

ASSESSING PRESENT AND FUTURE MEDITERRANEAN SEA LEVEL RISE IMPACT ON ISRAEL'S COAST AND MITIGATION WAYS AGAINST BEACH AND CLIFF EROSION

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This paper presents the outcome of a coastal engineering hydro and morpho-dynamic model study using a number of numerical models which was conducted by the author on the erosion state of the Mediterranean coast of Israel for a time horizon of 100 years. The study assessed future sea levels, and compared wave setup and runup and beach profile erosion at the coastal cliffs in order to determine the relative sensitivity of the various coastal sectors of the Israeli shore. Finally it investigated measures and means for effective the mitigation of the forecasted beach and cliff erosion. The study was carried out as part of a multi disciplinary work involving various additional disciplines, and was used to establish a national policy document in regards to the coastal cliffs collapse and erosion by natural and anthropogenic induced factors, including global warming induced sea level rise and reduced return period of extreme events. The approach and outcomes are estimated to be useful for coasts of similar conditions elsewhere on the globe.

Keywords: sea level rise; wave setup; erosion; cliffs; wave climate;

Introduction

The present state of the Mediterranean coast of Israel is characterized as being in a mild erosive state, evidencing beach erosion and coastal cliffs retreat. The forecasted sea level rise induced by global warming, confirmed also in the Mediterranean, as well as the forecasted increase in the frequency of extreme storm conditions induced by climate change impact on wind and wave climate statistics, as well as the recent awareness of tsunami hazard in the Mediterranean, pose a joint hazard to this coastal sector. The coastal sector is the last and northern part of the Nile littoral cell, extending from the Nile delta throughout the bay of Haifa, being characterized by a major, beaches and near-shore quartz sand content (Fig. 1). The sand was originally brought until 1965 by the Nile river to its delta, when it stopped coming due to the completion of the high Aswan dam then. Nevertheless, the huge amount of sand which accumulated there has been continuously transported by the net joint actions of the waves, wind and currents partly offshore and partly eastward along the Sinai coast and then further northward on the Israeli coast until its end at Haifa bay up to Acre, both within and beyond the surf zone. On its alongshore way, some sand volume has been transported inshore to the beach and then to coastal dunes by the wind blowing on the beaches, some moved offshore beyond the closure depth and accumulated on the sea bottom profile and some moved further towards Haifa bay. At the same time, the coastal cliffs, which are present in the sector from Gaza to Hadera, have been eroding and retreating, providing an additional input to the total sand balance.



Fig. 1. Nile littoral cell location map (arrows indicate net longshore sediment transport direction)

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Recent severe beach and cliff erosion encountered at a number of locations along the Israeli coast (Figures 2 -5) led to the necessity to investigate and assess the present and future impact of climate change induced sea level rise as well as the optimum mitigating means against beach and cliff erosion, as part of the preparation of a National Policy Plan for Coastal Cliffs Management (recently approved by the Israeli Government), within a multi disciplinary study, jointly with other geological, planning, engineering, social and law bodies and consultants.



Figure 2. Collapse of the Apolonia fortress wall at Herzliya due to severe beach and cliff erosion



Figure 3. Cliff and beach erosion during mild waves at Hasharon coastal sector



Figure 4. Beach and cliff erosion at Havazelet Hasharon coastal sector north of Netanya



Figure 5. Cliff collapse at Herzliya coast north of Apolonia ancient fortress

The Israeli Mediterranean coast is in a state of mild erosion expressed by beach and cliff set back due to anthropogenic past actions of sand beach mining and coastal development.. The present and future sea level rise due to global warming, the forecasted increased frequency of extreme storms induced by climate change on wind and wave statistics, and the confirmed serious tsunami hazard in the Mediterranean, imposed studying the sensitivity of this coastal sector to the above impacts up to

2100, and to evaluate the needed ICZM policy of coastal engineering mitigation means to be implemented. While a number of methods and tools have been developed for such assessment, such as the DIVA model (DINAS-COAST Consortium, 2004; Hinkel, 2005), or by just assessing the flooded areas for certain sea level rise elevations (e.g. Clus-Auby et al. 2004) or even more sophisticated numerical tools such as sedimentological 2Dh or 3D commercial models were available on the market (Delft 3D, MIKE 21, etc.), the funding for the study was very limited while the goal was to obtain reliable results. Alternative assessment methods considered were:

- a) Assessment of future sea levels including its rise by climate change, tide and future extreme wave and wind induced sea levels and marking of the positions of the various elevations on a topographic chart of the coast (simple approach).
- b) As above combined with a full 2D detailed sedimentological model and a parallel qualitative study of the relative strength and stability of the coastal cliffs and utilization of global climate model forecasts in study area (difficult).
- c) As a) in combination with a storm profile development model of typical coastal sectors and with a detailed wave transformation and setup model along all the coast and a parallel study of the relative strength and stability of the coastal cliffs (moderate). This method, imposing the selection of a more simplistic approach, which, nevertheless was estimated to enable yet reaching reasonably correct assessment of future expected impact and effectiveness of mitigating means and was selected for the present study.

Scope of the study

The investigation conducted consisted of:

1. Analysis of the present state of the Israeli coast in regards to beach and coastal cliff erosion by performing differential high resolution volumetric maps of the shore and cliffs erosion and accretion, induced by both natural and anthropogenic activities (not presented in this paper),
2. An updated analysis of the directional wave climate, of the local and regional sea level changes and an assessment of future changes of the meteo-marine statistics and the resulting coastal erosion for a time horizon of 100 years under future sea level rise and wave statistics change scenarios. This has been performed using various modelling tools such as the hydrodynamic wave propagation model SWAN ver. 4 (Holthuijsen et al. 2007), the Cross shore model SBEACH (Sommerfeld et al. 1996) as well as additional tools included in the CEDAS software package version 4.03 Pro (Veritech Inc. 2006), in order to assess the future coast erosion along the coast and determine the most sensitive coastal sectors. A bathymetric and topographic grid with a cell size of 5 m has been prepared for 3 coastal sectors covering most of the coastal cliffs along the Mediterranean coast of Israel, for a total length of about 60km. An exception were the coastal sector north of Poleg river, where the existing bathymetric data were found to contain many unreliable data. However, the results obtained for the other sectors enabled to make estimates also about this shorter coastal sector which was not modelled.
3. Analysis of a number of types of coastal erosion mitigating means (e.g. submerged breakwaters, submerged underwater reefs, etc.) and
4. Re-modelling of typical coastal sectors with various mitigation means for the same time horizon.

Investigation program

The IOLR investigation was composed of:

- Assessment of past & present coastal beach and cliff erosion (extent and rates) by differential charts and water line retreat,
- Assessment of future sea level rise and selection of wave climate scenarios for a time span horizon up to 2100,
- Simulations of wave action on coastal sectors with exposed cliffs using the SWAN model on a 10m X 10m grid cell size and by comparative investigation of the wave setup and runup, to rank the most endangered coastal sectors,
- Simulation of cliff erosion using storm profile change sedimentological model SBEACH at 1 km intervals using a 5m grid cell and various storm scenarios for up to 2100, in order to assess the relative potential beach and cliff erosion at the various coastal cliff sectors, assuming sandy cliffs.
- The relative state of coastal sectors located between the sections investigated in SBEACH was determined using the relative percentage of time and extent the cliff toe was estimated to be attacked for the time horizon of 10, 20, 50 and 100 years by wave induced setup and run-up, derived using the SWAN model.

- Finally, using the meteorological climate observed in the last decade, the future coastal cliff recess rate was assessed, by comparing the recession rate determined in the model assessment for the last decade versus the outcome of field monitoring of quantitative cliff recess at the various coastal sectors in the same 10 years period, combined with the relative strength and stability of the cliffs as determined by the other parallel studies.

Assessment of the wave setup and runoff at the cliff during present and future sea level rise

While the 3rd Intergovernmental Panel on Climate Change Assessment (IPCC. 2001) of surface temperature & sea level rise until 2100 for Business As Usual scenario (BAU) provided the following estimates of global sea level rise of up to 0.89m by 2100, lower estimates were derived by 4th IPCC assessment (IPCC. 2007) shown in table 1.

Assessor	IPCC 2001	IPCC 2007	Rahmstorf (2006)
Year			
2025	+3cm to 14cm		+10cm to +20 cm
2050	+5cm to 35cm		+20cm to +40 cm
2100	+9cm to 89 cm	+0.26cm to +0.59cm	+50cm to +135 cm

The sea level rise forecast of IPCC 2007 was criticised as misleading by a number of recent studies, which showed that there is potential for sea level rise beyond +1.0m by 2100. The main reasoning was that the IPCC 2007 assessment did not account for the ice cover melting. These assessments were compared also against the local sea level rise trends at the GLOSS station 80 - Hadera, operated by IOLR. The most recent results are shown in Figure 6. The rise trend indicated that the local sea level rise is slightly higher than the global measured values (at present about 5.8 mm/year vs the global average of almost 4 mm/year), so it was decided to select a sea level rise of +100cm by 2100 for the Israeli coast.

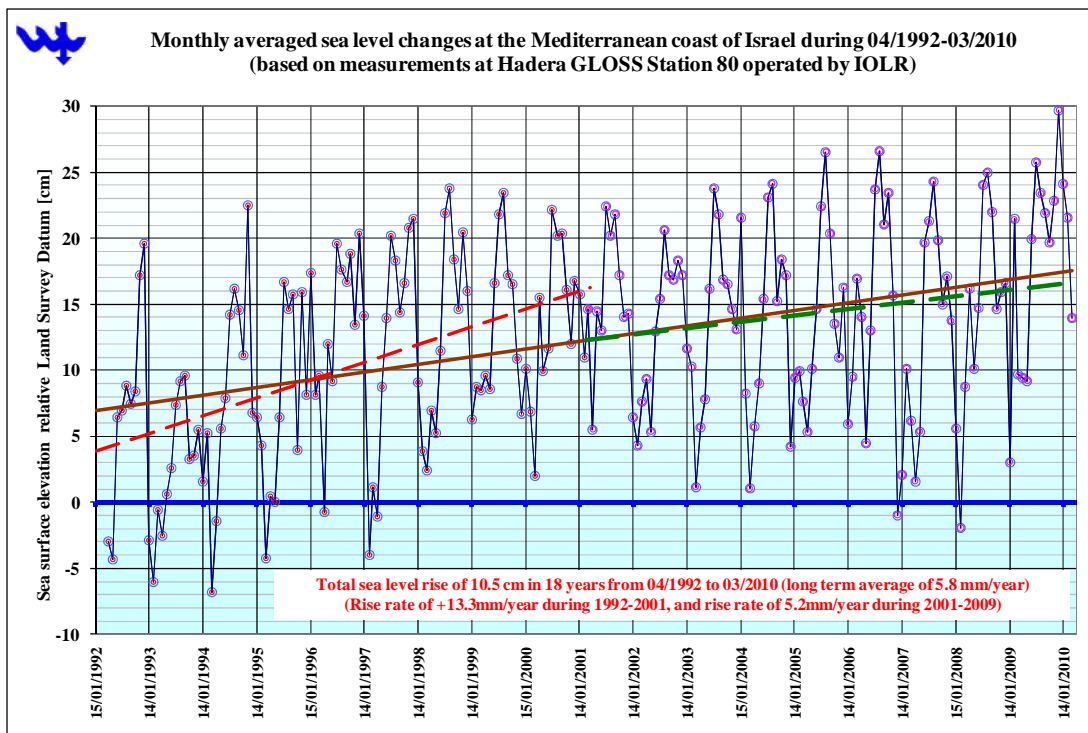


Figure 6 - Trends of sea level rise off the Israeli coast of Israel during the last 18 years

As shown by a number of recent studies (Rahmstorf. 2006/2007; Grinsted et al. 2009; Vermeer and Rahmstorf. 2009; Vellinga et al. 2009; Jevrejeva et al. 2010; Rahmstorf. 2010) the sea level rise by 2100 is considered to be able to exceed 100 cm. Consequently the accepted sea level rise for the Israeli coast seems to be reasonable, and the simulations were based on a linear sea level rise from 2000 to 2100. Return periods of extreme sea levels were also assessed, and based on these the computed values

were derived for the sea level at the cliff position, as indicated in Table 2. The extreme sea states and the resulting sea levels and run-up at the cliff are shown in Figure 10 and the simulated sea states are represented in Table 3 and in Table 4 are provided the sea conditions tested with SWAN

	Period: during 1966-1984	date
Max sea level (cm)	93.0	22.12.1967
Min sea level (cm)	-53.0	09.01.1977
Max astronomic tide in 19 years HAT (cm)	44.5	07.08.1967
Min astronomic tide in 19 years LAT (cm)	-36.4	04.03.1976
Max high surge level (cm)	70.7	22.12.1967
Min lowering sea level by winds (cm)	-42.9	15.12.1971

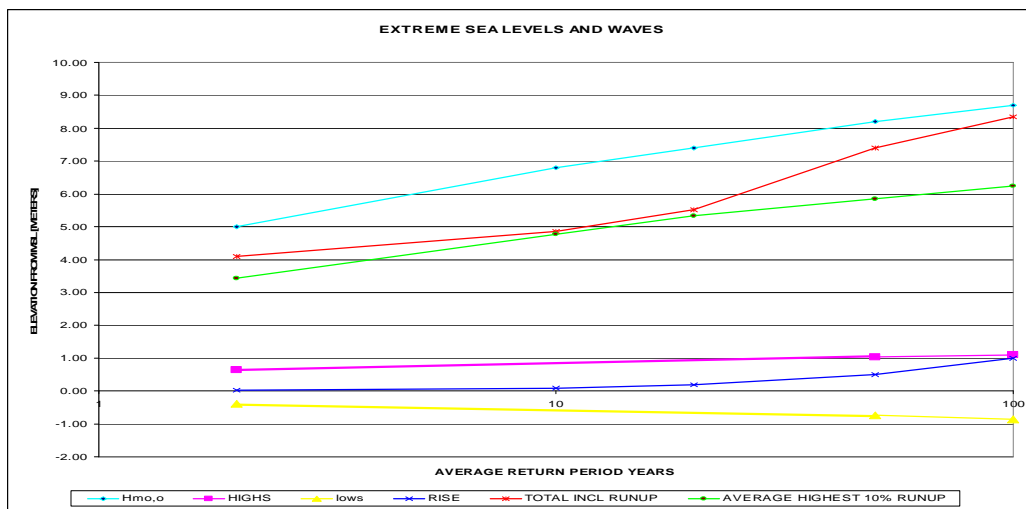


Figure 9. Extreme water levels and sea states assessed for the study prior to the SWAN modelling

Deep Wave direction Az deg	Water level (m) vs ILSD	Hs,o (m)	$T_p(\text{sec}) = 5.45 \cdot (H_{s,o})^{0.5}$	duration(hours)
270	0	2	7.68	
270	0.10	3.00	9.44	12.80
270	0.20	4.00	10.90	12.80
270	0.30	5.00	12.19	10.60
270	0.40	6.00	13.35	10.40
270	0.60	7.00	14.42	10.30
270	1.00	8.00	15.41	9.00
270	1.00	9.00	16.35	3.00
270	1.00	10.00	17.23	3.00
270	1.00	11.00	18.08	3.00

Sea level	Sea state duration	T_p	$H_{s,o}$	Return period
m	hours	sec	m	years
0.0	13.1	11.5	4.80	1
0.0	10.4	13.0	6.15	5
0.0; +0.1	10.2	13.5	6.80	10
0.0; +0.2	9.5	14.0	7.40	20
0.0; +0.5	8.8	15.0	8.20	50
0.0; +1.0	4.0	15.5	8.70	100

Results

An example of the bathymetry and wave setup induced during various sea level rise conditions and sea states is shown in Figures 10 and 11.

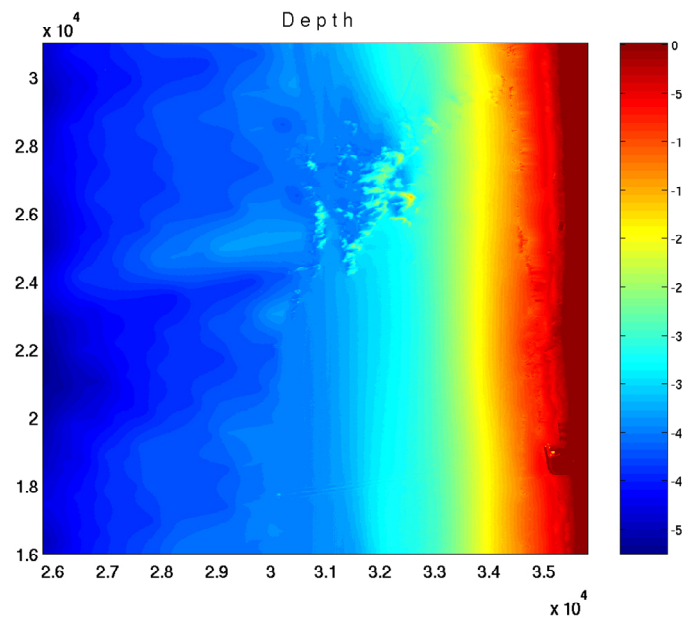


Figure 10. Central coastal sector northern part Bathymetric & topographic chart

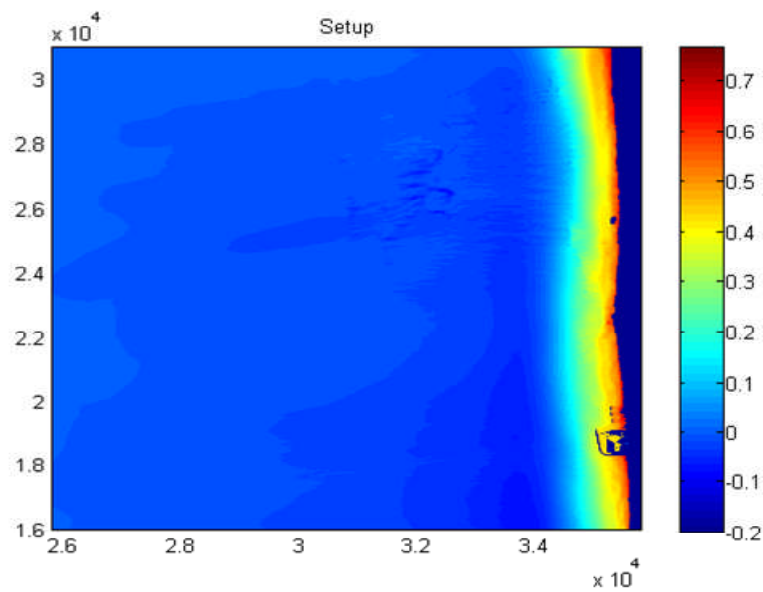


Figure 11. Central coastal sector – northern part – wave setup
 $H_{m0}=8.7\text{m}$; $T_p=15.5\text{s}$; $D=270\text{deg}$ Az; $n=+1.0\text{m}$

Example of results of the SBEACH outcomes are shown in Figure 12,

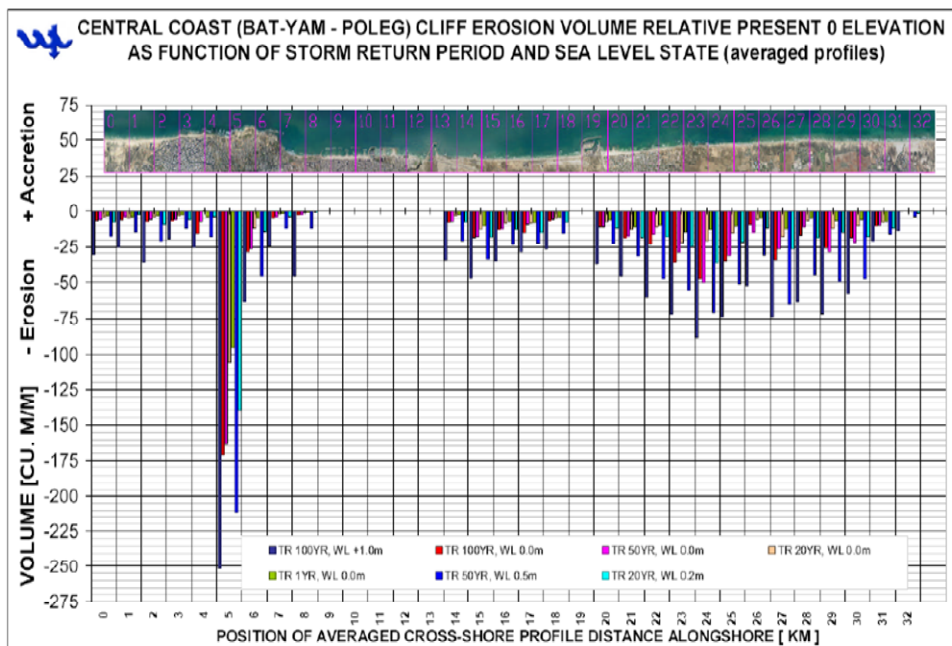


Figure 12. Example of SBEACH results for the same coastal sector

The outcome of the study conducted provided quantitative estimates of the beach and cliff erosion both as retreat rates and as volumetric rates, pinpointing the location of the coastal sectors with the highest rates of erosion expectancy (Figure 12). Analysis of the mitigation means led to the validation of the effectiveness of a new mitigation method against coastal erosion due to sea level rise and increased storminess. This mitigation consists of utilization of detached submerged breakwaters chains, with the tops near the MSL, located relatively remote from the original shoreline, well beyond the predominant surf zone, in combination with singular beach nourishment and cliff toe protection using sand filled geotextile sacks/geotubes. The mitigation is achieved by limiting the wave height at the beach and cliff toe due to the breakwaters chain, and compensation of the almost constant but low sea surface elevation (~0.5m) at the cliff toe by the sand nourishment of the beach face and protection of the cliff toe scouring by the sand filled geotextiles. The results are expected to be useful for design of effective coastal protection at similar coastal environments and of relatively low astronomic tide range, elsewhere in the world.

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