Assessing the risks of climate change for cultural heritage – The CLIMASCAPE project

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Abstract The protection of cultural heritage sites from the climate change effects is a central priority for protecting the cultural capital of Greece, and the sustainability of the related touristic flows. This paper describes the conceptual framework of the CLIMASCAPE project which aims to develop a methodology to be rolled out as a multi-criteria system for the evaluation of exposure, sensitivity, adaptive capacity and eventually vulnerability of archaeological areas to climate change. Eight UNESCO archaeological sites in Greece are selected as case studies namely; Olympia, Delphi, Delos, Sanctuary of Asklepios, Mystras, Apollo Epicurius, Philippoi and Heraion of Samos. Climate model projections are used to identify possible climate change related risks such as heatwaves, floods, droughts, fires and sea level rise and associate them with each of the eight selected study areas. A methodological framework for assessing the vulnerability and its components is also presented along with examples of possible data that are useful for the quantitative estimation of the above. The preliminary finding of the project suggest that differentiated adaptation plans for each site based on (a) the specific projections regarding the impacts of climate change and (b) the specific characteristics of each site are needed.

Keywords: Cultural heritage, Climate change, Adaptation, Tourism

1. Introduction

The protection of monuments and archeological sites from the effects of climate change is a central priority of international bodies active in the protection of cultural heritage such as UNESCO and ICOMOS. The European Commission has recently converged on this priority, both in terms of the protection of cultural capital and in terms of the sustainability of tourism developing in areas that include archeological sites and monuments.

According to UNESCO, climate change may present a threat to cultural heritage sites' outstanding universal value, integrity and authenticity. Threats include increasing extreme weather events, increasing insurance costs and safety concerns, water shortages, and loss and damage to assets and attractions at destinations. Continued climate-driven degradation and disruption to cultural heritage sites will negatively affect the tourism sector, reduce the attractiveness of destinations and lessen economic opportunities for local communities (Markham et al., 2016; Hall, 2016).

Researchers, policy-makers, central and regional administrators need to address short- and long-term challenges to enhance preservation and/or adaptation of cultural heritage sites through systematic access to scientific-based knowledge on climate change impacts. Such knowledge can support preservation or adaptation research, which in turn can assist and support decision-making that requires new ways of interdisciplinary approaches (Fatoric & Seekamp, 2017).

Interdisciplinary approaches utilize the use all available scientific data such as remote sensing, climatic, census, geospatial etc. in order to assess the risks and estimate the vulnerability of cultural heritage sites due to climate change. One of the most prominent definitions is the one reflected in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, which describes vulnerability as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001).

The CLIMASCAPE project is an interdisciplinary research that seeks to contribute to the protection of archaeological sites from the risks of climate change through the threefold "prediction, detection and management". The main objective of the project is the development of a multi-criteria platform that will support the forecasting, detection and management of climate change related risks on eight selected UNESCO archaeological sites in Greece.

2. Identifying climate change related risks

The basic tool to assess the impacts of climate change in is the projections of General Circulation Models (GCMs) for various climate parameters and indices using different climate future scenario's called Representative Concentration Pathways (RCPs), all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come. Scientists use Regional Climate Models (RCMs) to increase the resolution of climate projections, with boundary and initial conditions from a GCM as inputs. Although RCMs are computationally expensive, RCM outputs have been made available recently through the Coordinated Regional Climate Downscaling Experiment (CORDEX) at a spatial resolution of 0.11 degree (EUR-11, ~12.5km).

In the CLIMASCAPE project an ensemble of at least sixteen models is used, depending on the climate parameter, to project the future values of parameters such as the air temperature, precipitation, wind etc. and climate indices such as the number of heatwaves, number of summer days, number of heavy rain days and many more. Future projections refer to the period 2046-2065 and are compared to present day situation (1971-2000) for three RCPs (namely RCP 2.6, RCP 4.5 and RCP 8.5). Indicatively Figure 1a depicts the present day's situation for the air temperature (in °C) while Figure 1b depicts the projections based on the RCP 8.5 scenario for this climate parameter.

Respectively, Figure 1c depicts the present day's situation for the precipitation (mm/day) and Figure 1d the RCP 8.5 projection for the future period (2046-2065). Table 1 presents a comparison between present day and future projection values for the eight selected UNESCO archaeological sites in Greece. Figures 1a and 1b demonstrate the increase of future air temperatures across the country something that is associated with increasing risk of fires, heatwaves and drought. The average air temperature increase in the eight selected sites is 2.3 °C.

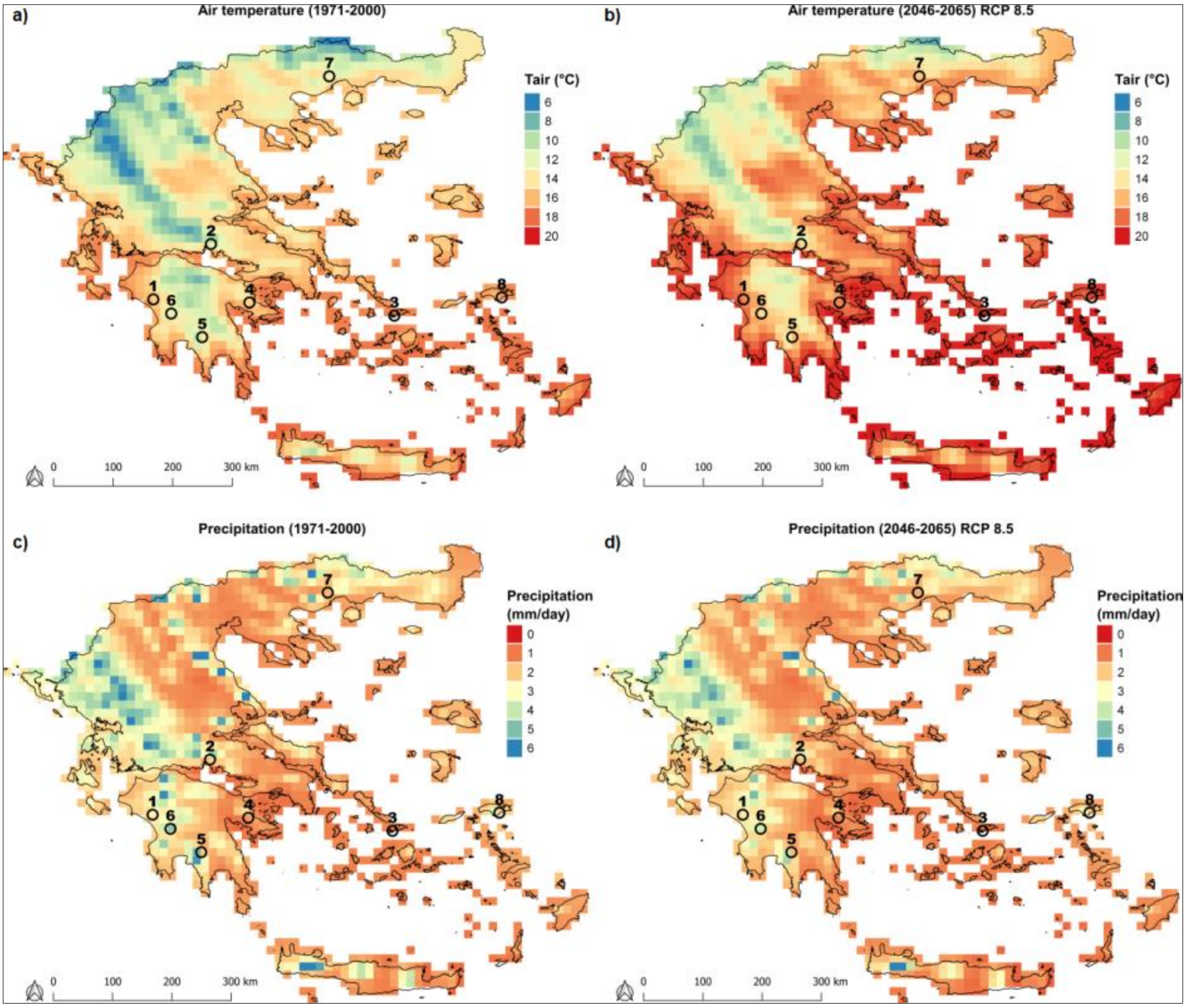

Figure 1. Climatic characteristics of Greece a) Air temperature (°C) and c) Precipitation (mm/day) for the period 1971-2000. Also climate projections for the period 2046-2065 based on the RCP 8.5 scenario for b) Air temperature and d) precipitation. The location of the eight selected UNESCO archaeological sites is denoted with circles: 1.Olympia, 2.Delphi, 3.Delos, 4.Sanctuary of Asklepios, 5.Mystras, 6.Apollo Epicurius, 7.Philippoi and 8.Heraion of Samos.

Concerning precipitation a decrease is observable especially in the western parts of Greece (Figures 1c and 1d). The average precipitation decrease (in mm/day) of the eight selected sites is 0.26 mm/day (Table 1). Especially in the case of Apollo Epicurius in West Peloponnese the decrease in future precipitation rates reaches 0.9 mm/day. Changes in precipitation patterns are associated with increasing risk of droughts and floods.

Table 1. Present day and future projected values for the air temperature (in °C) and the precipitation (mm/day) of the eight selected UNESCO archaeological sites.

Site	Tair (1971-2000)	Tair (2046-2065)	Rain (1971-2000)	Rain. (2046-2065)
1	14,86	17,11	2,95	2,76
2	12,17	14,74	2,21	1,96
3	17,28	19,25	1,15	1,07
4	14,88	17,32	1,31	1,14
5	13,77	15,99	2,04	1,79
6	12,03	14,55	4,75	3,84
7	12,97	15,27	1,77	1,66
8	16,72	18,96	2,39	2,21

It is therefore obvious that each area of cultural and tourist interest is exposed to different climate changes. Furthermore the impact and the arising risks of these changes to each area depend on the specific environmental, geological and topographical characteristics. The identification of the specific risks in each site is inevitably a site specific procedure and requires a good knowledge of the area and interdisciplinarity among the research team. In the CLIMASCAPE project the following climate change risks were identified: a) Heatwave, b) Flood, c) Drought, d) Fire and e) Sea level rise. Table 2 presents the risks associated with each of the eight selected study areas.

Table 2. Climate change related risks associated with each study area

Risk \ Site	1	2	3	4	5	6	7	8
Heatwave	x	x	x	x	x	x	x	x
Flood	x						x	
Drought	x	x	x	x	x	x	x	x
Fire	x	x		x	x	x	x	x
Sea level rise			x					x

3. Adapting cultural heritage to climate change risks

In general every system is considered vulnerable if it is exposed to climate change impacts, while it is sensitive to those impacts, and has low capacity to cope with them (Jun et al., 2013). In order to develop a methodology for assessing climate change vulnerability for archaeological sites, a conceptual framework was adopted following the IPCC (2001).

Specifically, vulnerability is comprised of three components: (1) exposure, referring to a vast variety of climate-related stimuli such as sea level rise, temperature change, precipitation change, etc., (2) sensitivity, defined as the "degree to which a system is affected, either adversely or beneficially, by climate-related stimuli and (3) adaptive capacity, referring to the ability of a system to adjust to climate change" (IPCC, 2001).

For the eight selected archaeological sites a series of proxy variables were selected to capture each of the three components of vulnerability and are described in detail below. Table 3 and Table 4 present the selected proxy variables for exposure, sensitivity and adaptive capacity indicatively for the climate change related risks of heatwave and flood respectively.

Since heatwaves are mainly a result of extreme air temperature and low wind speed, the following six proxy variables were selected to estimate the exposure component of vulnerability: air temperature (°C), daily max air temperature (°C), summer days (max>25°C), tropical nights (min >20°C), wind speed (m/s), and heatwave frequency. Furthermore sensitivity is estimated by using geospatial parameters related with the thermal environment of an area. Three proxy variables were chosen: land surface temperature, imperviousness degree and vegetation degree. Finally in order to assess the adaptive capacity three proxy variables closely related with the current socio-economical and socio-ecological status were selected: infrastructure projects to improve energy efficiency (i.e. public buildings energy efficiency), strengthening health services and shading and air conditioning infrastructure in archaeological sites-museums.

Table 3. Proxy variables used to assess the vulnerability components for the climate change related risk of heatwaves.

	Heatwave
Exposure	Air temperature (°C)
	Daily max air temperature(°C)
	Summer days (max>25°C)
	Tropical nights (min >20°C)
	Wind speed (m/s)
	Heatwave frequency
Sensitivity	Land surface temperature
	Imperviousness degree
	Vegetation degree
Adaptive Capacity	Infrastructure projects to improve energy efficiency (i.e. public buildings energy efficiency)
	Strengthening health services
	Shading and air conditioning infrastructure in arch. sites-museums

Since floods are related with extreme precipitation (duration or intensity), the following eight proxy variables were selected for estimating the exposure component of vulnerability: precipitation (mm), simple daily intensity index (mm/wet day), heavy precipitation days (10mm) (days), heavy precipitation days (20mm) (days), highest 1-day precipitation amount (mm), highest 5-day precipitation amount (mm), wet days (mm) (days) and maximum number of consecutive wet days (days). Sensitivity is estimated by taking into account the actual state of the geological environment (water surfaces degree, distance from rivers and streams, erosion), the increased flood risk (area flood risk, structured surfaces flood risk and archaelogical protection zones flood risk) and historical records of flood associated damages. Finally in order to assess the adaptive capacity of the areas, two proxy variables were selected , the existance of drainage facilities and the percentage of infastructure close (<100m) to the hydrographic network.

Table 4. Proxy variables used to assess the vulnerability components for the climate change related risk of floods.

	Flood
Exposure	Precipitation (mm)
	Simple daily intensity index (mm/wet day)
	Heavy precipitation days (10mm) (days)
	Heavy precipitation days (20mm) (days)
	Highest 1-day precipitation amount (mm
	Highest 5-day precipitation amount (mm)
	Wet days (mm) (days)
	Maximum number of consecutive wet days (days)
Sensitivity	Water surfaces degree
	Distance from rivers, streams
	Area flood risk
	Erosion
	Flood history
	Structured surfaces flood risk
	Archaeological protection zone flood risk
Adaptive Capacity	Existance of drainage facilities
	Percentage of infastructure close (<100m) to the hydrographic network.

The importance of each proxy variable for the estimation of vulnerability is unequal, so it is necessary to apply weights. Nardo et al. (2005) classify weighting techniques in two broad categories, which are statistical-based methods and participatory-based methods. Weights are assigned based on the analysis on the data of the indicators in the former method and given based on opinion from experts or the general public in the latter method. Different techniques can be selected according to the different conditions of the study area.

4. Conclusions

The effects of climate change and the associated risks vary in each archaeological area, as the vulnerability of depends on its environmental, geological, topographic, residential and other characteristics, as well as the intensity and frequency of observed or estimated extreme events that also vary spatially and temporally.

It is therefore obvious that there is no common adaptation strategy for all archaeological sites to the risks imposed by the effects of climate change but a need arises for differentiated adaptation plans for each site based on (a) the specific projections regarding the impacts of climate change and (b) the specific characteristics of each site.

The CLIMASCAPE project (http://climascape.gr) presents a methodology to be rolled out as a multi-criteria system for the evaluation of the vulnerability of archaeological areas to climate change related risks. The final aim is develop on the basis of the above, adaptation measures per archaeological site and to assess the anticipated changes in climate vulnerability once these measures are applied.

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