Deliverable Phase 1 – Climate risk assessment

CliMAaXImal COntribution to building the resilience of the ZilinA region (MAXICONZA)

Slovakia, Žilina Region

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HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

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Abbreviations and acronyms

Abbreviation / acronym	Description
CA	Copernicus Atlas
CAP	Common Agriculture Policy
CDS	Copernicus Data Store
CRA	Climate Risk Assessment
CSDP	Concept of Spatial Development of Slovakia
EEA	European Environment Agency
ESIF	European Structural and Investment Funds
EU	European Union
GCM	Global Climate Model
GIS	Geographic Information System
IEP	The Institute for Environmental Policy
LST	Land Surface Temperature
MESR	Ministry of the Environment of the Slovak Republic
NGO	Non-Governmental Organization
OS ZZS	*"Operačné stredisko záchrannej zdravotnej služby"* (Operational Center of the Emergency Medical Service of the Slovak Republic)
PESD 21+	Programme of Economic and Social Development 21+
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RP	Return period
SHMU	*"Slovenský hydrometeorologický ústav"* (Slovak Hydro-Meteorological Institute)
STU	*Slovak Univesity of Technology in Bratislava*
UHI	Urban Heat Island
ŽSK	*"Žilinský samosprávny kraj"* (Žilina Self-Governing Region)

Executive summary

This deliverable provides the overall 1st phase outcomes of the project *CliMAaXImal COntribution to building the resilience of the ZilinA region*, during which the CLIMAAX common methodology for multi-risk assessment has been implemented in the Žilina Self-Governing Region (ŽSK), Slovakia. The project aims to fill the gap in scientific data on local risk assessment so that ŽSK can improve the decision-making process in investments and strengthen regional resilience. The CLIMAAX framework, handbook, and toolbox have been utilized for extreme rainfalls and heatwaves that were identified as primary hazards, according to previous major extraordinary events that happened in the region. The hazards have been dealt with concerning tourism as a core industry, and with special attention to vulnerable groups. All relevant stakeholders, including public and national authorities, the private and NGO sectors, and academia and research institutions, have been involved in the climate risk assessment (CRA).

The CRA has come to several major conclusions:

- **extreme precipitation** events will return more frequently and with much higher intensity. The intensity will increase by 23% to 34% depending on return periods, which will shorten by 40% to 65% (for RCP 4.5 and 8.5). Most of the region is thus at major risk due to its mountainous surface.

- number of **heat waves** days will double or triple in the Žilina region (from 8 to 16-24 days annually). Vulnerable people, lacking experience with heat, will raise the pressure on medical interventions while infrastructure that is not adapted for heat waves will require a significant modernization input.

The 1st phase has also revealed several serious discrepancies that should be addressed, esp. insufficient and fragmented climate data and a lack of human and financial capacities on all levels of governance. The need to build a hazard impact database has emerged, which can help indicate areas most at risk.

According to the outputs, further steps are scheduled for the future development of the project. To fully utilize the CLIMAAX handbook and workflows, ŽSK has started to collect data to achieve more precise definitions of exposure and vulnerability and to identify shortcomings in workflows. As the 1st phase has brought attention to droughts and forest fires, these hazards will be further investigated during the next stage of the project.

1 Introduction

1.1 Background

Žilina Self-Governing Region (ŽSK) is a regional public administration body which, according to Act No. 539/2008 Coll., is responsible for the region's sustainable economic development and the preparation of regional strategies and policies. ZSK manages 114 organizations (57 secondary schools, 5 hospitals, 22 cultural facilities, 24 social services, and a road network). The Žilina Region is characterized by the highest annual rainfall in the Slovak Republic. As the unevenness of rainfall distribution during the year increases, so does the number of extreme rainfall events that negatively affect the Žilina Region, whether we are talking about flash floods, landslides, or intense water erosion activity. The Žilina Region is a mountainous, predominantly rural area. The rugged mountain relief significantly affects the road network. Villages in mountain valleys are often connected to larger urban settlements by only one road, and detours often cause long delays. This greatly impacts emergency response and access to health care. Road damage is one of the most significant impacts of extreme rainfall in the Žilina Region. This issue affects not only residents but also the region's visitors. Tourism is a crucial pillar of the local economy, with nearly 60% the Žilina Region designated as a protected area, making it one of Slovakia's most attractive tourist destinations. Famous spots such as Demänovská, Vrátna and Gaderská Valley are among the most visited in the country, drawing thousands of visitors annually. Extreme rainfall can severely disrupt tourism activities, leading to a decrease in visitor numbers.

1.2 Main objectives of the project

The main objective of the project is to enhance the resilience of the Žilina Region to selected climate hazards by applying the Climaax methodology to identify the most critical climate risks. Based on these findings, recommendations for adjusting regional investment and development policies, as well as recommendations for regional stakeholders on preparing adaptation solutions, will be developed through a participatory process. Before this project was implemented, no climate risk assessments were carried out in the Žilina region.

One of the important benefits of applying the Climaax Handbook for the ŽSK as a regional self-governing unit is participation in the climate risk assessment process itself. Although regional government does not and will never have the same level of expertise as is common in university or scientific circles, it must achieve a certain level of understanding of how climate risks are assessed and what results can be expected in order to properly address adaptation. By using the Climaax Handbook in collaboration with expert partners (Straton, a group of experts) to solve real cases, internal institutional knowledge is created that could not be gained by simply reading the methodology. This is one of the most significant but as yet unidentified benefits of the project for the proper direction of the region's adaptation in the future, e.g., for the best possible setting of public procurement conditions for the preparation of a regional adaptation strategy, which the ŽSK plans to launch after the completion of the Maxiconza project.

With regard to the expected benefits of applying the Climaax Handbook in relation to the assessed hazards, it can be said that:

A. for extreme rainfall:

Based on the assessment of this hazard, awareness arose of the need to build a database of extreme events in which infrastructure was damaged as a result of extreme precipitation. This database will be key to identifying the most vulnerable locations and will allow us to set a threshold value for them, i.e., the amount of precipitation that will cause damage to infrastructure. By applying the workflow for extreme precipitation, we will then be able to determine how much more intense or frequent this precipitation will be, which can be communicated very well to the general public (municipalities, businesses, population). There is an effort to define indicators that would reflect the sensitivity of these systems, and subsequently collect data for these indicators and, based on their structure or details, create a sensitivity scale for each indicator. Thanks to the Climaax Handbook, the most critical areas prone to the negative effects of extreme precipitation will be identified, which will be useful both for prioritizing investments by the ŽSK, and for other stakeholders responsible for the infrastructure management.

B. for heat waves:

By applying this workflow, the most overheated areas within larger cities will be identified, which will be combined with information about the occurrence of vulnerable populations and critical infrastructure. Thanks to the application of the workflow, it will be possible to say how much more frequently heat waves will occur in Žilina region and thus point out the need to address this hazard, as it has not been such a significant problem in this territory so far. The information will be particularly helpful to larger cities for which UHI has been assessed, especially in terms of spatial planning, such as identifying suitable locations for the application of blue-green infrastructure or establishing zoning regulations for new construction.

1.3 Project team

The project team consists of members of the ŽSK team, who hold the leading role in project coordination and planning. Straton Technologies provides technical and methodological support. To ensure the overall quality of results, an external expert group from leading Slovak environmental and ecological organizations and institutions has been engaged.

ŽSK team (overall lead): *Dana Gavalierová and Lucia Lašová (Department of the Regional Development):* project management, coordination of project activities and project administration, collaboration on project results, and utilization of knowledge from previous ŽSK activities in this area.

Straton Technologies (technical and methodological support): Straton Technologies is a pioneering tech startup founded by a team of aerospace enthusiasts at the University of Žilina. Its mission is to push the boundaries of high-altitude exploration and unmanned aerial systems, delivering innovative products and services that support advanced research, environmental monitoring, climate data collection, technology testing, and specialized UAV solutions.

The Expert group (overall results quality and feedback): The expert group includes representatives of the scientific community, regional development, local municipalities, NGOs, tourism organizations, experts in urban and landscape planning, as well as experts in climate change adaptation.

Table 1-1 List of experts

Name and surname	*Area of activity/ expertise*	*Institution*	*Sector*	*Operating level*
Milan Sarvaš	Slovak universities / the scientific community	National Forest Centre	public	national
Michaela Danáčová		Slovak University of Technology	public	national

Martina Paulíková	environmental non-governmental organization	WWF Slovakia	third	national
Ján Husák		Drop of Rajecká Valley	third	local
Ján Pavlík	local municipality	town of Ružomberok	public	local
Juraj Krumpolec	urban planning	AŽ PROJEKT s.r.o.	private	regional
Radim Misiaček	regional development, tourism sector	RADDIT consulting s.r.o.	private	regional
Gabriela Šimčíková	tourism organizations	Regional Tourism Board	public	regional
Zuzana Hudeková	landscape planning, adaptation to climate change	REC Bratislava	third	Regional

1.4 Outline of the document's structure

This document is composed of the following parts. An introduction describes project background, main objectives, team included as well as regional context. The core of the deliverable is focused on respective climate risk assessment, depicting scoping, analyses, and preliminary findings of extreme rainfall and heatwave workflows. The final parts of the document provide conclusions of the entire process, progress evaluation and outline further steps to be done in further stages of the project.

2 Climate risk assessment – phase 1

2.1 Scoping

2.1.1 Objectives

The CRA focused on two hazards in the Žilina region: extreme precipitation and its risks for tourism and the road network, and heatwaves with emphasis on the most at-risk areas. The results will inform regional policies such as the spatial plan (currently in preparation), investment planning for roads and social facilities, regional strategies, project development, and a future adaptation strategy. Broader recommendations will also address updates of emergency plans in cooperation with state civil protection authorities to better protect vulnerable groups.

For extreme rainfall, the goal is to identify areas most prone to flash floods and landslides, assess vulnerable infrastructure (mainly roads and tourism facilities), and analyse overlaps between hazard-prone areas and infrastructure. A hazard impact database, both tabular and spatial, is being developed, though data collection is complicated in Slovakia due to fragmented sources and inconsistent formats. Precipitation data from the SHMU must also be purchased, which is costly and time-consuming. Data already collected from freely available reports and news show high uncertainties in climate projections, where neighbouring pixels may give contradictory results. These can be reduced by applying zonal statistics for the region.

For heatwaves, the aim is to map overheated areas, vulnerable populations, and critical infrastructure, using climate scenarios for the coming decades. A key limitation is vulnerability and exposure data: WorldPop provides only static information on population distribution, without insight into actual presence during heatwaves or building conditions (e.g. insulation, cooling). Supplementary data will be obtained from pilot cities, but since this workflow only works at the city level, results cannot be scaled to the regional level, limiting their usability for ŽSK planning.

2.1.2 Context

Decision-makers in ŽSK recognise the need to adapt to climate change and have anchored political commitment in the *Framework Plan for Increasing the Resilience of ŽSK to Climate Change* (2024) and the *Programme of Economic and Social Development 21+,* where adaptation is among the key environmental objectives. However, no comprehensive climate risk assessment has yet been carried out. Knowledge about vulnerabilities remains fragmented, based mainly on partial studies (e.g. flood and erosion risks in selected basins, forest cover change), which cover only small parts of the region. At the national level, the *National Adaptation Strategy* (non-binding for regions) and the *Concept of Spatial Development of Slovakia* (binding) provide the framework, but adaptation regulations remain vague due to the absence of regional CRAs.

The project addresses this gap by analysing extreme precipitation and heatwaves. Heavy rainfall repeatedly triggers landslides and flash floods that damage roads and tourism infrastructure in mountain valleys, where many municipalities and resorts rely on a single access road. This creates serious accessibility and emergency response challenges, while also straining already limited regional road budgets. Heatwaves are an emerging hazard, with growing impacts on vulnerable groups, especially in 24 regional social service facilities housing over 3,300 people, most of which are in old, poorly adapted buildings (ŽSK, 2025).

ŽSK's economy is dominated by the automotive industry, but other important sectors include forestry, tourism, food and beverage production, construction and paper manufacturing. Forestry, covering more than 50% of the territory, is collapsing due to drought, bark beetle outbreaks and declining ecological stability. Tourism, with 1.3 million annual visitors (Regional Tourism Board, 2023), suffers from unreliable snow cover in ski resorts and infrastructure damage caused by extreme rainfall. Food production, closely tied to agriculture, is highly sensitive to changing precipitation patterns. Water scarcity is emerging as a cross-sectoral risk, threatening industries dependent on stable supplies, such as automotive and beverage production.

ŽSK is part of the EU Mission on Adaptation to Climate Change, which enables access to European best practices and peer exchange. At national level, it also participates in a bottom-up community of practice under the CLIMAAX project, where Slovak regions and cities support each other in developing CRAs. This involvement helps ŽSK to address key risks such as extreme rainfall and heatwaves more effectively. Possible adaptation measures include identifying the most at-risk hotspots, mapping the adaptation potential of public premises, prioritising investments in vulnerable facilities (especially social services), revising road reconstruction and maintenance standards for greater resilience, and integrating CRA results into the regional spatial plan, strategic documents and emergency planning.

2.1.3. Participation and risk ownership

In Phase 1 of the project, communication with multiple stakeholders was initiated (for more detailed information, see Attachment no. 1). An expert group was established, bringing together institutions from different sectors and levels of governance. The group supports the project by helping identify and collect relevant data and by contributing to the methodological development of workflows (e.g., definition of sensitivity indicators). A second important group consists of institutions that hold key datasets, such as information on emergency events, interventions by rescue services, or infrastructure damage caused by extreme weather. These stakeholders are approached directly with specific requests. They include mainly public and state administration bodies, as well as infrastructure management institutions. Along with NGOs, the private sector, and universities engaged in climate change issues, these groups are also the primary target audiences for the dissemination of project results. Outputs from the first phase were presented at a national workshop on the revision of the Slovak Adaptation Strategy. By the end of the project, five regional workshops are planned across the five sub-regions of ŽSK. Dissemination channels also include ŽSK's social media profiles, the regional website, press releases, and the Open Data portal.

Depending on the hazard, the CRA focuses on various vulnerable groups. This list is provided in Section 2.2.2. As the Žilina region is aging and rural, the CRA is targeting mainly elderly people living in remote areas. Mainly those who live in single-person households or low-income households and often have health complications or limited mobility.

Flood risk from extreme precipitation is regulated mainly at the state and municipal level: the Water Management Authority oversees watercourses, municipalities prepare local protection and emergency plans, and SHMÚ provides warnings. Landslide risk is less clearly assigned and often fragmented between municipalities and road administrators. For heatwaves, risk ownership is weakly regulated: the Ministry of Health may issue recommendations, but no legal obligations exist for municipalities or regions. In ŽSK, adaptation in social service facilities depends largely on resources and projects, not regulation.

There is currently no formally defined “acceptable” level of climate risk in the region. The approach is reactive, addressing impacts once they occur, which underlines the importance of developing a comprehensive CRA to support proactive adaptation.

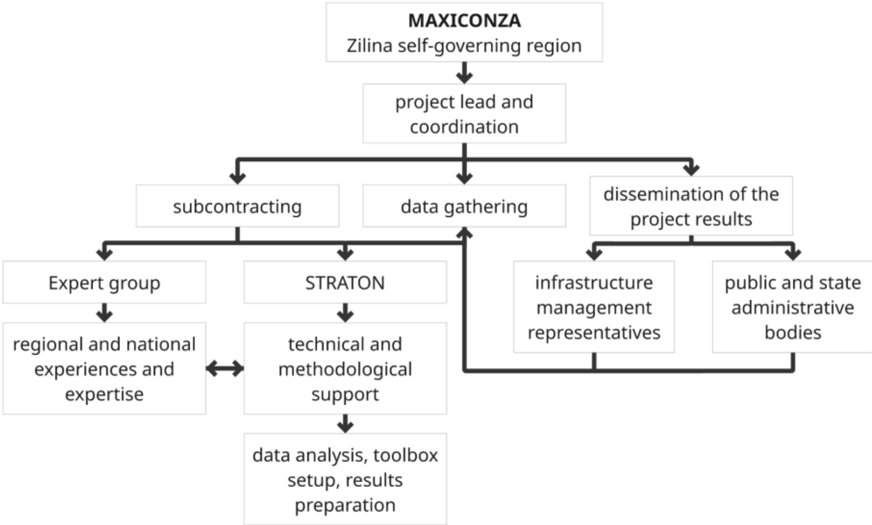

Figure 2-1 Organigram depicted involved stakeholders and their roles in the projects

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

By 2050, the SHMU scenarios project a sharp rise in summer and tropical days, with heatwaves starting as early as May and lasting until mid-September. Such events, similar to those in 2003, 2007, or 2015, are expected 3–5 times more often. The frequency of sultry days and dry springs will increase, while precipitation patterns will shift toward more variability: longer dry periods alternating with shorter but more intense rainfall. Under RCP8.5, rainfall intensity may grow by up to +25–35% by 2100, accompanied by stronger storms, wind gusts (+20–80%) and hail up to 5 cm (+40–150%).

ZSK has already faced dozens of flash floods in recent years (see tab. 2.3 or sec.2.4.1), typically alternating with soil drought, which often among the worst in Slovakia, as indicated by the Intersucho Drought Observation Service. Rising summer temperatures and prolonged heatwaves have strained infrastructure and public health, while drought and heat have also raised wildfire risks.

According to the Copernicus Climate Atlas, under SSP2-4.5 (2041–2060) mean daily temperature will rise by 1.6 °C, with 3.3 extreme hot days (>35 °C) per year. One-day maximum precipitation will increase by 2.7 mm/day (up to +6.2 mm/day at 95th percentile), with 0.6 additional very heavy rain days (>20 mm/day) annually. Drought risk will rise modestly, with up to +4.2 consecutive dry days per year at the upper end of projections.

For this CRA, ZSK selected extreme rainfall and heatwaves. The region’s mountainous terrain makes it highly prone to flash floods and landslides, which have already caused major infrastructure damage and economic losses. Heatwaves were chosen because, although ZSK is Slovakia’s coldest region, hot summers are becoming more frequent. With Europe warming twice as fast as the global average (EEA, 2024), and Slovakia already over +2 °C (SHMU, 2023), this hazard is expected to intensify.

Climate projections are mainly based on SHMU national datasets, which are not georeferenced and unsuitable for GIS workflows. To support regional planning, data need to be provided in standard spatial formats (.tif, .shp). The CLIMAAX Toolbox offers EU-wide climate layers but uses generalized or outdated exposure and vulnerability data. Therefore, the next project phase will prioritize collecting local datasets for ZSK to refine hazard, exposure, and vulnerability assessments.

2.2.2 Workflow selection

2.2.2.1 Workflow #1 Extreme precipitation

This workflow should consider the following exposed areas: critical infrastructure in flood-prone areas, including roads, railways, urban areas, housing, public buildings, and settlements near streams, rivers, or steep slopes. The following vulnerable groups should be considered: seniors (65+) in remote areas with limited transport accessibility and limited mobility, low-income individuals, individuals living alone, and marginalized communities.

2.2.2.2 Workflow #2 Heatwaves

This workflow should consider the following exposed areas: urban built-up areas with high population density, low vegetation cover, high proportion of impermeable surfaces, old buildings, and limited access to cooling infrastructure (e.g., green spaces, water features). The following vulnerable groups should be considered: people aged 65+, children under 5, people with chronic illnesses, low-income individuals, individuals living alone, and marginalized communities.

2.2.3 Choose Scenario

The scenario horizon 2041–2070 was selected to reflect the long lead time needed for regional adaptation and the fact that climate impacts often occur earlier than projected. This ensures that planned measures remain effective even under accelerated climate change. The chosen period also coincides with socio-economic pressures such as aging population, rising energy costs, and growing demands on infrastructure and social services, which may further amplify climate risks.

The scenarios available for heatwaves and extreme rainfall are derived from Euro-CORDEX data (CDS CORDEX, 2019) at a 12 × 12 km resolution, with heatwave projections additionally informed by EuroHEAT (CDS Heat Waves, 2019). Both workflows currently provide results only at the regional scale. For effective and well-targeted adaptation planning, however, more detailed assessments are required.

In the heatwave workflow, more detail is available at the municipal level, but the evaluation covers only four cities. This leaves large parts of the region without information, even though more comprehensive data on the development of extreme temperatures across the ŽSK was expected. Similarly, the extreme rainfall workflow relies on the hazard impact database, which identifies only point-based risks. As a result, it does not deliver a comprehensive picture of extreme rainfall risk across the ŽSK that is needed for adaptation planning.

2.3 Risk Analysis

2.3.1 Workflow #1Extreme precipitation

Table 2-1 Data overview workflow #1

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
EURO-CORDEX climate projections for *precipitation flux* (*CDS, Cordex*)	Flash flood analysis of the 3 catchments in the ŽSK region (prepared with the cooperation with	Exposure specified in hazard impact database (CLIMAAX, workflow)	*Relative change of frequency and magnitude to baseline*

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
	STU will be used in 2nd Phase)		*(1976-2005), 24h in 2041-2070*
Climate adapt climate projections. (CLIMAAX, handbook)	Vulnerability specified within the hazard impact database (CLIMAAX, workflow)	Flash flood occurrence reports from local sources. (imeteo, SHMU flood reports etc.)	Hazard impact database (CLIMAAX workflow)
SHMU climate scenario predictions (*Future climate scenarios, SHMU*)			
Expected precipitation for 3h event for 2041-2070 period in Zilina. (CLIMAAX workflow)			
Expected precipitation for 24h event for 10, 25, 50, 100–year return period (CLIMAAX worklflow)			
Relative change to baseline (1976-2005), 24h for 10, 25, 50, 100-year return period			

2.3.1.1 Hazard assessment

For the hazard assessment, the heavy rainfall workflow based on Euro-CORDEX data was selected. This workflow produced results showing projected changes in heavy precipitation for selected return periods. The combination of GCM *mpi_m_mpi_esm_lr* and RCM *knmi_racmo22e* was used under the RCP 8.5 scenario. The decision to use the more pessimistic RCP 8.5 pathway was intentional. It reflects the aim of using the results as a warning signal—to raise awareness among stakeholders and the general public about the potential severity of future climate impacts. In this first phase (out of three planned project phases), the goal is not to predict a worst-case scenario, but rather to encourage proactive adaptation and preparedness in response to increasing risks. The initial results clearly indicate a projected shift in the frequency and intensity of heavy precipitation events in the ŽSK region. However, it is acknowledged that uncertainties related to spatial resolution can significantly affect the results. Some pixels within the region show a decrease in precipitation intensity, while others indicate a significant increase. On average, however, the region shows a general upward trend.

These uncertainties were considered in the interpretation of results, but the core message remains clear: heavy rainfall events are projected to become more frequent and/or more intense. To help reduce these uncertainties, particular attention was paid to 24-hour events, for which bias-corrected data were available.

Firstly, a graph of the mean precipitation for 24-hour duration events was produced (Figure 2-2). This graph provides a visual comparison of the projected shift based on the selected model and the RCP 8.5 scenario.

Figure 2-2 Mean precipitation for 24 duration events over ŽSK for reference period 1976-2005 and projected period 2041-2070 RCP 8.5

Subsequently, the workflow continued with the production of maps showing the relative change from the baseline period 1976–2005 for 10-, 25-, 50-, and 100-year return periods of 24-hour heavy rainfall events in the projected period 2041–2070 (Figure 2-3, for 50 RP and others are uploaded on Zenodo). These results indicate a significant increase in the magnitude of projected heavy rainfall events. The outcomes of the hazard assessment served an informative role during the MAXICONZA expert group meeting and were considered a solid foundation for future heavy rainfall analyses.

However, while the results can inform improvements in local and regional urban planning, the provided data resolution and level of uncertainty limit their direct applicability within the ŽSK region. Therefore, the expert group will focus primarily on assessing local vulnerability, exposure, and risk in the next phases of the project.

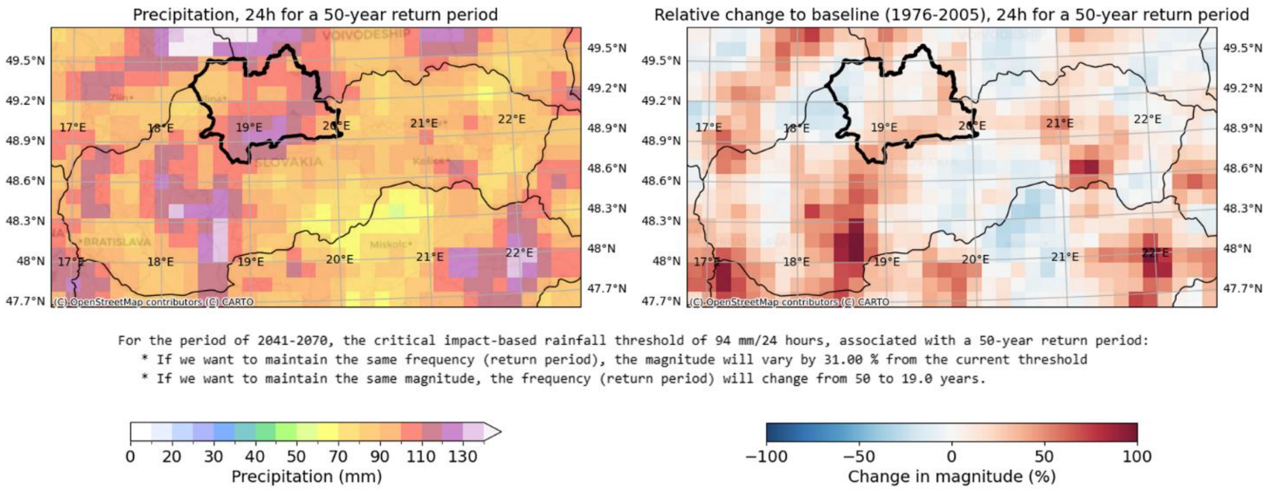

Figure 2-3 Extreme precipitation for the 24h event for 50-year return period (on the left), and relative change to baseline 1976-2005 of the magnitude for the period 2041-2070 (on the right).

2.3.1.2 Risk assessment

The risk assessment workflow provided more localized inputs and outputs than the hazard assessment. It builds on the results of the hazard assessment and incorporates local knowledge and experience. During the processing of the risk assessment workflow, the ŽSK team and the MAXICONZA group of experts identified missing elements in the ŽSK climate adaptation plans. In the next phases, they will aim to localize the most vulnerable areas to heavy rainfall events, as well as the potential causes of these problems in specific locations.

The workflow begins with the preparation of a hazard impact-based database for heavy rainfall events and their impacts in the ŽSK region. Since the ŽSK office does not maintain this type of database or a register of past heavy rainfall events, the database was compiled using publicly available sources (such as SHMU flood reports, academic papers, and online sources such as imeteo), along with the experience of the expert group. In total, more than 20 heavy rainfall events from the past 20 years were collected, with 16 of them including information on recorded rainfall accumulation (Table 2-3). Based on the hazard assessment results, return periods were also added to the database.

Additional information, such as general descriptions, risk to people, damage to buildings, and disruption of transport, was documented in detail along with the corresponding sources. The final assessment of impact severity was conducted collaboratively by the expert group.

For the evaluation of the workflow results, the table of the warning levels against the heavy rainfall events based on the last heavy precipitation event in ŽSK was prepared. The thresholds estimated from hazard impact database in CLIMAAX were close to the 3-point scale thresholds provided by SHMU.

Table 2-2 Hazard impact database based on the Extreme rainfall collected data in the ŽSK, only the first 4 events are displayed here (the whole table was uploaded to Zenodo), in total 21 events were collected from which 16 have the information about registered 24h accumulation

Date	Accumulations registered (mm/hrs)	Return periods associated	General description	Risk to people	Damage to buildings	Disruption of transport	Others or Comments	Impact severity scale
21.7.2014 (Vratna)	**100 mm/24h**	**T 65**	A slow-moving convective storm dropped ~90–100 mm of rain in under 2 hours, triggering a rock–debris avalanche.	High risk – ~200 tourists trapped in mountain huts; 122 people evacuated, including children and pregnant women.	Massive damage – debris flows buried 40+ cars, destroyed roads, and heavily damaged the Vrátna cottage and cable car infrastructure.	Complete loss of access – main access road destroyed over ~5 km; cable car service disabled; rescue teams deployed.	Emergency state declared; 100+ firefighters and mountain rescuers involved; ~100,000 m^3 of debris released; cleanup cost in millions of €; state financial aid allocated.	High impact (3)
17-19.5.2021(BY, CA KM, LM, MT, RK)	**60 mm/24h**	**T 19**	Persistent heavy rainfall (40–60 mm/day) across multiple basins; repeated flash-flood alerts at Level 3	Moderate – high river/stream levels, flow surges risk for people, some evacuations possible	Some basements/garages flooded; minor structural damage likely	Local road/bridge flooding; temporary closures likely	Fire/rescue crews pumped water; local authorities issued flash-flood warnings; no mass evacuations reported	Medium impact (2)
6.8.2021 (Tvrdosin)	**50 mm/24h**	**T 5**	Heavy storm + sustained rain saturated basin, triggered Oravica's 3rd-level flood alert (flow ~20-year return)	High – flash-flood risk from Oravica, rising waters threatened inhabitants and through traffic routes	No major structural damage in town reported, but potential water/groundwater intrusion in basements	Local roads near stream obstructed or flooded; emergency response required	Trstená's Oravica hit 3rd-level flood; mayor declared alert at 11:00; 126.7 m^3/s Qmax (~20-yr flood); peak water height ~349 cm	Low impact (1)

In the final local impact-based database, the heavy rainfall threshold ranges were estimated. To achieve better results, it will be necessary to collect more data on heavy rainfall events. The MAXICONZA team is currently working on gathering all recorded heavy rainfall events from all available sources (both free and paid), with the goal of preparing a hazard impact database not only in tabular form but also in map format. This will support decision-making on financing and help identify the most urgent areas as well as appropriate heavy rainfall thresholds for different parts of the region.

The estimated extreme rainfall threshold, derived using the hazard impact database and the CLIMAAX methodology, was compared with the warning level thresholds provided by SHMU for the extreme rainfall event in the ŽSK region on July 8–9, 2025. It is important to note that these threshold levels changed between July 8 and July 9, which is understandable given that the soil layers had become saturated and could no longer absorb additional water.

The comparison of CLIMAAX-based thresholds (Table 2-4) with those from SHMU (Table 2-5) shows that they yield similar values. However, the threshold levels from both sources align more closely with the values observed on the second day of the extreme rainfall event.

Table 2-3 Estimated Extreme rainfall thresholds based on the hazard impact database.

Location	***Low impact***		***Medium impact***		***High impact***	
ŽSK	Impact	*Thresholdmm/24h*	Impact	*Thresholdmm/24h*	Impact	*Thresholdmm/24h*
	Small and isolated flooding of lands and flood prone areas	***30-60***	*Localized flooding of lands and roads causing possible danger to life due to fast flowing water and overtopping. Disruption of travel time is expected*	***56-76***	*Widespread flooding of lands and roads is causing danger to life due to fast flowing water and overtopping. Evacuations and rescue actions may be required*	***80-100***

SHMU thresholds are only made visible during ongoing extreme rainfall events on SHMU website. Therefore, it was a coincidence that such an event occurred during the MAXICONZA project, offering a rare opportunity to observe the SHMU thresholds in real time (Table 2-5). Since these values are dynamic and not freely available, historical threshold information—along with corresponding return period estimates—must be purchased from SHMU.

Nevertheless, it is encouraging to see that the CLIMAAX warning levels, which are based on freely available informations from online sources, are comparable to those provided by SHMU.

Table 2-4 Extreme rainfall warning level thresholds by SHMU from 8.-9. of July 2025 in ŽSK

Extreme rainfall event warning levels by SHMU from 8-9.7.2025			
Level warning 1	***Level warning 2***	***Level warning 3***	***Date***
70 mm/24h	90 mm/24h	130 mm/24h	8.7.2025
50 mm/24h	75 mm/24h	130 mm/24h	9.7.2025

Within the risk assessment workflow, a table showing the relative change in frequency and magnitude compared to the baseline was prepared (Table 2-6). The results indicate a substantial shift in projected intensity and frequency. These projections suggest that heavy rainfall events in the ŽSK region will pose a serious threat in the future.

Table 2-5 Relative change of the frequency and magnitude to baseline 1976-2005 for 24h Extreme rainfall in 2041-2070

Relative change of frequency and magnitude to baseline (1976-2005), 24h in 2041-2070		
Return period	*Intensity (magnitude)*	*Frequency*
10 years RP	From 61 to **75 mm/24h**	From 10 to **6 years**
25 years RP	From 78 to **99 mm/24h**	From 25 to **11 years**
50 years RP	From 94 to **123 mm/24h**	From 50 to **19 years**
100 years RP	From 112 to **150 mm/24h**	From 100 to **35 years**

The extreme rainfall workflow also provides a method for incorporating potential climate change–driven changes in the return period of extreme rainfall into maps. However, return period maps must first be available. In Slovakia, the official return period maps are provided by SHMU, but they are not publicly accessible in a GIS-usable format, as they are only available as images. These maps are planned to be obtained from SHMU and used in the second phase of the project.

2.3.2 Workflow #2 Heatwave

Table 2-6 Data overview workflow #2

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
Heat days occurrence EuroHEAT RCP 4.5 and 8.5 (CDS Heat days, 2019)	Distribution of the vulnerable population (WorldPop)	Heat exposure areas with the identification of the most exposed areas (RSLab; CLIMAAX Heatwave workflow)	Heat risk to vulnerable population maps (CLIMAAX, Heatwave workflow)
Copernicus Interactive climate atlas (CA)	Places with the potential to be overcrowded during the hot summer days (shopping centres, industrial zones, railway station, residental zones)		
SHMU climate reports (*Future climate scenarios, SHMU*)			
LST maps (RSLab)			
Heat days occurrence relative change zonal statistic for Slovakian region (CLIMAAX workflow)			

2.3.2.1 Hazard assessment

This workflow starts with downloading EuroHEAT data from the Copernicus Climate Data Store (CDS). The data on projected occurrence of heatwave days are based on the ensemble mean of multiple climate models, which helps to reduce the level of uncertainty. Since the workflow relies on selecting specific points for extracting projected data to prepare the final graph, we selected the four largest cities in the ŽSK region to highlight potential differences in the results. The selection was based on cities with a population greater than 25,000 (Figure 2-4), as smaller cities generally do not have extensive built-up areas that could potentially form larger heat islands. The results of the heatwave days occurrence for years 1986-2085 for Martin city are displayed on Figure (2-5), graphs for other 3 cities are uploaded to Zendo.

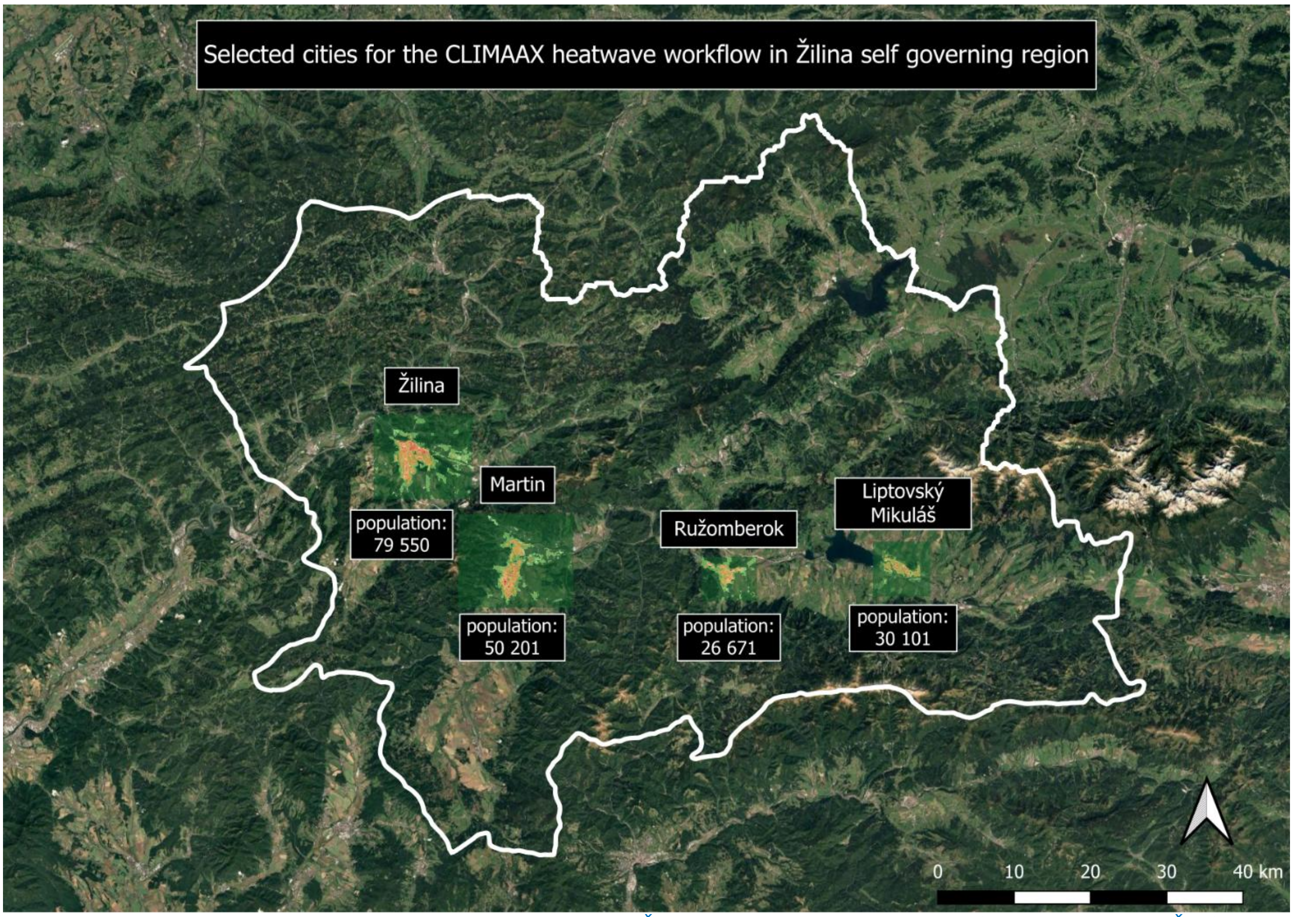

Figure 2-4 Cities selected for the heatwave risk analysis from ŽSK with the number of citizens (4 biggest cities in ŽSK)

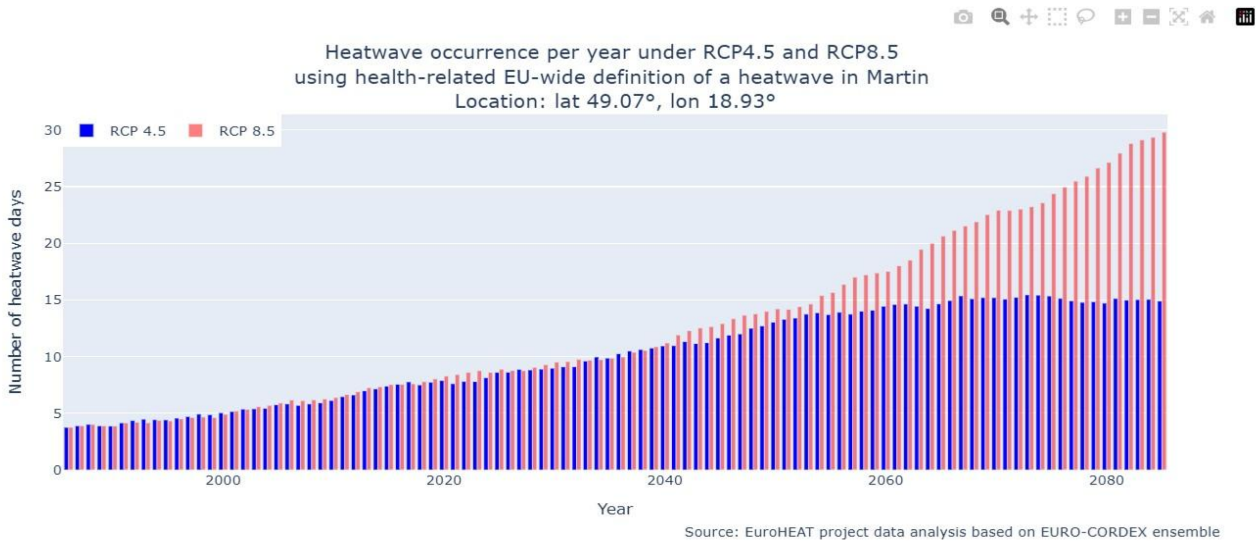

Figure 2-5 Heatwave days occurrence per year under the RCP 4.5 and 8.5 using health related EU-wide definition of a heatwave for Martin city.

To provide better visual support for interpreting the results, a map of the relative change in the ŽSK region was prepared for the projected period 2041–2070 under the RCP 4.5 and RCP 8.5 scenarios (figures uploded to Zenodo as *rel_change_rcp45 and rcp85*). The magnitude of the relative change across Slovakia ranges from 289% to 338% for RCP 8.5, and from 200% to 228% for RCP 4.5.

2.3.2.2 Risk assessment

The risk assessment workflow, based on observed remote sensing data and available vulnerable population data from WorldPop was also prepared for selected cities in the ŽSK with populations over 25,000. For the representation of the workflow results, the city of Martin was selected, results for other cities are uploaded on Zenodo.

Initially, the original version of the workflow was used. After exploring the initial results, the workflow was slightly updated for application in the ŽSK. The structure and technical setup of the workflow allowed for easy modifications and updates.

The LST classification was simplified from the original 10 classes to 5 groups based on temperature thresholds (Figure 2-6). The classification of vulnerable population groups was adjusted accordingly to match the same 5 interval groups. The final map of *Possible Heat Risk to Vulnerable Population* was then calculated using a 5×5 risk matrix instead of the original 10×10. Since the selected cities in the ŽSK are relatively small compared to larger European cities, the 5×5 classification was suitable, as the urban structure is less diversified. The selected temperature classes are displayed on the Figure 2-6.

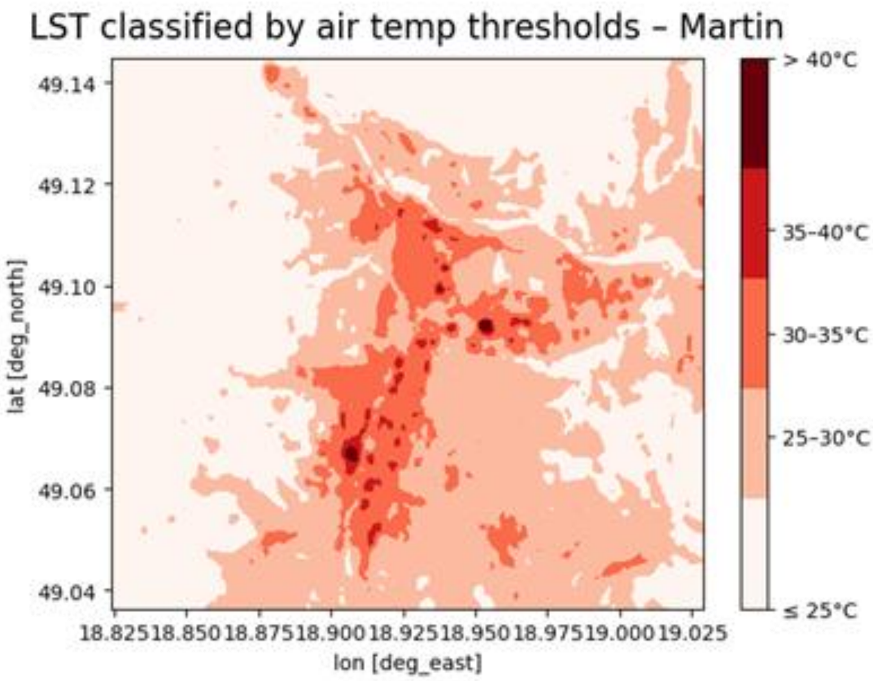

Figure 2-6 Median of LST for summer months 2013-2014 based on the available Landsat8 pictures form RSLab in Martin City

The workflow continues by combining the classified data with the risk matrix. The classified layers for Land Surface Temperature (LST) – representing overheated areas – and the density of vulnerable populations are shown in Figure 2-7. LST was categorized based on predefined temperature thresholds, while the vulnerable population data represent the number of people aged over 65 and under 5 years per 100 × 100 m pixel, based on data from the year 2020. The population values were divided into five equal intervals, calculated from the minimum and maximum values within the selected area.

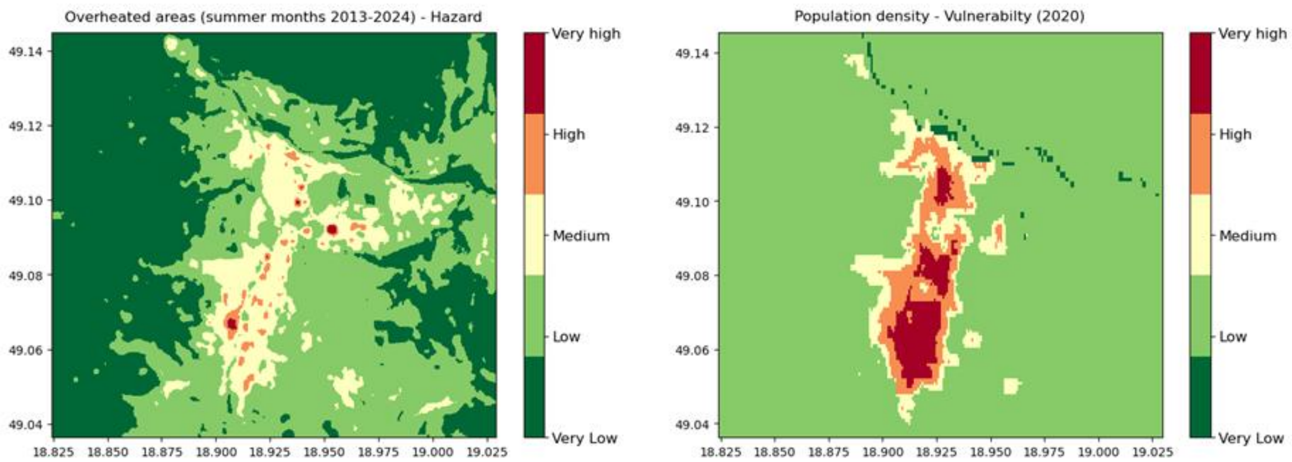

Figure 2-7 Map of the overheated areas based on the median of LST for summer months 2013-2014 based on the available Landsat8 pictures form RSLab classified to 5 risk classes (left) and map of the distribution of the vulnerable population based on the WoldPop data classified to 5 risk classes in Martin city

Since the goal of the ŽSK team was clear, they aimed to identify the most vulnerable areas—those most overheated during hot summer days. The map of heat distribution during the summer months proved to be a valuable output. These maps were prepared for the four largest cities in the ŽSK, with the goal of highlighting the most overheated parts and identifying the functional zones within the cities (Figure 2-8).

In preparing the final maps, median LST values were used instead of the original maximum values. This decision was based on the observation that the selected cities are surrounded by agricultural areas, which often form small, temporary heat islands after crop harvesting. Since the focus is on urban heat islands, these peripheral agricultural hotspots introduced distortions in the original maps and complicated their interpretation. Figure 2-8 displays the most overheated areas based on median LST values, with highlighted functional city zones located within these hotspot regions. To enhance visual interpretation, the highlighted areas were selected based on LST values exceeding 35 °C, corresponding to the classes High (35–40 °C) and Very High (>40 °C).

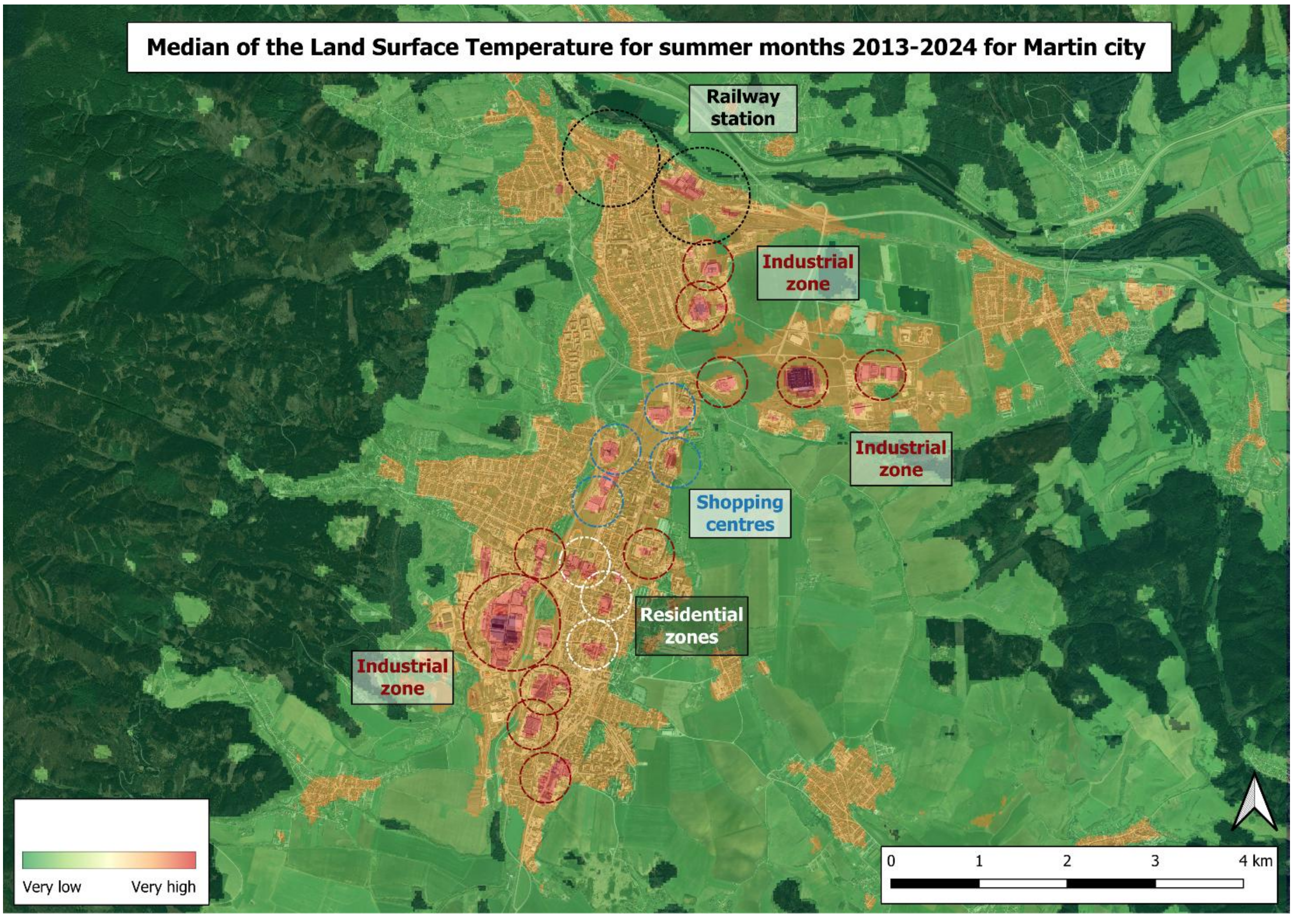

Figure 2-8 Median LST for the summer months of 2013–2024 in the city of Martin, with highlighted areas where the median LST exceeds 35 °C, classified as High and Very High according to the overheating area classification (Figure 2-6)

The final heat risk map for vulnerable populations (Figure 2-9) highlights the most at-risk areas in a more nuanced way than a simple heat island map. By combining LST mapping with the distribution of vulnerable populations, some locations identified as overheated in the LST map were excluded due to low population density. Since the original 10×10 classification was revised to a 5×5 matrix, the final map's color classification was also adjusted to five equal intervals: **1–5 (very low), 6–10 (low), 11–15 (medium), 16–20 (high), and 21–25 (very high).**

The greatest potential for improving the heatwave risk results lies in integrating local knowledge of vulnerability into the risk assessment tool—for example, identifying locations with a high potential for the gathering of vulnerable population groups during hot summer days.

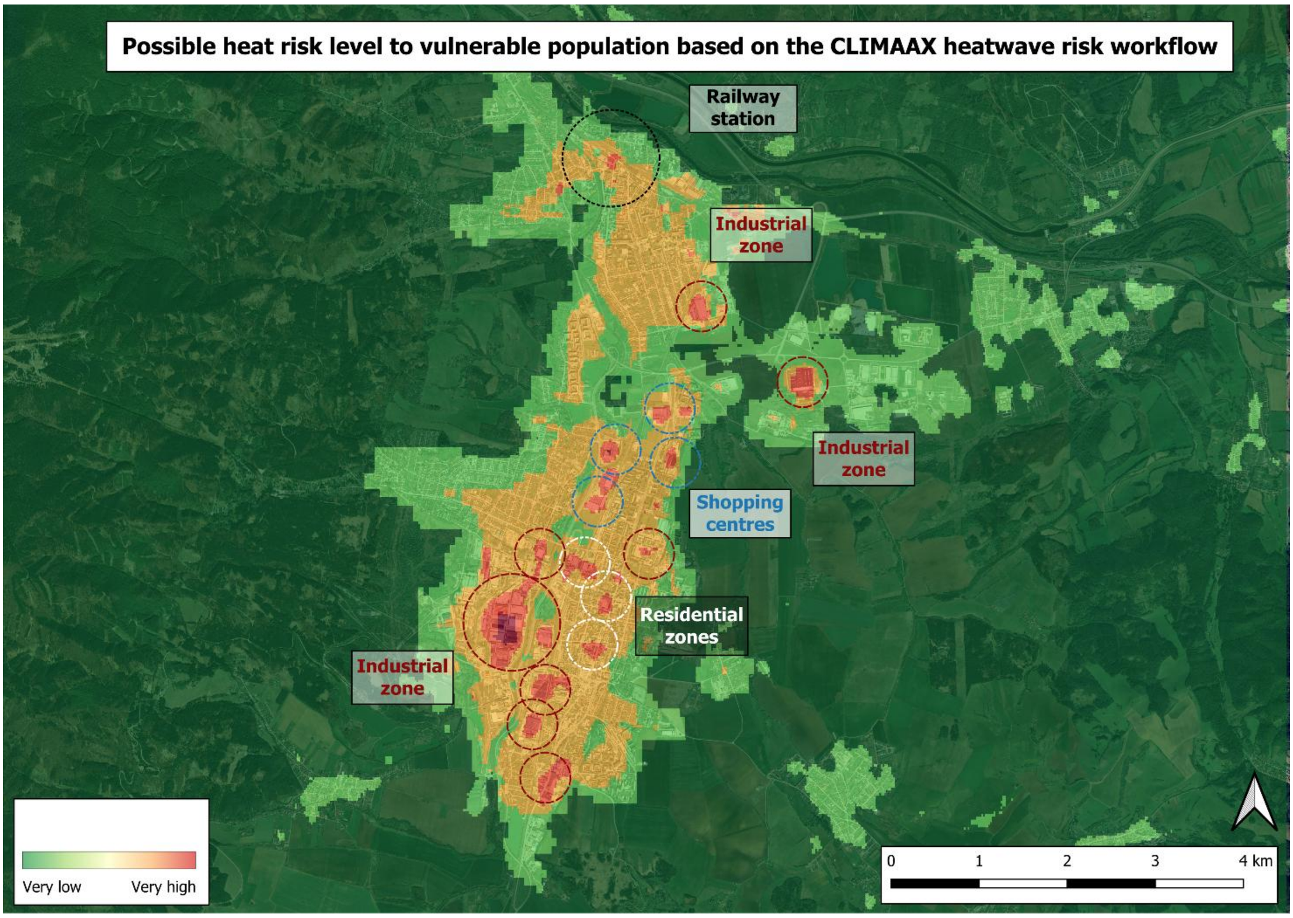

Figure 2-9 Map of the heat risk to vulnerable population over the Martin city based on the CLIMAAX heatwave workflow, the highlighted places are with High and Very high level of risk based on the heatwave risk workflow classification (Figure 2-6)

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The severity of climate hazards in ŽSK differs based on past experience. While the region has long faced serious impacts from extreme rainfall, heatwaves were not historically considered a problem. In recent summers, however, dozens of heat-related collapses requiring medical assistance or hospitalization have been reported, marking the emergence of a new trend. In 2025, ŽSK even recorded the highest number of heatwave-related interventions among all Slovak regions (teraz.sk, 2025). Projections from the heatwave workflow indicate a significant increase in the number of heatwave days in the coming decades. Combined with an aging population, this trend is expected to worsen and may unfortunately result in future loss of life. Since heatwaves in Slovakia are typically characterized by high temperatures and dry spells, they are also likely to intensify other challenges. With nearly 60% of ŽSK covered by forests, the risks of wildfires and droughts (both hydrological and soil) are expected to grow. A declining trend in groundwater availability is already evident, and during dry periods this translates into local water supply shortages for residents (mykysuce.sme.sk, 2025)

Regarding extreme rainfall, the hazard impact database for Phase 1 recorded a total of 3 high-impact, 8 medium-impact, and 9 low-impact events from publicly available sources. Hazard scenarios based on the CLIMAAX methodology point to a significant increase in both frequency and intensity of extreme rainfall in the region. These results are consistent with climate projections from SHMU. The problem extends beyond direct infrastructure damage: washed-out roads disrupt supply chains, affecting the regional economy, while contaminated drinking water sources or flooded waste sites can create serious public health risks. Increasingly intense rainfall also accelerates soil erosion. In agricultural landscapes this removes fertile topsoil, reducing productivity and yields, while on forest roads erosion often cuts through to bedrock, draining water from ecosystems and adding further stress to forest stands already weakened by rising temperatures.

2.4.2 Urgency

Both extreme rainfall and heatwaves are already affecting the Žilina Region, and both hazards are projected to become significantly more frequent and intense between 2041–2070, especially under high-emission scenarios. Results from the CLIMAAX workflows and official SHMU projections confirm that both will persist and intensify throughout the 21st century.

The urgency, however, differs. Extreme rainfall is a sudden hazard requiring immediate response. In 2024 alone, floods cost over €380,000 in emergency operations (MESR, 2025) and more than €2.1 million in damages (MESR, 2024). Projections suggest this burden will rise sharply: under RCP 8.5, a 10-year return period rainfall event is expected to increase in intensity from 61 mm/24h to 75 mm/24h (a 23% rise) or occur every 6 years instead of every 10. This increase in frequency and intensity indicates a clear shift from low- to medium-impact events. This trend is especially pronounced in a mountainous region such as the Žilina Region, where convective storms are projected to intensify.

Heatwaves, as previously noted, have only recently become a growing concern. Projections indicate that by 2041–2070, the number of heatwave days may increase by 200% under RCP 4.5 and nearly 300% under RCP 8.5. While dozens of medical interventions already occur each summer, their costs remain in the tens of thousands of euros—far below the millions associated with extreme rainfall events.

Adaptation measures for both hazards should begin now, but priority should be given to addressing extreme rainfall due to its immediate and severe impacts.

2.4.3 Capacity

ŽSK has begun developing climate risk management measures, though current capacities remain limited. Ongoing work focuses on knowledge building, analysis, and awareness-raising. Two specific analyses on flood and erosion risks, as well as forest cover change, have been developed to deal with the affected parts of the region. The ongoing assessment of the region's hydrological vulnerability will inform the development of binding land use regulations in the new regional spatial plan. This analysis will also provide key information on the country's exposure and vulnerability to droughts and floods, which will inform the region's future adaptation strategy, scheduled for completion by the end of 2027. ŽSK is also involved in several Horizon Europe projects to contribute to improving climate resilience, e.g., RETIME (climate-resilient building solutions for vulnerable populations), JUSTSAFE (just and inclusive strategy for enhancing climate resilience), GRACE (nature-based solutions for water retention in rural landscapes, to be launched on the 1st of October 2025).

Financial capacity relies mainly on EU funds (ESIF, CAP), as regional and municipal budgets are very limited. It is important to note that self-governing regions issue statements on whether ESIF applications align with their adaptation strategy. However, this criterion does not apply in the absence of such a strategy. Human capacity is insufficient, especially in small municipalities. ŽSK currently employs two staff on adaptation but highlights the need for a dedicated coordination unit. Physical capacity (forecasting, civil protection) lies with state authorities, while ŽSK focuses on stakeholders coordination and awareness (workshops, conferences, publicly available datasets). Social capacity is fostered through participatory processes and inclusion of vulnerable groups. ŽSK has a dedicated unit for the participatory preparation of public policies, which has been in operation for three years and cooperates closely on the adaptation topic as well.

2.5 Preliminary Monitoring and Evaluation

The first phase of the climate risk assessment provided a solid scientific foundation. The ŽSK team had expected to obtain more detailed information about the hazard of extreme rainfall, but found that it can only be predicted for large orographic units. As a result, more emphasis must be placed on understanding exposure and vulnerability. Another key finding was that heat waves will become a serious problem. The ŽSK team did not expect that there would be a doubling or tripling of heatwave days by mid-century.

The greatest challenges were linked to the development of the hazard impact database and the availability of reliable data. In Slovakia, data are scattered across institutions, often inconsistent, incomplete, or treated as internal know-how that is difficult to access. Another difficulty arose during the downloading of hundreds of LST images from the RSLab. The lack of an API-based download option made the process highly time-consuming; the introduction of such functionality would be greatly welcomed in the future.

Stakeholder feedback showed that the results from the extreme rainfall workflow were difficult to interpret. This highlights the need to find a suitable interpretation method to ensure they can be properly understood and applied in practice. In contrast, heatwave results were well received, especially by municipalities. However, the next phase will require their active involvement to provide complementary data on vulnerable buildings, critical infrastructure, and vulnerable groups, including their daily mobility.

To improve the extreme precipitation risk assessment, cooperation with an expert group will continue in order to help set system sensitivity indicators and identify relevant data sources. While the Maxiconza project focuses mainly on tourism and road infrastructure, a more comprehensive understanding of flash floods and landslides requires a hydrological regime analysis covering geomorphology, soils, land use, and urbanization. This analysis will not be carried out within the Maxiconza project, but will be implemented by the ŽSK over the next two years.

2.6 Work plan

The second phase will focus on enhancing the completed workflows with more precise data on exposure and vulnerability. A major task will be collecting and processing datasets so they can be effectively integrated into the workflows. Sensitivity indicators will be scaled according to the level of detail available. For the extreme rainfall workflow, a key priority will be building a robust hazard impact database by gathering information on past events, including rainfall intensity data from SHMU and impact records from municipal authorities or crisis management centers. All data will be processed into a unified shapefile (.shp) format to ensure compatibility with GIS-based analysis and smooth integration into the CRA workflows. In parallel, the project will seek to establish a sustainable methodology for regularly updating these datasets to ensure their long-term relevance for adaptation planning and risk communication.

Since the heatwave workflow covered only four urban areas and did not provide a region-wide perspective, the second phase will also include drought and wildfire workflows. These hazards, closely linked to rising temperatures, will complement the regional picture. Furthermore, the second phase will include mapping the adaptation potential of ŽSK-owned buildings and land, identifying opportunities for blue and green infrastructure to mitigate hazard impacts (e.g., water retention, cooling effects).

The third phase will focus on maximizing the use of CRA and adaptation potential results by developing recommendations for regional investment and development policies. To this end, five workshops will be held across ŽSK to present results and gather stakeholder feedback, complemented by two internal meetings with the regional council, key department representatives, and management.

3 Conclusions Phase 1- Climate risk assessment

For extreme precipitation, the main finding is how the intensity and frequency of extreme precipitation will change. These changes were calculated for four different return periods (10, 25, 50, and 100 years). The results show that intensity increases are relatively similar across all return periods, ranging between 23% and 34%. However, the higher the return period, the greater the increase in intensity. The shortening of return periods shows even more striking differences. Expressed as percentages, these reductions illustrate the scale of change more clearly. For a 10-year return period, the interval shortens by about 40% (to 6 years), while for a 100-year return period it shortens by 65%. Again, the longer the return period, the greater the reduction. Considering that rainfall with 50- or 100-year return periods already causes massive damage today (see Table 2-3), such drastic shortening will pose a major challenge for the Žilina Region in the future. Preparation for this phenomenon is therefore essential.

What is missing, however, is better knowledge of which parts of the region are most at risk from such events, whether due to unchangeable factors such as geomorphology, or manageable ones such as poor land use or unsuitable urbanization. The ŽSK team had expected greater detail in this regard from the workflow but will seek to achieve it in the second phase through more precise definitions of exposure and vulnerability and by incorporating more detailed data. Another important finding is the need to create a database of hazard impacts. Such a database would provide a CRA based on actual events rather than theoretical calculations, offering the most accurate view of the critical total precipitation amounts for specific locations. As previously mentioned, obtaining data in Slovakia is difficult, and very little data is publicly available. For this reason, the hazard impact database is still relatively limited and is mainly based on information from media sources. In the second phase, however, a large part of the work will be devoted to data collection. In this regard, the contribution of the expert group is invaluable, as its members are familiar with the relevant datasets and sources in their fields. Sometimes they can even provide data directly, which significantly streamlines and speeds up the collection process.

For heat waves, the most significant finding is a relatively large increase in the number of heatwave days per year, which doubles or even triples in the Žilina region (the lower value applies under the milder RCP 4.5 scenario). Currently, about 8 such days occur annually; in the future, this could rise to 16–24 days. While this number is still low compared to southern European countries, the local population is not accustomed to this phenomenon. This was evident during the past summer, when the Žilina Region recorded the highest number of emergency medical interventions for heat-related collapses in Slovakia. With an aging population, the impacts of this hazard are likely to increase further.

Since the heatwaves workflow focused on assessing UHI, the detailed risk assessment was limited to the four cities with more than 25,000 inhabitants. The ŽSK team had expected to receive an assessment of extreme future temperatures for the entire region. Consequently, the results are more suitable for city planning than for regional planning. Nevertheless, the workflow clearly shows that two types of areas are most at risk in all assessed cities: large treeless parking lots (usually near shopping centers) and industrial zones. It is therefore reasonable to assume that these areas will also be problematic in smaller municipalities. A particularly interesting finding was that small, temporary heat islands formed in agricultural fields surrounding selected cities after the harvest. Since the workflow operates in an urban environment, the months following the harvest were excluded due to calculation distortions, but this is a very important finding for understanding the issue. It suggests that towns and villages surrounded by large agricultural areas will be more vulnerable to heatwaves after the harvest season, as hot air from these areas will block the cooling influence of forests and mountains. In conclusion, it can be said that the visual output of this workflow is very understandable for various stakeholder groups, which cannot be said about the extreme rainfall workflow.

For both workflows, the ŽSK team values the fact that the results are based on actual measurements rather than purely theoretical models, as this makes them more relevant for decision-making purposes. The workflows allow outputs to be updated whenever any of the source datasets are updated. This ensures that decisions are always based on the most up-to-date findings. This is in contrast to many adaptation strategies, where measures are implemented for years based on a single static output. For future application of the workflows (after the end of the project), ŽSK will need to strengthen its internal capacities. A key limitation is the lack of staff, as all GIS-related tasks for the entire institution are currently managed by one person, leaving no space for further training in workflow use. On the other hand, participation in the project has significantly improved the ŽSK team's understanding of how climate risks can be assessed. In many respects, their theoretical knowledge and expectations have been confronted with practical realities, which have greatly enhanced its ability to increase the region's resilience to climate change.

4 Progress evaluation and contribution to future phases

Building on the work completed thus far, the next phase will primarily focus on finalising the extreme rainfall workflow, as this appears to be the most significant phenomenon in the Žilina region. In collaboration with the expert group, sensitivity indicators will be defined for the systems already identified in the project application—namely, the tourism sector and the road network, with a particular link to vulnerable populations.

For the road network, the assessment will draw on data about landslide-prone areas, the road system itself (including the importance and construction quality of individual roads), land use, forest roads (quality and density), torrent control structures on mountain streams, runoff lines, and critical catchment profiles. Results from previous analyses, such as the Analysis of Flood and Erosion Risk and the Forest Cover Change Assessment, will also be used. To assess population vulnerability, factors such as transport accessibility and the presence of vulnerable groups will be considered. Ideally, data on critical infrastructure will also be included, although such datasets may not be available.

For the tourism sector, key actors and tourism centers (identified by visitor numbers and/or overnight stays) will be mapped in cooperation with stakeholders. These actors will receive a questionnaire on whether they have already experienced damage from extreme rainfall and whether they plan adaptation measures. Visitor numbers will also be used to evaluate the importance of roads. To strengthen the hazard impact database, ŽSK will request summary flood reports and records of declared emergencies (floods, wildfires, landslides, water shortages) from relevant state authorities, covering the period from 2000 onwards. Non-flood data will also be used to expand other workflows on drought and forest fires. For flood events, corresponding rainfall data will be purchased from SHMU.

In the second phase, the adaptation potential of ŽSK-owned buildings and land will also be mapped. The mapping will look at surface permeability, water drainage, and existing retention measures. Based on this, the potential to retain rainwater on-site will be determined to minimize runoff from the premises. The mapping results will also include recommendations for suitable blue–green infrastructure measures. The results will be used to demonstrate how extreme rainfall can be mitigated in urban environments, especially in the most at-risk areas of the region.

For the heatwave workflow, additional vulnerability data will be collected in cooperation with the towns where UHIs were analyzed. Information will cover critical infrastructure, places where vulnerable people spend their days, and nearby blue–green infrastructure that can provide relief during heatwaves.

Two additional workflows—agricultural drought and forest fires—will be launched to complement the analysis of heat-related risks. These will provide insights into agricultural and forested areas, since the heatwave workflow is limited to urban settings. Drawing on experience from the first phase, the ŽSK team knows that obtaining data directly from farmers and forest managers will be necessary. This will be a major challenge, given that most forests and agricultural land in the Žilina region are privately owned and there is no unified database of these stakeholders. Partial datasets only contain physical addresses.

In the third phase, all outputs will be presented through five subregional workshops. Recommendations for joint local planning of adaptation pathways will be developed, since water-related risks in the landscape require cooperation at the micro-catchment level at least, and cannot be solved individually. The results will also be translated into recommendations for ŽSK's real estate investment plan (particularly roads and social facilities), for regional strategic planning, for project preparation, and for drafting a regional adaptation strategy.

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
Assessment of at least two climate hazards using the Climaax methodology	Two climate hazards using the Climaax methodology were assessed: heatwaves and extreme rainfalls. The results of the assessment are included in D1 and were presented to the expert group and also to the audience as a part of the regional workshop dedicated to the presentation of the new national adaptation strategy.
Summary of strengths and weaknesses of the Climaax toolbox	Summary was prepared at the end of the first phase by the ŽSK team
Six meetings of the expert group	Two meetings were held. One took place in person on July 17, 2025, at the ŽSK premises, and the other took place online on September 12, 2025.
Two press releases	One press release was published.
At least 6 social media posts	3 Facebook posts about the project's activities to date

Table 4-2 Overview of milestones

Milestones	***Progress***
M1. The opening meeting of the expert group took place	The opening meeting of the expert group took place on July 17, 2025. The meeting included a brief presentation of the Maxiconza project and the results of the climaax methodology applied to date, followed by a discussion.
M2. Participation in the meeting in Barcelona	One person from the ŽSK team participated in a meeting in Barcelona, where a project poster was displayed.
M3. Draft additional data for phase 2 developed	The draft for additional data for phase 2 was developed based on discussions of the expert group.
M4. The successful tenderer for data processing in the GIS environment and the application of the toolbox selected	The public procurement was won by Straton Technologies s. r. o. The contract with the company was successfully signed on July 1. The contract became effective on July 3.
M5. 2 climate hazards successfully evaluated	Two climate hazards using the Climaax methodology were assessed: heatwaves and extreme rainfalls.

5 Supporting documentation

During 1st phase of the project, following outputs have been developed:

- Main Report *Phase 1 – Climate risk assessment (Deliverable 1* - implementation *of the CLIMAAX common methodology for multi-risk assessment and analysis of the results within the project* CliMAaXImal COntribution to building the resilience of the ZilinA region, in PDF form)
- Visual outputs depicting extreme rainfall workflow: for more information see the CLIMAAX Extreme rainfall workflow

- ***extreme_rainfall_relative_change_100yRP.png***
- ***extreme_rainfall_relative_change_10yRP.png***
- ***extreme_rainfall_relative_change_25yRP.png***
- ***extreme_rainfall_relative_change_50yRP.png***
- ***mean_precipitation_for_24h_duration_events_over_ZSK_rcp85.png***

- Visual outputs depicting heatwave workflow – scenarios: for more information see the CLIMAAX heatwave workflow.

- ***rel_change_rcp45.png*** (relative change of the heat days occurence 2041-2070 to reference period 1986-2015 rcp 4.5)
- ***rel_change_rcp85_png*** (relative change of the heat days occurence 2041-2070 to reference period 1986-2015 rcp 8.5)
- ***ZSK_cities.png*** (cities selected for the MAXICONZA project urban heat islands analysis)

- Visual outputs depicting heatwave workflow in the four selected cities (listed according to the number of inhabitants form the highest to the lowest: Žilina – Martin - Liptovský Mikuláš - Ružomberok):

- ***HW_days_occurrence_RCP45_85_1986_2085_Zilina.png***
- ***Zilina_possible_heat_risk_level_to_vulnerable_population.tif***
- **Zilina_possible_heat_risk_level_to_vulnerable_population.eng.png**
- **Zilina_risk_LST.tif**
- **Zilina_risk_pop.tif**
- **HW_days_occurrence_RCP45_85_1986_2085_Martin.jpg**
- **Martin_heat_risk_to_vulnerable_population_median_temp_eng.png**
- **Martin_possible_heat_risk_level_to_vulnerable_population.tif**
- **Martin_risk_LST.tif**
- **Martin_risk_pop.tif**
- **HW_days_occurrence_RCP45_85_1986_2085_Mikulas.png**
- **Mikulas_possible_heat_risk_level_to_vulnerable_population.tif**
- **Mikulas_possible_heat_risk_level_to_vulnerable_population.eng.png**

- **Mikulas_risk_LST.tif**
- **Mikulas_risk_pop.tif**
- **HW_days_occurrence_RCP45_85_1986_2085_Ruzomberok.png**
- **Ruzomberok_possible_heat_risk_level_to_vulnerable_population.tif**
- **Ruzomberok_possible_heat_risk_level_to_vulnerable_population.eng.png**
- **Ruzomberok_risk_LST.tif**
- **Ruzomberok_risk_pop.tif**

- Datasets collected

- **extreme_rainfall_hazard_impact_database_ZSK.xlsx**

- Attachment 1 on detailed information on relevant stakeholders and their roles in the project (in PDF form)
- Attachment 2 on Communication Outputs (Press release, media) that have been publicized during the1st phase of the project (in PDF form)

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