Università degli Studi di Ferrara

UCA Universidad de Cádiz

INTERNATIONAL DOCTORAL COURSE IN
“EARTH AND MARINE SCIENCES (EMAS)”

CYCLE XXXVI

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Impact of climate extreme events on cultural heritage

ANNEXES

Scientific/Disciplinary Sector (SDS) GEO-09

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ANNEXES

ANNEXES 1. CASE STUDIES DESCRIPTION

ANNEX 1A. TROJA HAMLETS AND DISTRICT

ANNEX 1B. WACHAU CULTURAL LANDSCAPE

ANNEX 1A. RUINED HAMLETS - TROJA HAMLETS AND DISTRICT

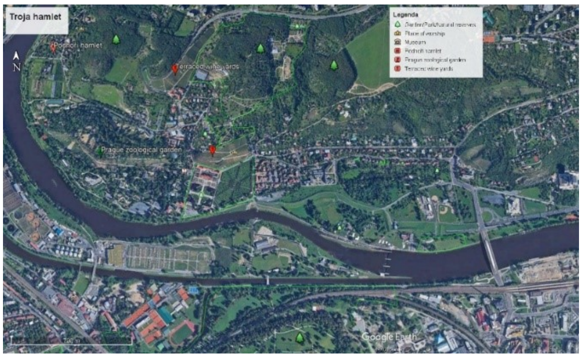
REGION	COUNTRY	EU ID	CITY	MUNICIPALITY
	Czech Republic	CZ	Prague	Troja

TYPOLOGY OF CULTURAL HERITAGE ASSETS	HAZARD TYPE
• Cultural landscapes (mainly terraced ones) • Hamlets in mountain areas • Historic parks	Flood Fire Windstorm

SITE LOCATION

Geographical coordinates	Lat. 50.109666	Long. 14.408998

Troja hamlet is located in Prague's north-west borough and it lies in the proximity of the Vltava river.



Geographical positioning of the site (left) with delimitation of the area extension (right).

SITE DESCRIPTION

The Troja Valley features important natural and cultural heritage assets with millions of visitors yearly. One of the largest and oldest natural parks, "Stromovka" sprawls in the river meadow along with various Troja sport facilities mainly for wild water canoeing, football or softball fields, and with diverse public recreation amenities. The second largest historic complex in Prague, the Baroque "Troja Château" with its gardens is situated in the vicinity of a protected hamlet of the historic fisherman village. The valley accommodates the Prague zoological and botanical gardens complemented with local art galleries. Steep slopes and cliffs skirt the valley. Some parts are cultivated with historic vineyards, some are covered with original herbs and plants and protected as natural reserves.

TYPOLOGY OF CULTURAL HERITAGE ASSETS

Cultural heritage assets include one of the most significant examples of the 17th century Bohemian palace in Baroque style surrounded by an extensive French garden decorated with terracotta vases, stucco prospects and orangeries with busts of imperators. Protected Cultural Heritage Monuments include Troja Mill, Troja Brewery, wine-yard homesteads, chateau farm, Vernacular Heritage Zone (Fisherman village). Besides the architectural heritage – the historic buildings, structures, walls and sculptures – moveable heritage in galleries as well as in private collections or in homes are also endangered. In regard to the landscape, the biological cover – mainly isolated trees – and exposed slopes are at risk.


Troja Chateau garden façade (left) and during wine harvest festival in 2019 (right)


Troja Mill and Troja Brewery in 1940 (left). Chateau farm after reconstruction in 2020 (right)

MAIN RISKS IMPACTING THE SITE

Proximity to the Vltava river. Frequent high water level situations with major flooding are the main natural risks threatening the cultural heritage of the site along with the large numbers of visitors. Minor risks include local flash floods intensified with insufficient capacity of the rain drainage system, harsh weather situations with drought, strong winds and temperature fluctuations.

Historical constructions and their contents are mostly made of porous material with is highly susceptible to floods; building components as well as natural heritage is vulnerable to dynamic and static forces, flowing objects, moisture degradation of materials and biological colonisation.

Lack of specific management plan for cultural heritage risks in particular maintenance schemes.

Structural and architectonic elements typical of the Baroque period, in particular roofs and spires, are particularly prone to vibration included during windstorm.

Flash flood in August 2020 – transported stones from terraced slopes -

River flood in the year 2002 in the Chateau Troja garden (left), in the year 2021 in the Vltava valey.

RECORDED PAST EVENTS

Flood

- August 2002, Vltava and Labe (Elbe) rivers flood in Prague. Erosion, hydrostatic and debris actions were identified as principal flood actions on structures; in most cases combinations of the flood actions occurred. Main causes of structural damage included geotechnical aspects, inadequate structural properties, and insufficient communication among responsible authorities.

ADOPTED MEASURES

- Presence of a mobile flood barrier which protects only specific areas along the river.
- Creation of a flood warning system and local crisis management unit.

POINTS TO BE ADDRESSED AT LOCAL LEVEL

- Managerial issues such as planning, communication and awareness raising for local community.
- Implementation of local maintenace schemes to increase the resilience of cultural heritage assets with respect to flood, fire and wind hazards.

SUPPLEMENTARY MATERIAL

Regional/Local Strategies/Plans for the protection of Cultural Heritage

- Strategies for adaptation to climate change in the conditions of the Czech Republic: the document presents the national adaptation strategy of the Czech Republic, which, in addition to assessing the likely impacts of climate change, contains proposals for specific adaptation measures, legislative and partial economic analysis, etc. https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie
- The concept of solving the problem of flood protection in the Czech Republic using technical and nature-friendly measures: the objective of the Concept is to assess and manage flood risks in accordance with Directive 2007/60 / EC and in accordance with the objectives of Directive 2000/60 / EC regarding the sustainable development of society and the interests of nature and landscape protection. http://eagri.cz/public/web/mze/ministerstvo-zemedelstvi/koncepce-a-strategie/koncepce-reseni-problematiky-ochrany.html
- Methodical instruction of the Ministry of Culture on fire risk assessment of monuments and determination of the minimum standard of fire protection for immovable monuments. https://www.mkcr.cz/doc/cms_library/metodicky-pokyn-ochrana-pamatek-4971.docx

Regional/Local Web GIS Platforms for Hazard/Risk assessment

- Flood risk map: map of flood danger and flood risks for the 2nd planning period 2021 - 2027 according to the European directive on the assessment and management of flood risks
https://cds.mzp.cz/
- ELECTRONIC DIGITAL FLOOD PORTAL: focused on flood prevention, management and instructions for processing digital flood plans of individual municipalities, cities, ORP and regions, as well as a catalog of products and services focused on flood protection, expert articles and discussions about the issue. https://www.edpp.cz/online-povodnova-mapa-cr/

Regional/Local Maps for Hazard/Risk assessment including cultural/natural heritage

Online maps of inundation during various flood situations are available on the portal https://www.edpp.cz/online-povodnova-mapa-cr/ . The maps have layers for the flood danger of Q5, Q20 and Q100 equivalents. The map is related to the orthophoto maps in which the architectural heritage objects are presented. No specific hazard/risk map with cultural heritage description is available.

3D Models for risk management

Physical 3D model was elaborated to assess the flow of flood waters in the Troja basin.

3D model of the capital City of Prague - terrain and buildings is available at

http://en.iprpraha.cz/clanek/1437/explore-prague-with-a-new-3d-model-application

Videos/Virtual tour

n.a.

Photographic archives

Prague geographic data including for example Archive of Prague's Orthophotomaps available on https://www.geoportalpraha.cz/en

More photographs of Troja District and from flood events available on the web site of the Municipal District Praha-Troja, www.mctroja.cz and in the Digital Archive at the Municipal District office

App

n.a.

Time Series

n.a.

Other

n.a.

ANNEX 1B. WACHAU CULTURAL LANDSCAPE

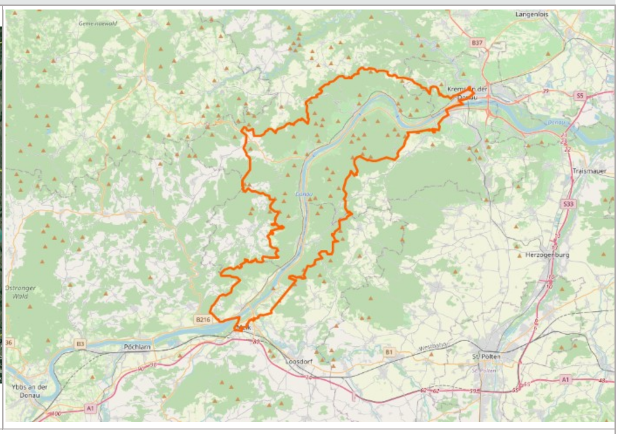
REGION	COUNTRY	EU ID	CITY	MUNICIPALITY
Lower Austria	Austria	AT		

CULTURAL HERITAGE CATEGORY	HAZARD TYPE
• Cultural landscapes • Hilly hamlets • Ruins	Flood/Flash flood Landslide Fire due to drought Heavy rain

SITE LOCATION

Centroid geographical coordinates (WGS84)	Lat. 48.39018	Long. 15.47489

The Wachau region (AT) is a riverine landscape encapsulated by steep mountainous terrain (granite & gneiss) on each side of the Danube river; it spans 36 km in length. The cultural landscape is characterized by terraced viticulture and medieval town centres, located on the banks of the Danube.



Geographical positioning of the site (left) with delimitation of the area extension (right).

SITE DESCRIPTION

The Wachau is a stretch of the Danube located between the cities of Melk and Krems, with high landscape qualities. The valley shows many traces of its continuous, organic evolution since prehistoric times, be it in terms of architecture (monasteries, castles, ruins), urban design (towns and villages with basic layouts dating back to the 11th and 12th centuries), or agricultural use (mainly for the cultivation of vines and apricot trees).

The clearing of the natural forest by local peoples began in the Neolithic period, although radical changes did not take place until around 800, when the Bavarian and Salzburg monasteries began to cultivate the slopes of the Wachau, giving the landscape its present characteristic pattern of vine terraces (historic dry stone wall terraces, and orchards of apricot).

In 2000, the "Wachau Cultural Landscape" has been inscribed in the UNESCO List of World Heritage Sites.

TYPOLOGY OF CULTURAL HERITAGE ASSETS

The Wachau is characterised by a multitude of cultural and natural heritage: historic (medieval) city centres, monasteries, ruins, artistic treasures of all periods (starting from the Paleolithic period), various hamlets in the hinterland, terraced vineyards (dry stone walls) and apricot trees.


View of the northern riverbank Rothenhof (left). Northern riverbank vineyards of Weissenkirchen as seen from the nature reserve Steinige Ries © Kaiser


Northern riverbank of Wösendorf in der Wachau as seen from the nature reserve Steinige Ries (left). Danubian cruise ship Wachau (right). © Kaiser

MAIN RISKS IMPACTING THE SITE

Hamlets located directly on the banks of Danube river and at the foot of the descending hills of the valley are vulnerable to Danube floods, landslides from the steeply ascending walls of the

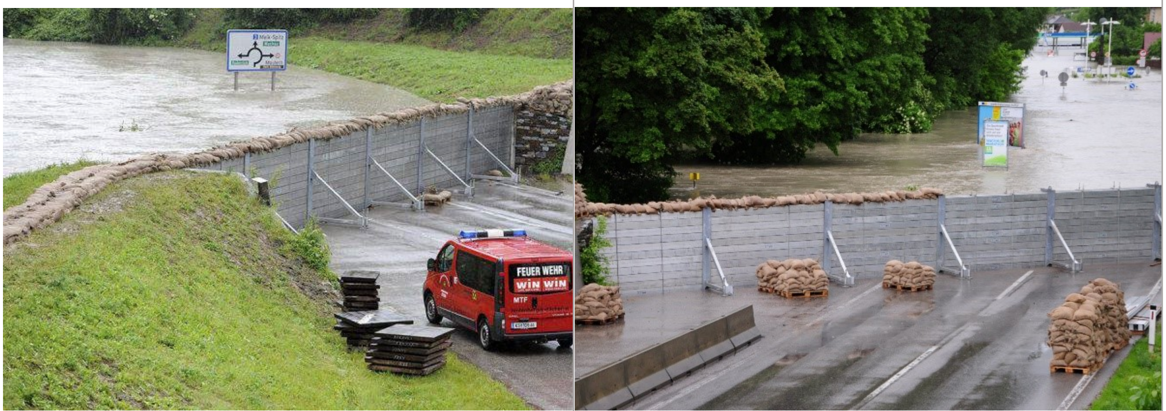
Danubian water gap and flash floods from tributary creeks. Museums and galleries located in inundation zones.

Heavy rain can swamp and soak the steep vineyards of the Wachau valley and can cause strong erosion and landslides.

Climate change is a major challenge for ensure the traditional cultivation and the agricultural and forestry land use in the Wachau: e.g., sensitivity of apricot tree to hail and freezing during blossoming period which causes failure of the crop with subsequent damage to the region's economy.

Fire is recognised as big risk the old towns of Wachau, since the roofs of the buildings often are immediately connected, as well as for the natural (and cultural) landscapes, as the pastures and shrubs are often highly dried up due to long drought periods.

Flooding of the historc center of Melk during the 2013 Danube flood. © KERMER



Reinforced flood barricades in Krems/Stein during the 2013 Danube flood. © APA/Helmut Fohringer

RECORDED PAST EVENTS

Flood

- 13/07/1954, river flood in Danube region.
- 02/07/1975, river flood in Danube region.

- 04/08/1991, river flood in Danube region.
- 14/08/2002, river flood in connection with heavy rain in Danube region.
- 04/07/2013, river flood in connection with heavy rain in Danube region: water penetration in the churches of Mitterarnsdorf and Hofarnsdorf with destruction of the floor.
- 2008, flash flood/overflow of the tributary Grubbach (during the construction of the flood protection) in Weißenkrichen town (Wachau).

Landslide

- 14/08/2002, heavy rain with consequent landslides in the whole Danube region: partial collapse and destruction of the characteristic dry-stone walls.
- 04/07/2013, heavy rain with consequent landslides in the whole Danube region: partial collapse and destruction of the characteristic dry-stone walls.

ADOPTED MEASURES

- In towns along river Danube exist mobile flood barriers or other flood protection.
- Fire management plan: plans and strategies for firefighting in the old towns of Krems and Stein exist and are currently updated.
- Hail planes which mitigate the damage caused by hail (particles of silver iodide are introduced into the cloud base, which is to prevent the hailstones from becoming too large).
- Some winemakers try to cultivate new vines which root deeper and therefore become more resistant against long lasting drought periods.Public security advisory board including the following bodies/organizations: county police headquarters, county disaster management directorates, water police, civil protection, ambulance service, water ambulance service.

POINTS TO BE ADDRESSED AT LOCAL LEVEL

There are several cultural sites (galleries, museums, churches etc.) in the Wachau valley which do not have an emergency plan in the event of a disaster.

SUPPLEMENTARY MATERIAL

Regional/Local Strategies/Plans for the protection of Cultural Heritage

- Flood emergency plan for Melk: well-structured procedure defined in clear phases in accordance with the water level; the municipality of Melk has tailored the general plan to their special needs.
- Emergency plan Dürnstein: the basic emergency plan for the whole county has been adapted for the local needs of the municipality of Dürnstein, taking rock fall into account.
- Danube River Basin Management Plan: the DRBM Plan aims to protect and enhance the status of all waters, to prevent their deterioration and to ensure the sustainable, long-term use of water resources. It includes latest assessments on significant

pressures, water status and a programme of measures jointly agreed by the Danube countries for the period 2015 until 2021.
https://www.icpdr.org/main/management-plans-danube-river-basin-published

- Management Plan Wachau World Heritage: including a presentation of the territory, potential risks, regional strategies and initiatives, etc.
https://www.weltkulturerbe-wachau.at/fileadmin/Bibliothek/projects/_Projekte/WachauProjekte/ManagementPlanWorldHeritageWachau_20170710.pdf

Regional/Local Web GIS Platforms for Hazard/Risk assessment

- HORA (Natural Hazard Overview & Risk Assessment Austria): a digital map of the natural hazards that includes flood (water outflow, risk areas, height. etc.), earthquake, landslides, storm, snow load, pollution available after registration.
https://www.hora.gv.at/
- Forest Fire Database Austria: a detailed description and location is currently available for over 6000 fire events in Austria, of which around 5000 are forest fires.
https://fire.boku.ac.at/firedb/en/
- NOE Government: measure of precipitation and other value related to water in Lower Austria.
https://www.noe.gv.at/wasserstand/#/de/Messstellen
- NOE Atlas: maps of the Lower Austria with several information (nature reserves, cultural heritage, registration of atmospheric emissions, floods, etc.)
https://atlas.noe.gv.at/webgisatlas/(S(vqlk54vxqv4wsxwod1cxdrjo))/init.aspx?karte=atlas_hochwasser&ks=wasser&cms=atlas_wasser&redliningid=5vgu1ubiplpvrr1ejrowctuv&box=551644.461752033%3b310899.347151007%3b752003.758780466%3b403057.161612875&srs=31259&t=637497792874382984

Regional/Local Maps for Hazard/Risk assessment including cultural/natural heritage

- Earthquake maps and lists: earthquakes recorded by the ZAMG network of seismic stations in Austria over the last 14 days.
https://www.zamg.ac.at/cms/de/geophysik/erdbeben/aktuelle-erdbeben/karten-und-listen
- Risk of forest fires: based on parameters such as air temperature, humidity, wind speed and amount of precipitation) and is therefore a purely meteorological assessment.
https://www.zamg.ac.at/cms/de/wetter/wetter-oesterreich/waldbrand
- Pollution: map of predicted pollution, expressed as air quality index, for the current and upcoming days.
https://www.zamg.ac.at/cms/de/umwelt/luftqualitaetsvorhersagen/caqi
- Flood hazard areas: maps and data provided by ICPDR containing flood risk information for the Danube basin.
https://www.icpdr.org/main/issues/floods

3D Models for risk management

N.a.

Videos/Virtual tour

N.a.
Photographic archives
Pictures presented in this file were taken by Dr. Anna Kaiser, the APA (Austrian Press Agency) Helmut Fohringer and the Austrian Armed Forces (KERMER)
App
N.a.
Time Series
N.a
Other
N.a.

ANNEXES 2: VULNERABILITY EVALUATION

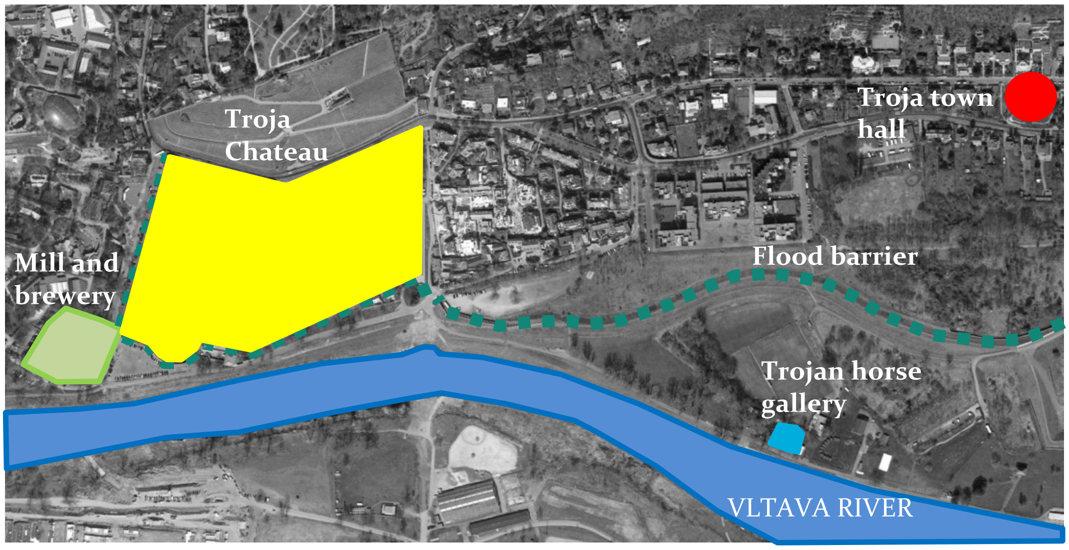
ANNEX 2A. RUINED HAMLET: TROJA HAMLETS AND DISTRICT

ANNEX 2B. WACHAU CULTURAL LANDSCAPE: MELK

ANNEX 2C. WACHAU CULTURAL LANDSCAPE: DÜRNSTEIN

ANNEX 2D. WACHAU CULTURAL LANDSCAPE: KREMS

ANNEX 2A. RUINED HAMLET: PRAHA-TROJA CHÂTEAU



Evaluation of susceptibility (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
SUSCEPTIBILTY (RQ1)			
CR1.1a	Construction & materials	Structurally sound constructions made of materials prone to degradation or impact damage	0.50
CR1.1b	Use	In continuous use	0.10
CR1.1c	State of conservation	Good	0.00
CR1.1d	Previous harming interventions	Yes, previous interventions	1.00
CR1.2a	Built elements of decoration	Presence of elements of decoration	1.00
CR1.2b	Water features	Presence of water features	1.00
CR1.2c	Circulation features	Presence of circulation features	1.00
CR1.2d	State of conservation	Fair	0.18
CR1.3a1	Species	Presence of species tolerant to local natural and climate threats	0.00
CR1.3a2	Age	Absence of mature/veteran trees	0.00
CR1.3a3	Slenderness ratio	h/d < 70	0.00
CR1.3b	Grass/shrub cover	Presence of species not tolerant to local natural and climate threats	0.30
CR 1.3c	Use	Intensive land-use with natural elements	0.30
CR 1.3d	State of conservation	Good	0.00
CR1.4	Topography	Stable slopes with inclination less than 15 degrees	0.15
CR1.5a	Bedrock	Presence of stable bedrock	0.00
CR1.5b	Soil	Coarse-grained soil (sand, gravel)	0.00
CR1.5c	Geomorphology	Presence of stable geological formation	0.00
CR1.6a	Groundwater	Water table prone to sudden fluctuations	1.00
CR1.6b	Surface water	Close to permanent, seasonal and man-made water course	1.00
CR1.6c	Sea	Far from sea	0.00

From the weight assignment in Chapter 4.2, it is known that:

Susceptibility= (0.20xBuildings) + (0.15x Built/manmade features) + (0.35 x Vegetation) + (0.10x Topography) + (0.10x Geosphere) + (0.10 x Hydrosphere)

→ **Susceptibility = 0.330**

Evaluation of exposure (sub-)criteria

Ref	**Criterion/sub-criterion**	**Value meaning**	**Value**
		EXPOSURE (RQ2)	
CR2.1a	Built systems and features	Presence of built systems and features	1.00
CR2.1b	Natural systems and biodiversity	Presence of natural systems and features with low/medium value for biodiversity	0.50
CR2.1c	Cultural traditions	Presence of cultural traditions	1.00
CR2.1d	Cultural acknowledgements	Grade II	0.86
CR2.2	Population	Population but no fragility	0.30
CR2.3	Economic	Livelihoods of local residents	0.50
CR2.4	Infrastructure	Presence of relevant infrastructure	1.00

From the weight assignment in Chapter 4.2, it is known that:

Exposure= (0.40xCultural significance) + (0.20x Population) + (0.20x Economic) + (0.20x Infrastructure)

→ **Exposure = 0.693**

Evaluation of resilience (sub-)criteria

Ref	**Criterion/sub-criterion**	**Value meaning**	**Value**
		RESILIENCE (RQ3)	
CR3.1a	Maintenance	Irregular maintenance	0.50
CR3.1b	Warning	Presence of early warning systems	1.00
CR3.1c	Knowledge and awareness	Knowledge and awareness ensured	1.00
CR3.1d	Information	Partial or complete info exist but not available	0.50
CR3.1e	Policy and regulation	Regulated CH protection	1.00
CR3.2a	Emergency resources	Existence of emergency human and economic resources	1.00
CR3.2b	Mitigating systems/measures	Existence of mitigating system	1.00
CR3.2c	Physical strengthening/protection	Existence of physical protection	1.00
CR3.3a	Financial recovery	Funds available but insufficient	0.30
CR3.3b	Social recovery	Absence of social recovery plan	0.00
CR3.3c	Physical recovery	Risk management plan exists and up to date	1.00

From the weight assignment in section 4.2, it is known that:

Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)

→ **Resilience = 0.760**

Vulnerability evaluation

Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience

V = (0.70x0.330) + (0.30x0.693) - (0.30x0.760) = 0.211

For the case study analysed:

Vulnerability = 0.211

With 0≤V≤1 (low to high vulnerability).

ANNEX 2B. WACHAU CULTURAL LANDSCAPE - MELK ABBEY

©KERMER

Located at the western end of the Wachau Area the Melk Abbey founded in 1089 is a popular tourist destination attracting roughly half a million visitors annually in the years prior to the Covid-19 pandemic. The Abbey itself is located on a hill close to the riverbanks of the Danube River and is filled with cultural heritage assets dispersed throughout the abbies park, museum, historic library as well as the church.

Weblink: https://www.stiftmelk.at/de/

For the assessment of the Melk Abbey the safety officer of the abbey Mr. Gerhard Scheiber was kind enough to give us his input.

Evaluation of susceptibility (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
		SUSCEPTIBILTY (RQ1)	
CR1.1a	Construction & materials	Structurally sound constructions made of resistant materials	0.00
CR1.1b	Use	In continuous use	0.10
CR1.1c	State of conservation	Good	0.00
CR1.1d	Previous harming interventions	No interventions made	0.00
CR1.2a	Built elements of decoration	Presence of elements of decoration	1.00
CR1.2b	Water features	Presence of water features	1.00
CR1.2c	Circulation features	Presence of circulation features	1.00
CR1.2d	State of conservation	Good	0.00
CR1.3a1	Species (Trees)	Presence of species tolerant to local natural and climate threats	0.00
CR1.3a2	Age (Trees)	Presence of some mature/veteran trees	0.30
CR1.3a3	Slenderness ratio (Trees)	Presence of trees with h/d > 70	0.30
CR1.3b	Grass/shrub cover	Presence of species tolerant to local natural and climate threats	0.00
CR 1.3c	Use	Intensive land-use with natural elements	0.30
CR1.3d	State of conservation	Good	0.00
CR1.4	Topography	Stable slopes with slope inclination higher than 30 degrees	0.30
CR1.5a	Bedrock	Presence of stable bedrock	0.00
CR1.5b	Soil	Fine-grained soil (silt, clay)	0.30
CR1.5c	Geomorphology	Presence of stable geological formation	0.00
CR1.6a	Groundwater	Stable water table	0.00

CR1.6b	Surface water	Close to permanent, seasonal and man-made water course	1.00
CR1.6c	Sea	Far from sea	0.00

From the weight assignment in Chapter 4.2, it is known that:

Susceptibility= (0.20 x Building) + (0.15 x Built/man-made features) + (0.35 x Vegetation) + (0.10 x Topography) + (0.10 x Geosphere) + (0.10 x Hydrosphere)

→ **Susceptibility = 0.219**

Evaluation of exposure (sub-)criteria

Ref	**Criterion/sub-criterion**	**Value meaning**	**Value**
		EXPOSURE (RQ2)	
CR2.1a	Built systems and features	Presence of built systems and features	1.00
CR2.1b	Natural systems and features	Presence of natural systems and features	1.00
CR2.1c	Cultural traditions	Presence of cultural traditions	1.00
CR2.1d	Cultural acknowledgements	Grade I	1.00
CR2.2	Population	Population but no fragility	0.30
CR2.3	Economic	Presence of stable and ramified system with high economic value	1.00
CR2.4	Infrastructure	Presence of relevant infrastructure	1.00

From the weight assignment in Chapter 4.2, it is known that:

Exposure= (0.40 x Cultural significance) + (0.20 x Population) + (0.20 x Economic) + (0.20 x Infrastructure)

→ **Exposure = 0.860**

Evaluation of resilience (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
		RESILIENCE (RQ3)	
CR3.1a	Maintenance	Regular maintenance	1.00
CR3.1b	Warning	Absence of early warning systems	0.00
CR3.1c	Knowledge and awareness	Knowledge and awareness ensured	1.00
CR3.1d	Information	Complete info is available	1.00
CR3.1e	Policy and regulation	Regulated CH protection	1.00
CR3.2a	Emergency resources	Existence of emergency human and economic resources	1.00
CR3.2b	Mitigating systems	Existence of mitigating system	1.00
CR3.2c	Physical strengthening/protection	Existence of physical protection	1.00
CR3.3a	Financial recovery	Funds available and accessible	1.00
CR3.3b	Social recovery	Absence of social recovery plan	0.00
CR3.3c	Physical recovery	Risk management plan exists and up to date	1.00

From the weight assignment in Chapter 4.2, it is known that:

Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)

→ **Resilience = 0.825**

Vulnerability evaluation

Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience

V = (0.70x0.219) + (0.30x0.860) - (0.30x0.825) = 0.1638

For the case study analysed:

Vulnerability = 0.164

With 0≤V≤1 (low to high vulnerability).

ANNEX 2C. WACHAU CULTURAL LANDSCAPE: DÜRNSTEIN

©Kaiser

Dürnstein is a small municipality within the Wachau Region which is visited by roughly one million people per year (pre Covid-19). The old town and near by hamlet, in which the popular historic figure King Richard I of England was held hostage, are popular tourist destinations. Dürnstein is litered with cultural hertiage sites strongly contributing to the cultural landscape of the Wachau Region.

Weblink: https://www.duernstein.at/

For the assesment of Dürnstein Mr. Martin Jung a scientist at the AIT (Austrian Institute of Technology) who recently featured Dürnstein in the EU Interreg project CHEERS was kind enough to provide us with his input.

Evaluation of susceptibility (sub-)criteria

Ref	**Criterion/sub-criterion**	**Value meaning**	**Value**
		SUSCEPTIBILTY (RQ1)	
CR1.1a	Construction & materials	Stocky constructions made of resistant materials	0.00
CR1.1b	Use	In continuous use	0.10
CR1.1c	State of conservation	Good	0.00
CR1.1d	Previous harming interventions	No interventions made	0.00
CR1.2a	Built elements of decoration	Presence of elements of decoration	1.00
CR1.2b	Water features	Presence of water features	1.00
CR1.2c	Circulation features	Presence of circulation features	1.00
CR1.2d	State of conservation	Good	0.00
CR1.3a1	Species	Presence of species not tolerant to local natural and climate threats	0.30
CR1.3a2	Age	Presence of some mature/veteran trees	0.30
CR1.3a3	Slenderness ratio	Presence of trees with h/d > 70	0.30
CR1.3b	Grass/shrub cover	Presence of species tolerant to local natural and climate threats	0.00
CR 1.3c	Use	Intensive land-use with natural elements	0.30
CR1.3d	State of conservation	Good	0.00
CR1.4	Topography	Stable slopes with slope inclination higher than 30 degrees	0.30
CR1.5a	Bedrock	Presence of stable bedrock	0.00
CR1.5b	Soil	Fine-grained soil (silt, clay)	0.30
CR1.5c	Geomorphology	Presence of stable geological formation	0.00
CR1.6a	Groundwater	Stable water table	0.00
CR1.6b	Surface water	Close to permanent, seasonal and man-made water course	1.00
CR1.6c	Sea	Far from sea	0.00

From the weight assignment in section 7.1, it is known that:

Susceptibility= (0.20 x Building) + (0.15 x Built/man-made features) + (0.35 x Vegetation) + (0.10 x Topography) + (0.10 x Geosphere) + (0.10 x Hydrosphere)

→ **Susceptibility = 0.230**

Evaluation of exposure (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
EXPOSURE (RQ2)			
CR2.1a	Built systems and features	Presence of built systems and features	1.00
CR2.1b	Natural systems and biodiversity	Presence of natural systems and features	1.00
CR2.1c	Cultural traditions	Presence of cultural traditions	1.00
CR2.1d	Cultural acknowledgements	Grade II	0.86
CR2.2	Population	Presence of fragile population	1.00
CR2.3	Economic	Livelihoods of local residents	0.50
CR2.4	Infrastructure	Presence of relevant infrastructure	1.00

From the weight assignment in Chapter 4.2, it is known that:

Exposure= (0.40 x Cultural significance) + (0.20 x Population) + (0.20 x Economic) + (0.20 x Infrastructure)

→ **Exposure = 0.833**

Evaluation of resilience (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
RESILIENCE (RQ3)			
CR3.1a	Maintenance	Regular maintenance	1.00
CR3.1b	Warning	Absence of early warning systems	0.00
CR3.1c	Knowledge and awareness	Knowledge and awareness ensured	1.00
CR3.1d	Information	Complete info is available	1.00
CR3.1e	Policy and regulation	Lack of regulations for CH	0.00
CR3.2a	Emergency resources	Absence of evacuation and rescue plan	0.00
CR3.2b	Mitigating systems/measures	Existence of mitigating system	1.00
CR3.2c	Physical strengthening/protection	Absence of physical protection	0.00
CR3.3a	Financial recovery	funds available and accessible	1.00
CR3.3b	Social recovery	Fbsence of social recovery plan	0.00
CR3.3c	Physical recovery	No risk management plan	0.00

From the weight assignment in Chapter 4.2, it is known that:

Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)

→ **Resilience = 0.475**

Vulnerability evaluation

Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience

V = (0.70x0.230) + (0.30x0.833) - (0.30x0.475) = 0.283

For the case study analysed:

Vulnerability = 0.283

With 0≤V≤1 (low to high vulnerability).

ANNEX 2D. WACHAU CULTURAL LANDSCAPE: KREMS / STEIN

©Kaiser

Krems/Stein marks the east end of the Wachau Region. The Town is composed of two historic old towns (Krems & Stein) several museums including numerous cultural heritage objects attrackting a substantial amount of tourists with a quarter of a million overnight stays recorded in 2019 (pre-Covid19). Other attractions include the Stein Prison which harbours Austrias most famous inmate Jofef Fritzl (visiting hours are Tuesday and Thursday from 08:00-11:00 &12:00-14:30, Friday and Satruday from 08:00-11:00).

Weblink: https://www.krems.at/

Evaluation of susceptibility (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
		SUSCEPTIBILTY (RQ1)	
CR1.1a	Construction & materials	Structurally sound constructions made of resistant materials	0.00
CR1.1b	Use	In continuous use	0.10
CR1.1c	State of conservation	Fair	0.18
CR1.1d	Previous harming interventions	No interventions made	0.00
CR1.2a	Built elements of decoration	Presence of elements of decoration	1.00
CR1.2b	Water features	Presence of water features	1.00
CR1.2c	Circulation features	Presence of circulation features	1.00
CR1.2d	State of conservation	Fair	0.18
CR1.3a1	Species	Presence of species tolerant to local natural and climate threats	0.00
CR1.3a2	Age	Presence of some mature/veteran trees	0.30
CR1.3a3	Slenderness ratio	Presence of trees with h/d > 70	0.30
CR1.3b	Grass/shrub cover	Presence of species tolerant to local natural and climate threats	0.00
CR 1.3c	Use	Intensive land-use with natural elements	0.30
CR1.3d	State of conservation	Fair	0.18
CR1.4	Topography	No surrounding slopes & Stable slopes with inclination less than 15 degrees	0.20
CR1.5a	Bedrock	Presence of stable bedrock	0.00
CR1.5b	Soil	Coarse-grained soil (sand, gravel)	0.00
CR1.5c	Geomorphology	Presence of stable geological formation	0.00

CR1.6a	Groundwater	Stable water table	0.00
CR1.6b	Surface water	Close to permanent, seasonal and man-made water course	1.00
CR1.6c	Sea	Far from sea	0.00

From the weight assignment in Chapter 4.2, it is known that:

Susceptibility= (0.20 x Building) + (0.15 x Built/man-made features) + (0.35 x Vegetation) + (0.10 x Topography) + (0.10 x Geosphere) + (0.10 x Hydrosphere)

→ **Susceptibility = 0.228**

Evaluation of exposure (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
EXPOSURE (RQ2)			
CR2.1a	Built systems and features	Presence of built systems and features	1.00
CR2.1b	Natural systems and biodiversity	Presence of natural systems and features	1.00
CR2.1c	Cultural traditions	Presence of cultural traditions	1.00
CR2.1d	Cultural acknowledgements	Grade III	0.61
CR2.2	Population	Population but no fragility	0.30
CR2.3	Economic	Livelihoods of local residents	0.50
CR2.4	Infrastructure	Presence of relevant infrastructure	1.00

From the weight assignment in section 7.1, it is known that:

Exposure= (0.40 x Cultural significance) + (0.20 x Population) + (0.20 x Economic) + (0.20 x Infrastructure)

→ **Exposure = 0.713**

Evaluation of resilience (sub-)criteria

Ref	Criterion/sub-criterion	Value meaning	Value
		RESILIENCE (RQ3)	
CR3.1a	Maintenance	Regular maintenance	1.00
CR3.1b	Warning	Presence of early warning systems	1.00
CR3.1c	Knowledge and awareness	Knowledge and awareness ensured	1.00
CR3.1d	Information	Complete info is available	1.00
CR3.1e	Policy and regulation	Regulated CH protection	1.00
CR3.2a	Emergency resources	Existence of emergency human and economic resources	1.00
CR3.2b	Mitigating systems/measures	Existence of mitigating system	1.00
CR3.2c	Physical strengthening/protection	Existence of physical protection	1.00
CR3.3a	Financial recovery	Funds available but insufficient	0.30
CR3.3b	Social recovery	Absence of social recovery plan	0.00
CR3.3c	Physical recovery	Risk management plan exists and up to date	1.00

From the weight assignment in Chapter 4.2, it is known that:

Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)

→ **Resilience = 0.873**

Vulnerability evaluation

Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience

V = (0.70x0.228) + (0.30x0.713) - (0.30x0.873) = 0.18242

For the case study analysed:

Vulnerability = 0.112

With $0 \leq V \leq 1$ (low to high vulnerability).

ANNEXES 3: CLIMATE HAZARD MAPPING TOOLS

ANNEX 3A – WEB GIS TOOL APPLICATION AT TROJA HAMLETS AND DISTRICT

ANNEX 3B – WEB GIS TOOL APPLICATION AT THE WACHAU REGION

ANNEX 3A. WEB GIS TOOL APPLICATION AT TROJA HAMLET

The WebGIS Tool (WGT) performs an analysis of changes in climate extremes, such as dry spells or intense precipitation, using indices to evaluate statistics of extreme events for temperature and precipitation and to compare them with observed extremes. Among the available climate indices, those considered for the Troja hamlet are outlined in the table below. These strongly relate to the types of extreme events observed at the site, in particular flooding, flash floods and partially fire.

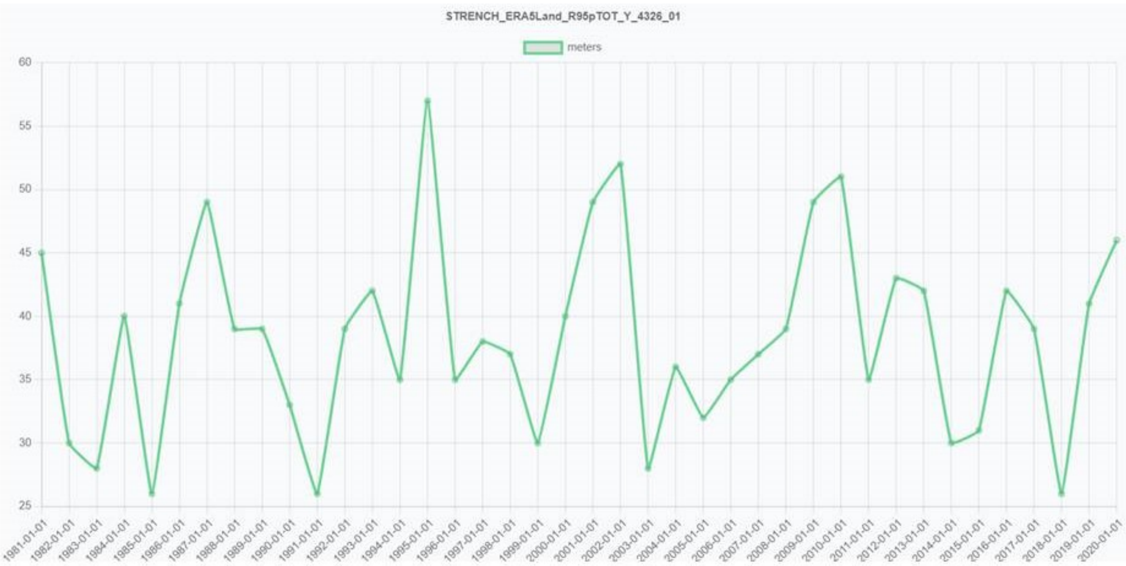
Index	Description	Rationale for choice
R20mm	**Very heavy precipitation days** Number of days in a year with precipitation larger or equal 20 mm/day.	Major index governing flooding.
R95pTOT	**Precipitation due to extremely wet days** The total precipitation in a year cumulated over all days when daily precipitation is larger than the 95th percentile of daily precipitation on wet days. A wet day is defined as having daily precipitation ≥ 1 mm/day. A threshold based on the 95th percentile selects only 5% of the most extreme wet days over a 30 year-long reference period.	Major factor governing flooding.
Rx5day	**Highest 5-day precipitation amount** Yearly maximum of cumulated precipitation over consecutive 5-day periods.	Major factor governing flooding.
CDD	**Maximum number of consecutive dry days** Maximum length of a dry spell in a year, that is the maximum number in a year of consecutive dry days with daily precipitation smaller than 1 mm/day.	Climate index for determining potential drought as well as landslide hazard.
Tx90p	**Extremely warm days** Percentage of days in a year when daily maximum temperature is greater than the 90th percentile. A threshold based on the 90th percentile selects only 10% of the warmest days over a 30 year-long reference period.	Indicator of increased threat for fire.

Investigation of past climate data using the WGT

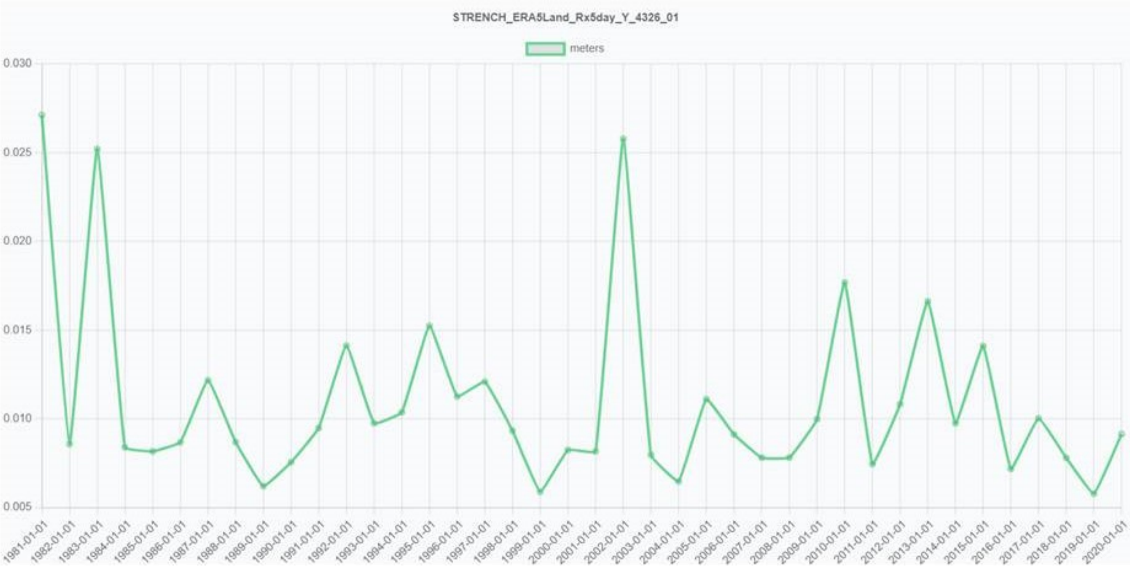
The Open Search Tool Box (OSTB) enables to discover, visualize, analyse and download climate data related to selected extreme climate indices based on change of temperature and precipitation and relate to heavy rain, flooding, drought and extreme heating.

In the perspective of investigating the development over the years of climate data at the pilot site, the time series of the Copernicus C3S ERA5 Land products (~9 km resolution, from 1981) are employed. These present the higher resolution and larger historical period covered among the options given. The indices considered (see table above) are the most significant for the case study as they are related to floods, flash floods, drought and landslides. The period investigated spans over almost 40 years, i.e. between 01/1981 and 01/2020. An annual frequency is used for the time series.

Climate index R20mm for the Troja hamlet over the period 1981-2020.

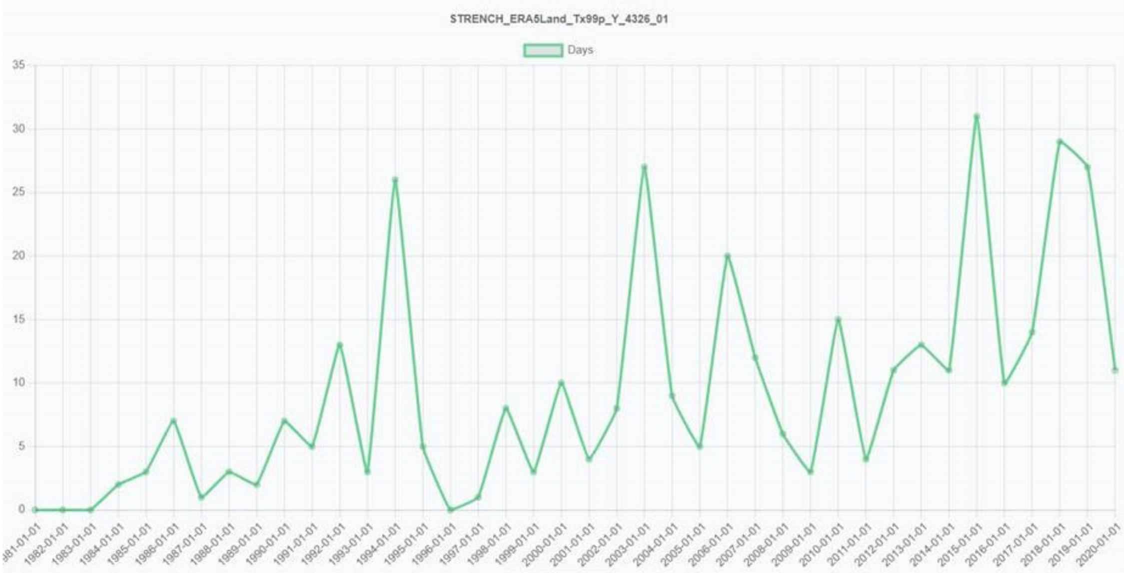


Climate index R95pTOT for the Troja hamlet over the period 1981-2020.



Climate index Rx5day for the Troja hamlet over the period 1981-2020.

Climate index CDD for the Troja hamlet over the period 1981-2020.



Climate index Tx90p for the Troja hamlet in days over the period 1981-2020.

From the graphs it is noticeable a significant correlation among the precipitation indexes R20mm, R95pTOT and Rx5day and the past events occurred at the site. In particular, the remarkable flood event of 2002 is clearly visible in the time series, where all the precipitation indices investigated score their maximum for the period considered: in 2002, R20mm equals to 7 days, same as for 2010 when other major floods occurred in the area; R95pTOT reaches over 50m of cumulative precipitation in 2002 (similar to 2010), the second highest value after that recorded in 1995 (above 55m); Rx5day is found to be equal to 0.025m in 2002, the second highest figure measured during the 40-year-long period.

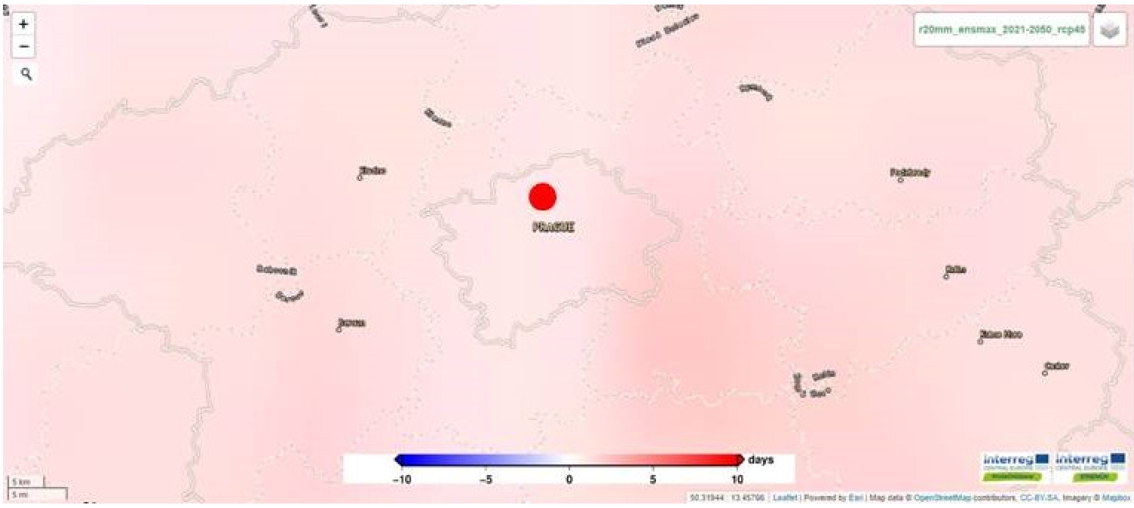
Concerning temperature variations, it is possible to observe the following from the climate data produced by the WGT: the number of consecutive dry days (CDD index) shows no clear trend with peaks in 1982 and 2003 (above 120 days) and minima in 1981 and 2009 (under 70 days); the index Tx90p (percentage of days in a year when daily maximum temperature is greater than the 90th percentile) shows instead how the daily maximum temperature increased especially when comparing the first 10 years of the reference period (1981-1991) to the last ten years (i.e. 2010-2020). In the first time frame Tx90p ranges between 0 and 5 days while in the second one it varies between 4 and 31 days. This shows also how the magnitude of temperature variation also exacerbated over time.

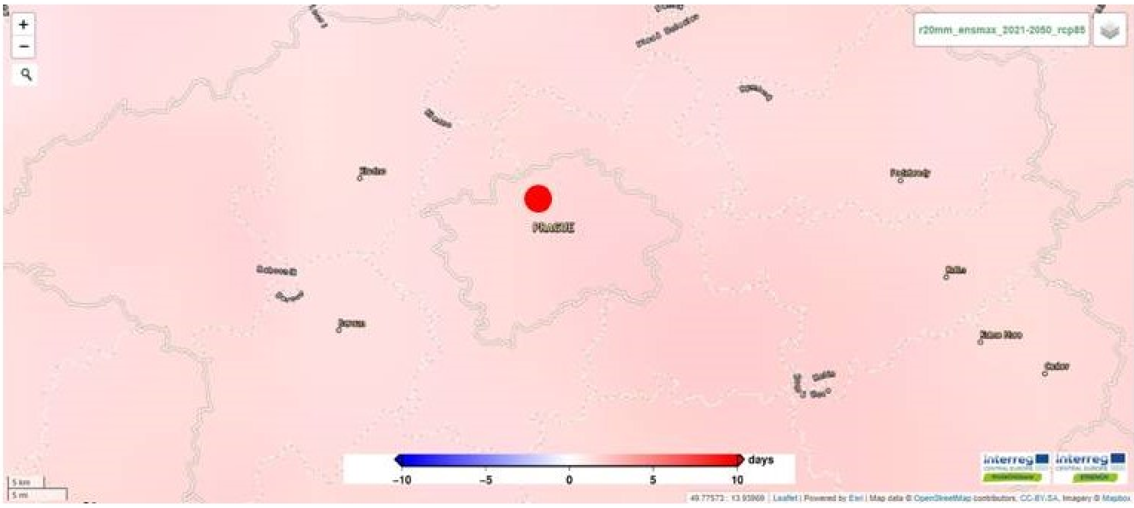
Climate projections using the WGT

Following the definition and analysis of the most relevant climate indices for the Troja hamlet, the WGT provides further insights on the hazard maps referring to heavy rain, flooding, drought, and extreme heat. The maps are elaborated covering the European and Mediterranean areas calculating climate extreme precipitation and temperature indices using data from the selected combination of models.

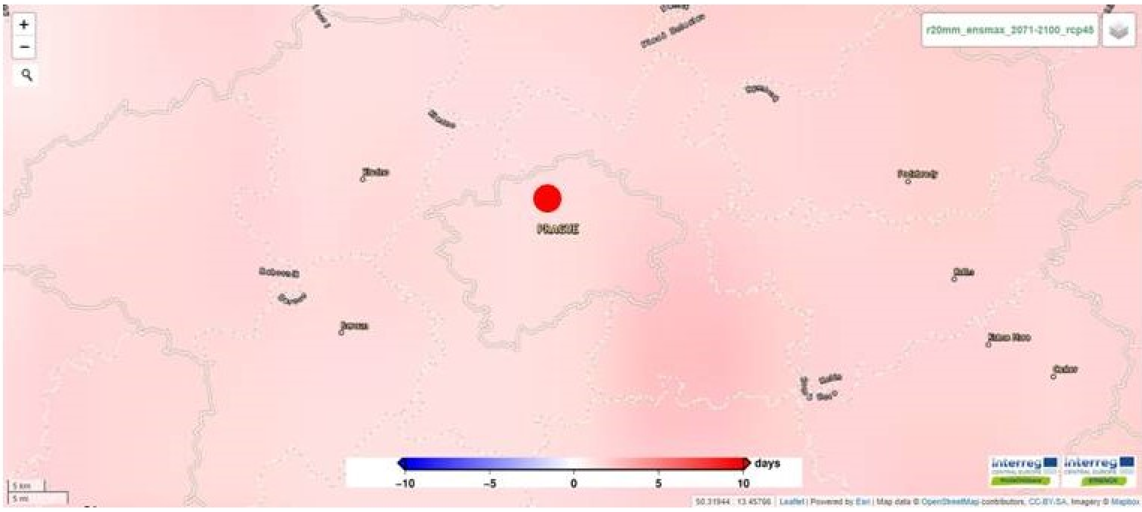
Different numerical climate model simulations have been analyzed to study the possible future evolution of the climate system. For the case study under investigation, the model ensemble statistics, maximum is used with near future (2021-2050) and far future (2071-2100) projections. Furthermore, two future emission scenarios, as described in detail in the latest IPCC , have been employed: RCP 4.5 is a stabilization scenario in which anthropogenic radiative forcing is stabilized at 4.5 W/m2 after year 2100, without overshooting the long-run radiative forcing target level; RCP 8.5 is a high pathway scenario characterized by increasing greenhouse gas emissions over time, for which anthropogenic radiative forcing reaches 8.5 W/m2 at year 2100 and continues to rise for some time. This is also known as the “business as usual” scenario.

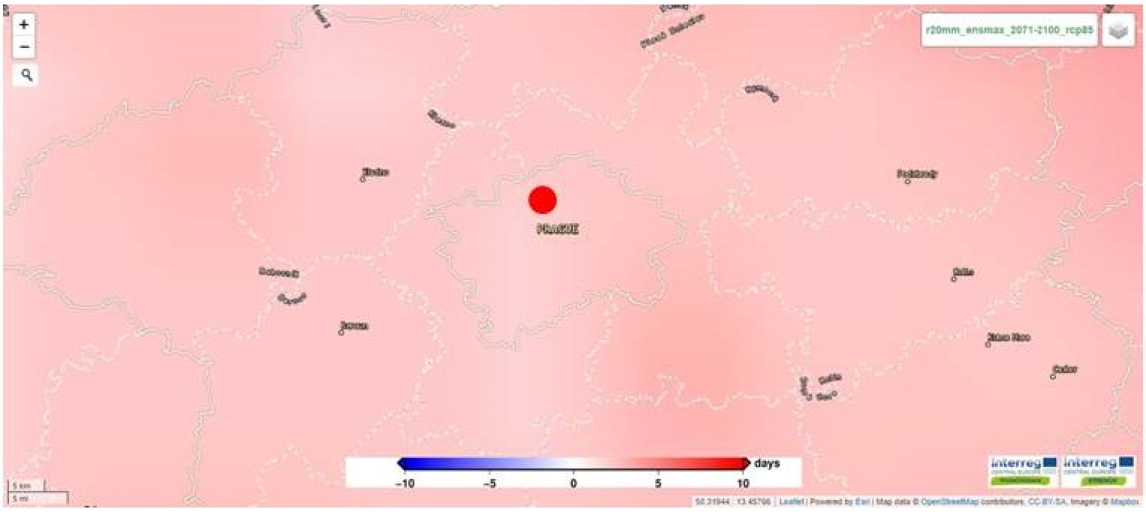
The maps below show, for the Troja hamlet, the projections for the selected climate indexes (see table above) and for the chosen scenarios (near/far future and RCP4.5/RCP8.5)



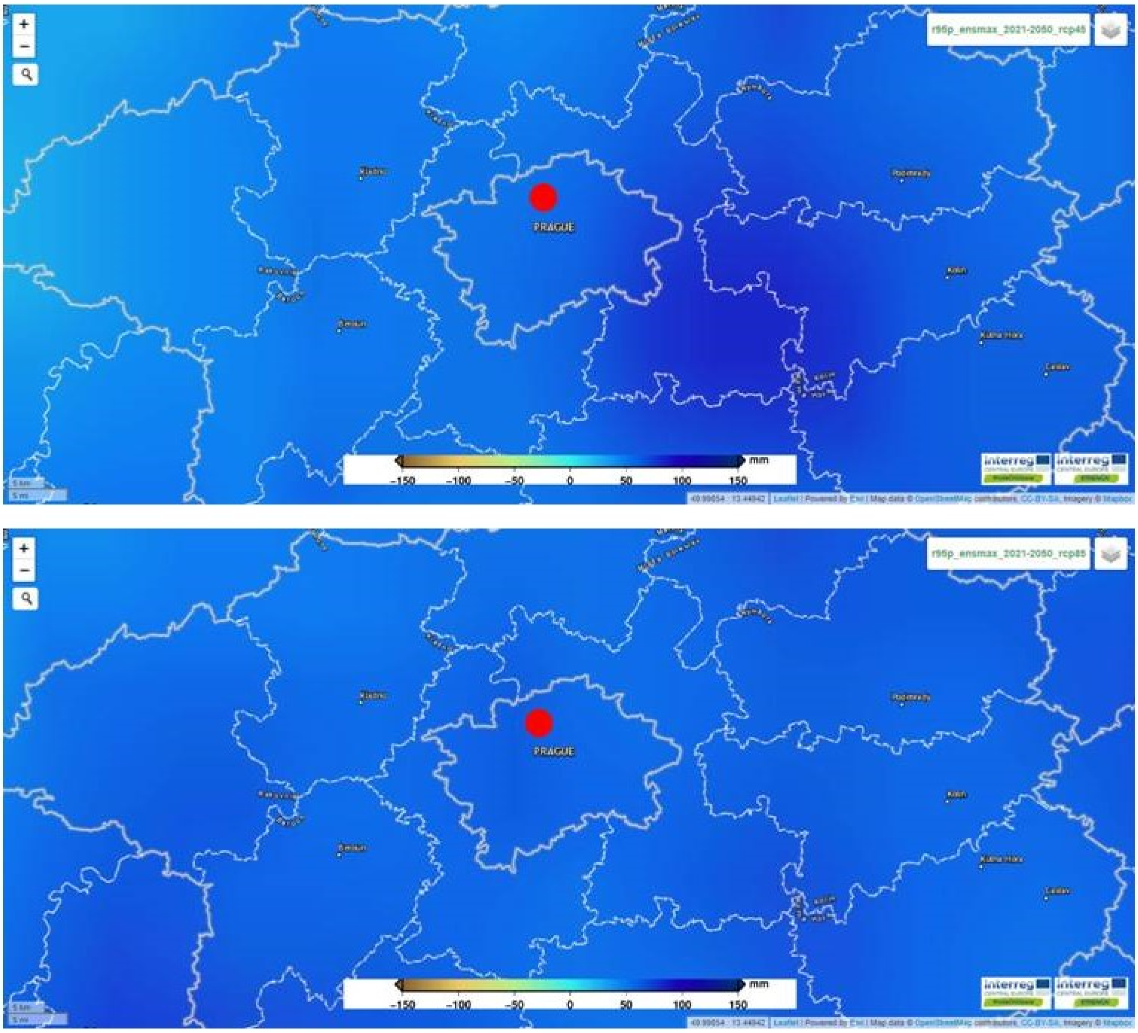


Near future (2021-2050) climate projections for Troja hamlet: R20mm RCP4.5 (above) and RCP8.5 (below).

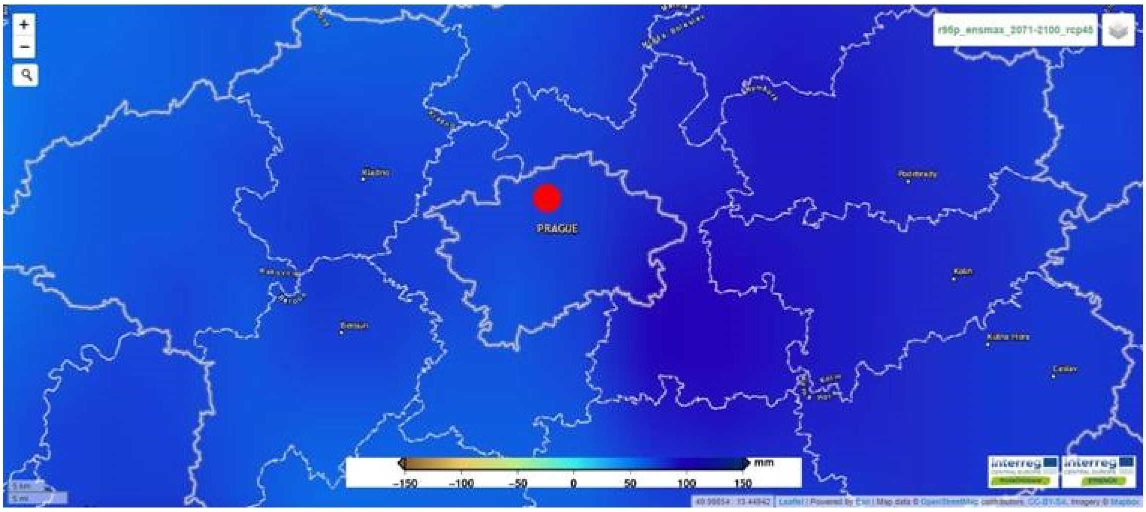


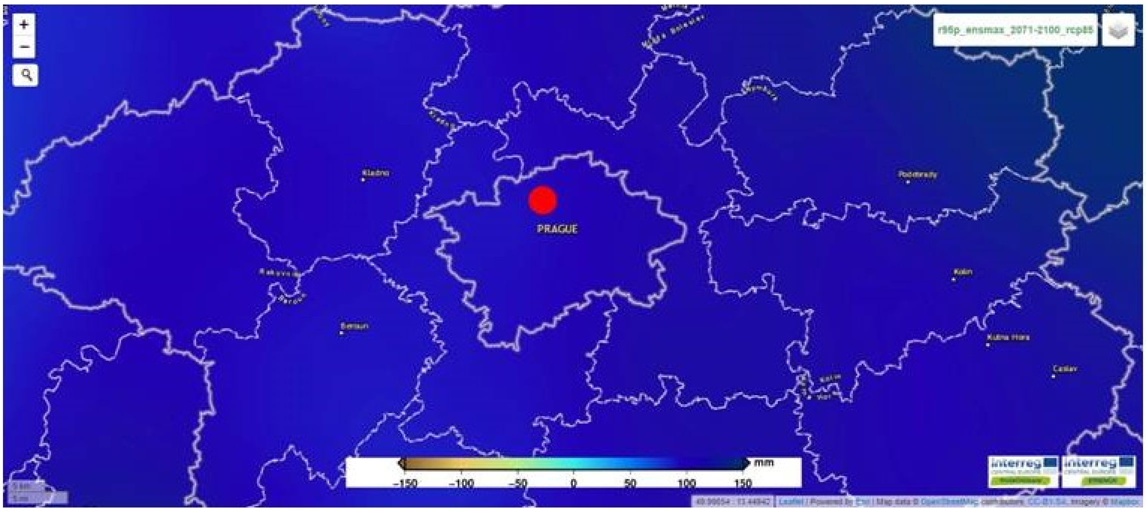


Far future (2071-2100) climate projections for Troja hamlet: R20mm RCP4.5 (above) and RCP8.5 (below).

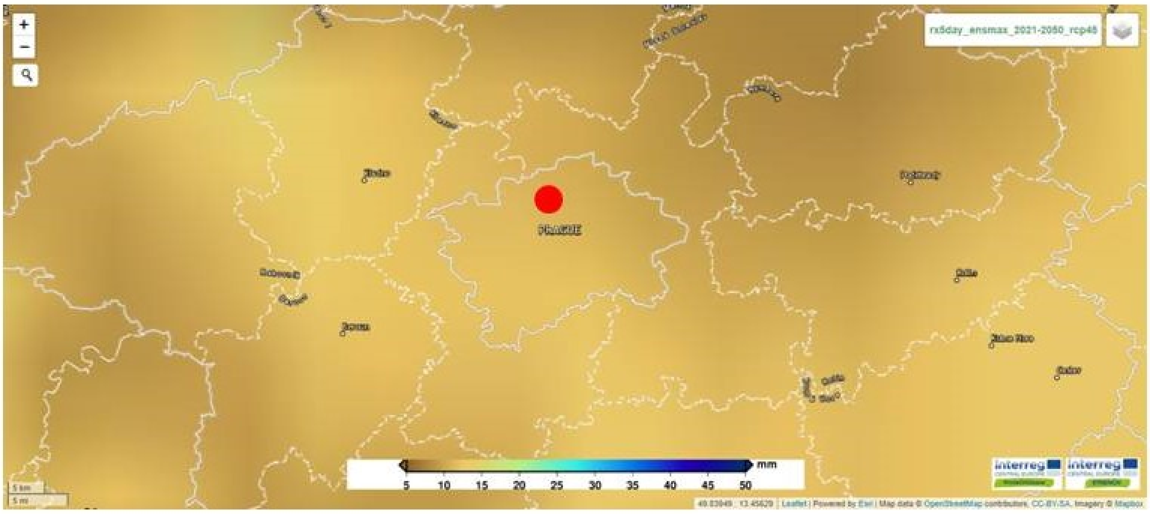


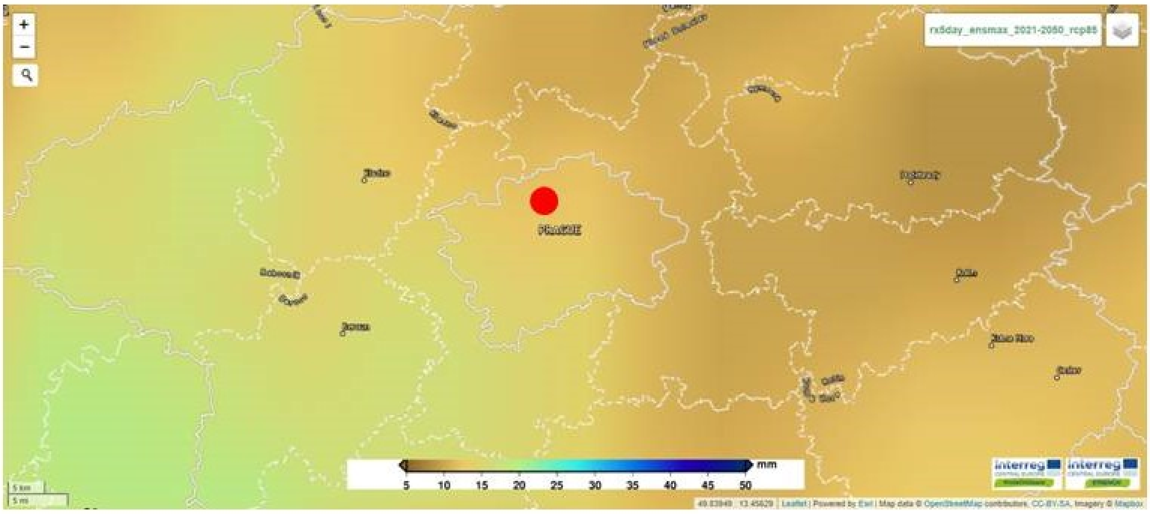
Near future (2021-2050) climate projections for Troja hamlet: R95p RCP4.5 (above) and RCP8.5 (below).



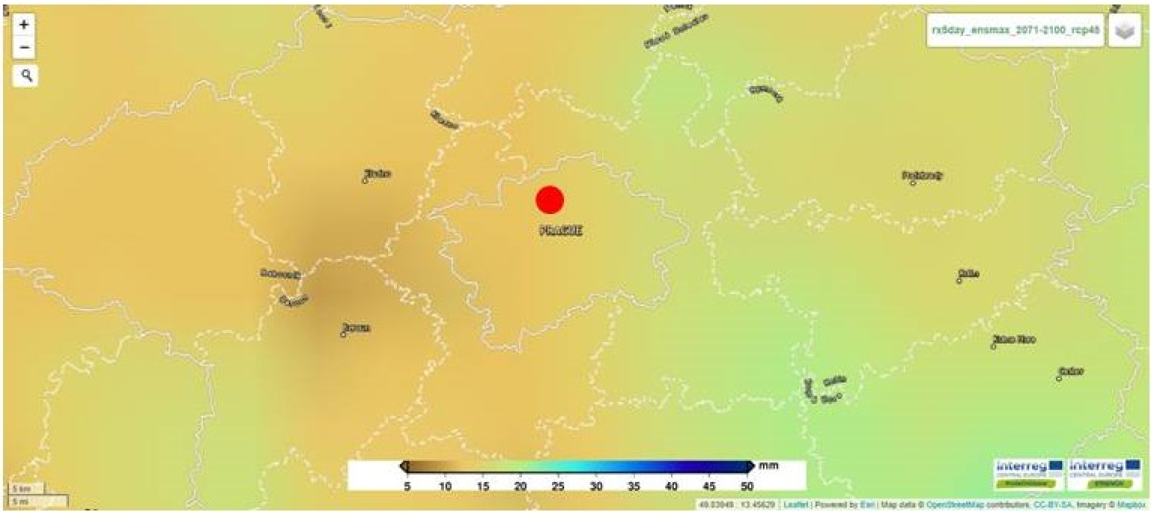


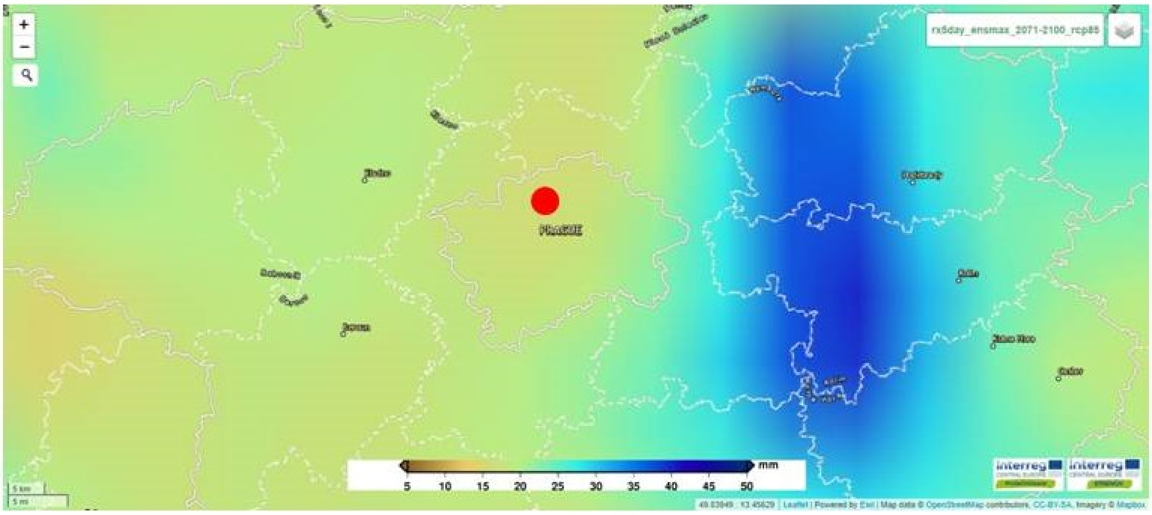
Far future (2071-2100) climate projections for Troja hamlet: R95p RCP4.5 (above) and RCP8.5 (below).



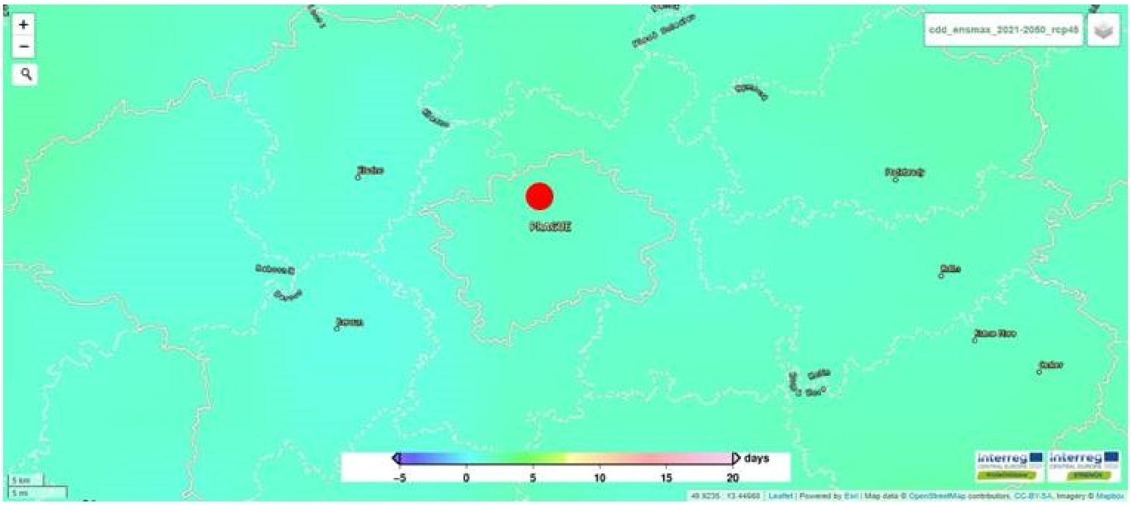


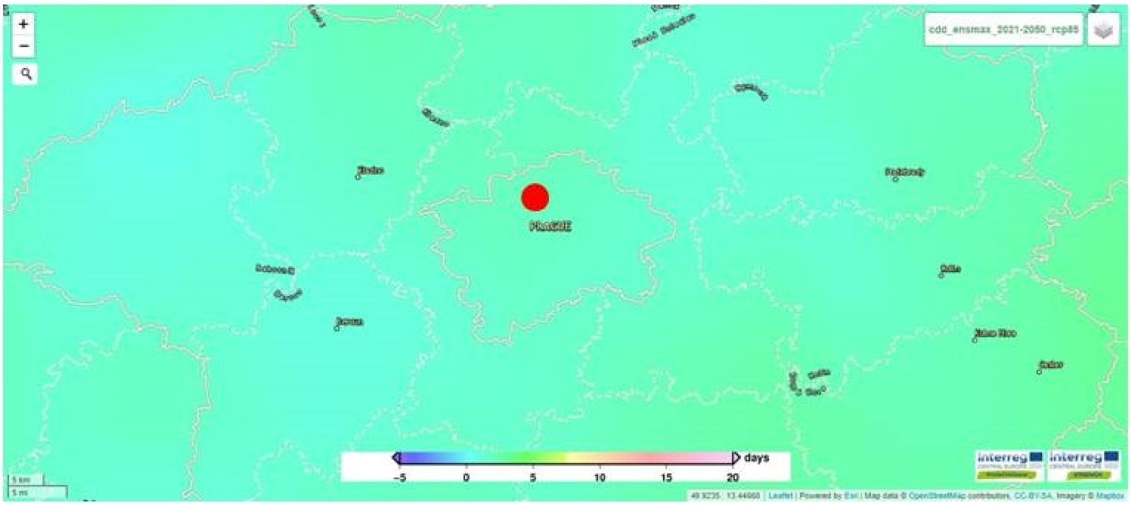
Near future (2021-2050) climate projections for Troja hamlet: Rx5day RCP4.5 (above) and RCP8.5 (below).



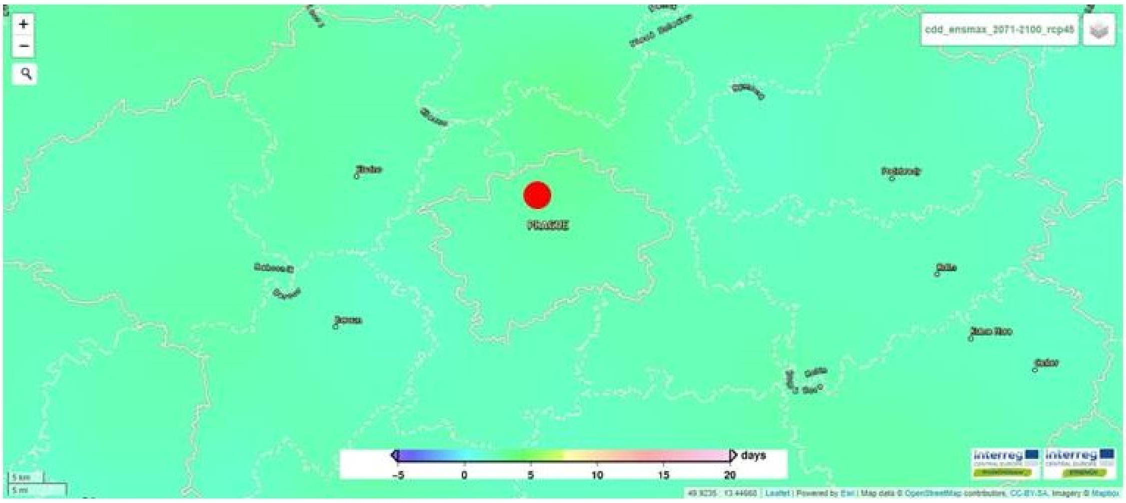


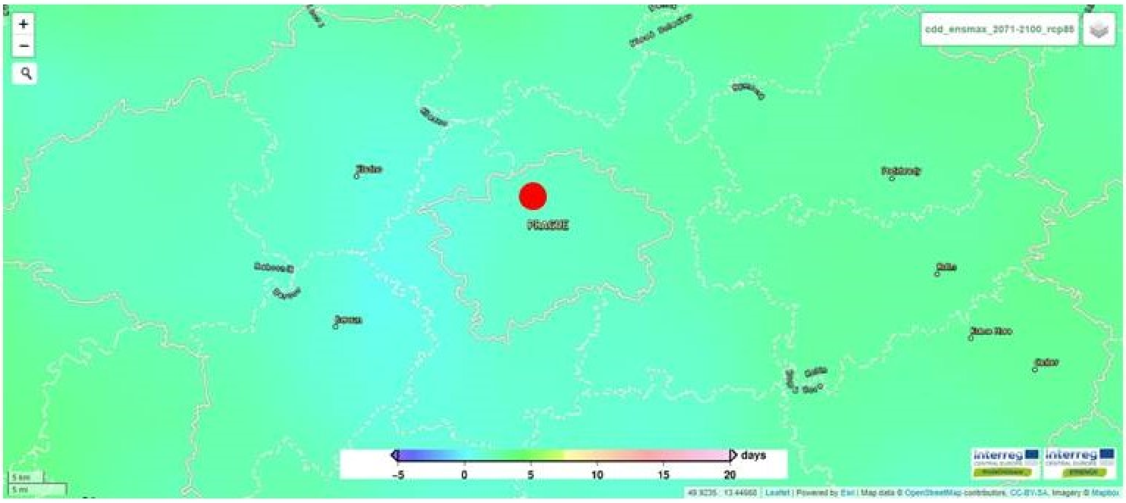
Far future (2071-2100) climate projections for Troja hamlet: Rx5day RCP4.5 (above) and RCP8.5 (below).



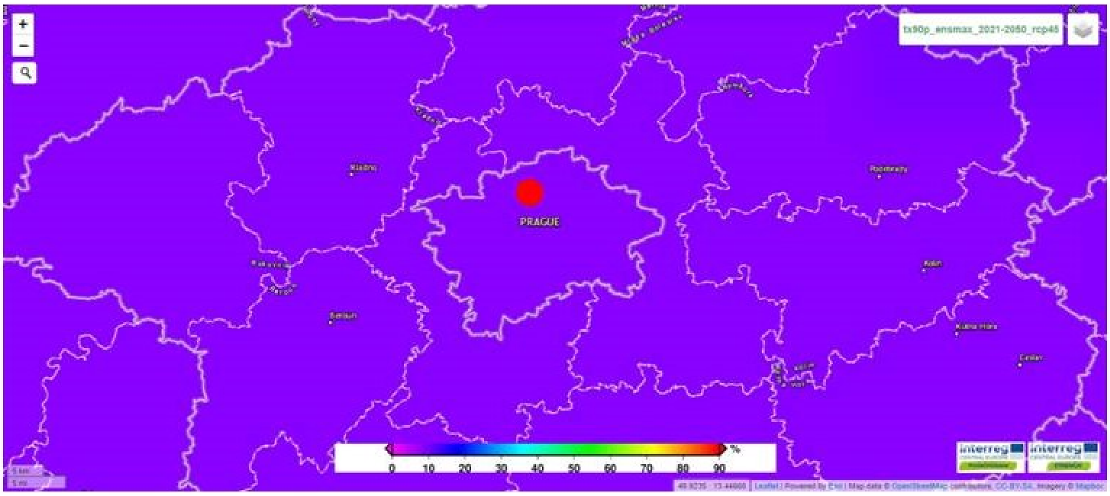


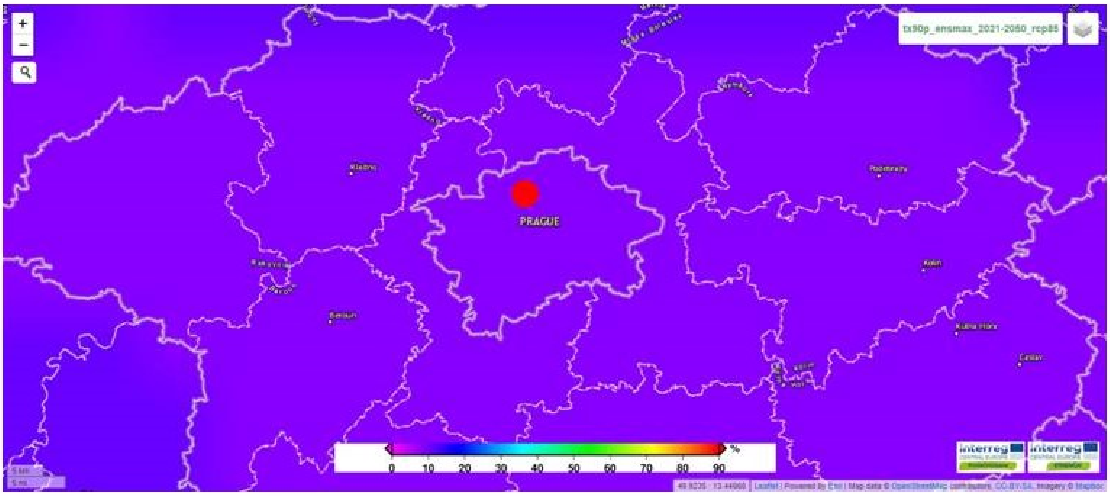
Near future (2021-2050) climate projections for Troja hamlet: CDD RCP4.5 (above) and RCP8.5 (below).



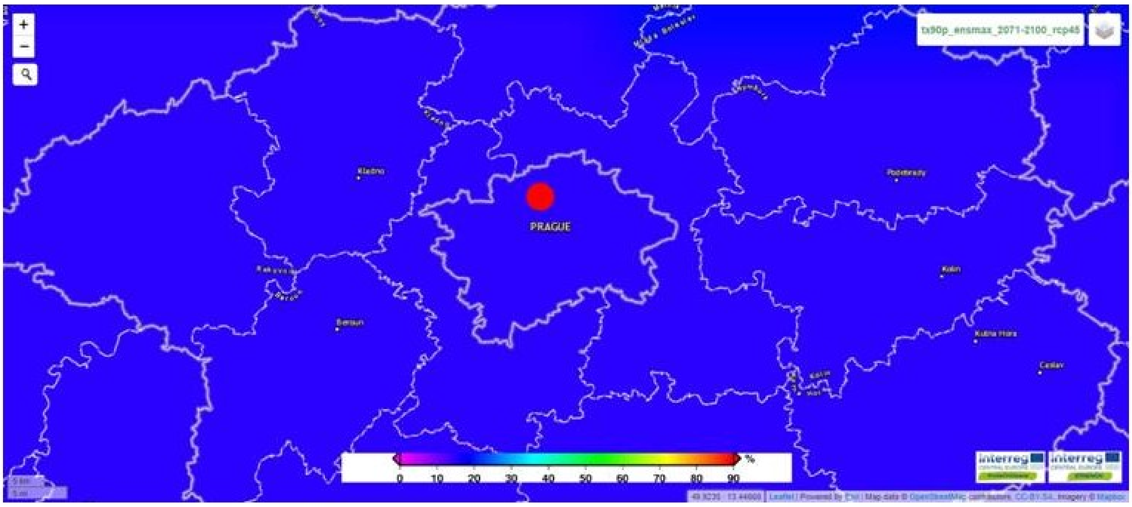


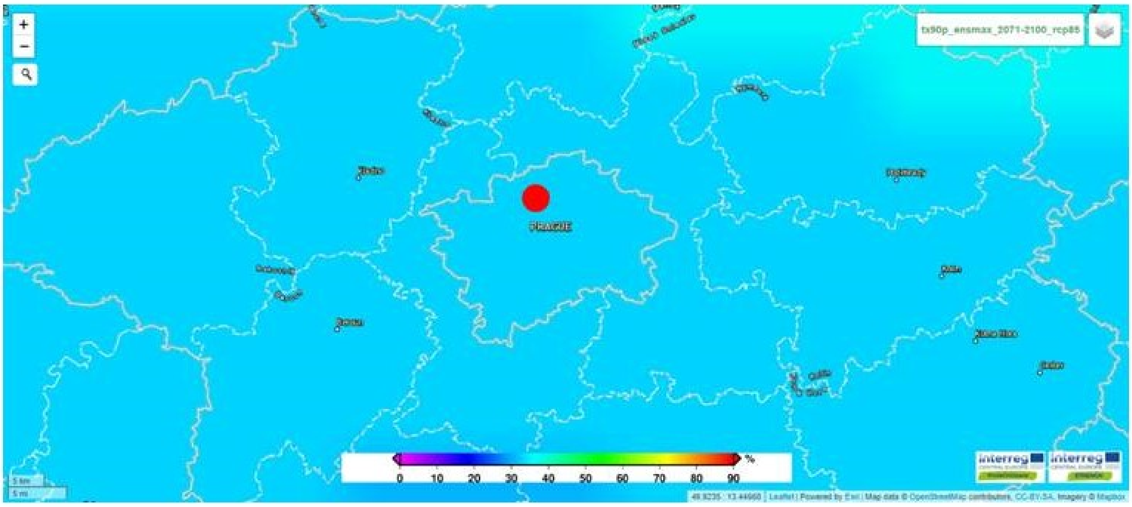
Far future (2071-2100) climate projections for Troja hamlet: CDD RCP4.5 (above) and RCP8.5 (below).





Near future (2021-2050) climate projections for Troja hamlet: Tx90p RCP4.5 (above) and RCP8.5 (below).





Far future (2071-2100) climate projections for Troja hamlet: Tx90p RCP4.5 (above) and RCP8.5 (below).

The results from the climatic projections are summarised in the table below.

	Near future/RCP4.5	***Near future/RCP8.5***	***Far future/RCP4.5***	***Far future/RCP8.5***
R20mm (days)	1	2	2	3
R95pTOT (mm)	40	50	50	80
Rx5day (mm)	10	15	15	20
CDD (days)	1	2	3	4
Tx90p (%)	5	10	20	40

Future changes are calculated as the difference between the period 2021–2050 and the period 1976–2005 (near future projection) and as the difference between the period 2071–2100 and the period 1976–2005 (far future projection), under both RCP 4.5 and 8.5 scenarios (spatial resolution 12 × 12 Km).

The near future projection (2021-2050) for the Troja hamlet yields the following results:

-stabilisation scenario (4.5RCP): the precipitation indices show a mild increase with R20mm recording a change of plus 1 day, R95pTOT plus 40 mm and Rx5day plus 10 mm with respect to the reference period (1976-2005). Similarly, the temperature indexes vary moderately, namely plus 1 day CDD and 5% Tx90p.

-pessimistic scenario (8.5 RCP): a slightly more significant change is observed for this scenario, where R20mm increases by 2 days, R95pTOT by 50 mm and Rx5day by 15 mm; on the other end the temperature indexes vary by plus 2 days (CDD) and plus 10% (Tx90p).

For the far future projection (2071-2100) for the Troja hamlet it is possible to outline the following:

-stabilisation scenario (4.5RCP): the precipitation indices show moderate changes increase with R20mm plus 2 days, R95pTOT plus 50 mm and Rx5day plus 15 mm with respect to the reference period (1976-2005). Temperature indexes present a rather marked change, namely plus 3 days for CDD and plus 20% Tx90p.

-pessimistic scenario (8.5 RCP): a rather significant change is observed for this scenario, where R20mm increases by 3 days, R95pTOT by 80 mm and Rx5day by 20 mm; also relevant increases are observed for the temperature indexes, with plus 4 days (CDD) and plus 40% (Tx90p).

Conclusions

The WGT provides useful insights on the hazards for the chosen site, enabling decison makers and cultural heritage managers to better investigate the potentially threatening scenarios and prioritise the measures to be taken in order to mitigate risk.

From the climate mapping, it is evidenced that the Troja hamlet will experience with time increasing rainfall as well as dry spells. This will impact the site possibly triggering soil erosion, speeding up the degradation of materials and influencing the conservation of the vegetation and other natural systems present on-site.

Under the stabilisation scenario (4.5RCP), both near and far future projection show a mild increase of precipitation and temperature indices. This translates in a significantly greater risk of flash floods for the site due to the intensification of rainfall. Remarkable climate changes are instead observed under the pessimistic scenario (8.5RCP). The far future projection, predicting strong changes to precipitation and temperature at the site, is of particular concern. This scenario would lead to a remarkable risk situation for flood and flash flood. Also the variation in soil moisture content due to extreme wet and dry cycles may induce larger volumetric changes (in particular for soils with lager clay content) and thus imposing movements to the overlying structures.

1 In the perspective of evaluating the applicability and efficacy of the WGT, it is interesting to underline some of the strengths and opportunities for risk management in cultural heritage protection as well as some of the limitations. The Open Search Tool Box (OSTB) enables to discover, visualize and download climate data related to selected extreme climate indices and successfully allows to tailor the climate mapping

in order to provide relevant insights on heavy rain, flooding, drought and extreme heating. This proves to be a very useful tool for hazard determination as well as for risk assessment when coupled with vulnerability data. On the other hand, it should be underlined the possibility of reading errors for the mapping mainly due to their limited resolution and the impossibility to adjust the scale to the ranged of value observed. Both resolution and scale rigidity limit the granularity of information. This would affect for example the analysis at building or site scale and the comparison among different locations within an area of only a few square kilometers (common for cities or hamlets).

ANNEX 3B. WEB GIS TOOL APPLICATION AT WACHAU REGION

Location: Lat. 48.39018 – Long.15.47489

Figure 1 Google Earth screenhots showing the location of the Wachau.

Utilized WebGIS Indices & Climate Variables:

Extreme Event / Index	**Description**	**Rationale for choice**
(Heavy Rain) R20mm	**Very heavy precipitation days** Number of days in a year with precipitation larger or equal 20 mm/day.	Being a major factor for flooding within the Wachau area. In 2021 a brief but powerful thunderstorm caused massive destruction by creating flooding along the tributaries of the Danube River resulting in the declaration of a local state of emergency in some municipalities
(Heavy Rain) R95pTOT	**Precipitation due to extremely wet days** The total precipitation in a year cumulated over all days when daily precipitation is larger than the 95th percentile of daily precipitation on wet days. A wet day is defined as having daily precipitation ≥ 1 mm/day. A threshold based on the 95th percentile selects only 5% of the most extreme wet days over a 30 year-long reference period.	Another major factor when considering flooding, which may increase with the ongoing urbanization and sealing of land along the entire Danube possibly resulting in steeper rises of water levels after increased precipitation.
(Flooding) Rx5day	**Highest 5-day precipitation amount** Yearly maximum of cumulated precipitation over consecutive 5-day periods.	Flooding arguably remains the biggest threat to the UNESCO world heritage Site Wachau and requires further consideration in disaster preparedness and cultural heritage protection
(Drought) CDD	**Maximum number of consecutive dry days**	A possible indicator for wildfire which in turn can act as additional indicator for flash floods. In addition, increased

	Maximum length of a dry spell in a year, that is the maximum number in a year of consecutive dry days with daily precipitation smaller than 1 mm/day.	drought may affect the cultural landscape created by viticulture and orchard farming should these be damaged.
(Extreme heating) Tx90p	**Extremely warm days** Percentage of days in a year when daily maximum temperature is greater than the 90th percentile. A threshold based on the 90th percentile selects only 10% of the warmest days over a 30 year-long reference period.	Indicator of increased threat for wildfire is also can indicate a weakening resilience of local forest towards such due to a combination of drought and pests.

WebGIS indices and climate variables used.

Regarding the usage of the WebGIS tool for decision making in cultural heritage protection future prognosis were deemed to be the most beneficial. Therefore, the extreme events as well as climate variables were observed for the near future (2021-2050) and the far future (2071-2100). Initially the model ensemble statistics, maximum, RCP 4.5 & RCP 8.5 were used for a numerical observation. When choosing the visual observation, the model ensemble statistics, maximum, RCP 4.5 was chosen. However, for the sake of visualization a baseline was seen as necessary in order to put the forecasted data into perspective. Therefore, when creating the visualized climate modelling in the WebGIS-Tool the historical observations were added as well.

Numerical observation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			Near future RCP 4.5			Near future RCP 8.5			Far future RCP 4.5			Far future RCP 8.5		
2	**Risk**	**Index**	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
3	Heavy rain	R20mm (days)	-1	1-2	2-3	0	2	3	0-1	2	3-4	1-2	3-4	4-5
4		R95pTOT (mm)	-10-0	25-35	50-60	-20 - -10	30-35	50-70	0-10	40-50	70-80	20-30	50-70	90-100
5	Flooding	Rx5day (mm)	-6 - -4	4-6	15-20	-5 - -3	5-6	10-15	-3 - -2	6-7	18-22	-2-0	8-9	25-35
6	Extreme heating	Tx90p (%)	0-5	5-10	10-15	5-7	8-10	15-20	8-10	15-20	20-25	20-25	25-30	30-35
7	Drought	CCD (days)	-5 - -3	-1-1	2-3	-5 - -3	-1-1	2-4	-5 - -3	0-1	2-3	-4 - -3	0-1	3-4

Figure 2 Numerical observation graph taken from the WebGIS tool.

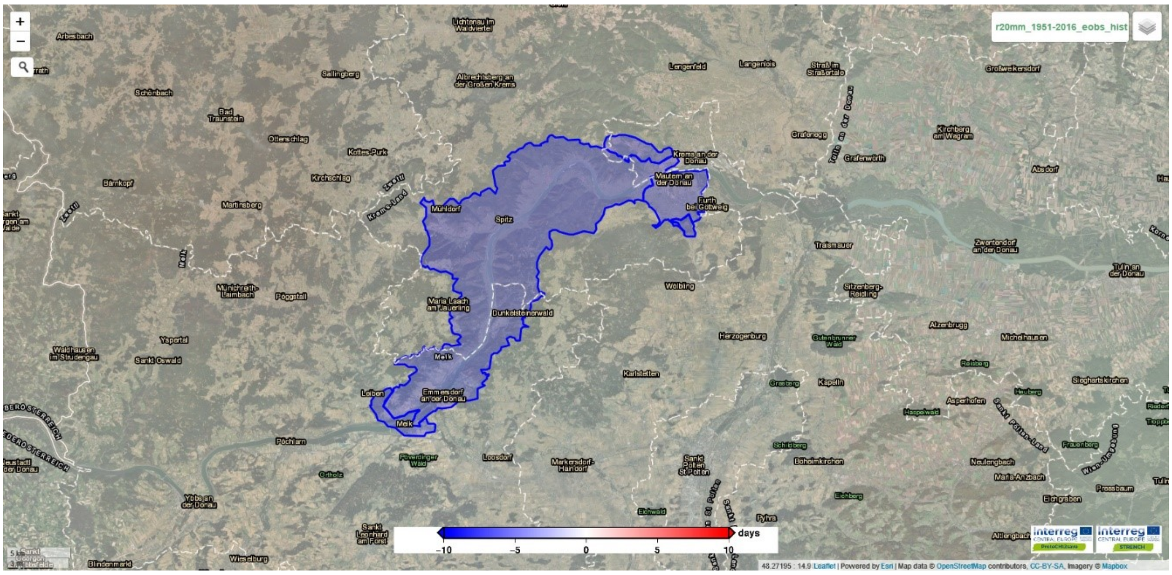
Upon brief inspectino one can observe that the chosen Extreme Events are forecasted to increse in the near and especially the far future.

However viewing output data from the WebGIS Tool in this fashion is arguably not presentable or pratical when communicating with decision makers and other stakeholders such as the broad public regarding cultural heritage protection. Fortunately the WebGIS Tool creates vivid images of these values.

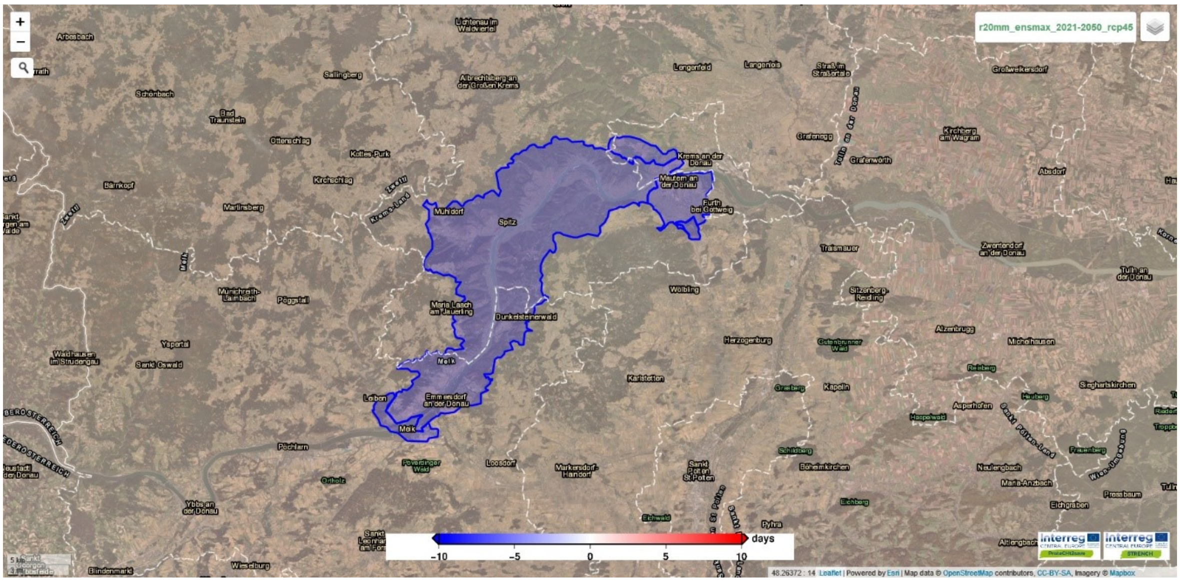
Visualization of Extreme Event Indices

For this purpose, the model ensemble statistics, maximum, RCP 4.5 was chosen. For better illustration the option to show "*UNESCO world Heritage*" was enabled as it encapsulates the pilot site Wachau perfectly. For each extreme event a historical observation as well as a near future and far future map was created in the WebGIS.

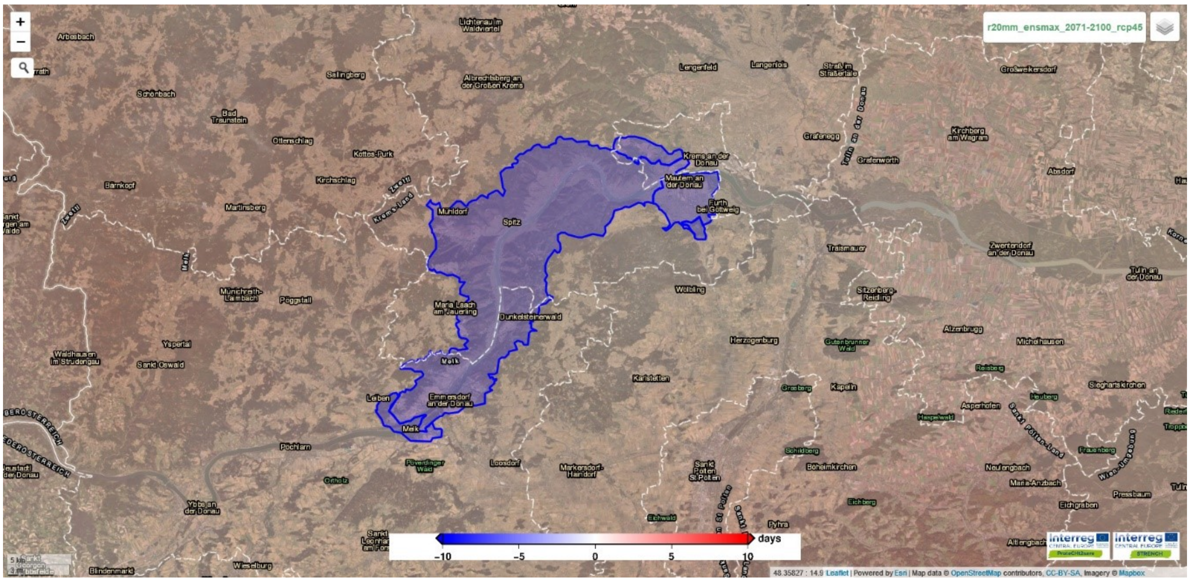
Very Heavy Precipitation Days (R20mm)



Historical Observation 1951 – 2016, WebGIS tool. (R20mm)



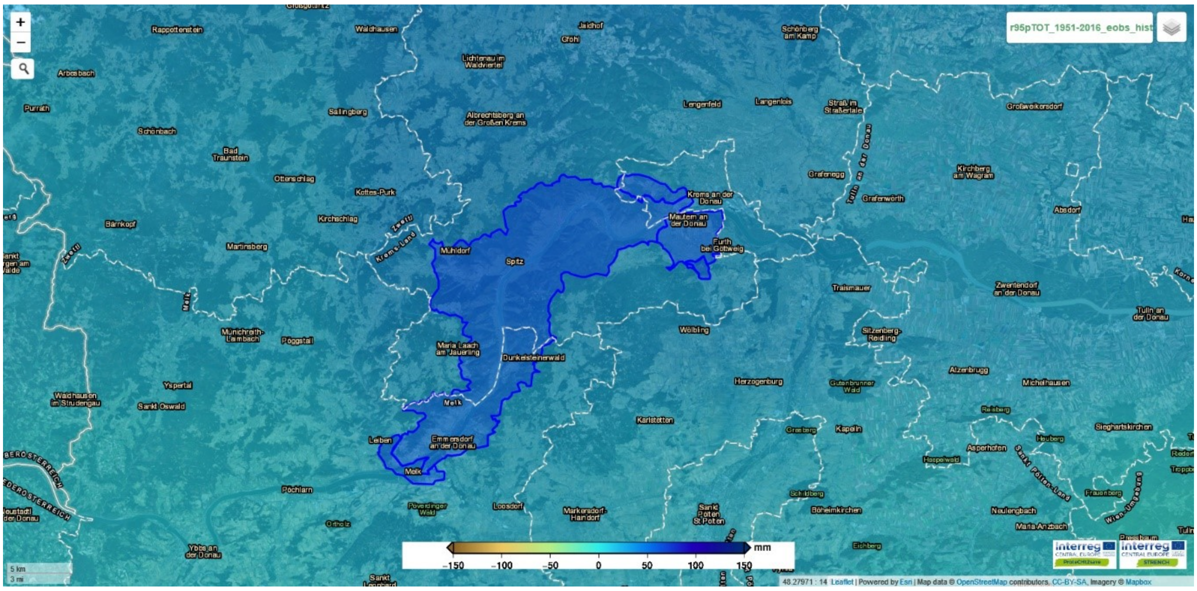
Ensemble statistics, maximum, RCP 4.5 Near Future (2021 – 2050), WebGIS tool. (R20mm)



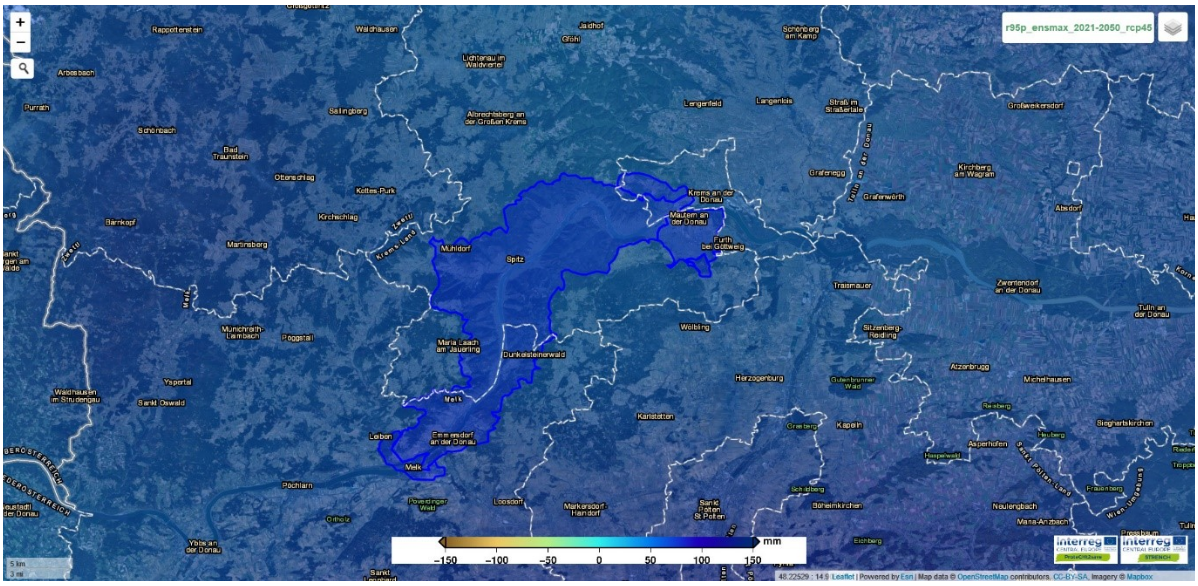
Ensemble statistics, maximum, RCP 4.5 Far Future (2071 – 2100), WebGIS tool. (R20mm)

After observing the more or less neutral first image of the historic observations the increase in red colour indicating an increased amount of very heavy precipitation days becomes evident and is illustrated well.

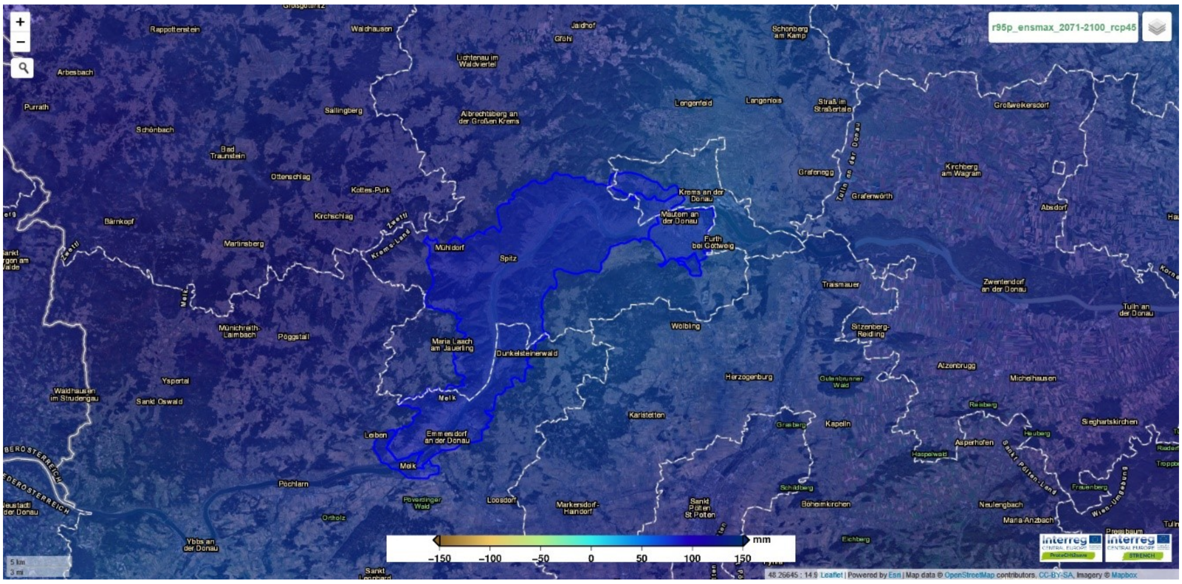
<u>Precipitation due to extremely wet days (R95pTOT)</u>



Historical Observation 1951 – 2016, WebGIS tool. (R95pTOT)



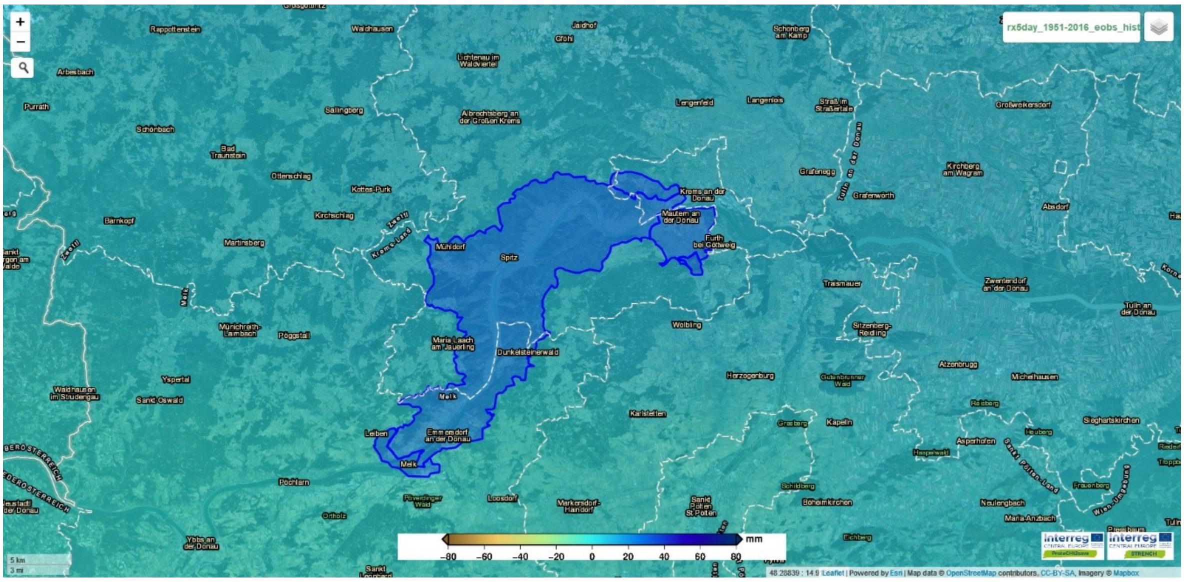
Ensemble statistics, maximum, RCP 4.5 Near Future (2021 – 2050), WebGIS tool. (R95pTOT)



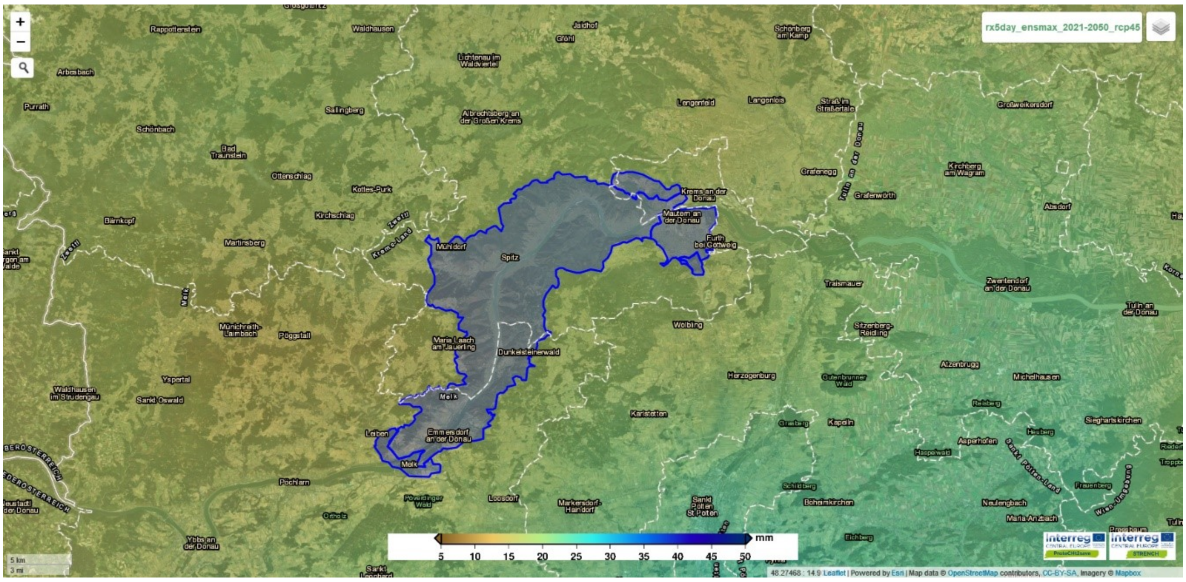
Ensemble statistics, maximum, RCP 4.5 Far Future (2071 – 2100), WebGIS tool. (R95pTOT)

By merely increasing the map filter from 0.5 to 0.6 on all 3 maps the illustration of the darkening and thus increase in extremely wet days became more concise than with the previously observed R20mm. Showing these 3 maps in sequence illustrates well the forecasted increase in extremely wet days.

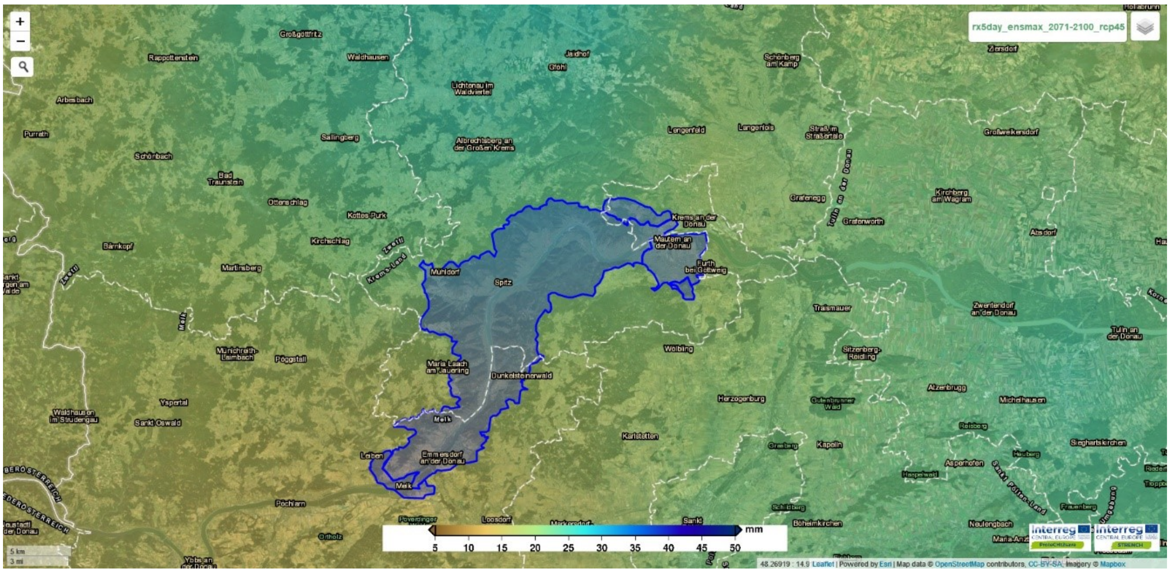
Highest 5-day precipitation amount (Rx5day)



Historical Observation 1951 – 2016, WebGIS tool. (Rx5day)



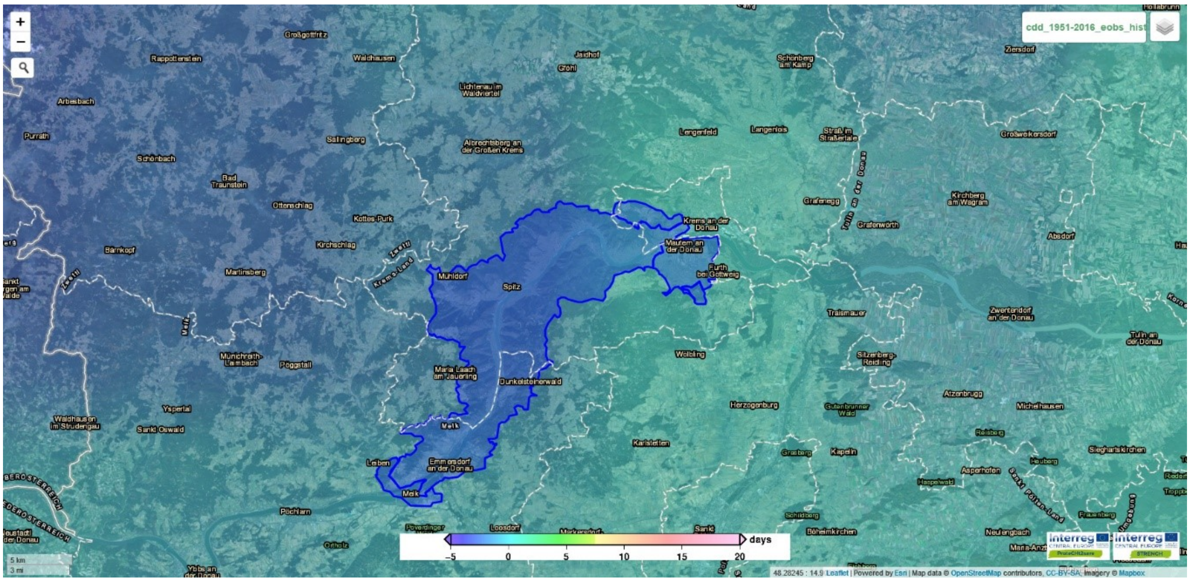
Ensemble statistics, maximum, RCP 4.5 Near Future (2021 – 2050), WebGIS tool. (Rx5day)



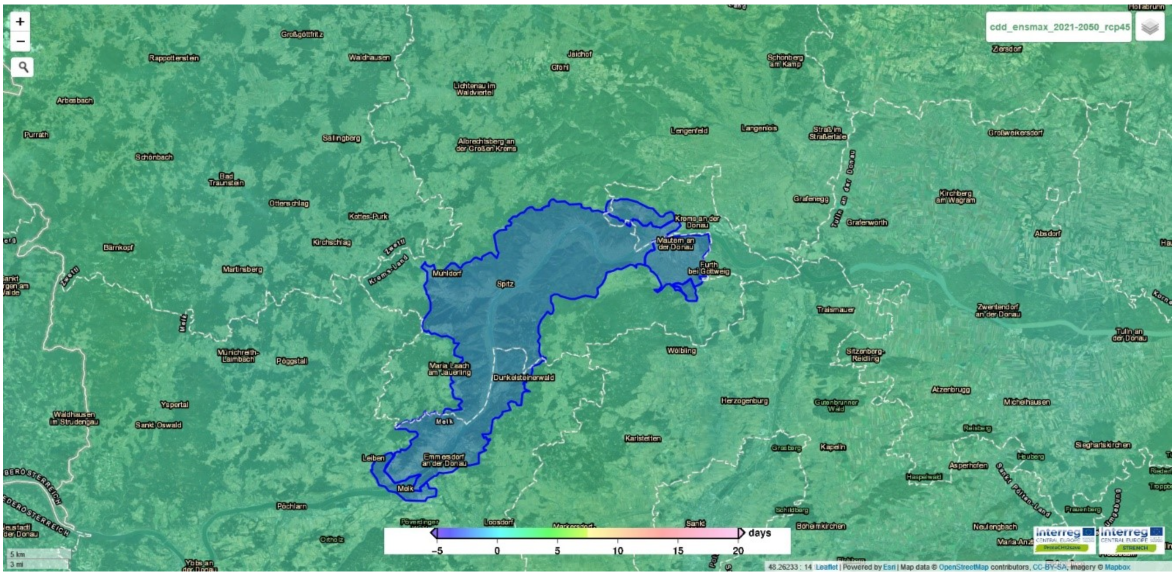
Ensemble statistics, maximum, RCP 4.5 Far Future (2071 – 2100), WebGIS tool. (Rx5day)

While the number of days with heavy rain as well as extremely wet days increase the 5-day precipitation amount strongly decreases. This may lead to an increase in dry periods followed by an extreme amount of rain resulting in an increased hazard of flooding and landslides. Overall, when considering the indicators above an increase of such hazardous events may be likely.

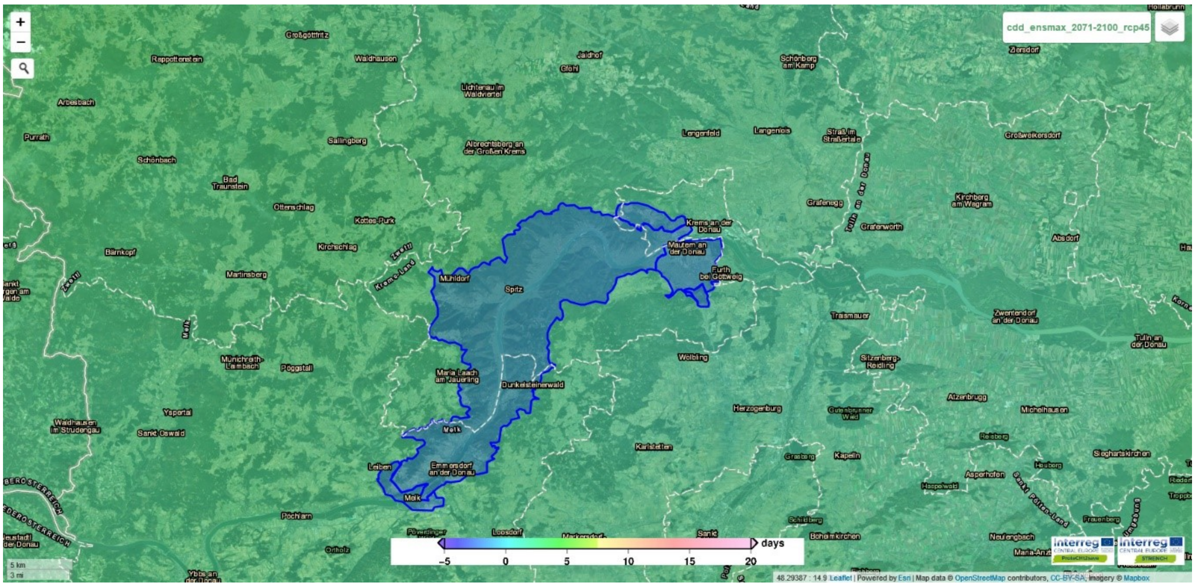
Maximum number of consecutive dry days (CCD)



Historical Observation 1951 – 2016, WebGIS tool. (CCD)



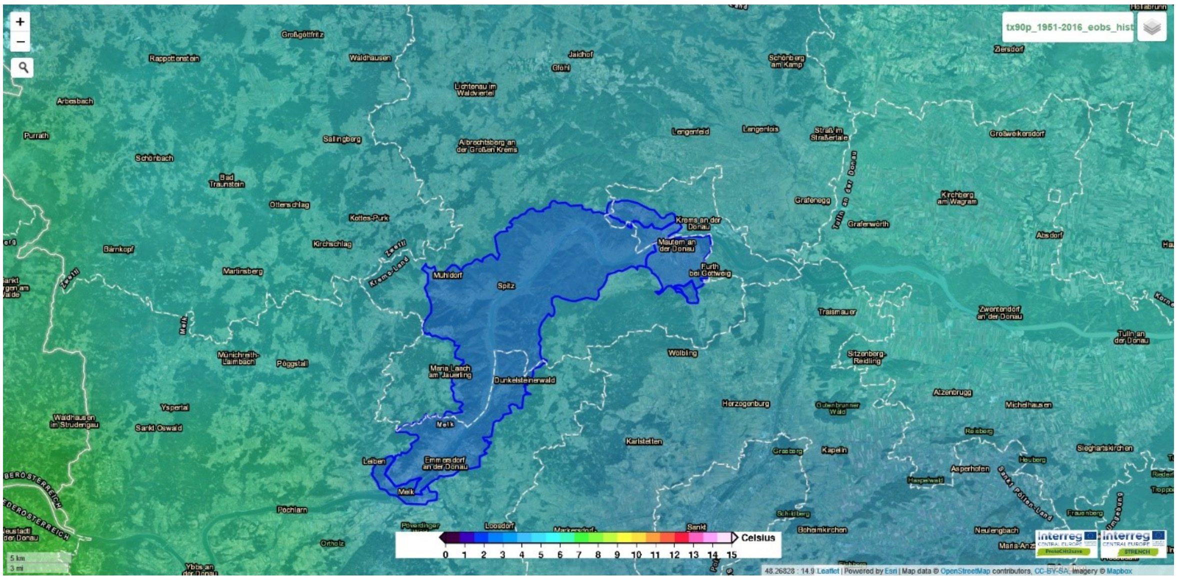
Ensemble statistics, maximum, RCP 4.5 Near Future (2021 – 2050), WebGIS tool. (CCD)



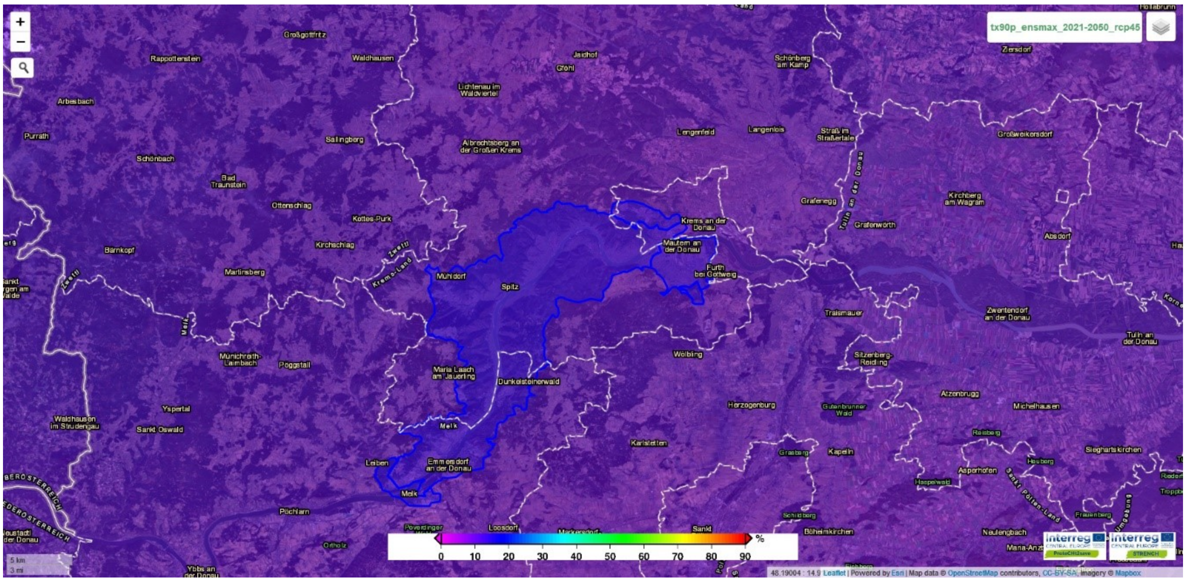
Ensemble statistics, maximum, RCP 4.5 Far Future (2071 – 2100), WebGIS tool (CCD)

Similar as with the 5-day precipitation amount the consecutive dry days are predicted to strongly increase. This further hardens the fear that drought followed by heavy rain may become an all too familiar pattern increasing floods and landslides alike.

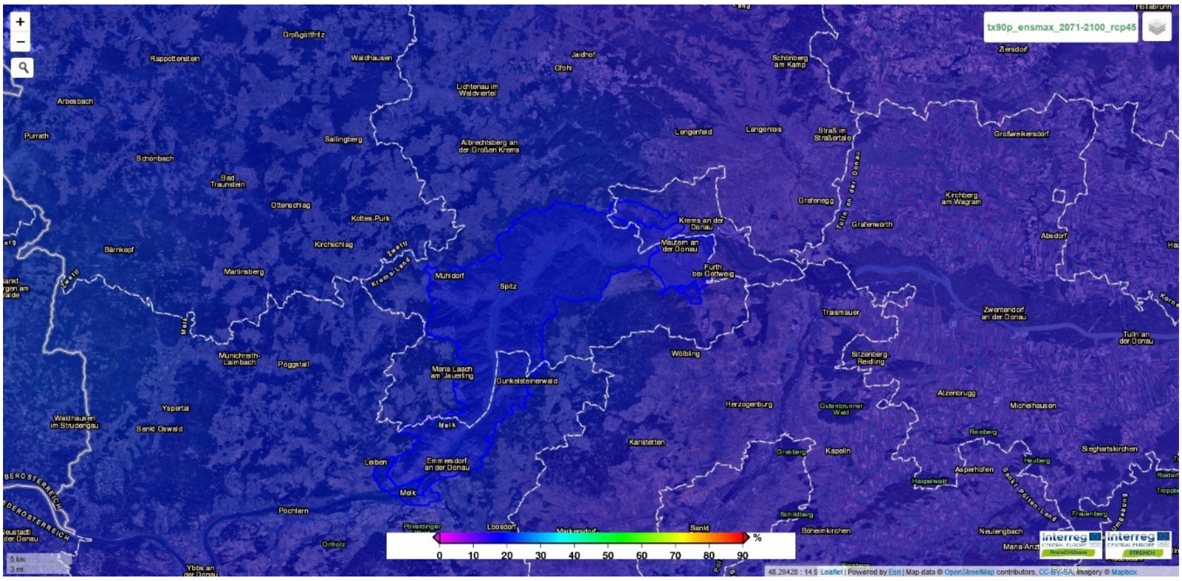
<u>Extremely warm days / percentage of extremely warm days (Tx90p)</u>



Historical Observation 1951 – 2016 in Celsius, WebGIS tool. (Tx90p)



Ensemble statistics, maximum, RCP 4.5 Near Future (2021 – 2050). Not in Celsius but in percentage, WebGIS tool. (Tx90p)



Ensemble statistics, maximum, RCP 4.5 Far Future (2071 – 2100). Not in Celsius but in percentage, WebGIS tool. (Tx90p)

Before drawing any conclusions for Tx90p one must bear in mind that the historic observation is based on Celsius which appear to be an average. However, the forecast (near and far) both depict the percentage of days in a year when daily maximum temperature is greater than the 90th percentile. A threshold based on the 90th percentile selects only 10% of the warmest days over a 30 year-long reference period. Therefore, the historic observation can be discarded in this case. Nonetheless the comparison between the near and far forecasted future show that a very strong increase in extremely warm days is predicted. This again falls in line with the observed increase in extreme weather events as shown in the other observed incidences.

Observations and possible conclusions

Overall, a strong trend can be observed in which the Wachau region will experience less rainy days, increased hot days and drought, combined with probably infrequent but strong rainfall. This is a perfect receipt for increasing the likelihood of all current major hazards mentioned earlier such as flooding / flash floods, heavy rain, landslides and fire due to drought.

A precursor of this trend may have already been observed with the flooding and flash flood in July 2021 during which as brief but heavy rainfall caused massive destruction along the tributaries of the Danube River while the Danube itself was experiencing a flood. This resulted in a regional state of emergency within the affected municipalities going as far as to receive aid by the Austrian armed forces. In another instance during the flood of 2013 the modern mobile flood protection wall of the town Krems was too low to ward of the flood alone and had to be further heightened by piling sandbags on top of its aluminium stop logs.

While the flood protection along the Danube itself is highly sophisticated, small tributaries flowing either from the southern or the northern bank into the river, and thus cross the Wachau from north to south or vice versa, are not protected by flood protection measures and thus can become a major threat to people, infrastructure and the cultural landscape as a whole, as seen in July 2021.

The four major floods discussed in detail above show that a combination of factors is essential for understanding the magnitude of large, regional floods: the soil moisture, the shift / time between flood peaks from main tributaries and the time between possible rainfall blocks. The 2013 flood fell on high antecedent soil moisture, there was little time between the flood peaks at the confluence of the Bavarian Danube and the Inn, and rainfall blocks close together resulted in a single, large volume flood with a small peak attenuation.

One question that might be interesting for the future is what happens if a heavy rainfall like in 2013 or in 1899 happens as flash flood and falls on very dry soil, soil that in the moment of the downpour cannot accommodate the water, even if not saturated. This is a scenario that might become possible in the future, following the worst-case predictions of the WebGIS tool.

Thus, the illustrative maps and information generated by the WebGIS could be a valuable asset for further fostering awareness towards cultural heritage protection and the need for risk management measures caused by climate change. It is most certainly a helpful tool which will aid in tackling future challenges for cultural heritage protectors. Combined with information and pictures in the minds of people that are provided by recent major floods in the Wachau area, the WebGIS tool has huge potential to raise the awareness of policy and decision makers an all levels that action is necessary, also on the level of the cultural landscape in general, including cultural and natural heritage that makes the Wachau region so very special and is the Outstanding Universal Value for which it received the status of UNESCO World Heritage.