The Risk Mapping Tool for Cultural Heritage Protection in Europe and Mediterranean Basin

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***Abstract* – Cultural and natural heritage (CNH) are persistently at risk due to the impact of extreme climate events, with an increasing frequency over time due to climate change. The assessment and monitoring of these effects impose new and continuously changing conservation challenges and urgently needs for innovative preservation and safeguarding approach. Research into user-driven solutions/tools and mitigation/adaptation strategies, is therefore urgently required, based on sound scientific studies, capitalization of achieved knowledge, transferring and dissemination of results and coordinated actions among the different actors involved in the decision-making process for protection and management of CNH (Public Authorities, scientific community, private sector, rescue bodies). The present contribution aims at illustrating the "Risk mapping tool for cultural heritage protection" specifically designed to support policy and decision makers, researchers and professional figures in charge for the protection of cultural heritage sites in the identification of risk areas and assessment of vulnerabilities for cultural heritage exposed to extreme events linked to climate change. Its development was strongly based on a user-driven approach and the multidisciplinary collaboration among the scientific community, public authorities and the private sector.**

I. INTRODUCTION

Nowadays, actors in charge for the protection of CNH assets often do not have appropriate expertise and skills in order to efficiently apply the huge amount of data from the scientific and academic world concerning the most recent studies on climate change impacts on cultural heritage and to exploit this knowledge with the aim to put in place the most suitable preparedness and preventive measures to increase the resilience of CNH of their territories [1, 2]. The Interreg Central EU projects ProteCHt2save and STRENCH [3, 4] were purposely funded with the main objective to support managers, policy-decision makers and first responders in the safeguarding of CNH with solutions and tools for risk assessment based on the exploitation of data and products from climate models and Earth Observation field. Within this framework, a Web GIS based "Risk mapping tool for cultural heritage protection" (WGT) has been designed and implemented in order to promote the production of strategies for cultural heritage protection to be integrated into plans for Disasters Risk Reduction in line with the 4 Priorities of the Sendai Framework for Disaster Risk Reduction 2015-2030.

Climate induced extreme events, such as flash floods, drought, heavy rain, were of major consideration; while monumental complexes, cultural landscapes, historic parks, archaeological sites and small ruined villages in mountain and coastal areas were addressed as principal cultural heritage categories.

II. THE RISK MAPPING TOOL FOR CULTURAL HERITAGE PROTECTION: STRUCTURE AND CONTENTS

The current web page of Risk Mapping Tool for Cultural Heritage Protection is composed of seven pages and only the Home Page is immediately available for all users, while a registration is required for the access at the further contents and pages (www.protecht2save-wgt.eu/). Detailed information and indication about the use of this tool is reported in the tutorial of the WGT [5]. Starting from a general overview of its history, from the design and first implementation in ProteCHt2save to the further integration and improvements in STRENCH, the WGT offers the possibility to browse within its tools and case histories to see and understand how the tools has been applied on selected case studies, as well as put into practice the acquired knowledge by using the same tools to perform an analysis of a case study assessing its potential exposure to any past and future extreme climate events and to assess the vulnerability for its protection.

A. Extreme Indices

The analysis of changes in climate extremes can be done using indices to evaluate statistics of extreme events for precipitation and temperature and to compare them with observed extremes. Climate indicators capture a specific weather and climate feature that can have diverse impacts on the ground. These indices, selected among the 27 climate index defined by the ETCDDI (Expert Team on Climate Change Detection Indices), are internationally accepted by the scientific community for representing change in climate extreme, such dry spell or intense precipitation. Other robustly recognized dataset such as European Climatology and Trend Atlas of Climate Indices (ECTACI), developed by the World Bank Group in the framework of the Climate Change Knowledge Portal (CCKP) were also applied. In the WGT an informative page is dedicated to the detailed description of the climate variable and extreme index selected and elaborated for the projects. Clicking on each short name of the indices it is possible to reach the original web page where it is possible to obtain deeper information about each climate risk index to better understand its meaning. In the same page we can also visualize the climate variables. The page is set to be integrated with additional climate indices linked to a specific natural hazard caused by intense precipitation and/or change in temperature

B. Case Studies

The page “Case Studies” offers an in deep knowledge of the case studies involved in ProteCHt2save and STRENCH in Central Europe by showcasing their geographical context with a focus on their unique cultural and natural heritage also highlighting main climate hazards impacting the sites. A survey on the past calamitous events recorded at the site and subsequent prevention, mitigation and adaptation measures put in place and finally, a series of additional information useful to understand what tools and data can be available at local level for the protection of cultural heritage at risk are also available for an in deep knowledge of the site and a correct analysis of the still existing gaps. All the key information used for presenting each case study in the WGT have been collected at local level in collaboration with the partners responsible for the case studies. The page is set to be integrated with additional case studies including cultural and Natural heritage assets at risk and linked to a specific natural hazard caused by intense precipitation and/or change in temperature (Figure 1).

Fig. 1. Image extracted from the WGT page “CASE STUDIES” showing, as example, the introduction of each case study involved in STRENCH Project.

C. Vulnerability

Cultural heritage vulnerability assessment is a complex process, involving both heterogeneous and multidisciplinary approaches. One of the main goals set in this study is the active participation of nontechnical users, such as owners and managers, in preventive risk reduction strategies. This necessitates adopting more accessible and comprehensive method for vulnerability evaluation. The basic idea is to empower such user groups and transform them into a first line of defence for the protection of cultural heritage. Their role would be to flag possible threatening situations, triggering a more technical evaluation. At the end, the result should be the stimulation of a continuous monitoring system based on the synergic efforts of technical/non-technical stakeholders. Finally, it should be underlined that in our projects the primary focus is strictly adressed to the analysis of the physical and managerial dimensions of vulnerability.

The page “Vulnerability” provides tools designed for the self-assessment of the vulnerability at building scale comprising either the methodology developed in ProteCHt2save, related to introduction of the concept of physical and managerial criticalities of the cultural heritage assets, and the methodology setup in STRENCH, considering the vulnerability as a result of interaction from susceptibility, exposure and resilience. More information about the methodology implemented in ProteCHt2save are available in Bonazza et al (2021) [1], while the project deliverable D.T1.2.2 "Definition of a methodology for ranking vulnerability of cultural heritage" and its Annex present the methodology and the conceptual model proposed for vulnerability assessment in STRENCH, outlining the requirements and criteria used [6]. In addition, a decision support tool in excel format for the assessment of the vulnerability by using the STRENCH methodology is also available for the users in order to rank the vulnerability of other case studies. The tool intends to facilitate the assignment of the values for each Sub-criteria necessary for the evaluation of the three requirements Susceptibility (RQ1), Exposure (RQ2) and Resilience (RQ3) with the final aim to ranking the vulnerability of the site. The vulnerability tools operate in an interactive way and require the active participation of non-technical users, who can assign the values and rank the vulnerability of the case studies under interest by following a guided procedure.

In the same page, it is possible to find examples on how these methodologies have been applied in the project case studies thanks to the chance to visualize a preview of the ranking and download the detailed cards of each vulnerability assessment (Figure 2).

Case study		Ranking of vulnerability				Download
		RQ1	RQ2	RQ3	Vulnerability	
WACHAU (AT)	Melk Abbey	0,22	0,86	0,83	0,16	pdf
	Durnstein	0,23	0,83	0,48	0,28	pdf
	Krems / Stein	0,23	0,71	0,87	0,11	pdf
PRAHA-TROJA (CZ)	Troja Château	0,33	0,69	0,76	0,21	pdf
KOLICI (HR)	Kolici hamlets	0,54	0,48	0,2	0,46	pdf
FRANCONIAN SWITZERLAND (DE)	Cherry	0,15	0,44	0,43	0,11	pdf
	Walberra	0,25	0,5	0,66	0,13	pdf
LAKE BALATON (HU)	Zichy Mansion	0,33	0,66	0,57	0,26	pdf
VILLA GHIGI PARK (IT)	Villa Ghigi buildings	0,48	0,68	0,63	0,36	pdf
VIPAVA VALLEY (SI)	Lanthieri Manor	0,21	0,66	0,77	0,11	pdf
	Vipava linden tree line	0,2	0,48	0,73	0,06	pdf
	House Miren 114	0,22	0,56	0,44	0,19	pdf
	House Miren 137	0,14	0,54	0,87	0	pdf
	Renče, Church of st. Mohor and Fortunat	0,16	0,54	0,86	0,02	pdf
	Renče, School	0,2	0,66	0,81	0,1	pdf

Figure 2. The preview summarises the ranking of the vulnerability performed for each case study in the framework of STRENCH project. The preview also shows the value of the three requirements Susceptibility (RQ1), Exposure (RQ2) and Resilience (RQ3) calculated at local level to rank the vulnerability and offers the possibility to download the detailed card for each elaboration.

D. Mapping Tools

The core of the WGT is represented by the implementation of three tools specifically conceived to visualize (online) and download climate data and maps elaborated by using climate modelling and earth observation climate dataset: 1) Climate modelling, 2) Earth observation and 3) Open search tool box.

The three tools present some common features immediately visible once each of them is opened:

- The INFO button, located in the top-left corner of each tool and permits to have information on the methodology and procedures applied to develop the selected tool.
- The map/data setting box, on the left side allows the user to set the parameters and customize some feature of the map before and after the visualization.
- The map/data visualization area, on the right side of the screen allow the user to visualize the created map after setting option. In this area there is also the possibility to zoom in/out and change the base map.

The climate modelling mapping tool allows users to create maps by investigating within the historic and future projections of selected extreme climate indices and variables elaborated using climate models. Detail on the methodology is available after clicking on the Info button of the tool and explained and discussed in Sardella et al. [7]. Maps of historical changes of the extreme climate index selected were done by using the climate dataset E-OBS (Figure 3).

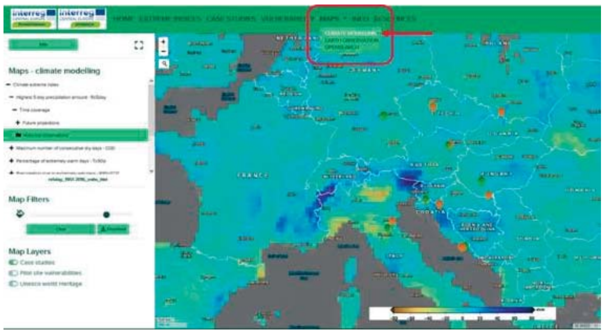

Figure 3. The image shows an example of historic map visualized on the WGT using the Climate Modelling Map tool. This map is related to historical change between the two 30-year periods (1987–2016 and 1951–1980), considering the Rx5day climate risk index.

E-OBS is the state-of-the-art station-based reference datasets, available for the European domain, which is a robust, and widely used dataset, regularly updated and provides long term daily precipitation and near surface air temperature climatology (from 1950 to present).

The Mapping Tool also includes high resolution maps of extreme indices future projections by using multi-models ensembles of regional climate projection based on the EURO-CORDEX initiative, which provides regional climate projections for Europe at the finer resolution of

0.11 degrees (EUR-11, ~12 km). Maps show the likelihood of increase/decrease of extremes climate. Specifically, changes projected referred to Europe and the Mediterranean Basin Regions considering two 30-year future periods (2021-2050, 2071-2100) with respect to historic reference one (i.e., 1975-2005) (Figure 4).

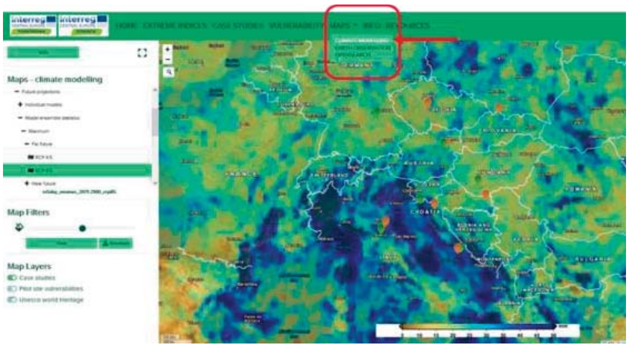

Figure 4. The image shows an example of map of climate future projection visualized on the WGT using the Climate Modelling Map tool. The map is related to the variation of Rx5day climate risk index elaborated considering the maximum of model ensemble statistics related to far future (2071-2100) under pessimistic scenario RCP8.5.

The hazard maps are obtained by the elaboration of the selected climate extreme indexes and refer to large basin floods, heavy rain and drought.

Figures 5 and 6 show for example the projections with likelihood of increase or decrease of flood and heavy rain in Central Europe with highlighted the case studies taken into consideration in ProteCHt2save. In the first case (Figure 5) the climate extreme index Rx5day (yearly maximum of cumulated precipitation over consecutive 5 day periods) is considered, while R20mm (number of days in a year with precipitation larger or equal 20 mm/day) is used for producing the second hazard map (Figure 6). Both maps are elaborated considering the maximum of model ensemble statistics for the far future (2071 – 2100) under pessimistic scenario RCP8.5. An increase of extreme precipitation events is foreseen thorough all Central Europe, mainly in the Alps, Adriatic and Northern Tyrrhenian coasts. All the case studies are expected to undergo potential consequent damage, particularly the municipality of Ferrara, Kocevje and Kastela when considering the variations of R5xday (Figure 5).

The maps allow to obtain a determination of hazard areas at territorial level (~12 km). This evaluation is then complemented with the assessment of vulnerability at a building scale on selected monuments and by using the tools presented in the previous section for the final risk assessment.

The WGT also exploit earth observation datasets of climate data, mainly from Copernicus Climate Change Service (C3S) reanalyses and NASA product. C3S ERA5 (~31 km – 0.25° resolution) and ERA5 Land (~9 km resolution) are the latest climate reanalysis produced by ECMWF, that combine past observations with models to generate consistent time series of multiple climate variables and providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty from 1981 to present day. The GPM IMERG product from NASA provides precipitation daily data at 10 Km resolution, from 2000. The earth observation mapping tool of the WGT allow the user to create climate maps referred to the selected extreme climate indices and variable elaborate at season time scale using satellite data from C3S ERA5 and GPM IMERG datasets.

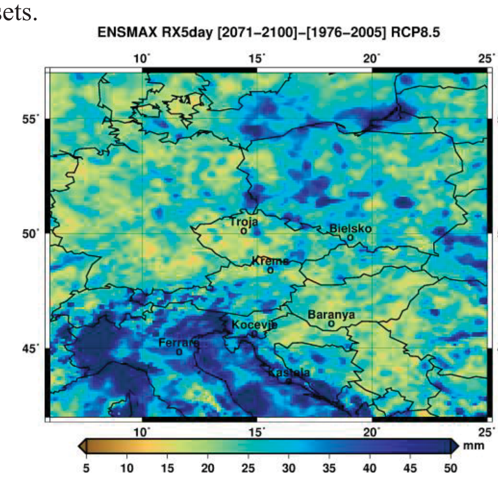

Figure 5. Map related to the variation of Rx5day climate risk index elaborated considering the maximum of model ensemble statistics related to far future (2071-2100) under pessimistic scenario RCP8.5.

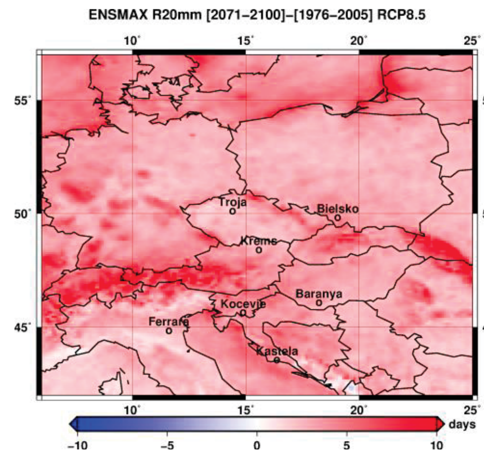

Figure 6. Map related to the variation of R20mm climate risk index elaborated considering the maximum of model ensemble statistics related to far future (2071-2100) under pessimistic scenario RCP8.5

The Open Search Tool Box deals with a search feature that allows access to a wide database of earth observation data developed by SISTEMA gmbh (https://www.sistema.at) and currently used for the elaboration of the maps and visualization of data linked to Earth Observation datasets exploited. This tool, gives the possibility to query the database independently by choosing the extension of the area of interest directly on the map or even just the position based on geographical coordinates or name. Once the point / area of interest has been identified, it will be possible to choose the climate index (among those elaborated using ERA5, ERA5 Land and IMERG) and the time period of interest. The final output can therefore be, depending on the choices, a numeric data (e.g. a time series of values on a specific point in a readable file format), a colour scale map or a numerical matrix. All information acquired with the "Open search" tool is always geocoded. The today's version of the Open Search Tool Box allows exploring selected climate indices re-computed following the full time series of:

- Copernicus C3S ERA5 Land products (~9 km resolution, from 1981).
- Copernicus C3S ERA5 products (~31 km – 0.25° resolution, from 1981)
- NASA GPM IMERG products (10 Km resolution, from 2000).

III. FINAL REMARKS

The functionalities of the "risk mapping tool" are currently under testing at European case studies representative of cultural landscape, ruined hamlets and historic gardens and parks. The preliminary results related to the testing of the WGT carried out by the partner at the case studies selected in STRENCH are reported in the Deliverables D.T2.2.1 "Testing of the WebGIS tool for landscape protection" [8] and D.T2.2.2 "Testing of the WebGIS tool for ruined hamlets protection" [9] downloadable from the web site of the project [4]. The methodological approach reported in these documents has been specifically setup to allow targeted users to exploit the different tools integrated in the WGT in any context ensuring its transferability in other geographical context and considering different cultural heritage categories. The setup methodology foresees to perform a guided path for in-depth knowledge of the case study on which we need to work to put in place strategies and measure addressed to the protection of a specific cultural heritage category. Starting from a general introduction of the case study and providing an overview of its geographical location and main environmental features, we need to focus then on an in depth study and description of the cultural heritage category that we need to protect against one or more environmental hazard linked to climate change. After we have collected the key information on the cultural heritage asset under study, we can start to assess its vulnerability by applying the Vulnerability tool integrated in WGT. Then, we have to investigate about the main risk impacting the site and carry out a detailed research of the past calamitous events occurred at the site also considering protective and recovery measure put in place during and after the events. Following step by the step the methodological approach, we can apply now the different map tools integrated in the WGT to study and analyse past calamitous events occurred at the site and compare them with the variation of the most appropriate climate extreme indices elaborated in Map tools. Furthermore, we can investigate on how and where identified indices vary in the near and far future under different emission scenario. At the end we'll be able to know all the relevant aspect about our case study with the final aim to put in place all the measure for its protection against extreme events liked to climate change

The tool is managed by CNR-ISAC, lead partner of ProteCHt2save and STRENCH, which takes care of its updating once additional data are available, particularly in relation to the analysis of new case studies. The application of Copernicus C3S, Earth Observation-based and products and their integration with climate projections from regional climate models constitutes a notable innovation that will deliver a direct impact to the management of CNH, with high potentiality to be scalable to new sectors under threat by climate change. By the achievement of the planned objectives, STRENCH is expected to proactively target the needs and requirements of stakeholders and policymakers responsible for disaster mitigation and safeguarding of CNH assets and to foster the active involvement of citizens and local communities in the decision-making process.

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