FLOOD RISK ASSESSMENT ON TWO GREEK ISLAND PORTS UNDER THE IMPACT OF RISING SEA LEVELS

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Abstract
Seaports play an important role in the global economy while in small islands they form the main transportation node for goods and passengers. At the same time they are highly exposed to rising sea levels and increased wave action induced by Climate Change and Variability. This study assesses the exposure to flood risk on two Greek island ports under Extreme Sea Levels for 2050 and 2100 with 2-D hydrodynamic simulations using LISFLOOD-FP and detailed topographic DEMs. Both ports are found to be highly exposed to flooding hazards with total inundated docks that would cease port functionality temporarily and may also cause damages to port infrastructures. Furthermore, flood extends on adjacent coastal roads and residential areas up to 180 m in Chios port and 65 m in Pythagorio port with serious implications for the properties. Given that extreme storm events are projected to increase both in frequency and magnitude it appears urgent therefore that adaptation measures should be taken on both ports in order to enhance their resilience towards future marine hazards.
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1. Introduction

Importance of seaports in the global economy is highly acknowledged as they form crucial nodes in the supply network and allow for access in marine economic activities including, among others, fisheries, offshore mineral resource and energy development, and cruise-ship tourism. With about 80 % of the volume of world merchandise trade carried by sea, ports are key assets for the current and future trade and sustainable development prospects (UNCTAD 2022). Ports at small islands in particular, are critical infrastructures forming usually the basic transportation and communication nodes (lifelines) allowing for the supply of food and energy on the local population (Monioudi *et al.* 2018). Nevertheless, ports remain exposed to various marine hazards and their variability and change, due to their locations along open coasts or in low-lying estuaries and deltas that make them susceptible to the impacts of rising sea levels, storm surges, waves and winds (Izaguirre *et al*. 2021).

Increases in the mean and extreme sea levels can cause coastal flooding and port inundation (Hanson & Nicholls 2020). Port inundation under extreme events can have a negative impact on harbor functionality, damaging terminals as well as cargo and vessels, causing substantial disruptions on supply chains and constraining vessel handling and berthing (UNECE 2014). Under Climate Variability and Change (CV & C) these phenomena are projected to increase both in magnitude and frequency threatening therefore harbor functionalities and having serious economic consequences (Camus *et al.* 2019).

This contribution aims to study the exposure at flood risk under the impact of CV & C of two island ports of the NE Aegean Sea, the main port of Chios island and the Pythagorio port at Samos island. The Chios port lies at the east side of the island and it is the main point of entrance of goods and passengers travelling to (and from) Chios with 150008 arrivals and 144229 departures in 2022 (Papaioannou *et al.* 2023). The ferries berth at the dock at the north side of the port. The port entrance has an ESE orientation while a breakwater at its northern side is the main protection against the waves coming from the North.

Pythagorio port is located at the southeast side of Samos, backed by the city of Pythagorio which has important touristic development. The harbor entrance has a SE orientation with a breakwater protecting the main dock from the waves arriving from the South and the West. The port connects Samos with other Aegean islands such as Rodos and Kos islands with 16991 departures and 17336 arrivals in 2022 (Papaioannou *et al.* 2023).

2. Material and Methods

Extreme Sea Levels – ESL driven by climatic extremes are defined as the summation of the rising Mean Sea Level - MSL, the astronomical tide and the episodic water level fluctuations due to the meteorological tides (storm surges) and the wave set up. Wave set up is approximated as 0.2 of the offshore significant wave height H_s.

For the current work, the ESLs correspond to 1-100 years storm events for the 2050 and 2100 reference years and under two IPCC emission scenarios, one moderate (RCP4.5) and one pessimistic (RCP8.5). The projections of ESL were retrieved from the database of Vousdoukas *et al.* (2018) which contains global predictions every 25 km of coastline and the values of the closest points were assigned to the two ports. For the two reference years, ESL are projected to reach 1.2 and 1.65 m at Chios port and 1.18 and 1.65 at Pythagorio Port.

A dynamic approach was used to assess the flood risk under CV&C in the two selected NE Aegean ports, using the 2-D model LISFLOOD-FP (Bates & de Roo 2000). The model uses a structured grid and a raster coastal Digital Elevated Model- DEM. Hydraulic continuity principles are applied to calculate water depth in each cell of the raster grid and water is routed across the terrain based on the difference in hydraulic head between adjacent cells. Flow rates are computed based on terrain slopes and the Manning friction coefficient. While the model was initially designed to simulate river floods, it is increasingly used also in coastal flood applications (e.g., Le Gal *et al.* 2022), including flood inundation on ports (Bove *et al*. 2020).

The ESLs were set as boundary conditions along the port docks, jetties and brekawaters; the storm duration of the simulation was set to 10 hours, following the analysis of Mediterranean storm events (Martzikos *et al.* 2021). A high resolution (2x2 m) DEM available from the Greek Cadastre (Chrisafinos & Kavvadas 2016) was applied for the subaerial topography, while the Manning friction coefficient was estimated through the Land Use/Land Cover types to according to Papaioannou *et al.* (2018).

3. Results

Focusing at the Chios port, in 2050 (Figure 1, left panel), 60300 m^2 are projected to be inundated including the total harbor area (~7000 m^2) with the flood depth at the main dock close to 60 cm while in the houses at the back of the coastal road the flood depth is approximately 10 cm of water. At the residencies behind the main dock at the north side the flood depth exceeds 65 cm at one location. The flood extend behind the main dock reaches 104 m further inland while at the southern part of the harbor where yachts are berthed the flood reaches as far as 165 m inland with approximately more than 15000 m^2 inundated, thus threatening the properties at the back. At the central part of the harbor area the coastal road will be totally inundated implying negative consequences for the touristic businesses while the flood is projected to reach up to 90 m at one location inland due to the low elevations.

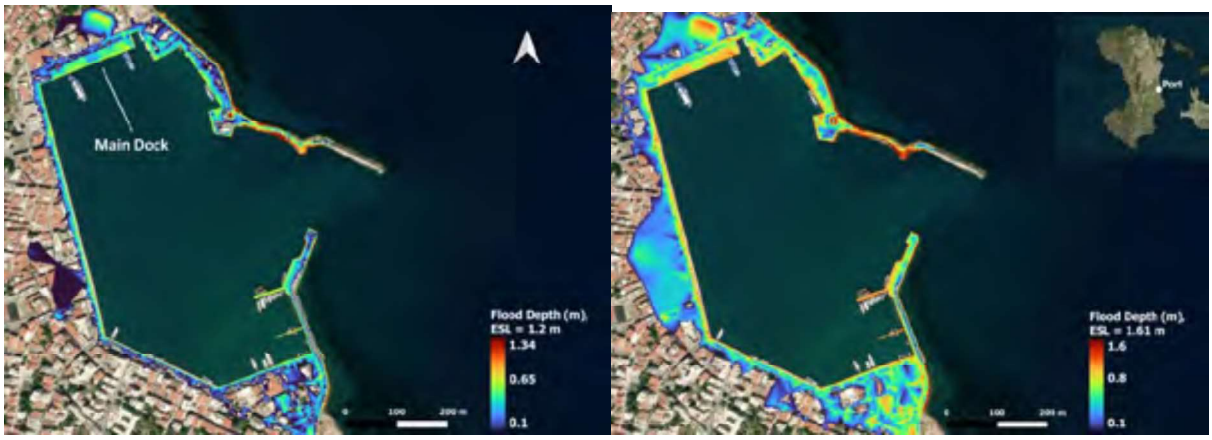

Figure 1. Flood map at Chios Port for 2050 and 2100. The different colors represent the various flood depths. The inset map at the right panel shows the location of port in Chios island

Predictions for 2100 are more severe (Figure 1, right panel) with more than 107000 m^2 inundated in the wider area. The maximum flood depth at the main dock reaches 1 m while ESL totally overtops the breakwater. At the back of the main dock the flood wave is predicted to propagate as far as 140 m inside the residential area. At the southern part approximately 28000 m^2 are projected to be inundated with the flood wave propagating 180 m inland while at the central part there is a remarked increase of inundation along the residential area behind the coastal road with more than 40000 m^2 covered by flood.

Figure 2. Flood map at Pythagorio Port for 2050 and 2100. The different colors represent the various flood depths. The inset map at the right panel shows the location of port in Samos island

In Pythagorio, in 2050 (Figure 2, left panel) the entire mooring dock appears to be flooded with water even more than 60 cm high, the breakwater is covered by the ESL while the flood propagates 55 m further inside covering the parking lot and affecting the residential area behind the dock. In addition, at the opposite pier where the Pythagoras statue and other touristic infrastructure are located more than 3000 m^2 are flooded. Predictions become noticeably more ominous in 2100 (Figure 2, right panel). In the port facilities, the water levels have increased to 0.8 m propagating inside the residential area 10 m more compared to 2050, while the flood wave extends up to 21 m at the beach east of the port threatening the stability of the coastal road at the backshore. In addition, flooding occurs also at some locations along the coastal road fronting the Pythagorio city, in small extend though.

4. Discussion and Conclusions

The exposure of two Greek island ports at flood risk under CV & C has been assessed with the application of the simplified LISFLOOD-FP hydrodynamic model. The model was benefited by the usage of high resolution topographic data allowing to predict water flow on a fine scale. Therefore it appears a useful tool for flood risk assessment since its detailed flood mapping revealed the areas most prone to flooding.

Concerning the hydrodynamic forcing, it must be noted that for the Aegean Sea waves and storm surges are predicted to retain their current values. Therefore the increase of ESL is dominated by the projected increase of MSL which under the RCP8.5 is projected to rise 0.2 m at 2050 and 0.8 m at 2100.

Both Chios and Pythagorio ports are found highly exposed to flood hazards under extreme storm events with low dock heights and breakwater crests that allow for flood inundation and overtopping. Flood predictions show that they will be totally inundated and therefore not operational for as long as the extreme events last, while damages on port infrastructure and moored vessels are also expected. Furthernore, marine flooding will reach also the residential areas around the harbors. Predictions are worse for Chios where the flood wave is predicted to propagate even 180 inside the residential area affecting many touristic businesses and residencies which are normally not designed to withstand the extreme marine forcing. Therefore and considering that extreme events are expected to become more frequent in the future, it is urgent that adaptation measures such as dock raising should be taken to strengthen both ports against the climatic extremes.

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