UNESCO WORLD HERITAGE AT RISK FROM COASTAL FLOODING IN THE MEDITERRANEAN REGION

Is it possible to evaluate the costs of flood impacts on cultural heritage?

Motivation & Goals

Many UNESCO World Heritage Sites (WHS) are located in coastal areas, being increasingly at risk from coastal flooding due to accelerated sea-level rise and storm events.[1] The Mediterranean coastal zone has a high concentration of cultural WHS as several ancient civilizations have developed in the region.[2] Few studies have assessed potential impacts of coastal flooding on cultural WHS, leaving decision-makers with limited information for adaptation planning.[3]

This study pursues two goals:

(1) to assess cultural WHS at risk from coastal flooding under different sea-level rise scenarios by calculating a risk index for each WHS.

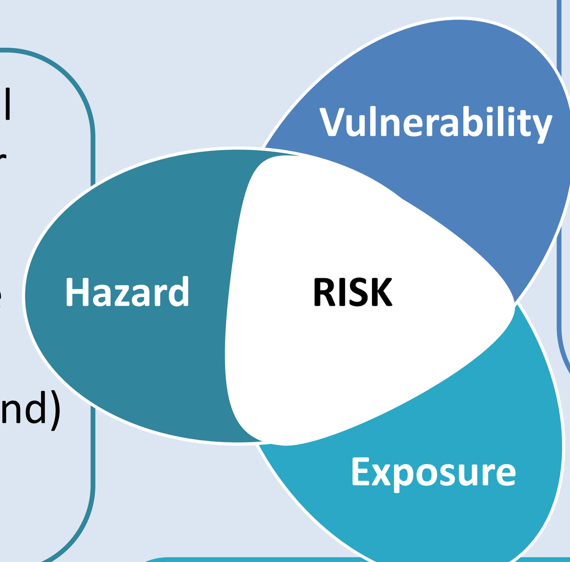
(2) to support decision-makers regarding further needs in adaptation planning for WHS and in prioritizing adaptation strategies in the short to medium term.

Methods

We employed the risk framework of the IPCC[4]:

We modeled the coastal floodplain of a 100-year storm surge.

We accounted for three sea-level rise scenarios (RCP2.6, RCP8.5, high-end) and vertical land movement until 2100.



We calculated a vulnerability index for each WHS based on its sensitivity to coastal erosion.

We used the indicators distance from the coast and erodibility of the coastal material (Table 1).

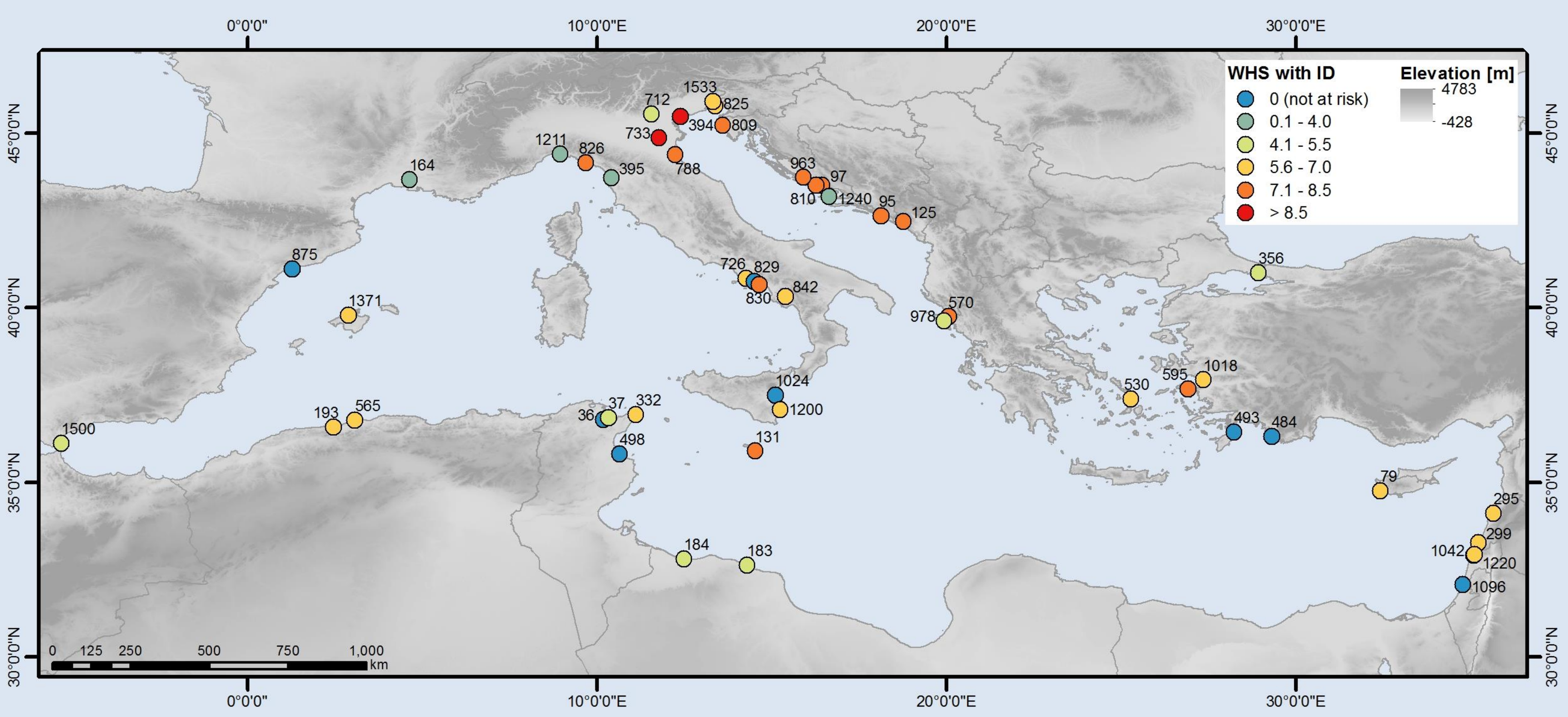
We corrected and extended WHS point data to WHS polygons using satellite imagery.

We overlaid the coastal floodplain with the WHS polygons to calculate an exposure index based on the area flooded and the flood depth (Table 1).

Table 1 Indices used to calculate the exposure index and the vulnerability index

INDEX / Indicator	0 – NOT EXPOSED	1 – VERY LOW	2 – LOW	3 – MODERATE	4 – HIGH	5 – VERY HIGH
EXPOSURE						
Flood area	0 %	< 5 %	5-10 %	10-25 %	25-50 %	> 50 %
Flood depth	0 m	< 0.1 m	0.1-0.3 m	0.3-0.5 m	0.5-1 m	> 1 m
VULNERABILITY						
Distance		> 1000 m	500-1000 m	100-500 m	50-100 m	< 50 m
Coastal type		rocky	-	muddy; rocky with pocket beaches	-	sandy

Results



36	Medina of Tunis	484	Xanthos-Letoon	830	Costiera Amalfitana
37	Archaeological Site of Carthage	493	Medieval City of Rhodes	842	Cilento and Vallo di Diano National Park with the Archeological Sites of Paestum and Velia, and the Certosa di Padula
79	Paphos	498	Medina of Sousse	875	Archaeological Ensemble of Tárraco
95	Old City of Dubrovnik	530	Delos	963	The Cathedral of St James in Šibenik
97	Historical Complex of Split with the Palace of Diocletian	565	Kasbah of Algiers	978	Old Town of Corfu
125	Natural and Culturo-Historical Region of Kotor	570	Butrint	1018	Ephesus
131	City of Valletta	595	Pythagoreion and Heraion of Samos	1024	Late Baroque Towns of the Val di Noto (South-Eastern Sicily)
164	Arles, Roman and Romanesque Monuments	712	City of Vicenza and the Palladian Villas of the Veneto	1042	Old City of Acre
183	Archaeological Site of Leptis Magna	726	Historic Centre of Naples	1096	White City of Tel-Aviv -- the Modern Movement
184	Archaeological Site of Sabratha	733	Ferrara, City of the Renaissance, and its Po Delta	1200	Syracuse and the Rocky Necropolis of Pantalica
193	Tipasa	788	Early Christian Monuments of Ravenna	1211	Genoa: Le Strade Nuove and the system of the Palazzi dei Rolli
295	Byblos	809	Episcopal Complex of the Euphrasian Basilica in the Historic Centre of Poreč	1220	Bahá'i Holy Places in Haifa and the Western Galilee
299	Tyre	810	Historic City of Trogir	1240	Stari Grad Plain
332	Punic Town of Kerkuane and its Necropolis	825	Archaeological Area and the Patriarchal Basilica of Aquileia	1371	Cultural Landscape of the Serra de Tramuntana
356	Historic Areas of Istanbul	826	Portovenere, Cinque Terre, and the Islands (Palmaria, Tino and Tinetto)	1500	Gorham's Cave Complex
394	Venice and its Lagoon	829	Archaeological Areas of Pompei, Herculaneum and Torre Annunziata	1533	Venetian Works of Defence between 15th and 17th centuries: Stato da Terra – western Stato da Mar
395	Piazza del Duomo, Pisa				

Figure 1 UNESCO WHS at risk from coastal flooding under the high-end scenario until 2100.

- 49 cultural WHS are located in low-lying coastal areas of which 84 % are at risk from a 100-year storm surge under the high-end scenario.
- The risk index ranges from 0 (not at risk) to 10 (very high), with a median of 6.5, reflecting high risk at most WHS.
- The largest number of WHS at risk is located in Italy (13), followed by Croatia (7), and Greece (3).

- WHS most at risk are located along the northern Adriatic Sea where exposure is highest.
- The highest risk index can be found at *Ferrara, City of the Renaissance, and its Po Delta*.
- The largest flood area of 98.5 % and the highest flood depth of 3.5 m can be found at *Venice and its Lagoon*.
- The risk index allows for ranking the WHS.

Table 2 UNESCO WHS most at risk under the high-end scenario along with the exposure and vulnerability indicators

ID	SITE NAME	EXPOSURE			VULNERABILITY			RISK
		Area [%]	Depth [m]	Index	Distance [m]	Coastal type	Index	Index
733	Ferrara, City of the Renaissance, and its Po Delta	78.7	3.2	10	0	sandy	7.5	10
394	Venice and its Lagoon	98.5	3.5	10	0	muddy	6.5	9.3
1042	Old City of Acre	13.9	0.8	7	0	rocky with pocket beaches	6.5	7.8
125	Natural and Culturo-Historical Region of Kotor	24.3	2.1	8	0	rocky	5.5	7.7
97	Historical Complex of Split with the Palace of Diocletian	30.4	1.0	8	0	rocky	5.5	7.7
95	Old City of Dubrovnik	11.0	1.4	8	0	rocky	5.5	7.7
810	Historic City of Trogir	64.1	0.9	9	53	rocky	4.5	7.5
595	Pythagoreion and Heraion of Samos	14.6	0.2	5	0	sandy	7.5	7.5
570	Butrint	46.5	1.7	9	338	muddy	4.5	7.5
788	Early Christian Monuments of Ravenna	75.9	1.7	10	6,660	sandy	3.5	7.3

Is it possible to evaluate the costs of flood impacts on cultural heritage?

Due to their so-called Outstanding Universal Value (OUV)[5], it is not possible to ascribe a certain value to UNESCO WHS. This impedes calculation of costs and damages after a storm surge. As a large number of WHS is at risk from coastal flooding due to accelerated sea-level rise until the end of the century, adaptation is urgently needed to ensure that their OUV is preserved.

This study provides decision makers with first-order insights into the needs for future adaptation planning. The risk index can help in prioritizing adaptation strategies in the short to medium term in countries with limited financial resources[6] and low protection standards[7].

In this context, devising a method that estimates the tangible costs of coastal flooding, for example accounting for loss of revenue from tourism or cost of repairs, may be helpful. Such a method requires more local-scale assessments and therefore goes beyond the scope of this study.

[1]UNESCO World Heritage Centre, 2007. Climate Change and World Heritage. World Heritage reports 22. [2]Cazenave, A., 2014. Anthropogenic global warming threatens world cultural heritage. Environ. Res. Lett. 9 (5). [3]Howard, A.J., 2013. Managing global heritage in the face of future climate change: The importance of understanding geological and geomorphological processes and hazards. International Journal of Heritage Studies 19 (7), 632–658. [4]Oppenheimer et al., 2014. Emergent risks and key vulnerabilities. In: Intergovernmental Panel on Climate Change (Ed.) Climate change 2014. Impacts, adaptation and vulnerability. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039–1099. [5]Phillips, H., 2015. The capacity to adapt to climate change at heritage sites—The development of a conceptual framework. Environmental Science & Policy 47, 118–125. [6]Phillips, H., 2014. Adaptation to Climate Change at UK World Heritage Sites: Progress and Challenges. The Historic Environment: Policy & Practice 5 (3), 288–299. [7]Scussolini et al., 2016. FLOPROS: An evolving global database of flood protection standards. Nat. Hazards Earth Syst. Sci. 16 (5), 1049–1061.

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