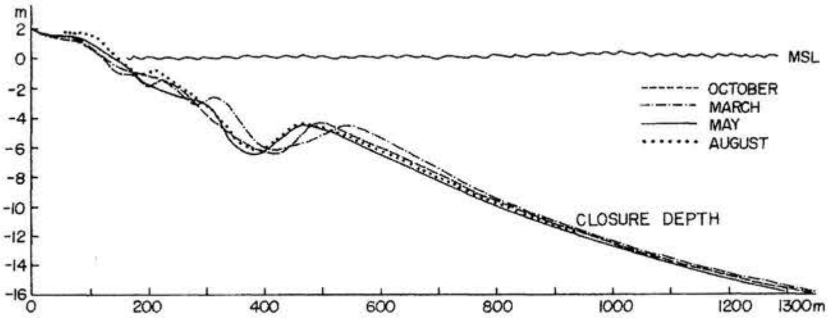

Figure 9 – Seasonal sea bottom fluctuation along a profile off Ma'agan Michael. After EITAM (1974).

Sand mining beyond the closure depth is also problematic because there are indications, mentioned above, that this sand drifts northward on the inner shelf and then feeds the beaches there. Also, at depths greater than 15 m, the relative abundance of fine material, silt and clay, increases and this may pose a difficulty for the building industry. Therefore, the issue of mining sand from the inner continental shelf must be further investigated before it is permitted.

Another possibility for offshore mining, which must be explored, is sand found in the middle, and maybe even the outer shelf, beneath a cover of mud. It is quite possible that on top of the erosional surface of the Kurkar (see Figure 8) unconsolidated sand, which was deposited during the Holocene transgression, may be found. Detailed shallow seismic survey accompanied with boring must be carried out in order to explore this possibility.

The other source is imported sand. The northern section of the Sinai Peninsula (Egypt) is covered by a huge area – 8,000 km^2 – of sand dunes (KAMEL *et al.*, 1982). Assuming an average thickness of sand cover of 20 m, the estimated volume of sand there is 180 billion m^3 which, for all practical purposes, is an endless source of sand. The fact that it could be shipped to Israel by sea makes this an attractive possibility which should be explored.

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