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The effect of sea-level rise in the 21st century on marine structures along the Mediterranean coast of Israel: An evaluation of physical damage and adaptation cost

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ABSTRACT

This study presents estimates of the impact adaptation costs due to damage to coastal and marine structures located along the Mediterranean coast of Israel caused by sea-level rise in the 21st century. The study examines the effects on various types of constructions, including seaports, power plants, marinas, desalination plants, sea walls, detached breakwaters, and bathing beach infrastructures for sea-level rises of 0.5 m and 1 m. To this end, we conduct an analysis of hydrodynamic forces on the structures and an uncertainty analysis of their occurrence. The study find that the impact of wave overtopping of breakwaters can lead to extensive damage to port infrastructure and to the vessels moored inside. Adaptation costs are computed as the corrective measures to be taken to maintain the functionality of the structures.

Introduction

A large number of marine structures are situated along the Mediterranean coast of Israel, including ports, marinas, power station cooling water stilling ponds, coal unloading jetties, seawater desalination plants, various drain lines to the sea, mooring buoys for unloading fuel and natural gas, detached breakwaters, groynes, sea walls, promenades, vacation and sailing facilities, and archaeological sites (Fig. 1). These structures play a significant role in shaping the geography and economy of Israel.

In 2007, the Intergovernmental Panel on Climate Change (IPCC), acting on behalf of the UN Environment Programme (UNEP) and the World Meteorological Organization (IPCC., 2007), reported that sea-level rose rapidly from the mid-19th century until the end of the 20th century, at an average rate of 2 mm per year. In some areas sea-level has risen faster, and in others it has dropped. Several papers analyzing the change in sea-level along the coast of Israel in the 20th century were published in the past decade. Among them is an analysis of a series of sea-level measurements from Ashkelon, Ashdod, and Tel Aviv (Fig. 1) from 1958 to 2001 (Shirman, 2004), which indicated that there was a sharp rise of more than 100 mm in sea-level along the Mediterranean coast of Israel from 1990 to 2001. This rise is additional to a previous rise of 50 mm from 1977 to 1991. Sea-level measurements taken at the end of the coal unloading pier at the Hadera power plant also indicated a rise of 100 mm from 1992 to 2002 (Lichter, Zviely, Klein, & Sivan, 2010). This rate is much higher than the 1.0–1.8 mm per year measured during previous decades. Since the beginning of the 21st century, the rate of sea-level rise has slowed, and the average measured rise at Hadera was 6.1 mm per year from 2001 to 2013 (Rosen, 2013).

The fifth IPCC report (2013) predicts that by the end of the 21st century sea-level will be 26–97 cm higher than at present. This prediction has been challenged at both ends of the scale. A number of researchers claim that it is too conservative, and that global sea-level will rise much more (Grinsted, Moore, & Jevrejeva, 2010; Horton et al., 2008; Rahmstorf, 2007; Vermeer & Rahmstorf, 2009). In contrast, other researchers claim that these predictions are excessive, and that if sea-level does rise, it will be at a much slower rate (Church & White, 2006; Hunter, 2009). Overall, this is higher than the previous prediction (IPCC., 2007), which estimated that sea-level will only rise by 18–59 cm.

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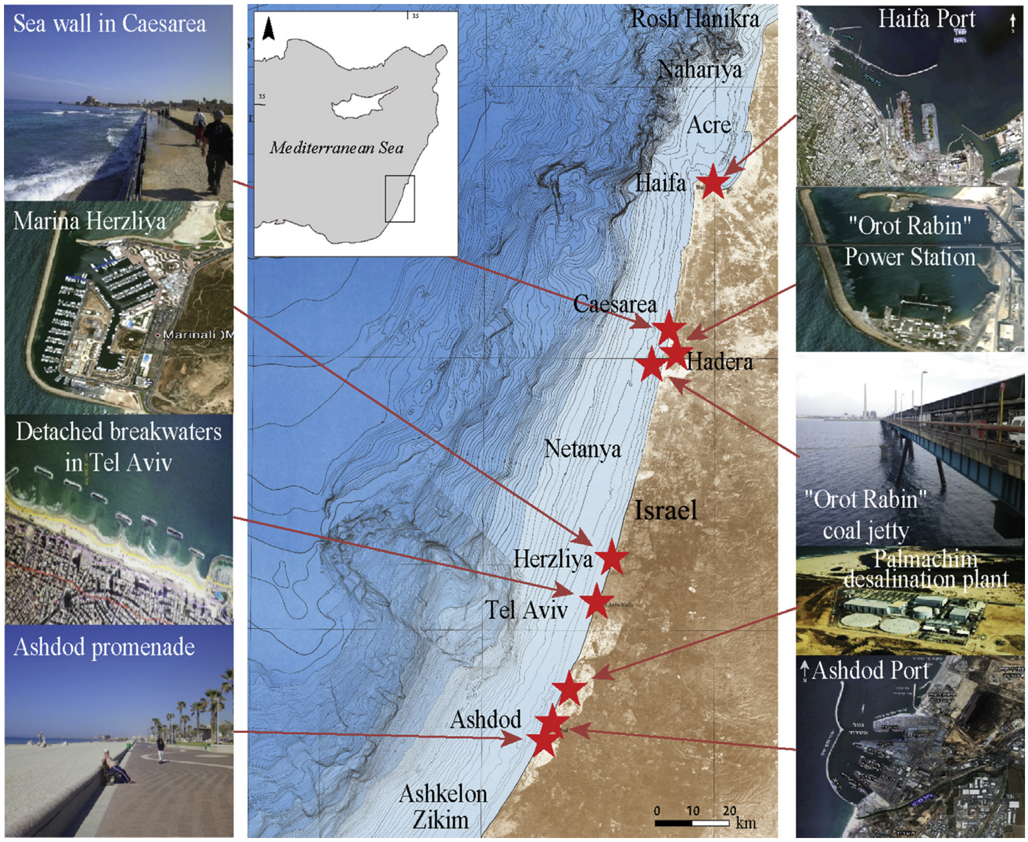

Fig. 1. Marine structures along the coast of Israel chosen for the study.

The present study has three objectives:

1. To survey the marine structures along the Mediterranean coast of Israel affected by sea-level rise during the 21st century.
2. To estimate the impact of sea-level rise (of 0.5 m and 1 m) on a range of key marine structures. These sea-levels have been chosen merely to illustrate and quantify the damage to the structures, and are not intended to take a stand on disagreements in the scientific community regarding the expected extent of sea-level rise in the current century.
3. To estimate the minimum actions required to preserve the continued unimpaired functioning of these structures under the physical and environmental impact of sea-level rise.

Previous research focusing on damage caused by the rise in sea-level in the 21st century

Economic valuation of the damage caused by sea-level rise on coastal areas around the World has focused mainly on the direct economic damage caused by migration and loss of workplaces. Dasgupta, Laplante, Meisner, Wheeler, and Jianping (2007) present an assessment of the damage and economic cost in 84 developing countries, as a result of a 1 m–5 m rise in sea-level during the 21st century. According to this study, the physical effects of the rise of sea-level in the eastern Mediterranean and North Africa are relatively minor compared to those in other areas of the world. In these areas the flooding as a result of a 1 m rise in sea-level would affect 0.25% of the land area, leading to a relatively high rate of migration (3.2% of the total population, compared to 1.28% on a global scale) and a reduction of 1.5% of the Gross National Product (GNP) of those countries. Such trends were also supported by the study of Bosello, Roson, and Tol (2007), which evaluated the potential damage to various coastal areas around the world, while focusing on the loss of urban areas, agricultural crops, and industrial products, and population migration on a macroeconomic scale. Hinkel and Klein (2009) and Hinkel, Nicholls, Vafeidis, Tol, and Avagianou (2010) focused on the impact of sea-level rise in the European Union countries, according to two scenarios presented in the IPCC reports: Scenario A2, in which population growth and greenhouse gas emissions continue at the current rate (business as usual), and Scenario B1, which estimates a maximum value of the above two parameters until 2050, after which they will slow down. Subject to these scenarios, and assuming no adaptation, the total monetary damage caused by flooding, salinity intrusion, land erosion, and migration was projected to be about US$ 17 billion in both scenarios in 2100. This suggests that taking measures to adapt to sea-level rise would be beneficial and affordable, and would be widely applied throughout the European Union.

Lichter and Felsenstein (2012) and Felsenstein and Lichter (2014) mapped the area in the eastern Mediterranean most sensitive to sea-level rise, using the GIS with a digital elevation model (DEM) of the surface, with a vertical accuracy of ±2 m, and considered the impact on the economy of Israel in four scenarios of sea-level rise: 0.5, 1, 1.5, and 2 m. They provided a spatial estimate of the geographic impact of sea level rise on Israeli residential and industrial, and quantified the value of built residential and industrial that could be affected by sea level rise. According to these studies, the impact of sea level rise on inland infrastructures is expected to result in loss of habitat area and earnings that are estimated at the level of $47 million and $95.5 million per year, for sea level rise of 0.5 m and 1 m respectively.

However, neither of these studies takes into consideration the impact of sea level rise on the marine structures and its direct