Deliverable Phase 2 – Climate risk assessment

STRENGTHENING TRNAVA'S CLIMATE RESILIENCE THROUGH ADVANCED RISK ASSESSMENT AND ADAPTATION STRATEGIES

(TRACAP)

Slovakia, Trnava city

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Author(s)	• Ladislav Glinda (City of Trnava) • Roman Výleta (Slovak University of Technology in Bratislava)
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Abbreviations and acronyms

Abbreviation / acronym	Description
API	Application Programming Interface
AWC	Available Water Capacity
CCA	Copernicus Climate Atlas
CDS	Copernicus Climate Data Store
CMIP6	Coupled Model Intercomparison Project Phase 6
CRA	Climate Risk Assessment
EEA	European Environmental Agency
ET0	Soil standard evapotranspiration
ETa	Actual crop evapotranspiration
ETc	Crop standard evapotranspiration
EU	European Union
EuroHEAT	Methodology for heatwave definition and assessment used in the heatwave workflow
FAO	Food and Agriculture Organization of the United Nations
GCM	Global Climate Model
IROP	Integrated Regional Operational Programme
KVHK	Katedra vodného hospodárstva krajiny (Department of Land and Water Resources Management)
LST	Land Surface Temperature
MTT	Mestská televízia Trnava (Trnava local television)
M&E	Monitoring and Evaluation
NBS	Nature-based solutions
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SSP	Shared Socio-economic Pathways
RP	Return Period
SHMU	Slovak Hydrometeorological Institute
STU	Slovak University of Technology
SVP	Slovenský vodohospodársky podnik (Slovak Water Management Enterprise)
UHI	Urban Heat Island
ZZS SR	Záchranná zdravotná služba slovenskej republiky (Emergency Medical Operations Centre of Slovakia)

Executive summary

The second phase of the TRACAP project focused on improving the data resolution, quality, and local relevance of the Heatwave and Agricultural Drought workflows for the city of Trnava. Compared with Phase 1, the main added value of Phase 2 was the transition from pan-European screening datasets EURO-CORDEX (Jacob et al., 2013) to locally relevant inputs. Locally downscaled and bias-corrected CMIP6 climate model data with a spatial resolution of 500 × 500 m were purchased and incorporated into both selected workflows. This significantly improved the spatial detail of the heatwave and agricultural drought analyses and made the outputs more suitable for municipal planning in a relatively small urban area such as Trnava.

The Heatwave workflow focused mainly on the identification of urban heat islands and cooling spots, combined with local exposure and vulnerability data. The assessment used projected heatwave-day occurrence, measured air temperature data from SHMÚ, Landsat 8 and Landsat 9 land surface temperature data (RSLab), vulnerable population groups (WorldPop), and vulnerable public buildings (Trnava adaptation strategy, 2015). The LST analysis was based on tropical days during 2021–2025, defined as days with maximum daily air temperature above 30 °C. This approach provided a more targeted picture of heat stress during periods that are most relevant for public health and adaptation planning.

The heatwave results show a clear increase in future heatwave conditions. Based on the local 500 × 500 m climate scenarios, the mean number of heatwave days is projected to increase from 17.62 days in 2021–2050 to 28.32 days in 2071–2100 under SSP2-4.5, and from 25.2 days in 2021–2050 to 49.7 days in 2071–2100 under SSP5-8.5. The analysis also identified persistent urban heat stress areas, cooling spots, and vulnerable facilities located within zones exceeding the local LST threshold of 40 °C. This threshold was used as a practical local indicator for spatial prioritisation and was supported by published studies using high or extreme LST classes, including Dimitriou et al. (2025), Samb et al. (2026) and Dang et al. (2020).

In total, 17 out of 34 vulnerable buildings, representing 50%, were located in areas with LST values above 40 °C. The estimated area of high and very high heat risk zones increased from 177.1 ha in the previous approach to 439.5 ha in the refined Phase 2 approach. These outputs support the prioritisation of urban greening, shading, cooling places, and building-level adaptation measures.

The Agricultural Drought workflow focused on the comparison between the original CLIMAAX workflow results, based on CLIMAAX-provided European-scale data using EURO-CORDEX CMIP5 climate scenarios with a spatial resolution of 12 × 12 km, and refined results based on local sources using locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m. The refined assessment used the purchased climate model data together with local crop distribution data and irrigation infrastructure data. Local crop maps from 2018–2025 were used to select the four dominant crops in the Trnava area: wheat, maize, rapeseed, and barley. Together, these crops represent approximately 86% of the planted cropland area. Irrigation availability was used as the vulnerability indicator.

The refined agricultural drought workflow quantified potential yield and revenue losses for wheat, maize, rapeseed, and barley under SSP2-4.5 and SSP5-8.5 for the periods 2021–2050 and 2071–2100. The results indicate that maize is the most economically exposed crop, with projected yield losses ranging from 41.6% to 54.11%, depending on the scenario and period. This corresponds to estimated revenue losses of approximately 13,500–17,500 EUR/km². Barley showed the second-highest revenue losses, ranging from 877 to 1,606 EUR/km². The total projected revenue losses

based on observed planted crop areas from 2018–2025 range from approximately 0.75 million EUR under SSP2-4.5 for 2021–2050 to approximately 1.05 million EUR under SSP5-8.5 for 2071–2100.

The results also show that irrigation infrastructure substantially reduces current agricultural drought vulnerability. In total, 57% of the cropland area is covered by irrigation infrastructure. However, the presence of irrigation canals, hydrants, and related infrastructure does not necessarily mean that the system is regularly operational. This is an important limitation and should be considered in future adaptation planning, especially in relation to maintenance, modernisation, water availability, and the selection of more drought-resilient crops.

The key risk assessment classified heatwaves as a very high-priority risk because they directly affect human health, vulnerable population groups, public buildings, and urban liveability. Agricultural drought was classified as a moderate-priority risk because it is a slower-onset risk and existing irrigation infrastructure provides relevant adaptation capacity, although its long-term effectiveness depends on maintenance and future water availability.

A further important outcome of Phase 2 was the strengthening of local capacity. A dedicated training session for representatives of the Trnava City Office was organised in June 2026. The training focused on the interpretation of CLIMAAX workflow outputs, the role of local data, and the possible use of the results in adaptation planning and communication with stakeholders.

The final part of Phase 2 focused on dissemination, communication, and the long-term sustainability of the project results. The outcomes of the TRACAP project were presented and discussed through scientific conferences, poster presentations, stakeholder communication activities, online media outputs, and knowledge-sharing meetings with other Slovak regions involved in climate adaptation initiatives. The main dissemination activities included the HydroCarpath, 2025 oral presentation, the 32nd Poster Day 2025 of the Institute of Hydrology of the Slovak Academy of Sciences, the EGU General Assembly 2026 poster presentation and abstract, the EGU General Assembly 2026 oral presentation, the Trnavské rádio public communication output, including the online article, and the CLIMAAX SK group meeting focused on discussion of TRACAP results and exchange of good practices among Slovak regions participating in CLIMAAX and Pathways2Resilience initiatives.

The main conclusion of Phase 2 is that local data substantially improve the practical value of the climate risk assessment for Trnava. The refined outputs provide a stronger evidence base for targeted heat mitigation, adaptation of vulnerable buildings, urban greening, cooling spots, irrigation planning, and drought-resilient agriculture. Phase 3 will focus on the dissemination of results, stakeholder communication, integration of the findings into a final document supporting the existing Trnava adaptation strategy (Trnava adaptation strategy, 2015), and the identification of practical adaptation measures for the highest-priority areas and sectors.

1 Introduction

1.1 Background

The city of Trnava, located in western Slovakia, is a historic urban centre situated in the Danubian Lowland, one of the warmest and driest regions in the country (Trnava adaptation strategy, 2015). With approximately 62,508 inhabitants (Trnava description), it is an important regional hub for industry, services, education, and culture. The city is also characterised by a compact historical centre, expanding residential and industrial zones, and a strongly agricultural peri-urban landscape, which together create different types of exposure to climate-related hazards.

Due to its geographic and climatic conditions, Trnava is particularly vulnerable to heatwaves and agricultural drought. Dense built-up areas, industrial zones, and limited green infrastructure in some neighbourhoods increase the risk of urban overheating, while the surrounding peri-urban agricultural areas are exposed to drought-related impacts. These risks are especially relevant because they affect both the urban population and public services, as well as agricultural production and water demand in the wider functional area of the city.

Although Trnava adopted a local adaptation strategy in 2015, the document is now outdated and does not fully reflect updated climate scenarios, detailed spatial risk assessment, or current stakeholder needs. Through the CLIMAAX project, Trnava aims to strengthen its climate risk governance, update its adaptation planning, and support science-based and targeted resilience measures. Phase 2 builds directly on the Phase 1 climate risk screening by refining the assessment with more detailed local datasets, locally downscaled and bias-corrected CMIP6 climate scenario data, and additional spatial information relevant for municipal decision-making.

1.2 Main objectives of the project

The main objective of Phase 2 was to improve the climate risk assessment for Trnava by moving from European-scale datasets used in Phase 1 towards more detailed local data and higher-resolution climate information. The assessment focused on two priority hazards: heatwaves and agricultural droughts, which are highly relevant for the city, vulnerable population groups, public buildings, and the surrounding agricultural landscape. This phase therefore represents a transition from a harmonised baseline assessment to a more regionalised and locally applicable assessment tailored to the specific conditions of the Trnava region.

The significance of Phase 2 lies in the improved local relevance of the results. Purchased locally downscaled and bias-corrected CMIP6 climate scenarios with a spatial resolution of 500 x 500 m were used to refine the heatwave and agricultural drought assessments. The dataset was prepared specifically for the Trnava region and includes daily climate variables for a 30 km radius around the city, covering the historical period 1981–2014 and future SSP scenarios for 2015–2100 For the assessment, the main future time horizons were 2021–2050 and 2071–2100, with a focus on selected SSP scenarios, mainly SSP2-4.5 and SSP5-8.5.. A detailed technical and methodological description of the purchased locally downscaled and bias-corrected CMIP6 climate scenarios, including the downscaling procedure, bias correction, variables, scenarios, model ensemble, output formats and limitations, is provided in the annexes.

In addition, purchased measured air temperature data from SHMÚ were used to support the selection of the Landsat 8 and Landsat 9 LST data from RSLab. The selection of the LST images was based on the measured data from SHMÚ and the thresholds for the tropical days, defined as days with maximum daily air temperature above 30 °C.

Finally, the local vulnerable building data (Trnava adaptation strategy, 2015), local crop distribution (PPA, 2025), and irrigation infrastructure (RPI, 2025) data were integrated into the workflows using locally relevant open-source datasets (products).

The CLIMAAX Handbook provided a structured and harmonized framework for conducting climate risk assessment. It supported the selection of suitable workflows, the organization of hazard, exposure, vulnerability, and risk components, and the transparent documentation of methods and assumptions. The inclusion of local data and models in Phase 2 made the results more suitable for Trnava's spatial scale and planning needs, and improved their usefulness for updating the existing climate adaptation strategy and supporting future decision-making. The purchased climate model datasets were used to refine the original CLIMAAX workflow outputs and to provide more spatially detailed and locally interpretable information for the city and its surroundings. This is important because the original European-scale datasets are useful for harmonised comparison, but they may not sufficiently capture local gradients, urban structure, or agricultural conditions relevant for the city of Trnava and its surrounding area.

This phase therefore does not only repeat the Phase 1 screening, but deepens it by adding locally purchased climate model datasets, measured meteorological observations, recent remote-sensing data, and local exposure and vulnerability layers. The resulting maps and tables are intended to be decision-ready inputs for the next phase, where adaptation options and risk management measures will be prioritised. In addition, Phase 2 contributed to capacity building through training activities for representatives of the City of Trnava, supporting future use and interpretation of CLIMAAX-based outputs within municipal planning processes.

1.3 Project team

The CLIMAAX project in Trnava is jointly implemented by the City of Trnava and the Slovak University of Technology in Bratislava (STU). The City of Trnava acts as the lead institution and coordinates the administrative, strategic, and planning aspects of the project. The municipal team includes Ing. Ladislav Glinda, Head of the Department of Investment Construction, and Ing. Monika Pavelková from the Department of Strategic Planning and Project Management.

The Department of Land and Water Resources Management (KVHK), at STU Bratislava, provides scientific and technical support. STU was responsible for customizing CLIMAAX workflows, processing climate and geospatial data, conducting spatial risk analyses, and preparing maps and materials for stakeholder communication. STU also provided methodological support and training for representatives of the City of Trnava on the interpretation and practical use of CLIMAAX workflow outputs. The STU team includes experts in hydrology, climate risk assessment, geospatial analysis, remote sensing, and urban climate adaptation. This cooperation combines local planning knowledge with scientific expertise and supports the use of climate risk assessment (CRA) results in future adaptation planning.

1.4 Outline of the document's structure

The document is structured as follows. Section 1 introduces the regional context, objectives, project team, and the purpose of Phase 2. Section 2 presents the refined climate risk assessment, including scoping, stakeholder engagement, scenario selection, the locally refined heatwave and agricultural drought analyses, and the key risk assessment findings. Section 3 summarises the main conclusions of Phase 2. Section 4 evaluates progress against the planned KPIs and milestones. Section 5 lists supporting documentation, outputs and datasets, and Section 6 provides references used in the assessment. Supporting materials, including dissemination outputs, posters, abstracts and training-related documents, are provided in the annexes.

2 Climate risk assessment – phase 2

2.1 Scoping

The scoping phase of the climate risk assessment defines the objectives, context, limitations, stakeholders, experts and priority groups involved in the refined Phase 2 assessment. Compared with Phase 1, the scoping was updated to reflect the availability of newly purchased high-resolution climate scenario data, additional local datasets, and the need to prepare results that can directly support the update of Trnava's adaptation strategy and the planning of concrete adaptation measures in Phase 3.

2.1.1 Objectives

The main objective of the heatwave and agricultural drought assessment is to provide scientifically based evidence of current risks and potential future risks caused by climate change. The results can support policy and decision-making, especially in the fields of urban planning, protection of vulnerable population groups, irrigation planning, agricultural adaptation, and the update of the Trnava Climate Adaptation Strategy (Trnava, 2015). The refined Phase 2 results are intended to identify priority areas where adaptation measures, such as cooling interventions, green infrastructure, water-retention measures or agricultural drought mitigation, should be considered first. The project results have been, and will continue to be, communicated to local policymakers and decision-makers through webinars and on-site conferences. Before being presented to policymakers, the results were discussed at several scientific and expert events. The final results will be added to the existing adaptation strategy with the aim of updating, supporting, and supplementing the original strategy. In this way, the CRA provides a technical evidence base for future municipal planning, risk management and climate adaptation decisions.

Since the area of the city of Trnava and its surroundings is relatively small, approximately 75 km², the interpretation of European climate datasets with a spatial resolution of 12 × 12 km, representing approximately 144 km² per grid, was challenging for stakeholders. One of the main limitations was obtaining high-quality, high-resolution, bias-corrected daily climate scenario datasets. The Slovak Hydrometeorological Institute (SHMÚ) provides only a limited number of climate variables, which are not available for this assessment as daily datasets but rather as pre-calculated 30-year mean values.

This limitation was addressed through project support and cooperation with the Department of Land and Water Resources Management at the Slovak University of Technology in Bratislava, which provided the data specifications required for successful integration into the selected CLIMAAX tools. Based on these specifications, the necessary high-resolution climate scenario data were purchased from a local external climate service provider in Slovakia. This made it possible to refine the original CLIMAAX workflow outputs and to produce results that are more understandable and usable at the municipal scale and more relevant for local decision-making.

The purchased dataset consists of daily CMIP6-based climate scenarios downscaled to a 500 × 500 m grid for a 30 km radius around Trnava. It includes 20 global climate models, the historical period 1981–2014 and four future SSP scenarios for 2015–2100: SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5. The dataset provides key variables needed for the refined heatwave and agricultural drought analyses, including temperature, precipitation, relative humidity, wind speed, potential evapotranspiration and approximated shortwave radiation. A detailed technical and methodological description is provided in the annexes.

2.1.2 Context

Currently, climate hazards, impacts, and risks have been addressed through the existing Climate Adaptation Strategy (2015) and national adaptation plans, which were reflected in the Integrated Territorial Strategy of the Urban Functional Area of the Nuclear City of Trnava for the Period 2022–2029 (Integrated Territorial Strategy MFO Trnava 2022–2029). The Trnava City Office and the Trnava Region have also been active in other climate-oriented projects aimed at adaptation to current and future climate change risks, such as:

- Towards a climate neutral EU efficient allocation of EU funds (CEEweb, 2021)
  - Notable examples include the shading and greening of the footbridge on Starohájská Street to mitigate the urban heat island effect, as well as the introduction of water elements (blue infrastructure) and tree planting.
- Improving urban climate change adaptation capacities by testing and promoting the 'sponge city' method (KeepEU, 2026)
  - Trnava has integrated nature-based solutions to combat urban flooding and prolonged drought. By reducing impermeable surfaces and adding rain gardens, bioswales, and permeable pavements, the city is better equipped to naturally absorb and manage excess stormwater.
- Eco mobility Transition (TTSK, 2025). Although the Trnava Self-Governing Region is not directly part of the CLIMAAX project, the City of Trnava is an important urban centre within the region, and several regional interventions are therefore relevant for the city.
  - Trnava has introduced municipal regulatory measures mandating that new large industrial halls incorporate at least 50% green roofing.
- Social vulnerability to heatwaves, from assessment to implementation of adaptation measures in Košice and Trnava, Slovakia (Climate Adapt, 2018).
  - Trnava empowers its residents and organizations by dedicating a municipal budget (minimum €10,000 annually) exclusively to public adaptation grant applications. This citizen-led initiative supports local awareness-raising, schoolyard greening, and grassroots adaptation projects.

However, there is still limited systematic national-level coordination supporting cities and regions in the practical implementation of climate adaptation measures, and some parts of the Trnava Climate Adaptation Strategy are outdated. The City of Trnava is therefore seeking to update its adaptation strategy, disseminate the project results, and strengthen long-term, evidence-based adaptation to climate change.

The national climate risk assessment is handled through the Ministry of Environment of the Slovak Republic, which provided the national adaptation strategy (Slovak adaptation strategy, 2018). SHMÚ is the official national provider of meteorological and climatological data and information in Slovakia.

In the Trnava region, the main relevant sectors are the public sector and agriculture. The public sector, including hospitals, social care facilities, and kindergartens, may be significantly affected by heatwaves, particularly in relation to vulnerable population groups. Many of these facilities are managed by public authorities, and some of them are in poor technical condition or are not sufficiently adapted to current and future climate conditions.

Agriculture may be strongly affected by droughts, especially through potential yield and revenue losses. Therefore, the heatwave and agricultural drought workflows were selected for the climate

risk assessment. These two sectors also represent the main link between Phase 2 risk assessment and practical adaptation planning.
No major external initiatives directly influencing the scope of the assessment were identified at Phase 2. However, the project is aligned with broader national and regional adaptation efforts and with knowledge exchange among Slovak CLIMAAX and Pathways2Resilience regions.
Relevant outside influences include national climate adaptation policy, SHMÚ warning and drought-monitoring services, regional low-carbon and eco-mobility initiatives, the Trnava Integrated Territorial Strategy, and other CLIMAAX and Pathways2Resilience activities in Slovakia. These initiatives can indirectly support data exchange, stakeholder engagement, and the mainstreaming of TRACAP results into wider regional adaptation and resilience planning.
In terms of heatwaves, nature-based adaptation measures are needed in the city, especially urban greening, tree planting, shading of public spaces, cooling spots, green roofs, and reduction of sealed surfaces. For this purpose, it is important to identify suitable areas for heat mitigation measures across Trnava. Therefore, the urban heat island identification workflow was selected to support the targeted prioritisation and spatial distribution of mitigation measures across the city.
The agricultural sector has experienced drought periods in the past, which is why irrigation infrastructure was developed in the region. However, it is important to prepare for even more severe drought events that may be caused by climate change in the future. Therefore, the selection of crops that are more resilient to future climate conditions, together with the maintenance and improvement of the current irrigation system, should be considered as key adaptation goals. Additional measures may include soil water-retention practices, improved irrigation efficiency, drought-resilient crop rotations, and better use of seasonal drought monitoring for agricultural planning.

2.1.3 Participation and risk ownership

The Trnava City Office is responsible for the local identification, assessment, and mitigation of specific climate-related risks. At present, these risks are addressed through the existing adaptation strategy and other climate-oriented projects. Through these activities, the city is preparing for current and future climate risks. In Phase 2, the main stakeholder involvement focused on cooperation between the City of Trnava and the Slovak University of Technology in Bratislava, with additional communication towards municipal departments and representatives responsible for planning, investment, public infrastructure, green infrastructure, and crisis response.
The early warning system for short-term climate hazards is provided at the national level by SHMÚ. The Trnava City Office then needs to respond to these warnings at the local level by managing local infrastructure, emergency services, and other relevant municipal responsibilities. Risk ownership is therefore shared across several levels. The City of Trnava is responsible for the local adaptation and implementation process, STU provides scientific and methodological support for climate risk assessment, SHMÚ provides official meteorological and climatological information, and sectoral stakeholders are responsible for using the results within their own fields, such as public buildings, social services, green infrastructure, water management and agriculture. The main coordination structure, stakeholder communication pathways, data and analysis responsibilities, and feedback loops are shown in Figure 2-1.
The identified vulnerable groups in relation to heatwaves include people over 65 years of age and children under 5 years of age. In addition, vulnerable people located in medical, social care, and pre-school education facilities were considered. These groups are represented in the assessment by

users of hospitals, social care facilities, and kindergartens, who may be more sensitive to heat due to their age, health status, or physical condition.

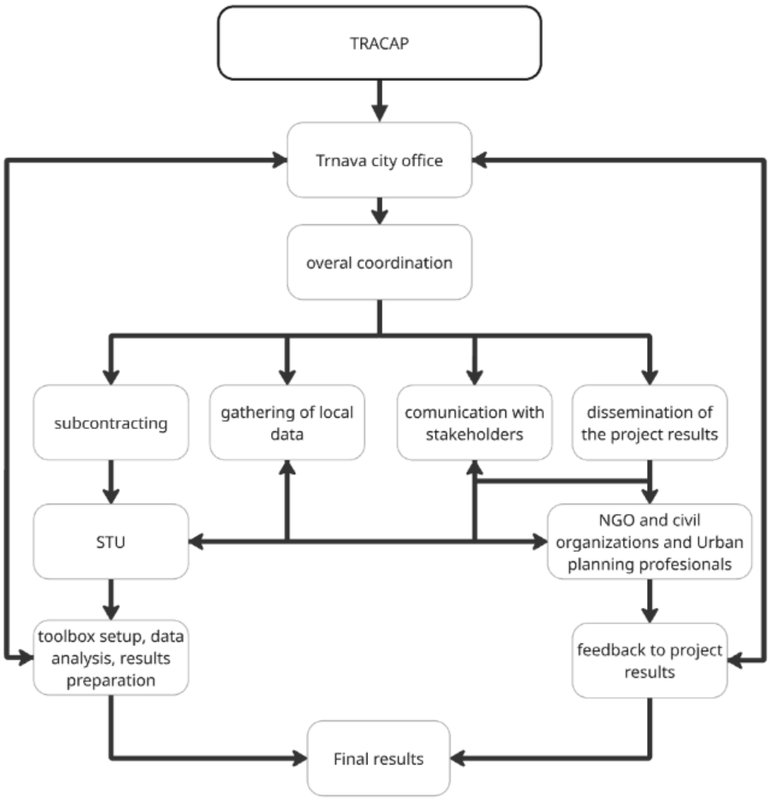

Figure 2-1 TRACAP project organigram showing the main coordination structure, stakeholder communication pathways, data and analysis responsibilities, and feedback loops within the project.

The relevant representatives of these groups are mainly the management bodies of vulnerable buildings and facilities, which are often under the responsibility of the Slovak Ministry of Health, the Ministry of Education, Research, Development and Youth, municipalities, or regional authorities. At the local level, municipal departments responsible for social services, education, public buildings, and crisis management are also important representatives for translating CRA results into practical measures.

In relation to agricultural drought, relevant representatives include the management of agricultural companies in the surroundings of Trnava, as well as agricultural workers whose jobs depend on crop production and revenue. Water management institutions and operators of irrigation infrastructure are also relevant, as the availability and efficiency of irrigation can influence drought vulnerability. The wider population may be indirectly affected through food supply chains, prices, and the economic stability of the agricultural sector.

To effectively reach these representatives, it is important to provide detailed and clearly communicated CRA results, as repeated engagement with stakeholders can be difficult. These stakeholders were already contacted during Phase 1 and informed about the expected project outputs. The City of Trnava also invited them to dissemination activities during Phase 2, where the refined heatwave and agricultural drought results were presented and discussed. Phase 3 will focus on dissemination and on the preparation of an updated version of the existing adaptation strategy, supplemented with TRACAP results specifically oriented towards heatwave and agricultural drought

risks. The updated strategy will include practical outputs such as maps, identified priority areas, and short explanatory summaries prepared for municipal departments and sectoral stakeholders.
Trnava has no formal definition of "acceptable risk." However, public discussions and the 2015 Climate Adaptation Strategy (Trnava, 2015) recognize heatwaves as a major public health threat, while droughts affect water supply, green spaces, and peri-urban agriculture.
The Phase 2 assessment identified that the Trnava region is not new to climate-related risks. The city regularly faces heatwaves and agricultural droughts and is already partly prepared for these hazards. This existing level of preparedness can be understood as the current practical reference level of tolerable risk. For heatwaves, this can be interpreted as a level of heat that does not lead to a significant increase in heat-related health impacts compared to normal conditions. For agricultural drought, it can be understood as a drought period that can still be managed by the existing irrigation infrastructure. Any event exceeding these conditions may be considered above the acceptable or tolerable risk level.
The Phase 2 results also identified an LST threshold of 40 °C as an important local indicator of high heat stress. Areas exceeding this threshold may represent locations where heat risk becomes particularly relevant for citizens and where adaptation or mitigation measures should be prioritized. This threshold is used as a practical indicator for spatial prioritisation within the TRACAP assessment, rather than as an officially adopted legal risk limit.

2.1.4 Application of principles

The principles of social justice, equity, and inclusivity were reflected by focusing the assessment on vulnerable population groups and exposed sectors that may be disproportionately affected by climate risks. In the heatwave assessment, special attention was given to people over 65 years of age, children under 5 years of age, and vulnerable groups located in hospitals, social care facilities, and kindergartens. In the agricultural drought assessment, attention was given to crop production, irrigation availability, potential revenue losses, and the possible impacts on farmers and agricultural workers.
Quality, rigour, and transparency were supported by applying the CLIMAAX workflows and by clearly documenting the input data, assumptions, thresholds, methods, and results. The Phase 1 assessment used European open datasets with a spatial resolution of 12 x 12 km, while Phase 2 improved the assessment with locally downscaled and bias-corrected climate scenarios with a spatial resolution of 500 x 500 m, measured air temperature data, Landsat 8 and Landsat 9 LST data, local crop distribution data, and irrigation infrastructure data. The results were also discussed at scientific and expert events before being communicated to policymakers and stakeholders. This supported transparent interpretation of the results and helped to verify their relevance before wider dissemination.
The precautionary approach was applied by considering both current risks and future climate projections. Future scenarios for different time periods and SSP scenario pathways were used to identify possible increases in heatwave and agricultural drought risks. Areas with high LST values, vulnerable buildings, vulnerable population groups, and projected agricultural losses were treated as priority areas for adaptation planning, even where some uncertainty remains. The LST threshold of 40 °C was used as a practical local indicator of high heat stress for spatial prioritisation, not as a formally adopted legal risk limit.

2.1.5 Stakeholder engagement

The final part of Phase 2 focused, and Phase 3 will continue to focus, on the dissemination and sustainability of the project results. The results were, and will continue to be, shared through online workshops, on-site meetings, conference presentations, posters, online media, and the prepared CLIMAAX data repository.

- Online workshop with project stakeholders: A stakeholder group was created, informed, and invited to project workshops. In total, representatives from more than 10 different institutions and initiatives were involved during Phase 1, including the Trnava Self-Governing Region, SVP, SHMÚ, SRZ Trnava, TAVOS, the Ministry of Interior, 15 mayors of surrounding cities and villages, ZZS SR, and local environmental initiatives such as Baterkáreň and Youth for Reality. The project goals, workflow selection, intermediate results, and possible applications of the results were communicated and discussed.
- CLIMAAX training for Trnava City Office, 09 June 2026: A dedicated training activity was organised for representatives of the Trnava City Office, with technical and methodological support provided by STU, as planned in the project proposal and KPI framework. The training focused on the logic of the CLIMAAX workflows, interpretation of heatwave and agricultural drought results, the role of locally purchased climate data, and the practical use of maps, tables and risk matrices in municipal adaptation planning.
- On-site meeting for project stakeholders, 17 June 2026: An on-site stakeholder meeting was organised to present the final Phase 2 results and discuss their use in local planning and adaptation activities. The same stakeholder group was invited, including representatives from regional and municipal authorities, water management, emergency services, local initiatives, and surrounding municipalities. The meeting focused on the interpretation and practical use of the final heatwave and agricultural drought results and their possible integration into local strategies and planning documents.
- Trnavské rádio – online media article and podcast, 24 June 2026: The TRACAP results were also disseminated to the wider public through an online article and related podcast/interview published by Trnavské rádio, titled “Trnavu čaká dvojnásobok extrémne horúcich dní. Lokálne merania odhalili najviac ohrozené ulice.” The article and podcast communicated the main findings of the Phase 2 heatwave assessment in an accessible form, with emphasis on the projected increase in extremely hot days, local measurements, and the identification of the most exposed urban areas in Trnava.
- HydroCarpath, 2025 – presentation: The project results were presented at the HydroCarpath conference. The scientific committee consisted of representatives from three universities: the Slovak University of Technology in Bratislava, the University of Sopron, and the Technical University of Vienna. The results were discussed with scientific experts in hydrology, climatology, and water resources management.
- The 32nd SAV Poster Day – poster: The project was presented through a poster at the SAV Poster Day, organized within the scientific environment of the Slovak Academy of Sciences. This provided an opportunity to present the methodology and intermediate results to the scientific community.
- EGU, 2026 – presentation and poster: The project results were also presented at the European Geosciences Union General Assembly through a presentation and poster. The participants included scientists, researchers, and experts from different fields related to climate risk, hydrology, urban climate, and adaptation.

- CLIMAAX SK group – discussion of project results and good practices: The project results were discussed within the CLIMAAX SK group, which supports the exchange of experience, good practices, and methodological approaches among Slovak regions participating in the CLIMAAX and Pathways2Resilience projects.

The Phase 1 and partial Phase 2 results received positive feedback during conferences, webinars, and expert discussions. Participants appreciated the practical focus of the assessment, the use of local data, and the improvement of spatial detail compared to the European-scale datasets. However, at that stage, the results were still presented as ongoing work. At the end of Phase 2, the refined results were also communicated through stakeholder activities and online media, including the Trnavské rádio article published. The final results achieved at the end of Phase 2 will be disseminated during Phase 3 through conferences, the Trnava city website, social media channels such as Facebook and Instagram, an updated version of the existing climate adaptation strategy containing TRACAP results, maps, identified priority areas and explanatory summaries, and the CLIMAAX data repository. The main objective is to achieve broad and targeted outreach and to support the further use of the project outcomes by local stakeholders, policymakers, and decision-makers.

One of the main difficulties was maintaining stakeholder engagement over a longer period, as repeated involvement of the same representatives can be challenging. This was addressed by preparing clearer, more detailed, and more locally relevant results before the final dissemination phase, so that stakeholders can directly see how the project outcomes may support their activities and decision-making.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

Compared with the first deliverable, the selected main hazards remained the same: heatwaves and agricultural drought. However, Phase 2 introduced several important methodological and data improvements that allowed a more detailed local assessment of these risks.

For heatwaves, the hazard assessment was improved by using locally downscaled climate scenario data to estimate the occurrence of heatwave days for the mid-term period 2021–2050 and the long-term period 2071–2100 under selected future climate scenarios. For the refined local assessment, CMIP6-based SSP scenarios were used, mainly SSP2-4.5 and SSP5-8.5. For comparison with Phase 1, the results were related to the previous EURO-CORDEX-based outputs under RCP 4.5 and RCP 8.5. This enabled a more detailed local comparison with the Phase 1 EURO-CORDEX-based (Jacob et al., 2013) results.

For the heatwave risk assessment, new vulnerability data on vulnerable buildings without additional heat insulation, taken from the existing Trnava Climate Adaptation Strategy (Trnava, 2015) were combined with newly selected LST data. In Phase 2, LST images from both Landsat 8 and Landsat 9 were used from RSLab (Parastatidis et al., 2017). The image selection was improved by applying a new approach based on purchased measured air temperature data from SHMÚ. Only LST images from tropical days, defined as days with maximum daily air temperature above 30 °C, were selected. The period 2021–2025 was used to reflect more recent land-use conditions, while keeping at least a five-year period to obtain a more complete set of suitable LST images.

For agricultural drought, the new locally downscaled climate scenarios were successfully incorporated into the CLIMAAX agricultural drought hazard workflow. The workflow script was adapted to work with higher-resolution scenario data, while the computational logic remained unchanged. The locally downscaled scenarios were used to estimate yield loss caused by precipitation deficit. For the risk assessment, local vulnerability data on available irrigation infrastructure and exposure data on observed planted crop areas were included. This allowed the assessment to better reflect local agricultural conditions in the Trnava area.

The purchased climate model data are therefore one of the central Phase 2 outputs. They enabled the same methodological logic to be applied at a spatial resolution more appropriate for Trnava, and they created a clearer bridge between the CLIMAAX workflow outputs and local decision-making needs.

The Phase 2 assessment therefore continued to focus on heatwaves and agricultural drought, as these hazards are highly relevant for Trnava. Heatwaves affect densely built-up urban areas, vulnerable population groups, and vulnerable public buildings, while agricultural drought affects crop production, revenue loss, irrigation demand, and agricultural planning. Further improvements would benefit from updated building condition data, detailed health impact data, continuous land-use updates, and long-term monitoring of irrigation infrastructure functionality.

2.2.2 Choose Scenario

For Phase 2, future climate conditions were considered through locally downscaled climate scenario datasets. For the heatwave assessment, the focus was on the occurrence of heatwave days, calculated using the CLIMAAX-recommended EuroHEAT methodology. In contrast to Phase 1, this methodology was applied to new locally downscaled climate scenarios, which are expected to provide more suitable results for a relatively small area such as Trnava.

The same locally downscaled scenarios were also applied in the agricultural drought workflow to estimate potential future yield and revenue losses. For both workflows, selected SSP scenarios were considered, mainly SSP2-4.5 and SSP5-8.5, with the main focus on SSP5-8.5. SSP2-4.5 was treated as a medium-emission scenario representing a less severe future development pathway, while SSP5-8.5 was used as a more conservative and pessimistic scenario to support preparedness planning for more severe future climate conditions. This approach supports the assessment of a wider range of possible future climate risks.

Future socio-economic developments were considered mainly through demographic vulnerability. Since the vulnerability and exposure data focus on vulnerable population groups over 65 years of age and under 5 years of age, population ageing in Slovakia was considered during the selection of indicators. This is important for future planning, as demographic ageing directly affects the vulnerability component of heatwave risk assessment.

Slovakia is one of the EU Member States most affected by population ageing. According to projected trends, Slovakia could become one of the countries with the oldest population in the EU by 2060 (Active ageing, 2016). This highlights the importance of considering older population groups in heatwave risk assessment and adaptation planning, especially in relation to public health, social care facilities, hospitals and other buildings with vulnerable users.

Future economic activities, food consumption, and food prices were not modelled directly in the assessment. However, the agricultural drought workflow considered potential yield and revenue losses for the main crops, which can indirectly indicate possible socio-economic impacts on agriculture, farmers, and local food production. These results therefore provide a proxy for possible future economic impacts of drought, although detailed modelling of market prices, food consumption, or future agricultural production systems was outside the scope of Phase 2.

Future climate conditions and future socio-economic developments were combined mainly during the vulnerability and exposure data selection process. Future climate conditions were represented by locally downscaled climate scenarios used in the heatwave and agricultural drought workflows. Future socio-economic developments were considered mainly through the selection of vulnerable population groups, especially people over 65 years of age and children under 5 years of age, as well as through the consideration of agricultural exposure and potential revenue losses. Therefore, socio-economic development was not modelled as a separate scenario, but was reflected through selected vulnerability and exposure indicators relevant for Trnava.

These aspects will also be considered during the preparation of the final document, which will support resilient planning and the update of the existing Trnava Climate Adaptation Strategy.

Since short-term adaptation measures are already considered in Trnava urban planning, the analysis focused mainly on the medium-term horizon 2021–2050 and the long-term horizon 2071–2100. These time horizons were selected to assess how heatwave and agricultural drought risks may develop in the future and to support long-term resilient planning. The medium-term horizon is relevant for current strategic and investment planning, while the long-term horizon supports preparedness for more severe climate conditions towards the end of the century.

2.3 Regionalized Risk Analysis

The selected CLIMAAX workflows were fine-tuned to the Trnava context by supplementing and, where appropriate, replacing European-scale EURO–CORDEX input data with a spatial resolution of approximately 12 × 12 km (CDS Heat, 2019) with local and higher-resolution datasets with a spatial resolution of 500 × 500 m. In Phase 2, locally downscaled and bias-corrected climate scenarios, measured air temperature data, local LST data, vulnerable building data, crop distribution data, and irrigation infrastructure data were integrated into the assessment.

For heatwaves, the EuroHEAT methodology (CDS Heat, 2019) was applied to locally downscaled climate scenarios to estimate heatwave days for 2021–2050 and 2071–2100 under selected SSP scenarios. The assessment mainly focused on SSP2-4.5 and SSP5-8.5 to represent medium-emission and high-emission future climate conditions. The risk assessment was improved by using Landsat 8 and Landsat 9 LST images selected only for tropical days, based on measured SHMÚ air temperature data from relevant climatological stations in and around the Trnava area. The analysis focused on the recent period 2021–2025 to better reflect current land-use conditions.

For exposure and vulnerability, vulnerable population groups over 65 years of age and under 5 years of age were used, together with hospitals, social care facilities, and kindergartens without additional heat insulation. New local outputs included urban heat islands above 40 °C, cooling spots below 35 °C, vulnerable buildings located inside heat islands, and updated heatwave risk matrix results. The 40 °C LST threshold was used as a practical local indicator of high heat stress for spatial prioritisation, rather than as a formal legal or health-based limit.

For agricultural drought, locally downscaled climate scenarios were incorporated into the CLIMAAX workflow to estimate yield loss caused by precipitation deficit. Local crop distribution data for 2018–2025 were used for exposure, focusing on wheat, maize, rapeseed, and barley. Irrigation infrastructure availability was used as the vulnerability indicator. The main risk output was potential revenue loss for the selected crops, supported by estimates of projected yield reduction under selected SSP scenarios and future time horizons.

Indirect impacts were considered qualitatively, including pressure on health and social care services, adaptation needs for public buildings, pressure on irrigation systems, reduced farmer income, and possible food price vulnerability. The main limitations are related to climate scenario uncertainty, limited cloud-free satellite images, uncertainty in gridded population data, and the need to update building condition and irrigation infrastructure data, including the operational functionality of irrigation systems, in the future.

2.3.1 Hazard #1 Heatwaves - fine-tuning to local context

Table 2-1 Data overview for workflow #1.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Locally downscaled CMIP6 climate scenarios with spatial resolution of 500 x 500 m, daily variables: max, min air temperature, humidity, wind speed, and others relevant variables for 1981-2100 under selected SSP scenarios (SSP2-4.5 and SSP5-8.5), [purchased]	Vulnerable hospitals, health-care facilities, social care facilities and kindergartens without additional heat insulation (Trnava, 2015)	Spatial distribution of the hospitals, health-care facilities, social care facilities and kindergartens (Trnava, 2015)	Heat risk to vulnerable kindergartens and hospitals with poor heat isolation from the tropical days during 2021–2025
Derived heatwave indicators from local climate scenarios like: number of heatwave days, heatwave events, and tropical days [CLIMAAX methodology]	Vulnerable population groups aged 65+ and children under 5 years of age [Worldpop, (Humdata, 2024)]	Spatial distribution of vulnerable population groups [WorldPop, (Humdata, 2024)]	Heat risk for the vulnerable population groups from the tropical days during 2021–2025
Measured air temperature from relevant SHMÚ climatological stations in and around Trnava city. [purchased, SHMU]	Not applicable – used for hazard/LST image selection	Not applicable – used for hazard/LST image selection	Selection and validation support for tropical days used in the LST analysis
LST from Landsat 8 and Landsat 9 with spatial resolution of 30 x 30 m [RSlab, (Parastatidis et al., 2017)]	Not applicable – used as a spatial heat-stress indicator	Urban surface areas covered by selected Landsat scenes	Identification of urban heat islands above 40 °C and cooling spots below 35 °C

2.3.1.1 Hazard assessment

For the hazard assessment in Phase 2, local climate scenarios were purchased and used for the analysis and comparison with the EURO-CORDEX (CDS Heat, 2019) Phase 1 results. The selection of the GCM and RCM was based on the CLIMAAX Bias and Uncertainty Tool (CLIMAAX Handbook, 2025), as shown in Table 2-2. This comparison was used to maintain consistency with the Phase 1 workflow and to support the interpretation of differences between EURO-CORDEX and locally downscaled results. The GCM model ncc_noresm_m was selected, since the local climate scenarios were downscaled and bias-corrected directly from the GCM, without additional RCM downscaling. The new local scenarios provide a significant spatial resolution advantage, with a resolution of 500 × 500 m compared to approximately 12 × 12 km for the EURO-CORDEX data. The full methodology behind the creation of the purchased local climate scenarios is provided in the annex (Locally downscaled climate scenarios, 2025).

Table 2-2 CLIMAAX bias and uncertainty tool: GCM/RCM comparison with the E-OBS reference dataset.

GCM	RCM	Temperature (C)	Precipitation (%)
ncc_noresm1_m	geric_remo2015	1.21	20.19
mpi_m_mpi_esm_lr	smhi_rca4	0.49	32.73
cnrm_cerfacs_cm5	knmi_racmo22e	-2.54	25.51
cnrm_cerfacs_cm5	cnrm_aladin63	-0.93	31.74
ncc_noresm1_m	**smhi_rca4**	**0.28**	**16.20**

The results based on the local climate scenarios provide an estimation of the climate-related heatwave variable: the occurrence of heatwave days for selected future periods and scenarios (Table 2-3). For the estimation of heatwaves, the same EuroHEAT methodology (CDS Heat, 2019) was applied as in Phase 1, with the aim of enabling a direct comparison for the selected future assessment periods 2021–2050 and 2071–2100 under two scenarios: SSP2-4.5 and SSP5-8.5. For comparison with Phase 1, the corresponding EURO-CORDEX-based results under RCP 4.5 and RCP 8.5 were also used. This methodology uses daily maximum and minimum temperature, together with humidity and wind speed:

$$Tappmax = Tasmax + 0.33 \times e - 0.70 \times wind - 4.0$$

$$e = RH / 100 \times 6.105 \times \exp((17.27 \times Tasmax) / (237.7 + Tasmax)),$$ (Steadman et al., 1979).

Table 2-3 Mean number of heatwave days based on locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m and EURO-CORDEX climate scenarios with a spatial resolution of 12 × 12 km.

Variable	SSP2-4.5 / RCP 4.5 equivalent		SSP5-8.5 / RCP 8.5 equivalent	
	2021-2050	2071-2100	2021-2050	2071-2100
Mean number of heatwave days (500x500m)	17.6	28.3	25.2	49.7
Mean number of heatwave days (12x12km)	11.2	18.3	12.8	37.5

The results presented in Table 2-3 show that the locally downscaled climate scenarios estimate a significantly higher number of heatwave days than the EURO-CORDEX-based Phase 1 results. This is an important result that needs to be considered in future urban planning in the city of Trnava. An example of the spatial resolution difference between the locally downscaled climate scenarios and EURO-CORDEX (CDS Heat, 2019) data is shown in Figures 2-2.

The next step was to incorporate the new approach for selecting LST maps developed by RSLab (Parastatidis et al., 2017). With the support of the project, measured air temperature data were purchased and used in the analysis. The measured air temperature data from three climatological stations in the Trnava area were used to select only LST images corresponding to tropical days, defined as days when the maximum daily air temperature reached or exceeded 30 °C.

For Phase 2, LST images from Landsat 9 were also included. This, in combination with Landsat 8, improved the temporal availability of suitable satellite images and shortened the effective image availability interval from approximately 16 days to approximately 8 days (NASA, 2021). The selected time period was also adjusted, as the analysis aimed to focus on more recent conditions and avoid potentially misleading values reflecting older land-use patterns. Therefore, the period 2021–2025 was selected. Based on the available data, no major land-use changes were identified during this period.

It was important to keep at least a five-year period because LST image availability is limited by the satellite revisit interval of 8–16 days, and cloud cover further reduces the number of images suitable for analysis. The differences between the Phase 1 and Phase 2 results are significant, as shown in Figures 2-3 and 2-4.

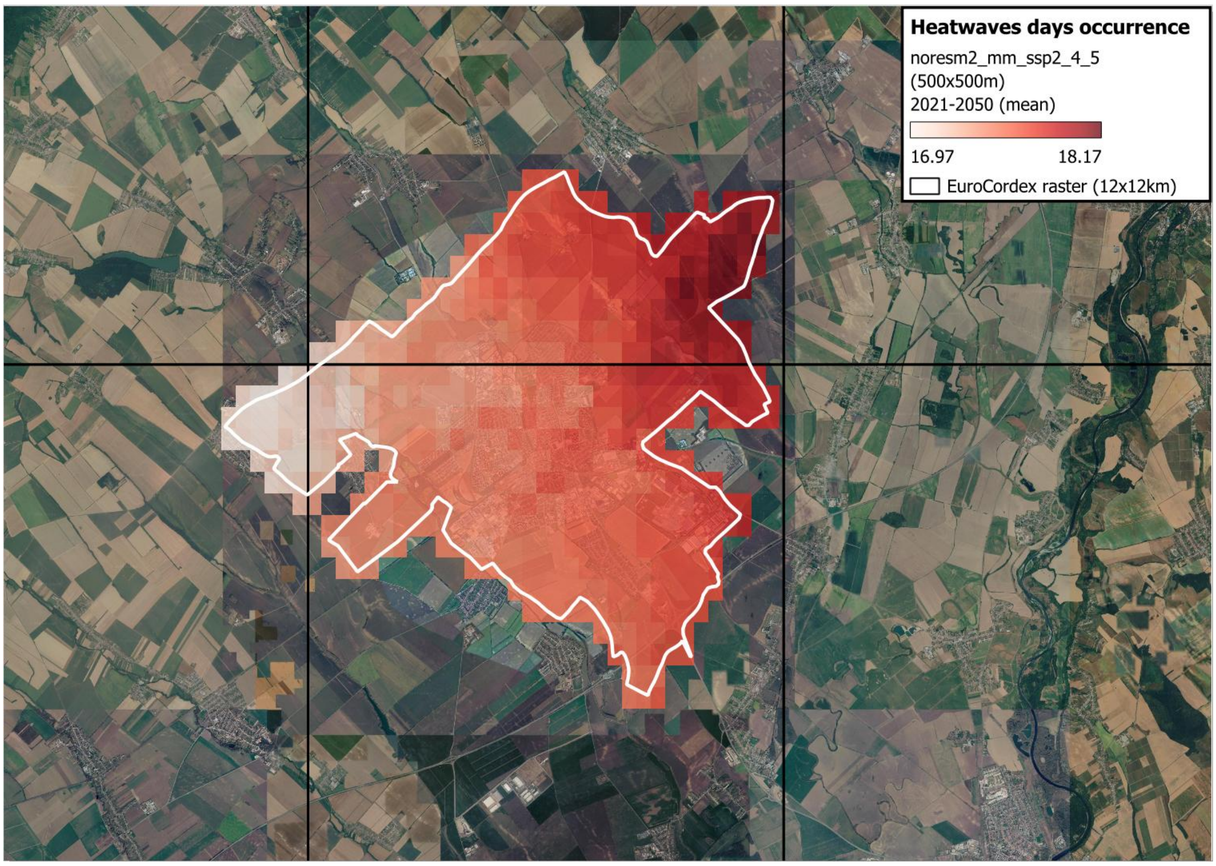

Figure 2-2 Mean number of heatwave days based on locally downscaled climate scenarios with a spatial resolution of 500 × 500 m, compared with the EURO-CORDEX raster grid with a spatial resolution of 12 × 12 km.

The Phase 2 approach shows a broader expansion of the urban heat island effect. The analysis mainly focuses on densely populated and built-up areas of the city. It also indicates the potential influence of the surrounding agricultural landscape, which can reflect and emit a significant amount of heat during tropical summer days.

The Phase 2 analysis focuses primarily on identifying urban heat islands that are suitable for the application of heat mitigation measures. At the same time, it highlights potential cooling spots where surface temperatures remain below 35 °C during tropical days. The spatial pattern of LST during tropical days in 2021–2025 is shown in Figure 2-4.

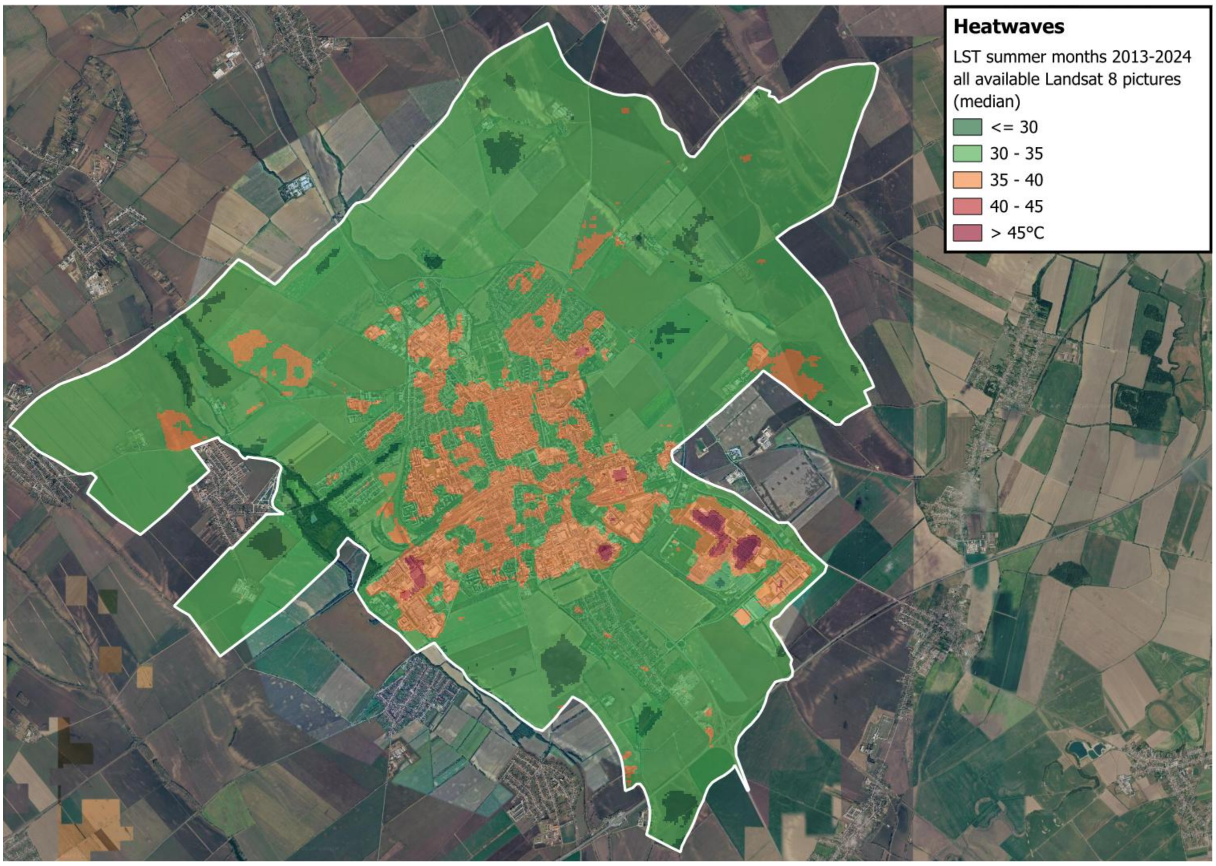

Figure 2-3 Median LST based on all available Landsat 8 images for the summer months during 2013-2024.

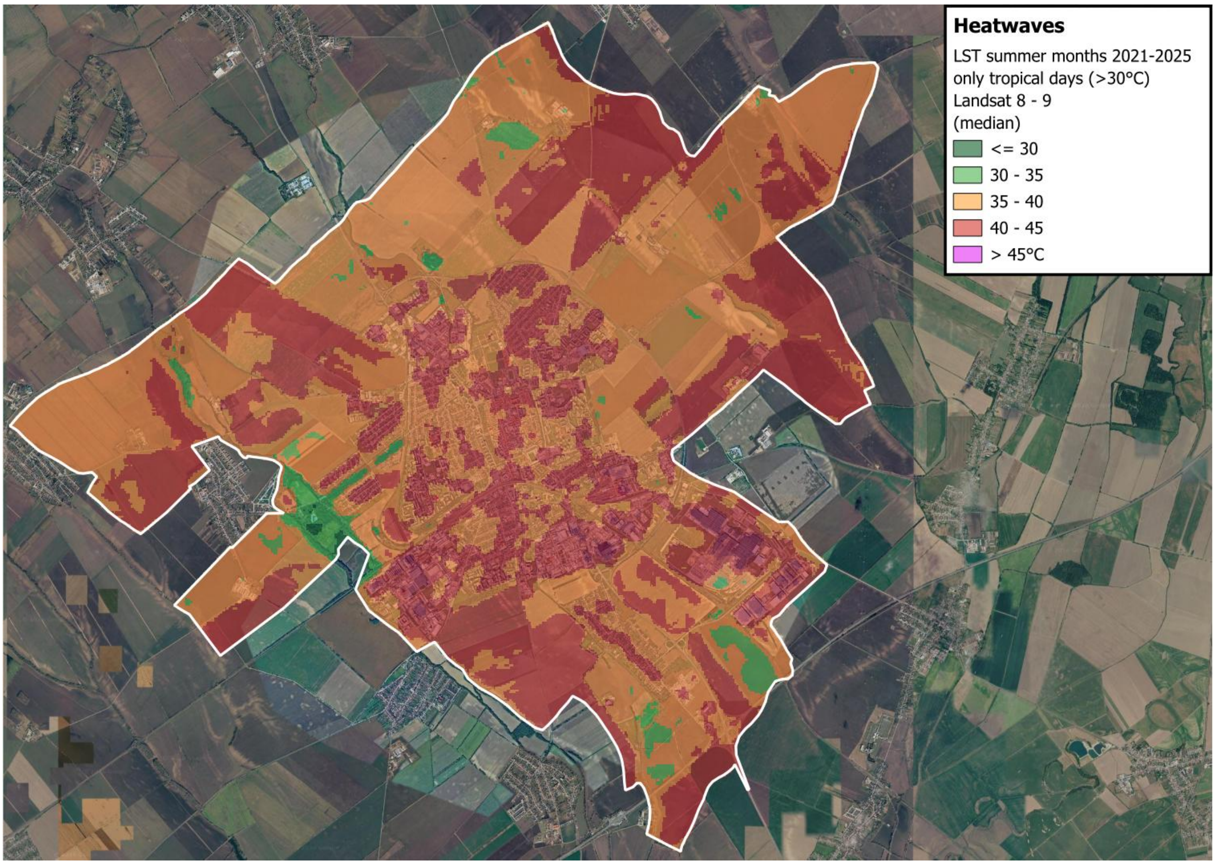

Figure 2-4 LST for tropical days, defined as days with maximum daily air temperature above 30 °C, derived from Landsat 8 and Landsat 9 for the period 2021–2025.

The identification of urban heat islands and cooling spots was based on two locally estimated thresholds. A threshold of 40 °C was used to identify heat islands, as this value also represents high to extreme LST conditions in other publications, such as Samb et al., (2026) and Dang et al., (2020). A threshold of 35 °C was used to identify the coolest parts of the city during tropical summer days. These thresholds were used as practical local indicators for spatial prioritisation, not as formally adopted legal or health-risk limits.

The results are displayed in Figure 2-5. To support better localization, the identified heat islands and cooling spots were divided into separate areas and named according to the most dominant or characteristic building, land use, or area located within them. In the next step, these areas were overlaid with vulnerable buildings without additional heat insulation to identify locations where heat exposure may be particularly relevant for public services and vulnerable users.

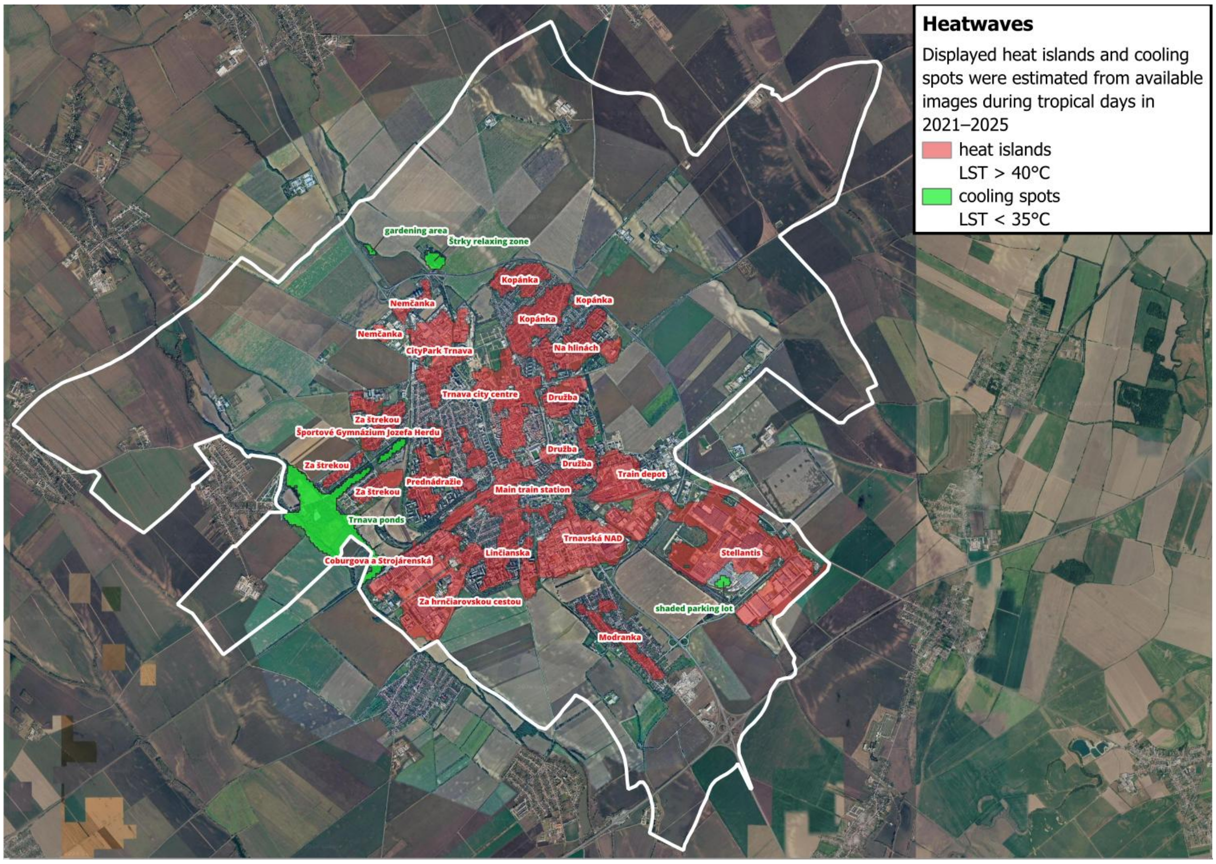

Figure 2-5 Estimated heat islands and cooling spots based on LST during tropical days in the period 2021-2025.

2.3.2 Exposure and Vulnerability

For the exposure and vulnerability assessment, data on the density of vulnerable population groups, specifically people over 65 years of age and children under 5 years of age (Figure 2-6), were selected from WorldPop (Humdata, 2024) and combined with the newly selected LST data for tropical days during 2021–2025.

Another addition in Phase 2 was the selection of vulnerable buildings occupied by vulnerable groups, including patients and persons with health conditions, senior citizens, and children under 5 years of age. These included hospitals, social care facilities, and kindergartens without additional heat insulation, based on the Trnava Climate Adaptation Strategy (Trnava, 2015). An overview of the vulnerable building categories and the number of buildings without additional heat insulation is provided in Table 2-4.

The combination of these vulnerable buildings with LST data and the projected occurrence of tropical days highlights the most urgent areas for the implementation of heat mitigation measures. The estimated heatwave-related indicator, represented by the occurrence of heatwave days, further emphasizes the urgency of these interventions.

Table 2-4 Vulnerable buildings without additional heat insulation under future climate conditions.

Building category	Vulnerable group	Total number	Number without heat insulation
Kindergartens	Children under 5 years of age	27	19
Hospitals	Patients and persons with health conditions	3	3
Social care facilities	Senior citizens over 65 years of age	4	4

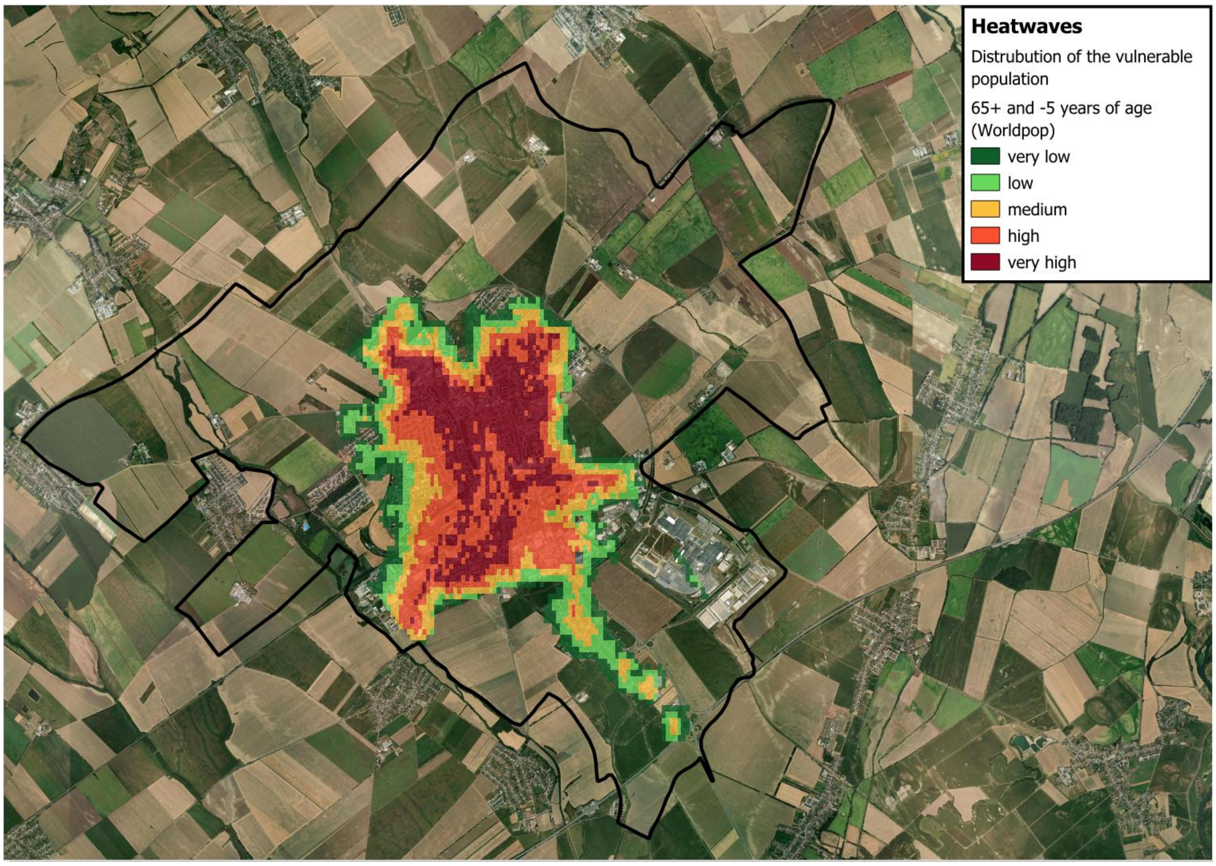

Figure 2-6 Distribution of the vulnerable population groups within build-up area of Trnava based on WorldPop (Humdata, 2024).

2.3.2.1 Risk assessment

For the Phase 2 risk assessment, vulnerable buildings, including hospitals, health-care and social care facilities, kindergartens, and selected school facilities, were selected and combined with LST data derived from tropical days. From all exposed vulnerable buildings, only those located within the estimated urban heat islands were selected (Figure 2-7). Based on these results, a map and table of the selected buildings were produced to identify facilities where heat exposure may be particularly relevant for vulnerable users and public services (Table 2-5).

Figure 2-7 Heat risk to vulnerable buildings inside the Trnava city, only buildings inside the heat islands.

In the second part of the assessment, a risk matrix was applied using the distribution of the vulnerable population and the newly selected LST data for tropical days during the period 2021–2025. The main difference compared to Phase 1 was that only the urban part of the city was selected for the analysis, excluding croplands and surrounding areas. These surrounding areas could mislead the focus away from urban areas, particularly because the original workflow uses equal-quantile classification.

The second major change was the use of newly estimated LST data derived only from tropical days, defined as days with maximum daily air temperature above 30 °C, for the more recent land-use period 2021–2025. This approach better captures heat risk during days when heat stress is most relevant for the population and urban adaptation planning.

Table 2-5 Selected buildings with the high heat risk (LST (hazard) + vulnerable buildings (vulnerability)) inside the Trnava city.

Building	Address	Additional heat insulation available	LST temperature zone
Kindergarten	Botanická 12	no	≥ 40 °C
Kindergarten	Hodžova 40	no	≥ 40 °C
Kindergarten	Limbová 4	yes	≥ 40 °C
Kindergarten	Okružná 27	no	≥ 40 °C
Kindergarten	Vajanského 3	yes	≥ 40 °C
Kindergarten	V Jame 3	no	≥ 40 °C

Building	***Address***	***Additional heat insulation available***	***LST temperature zone***
Kindergarten	Ružindolská 8	no	≥ 40 °C
Kindergarten and primary school	Atómová 1	no	≥ 40 °C
Kindergarten	Okružná 19	no	≥ 40 °C
Kindergarten and primary school	K. Mahra 11	yes	≥ 40 °C
Kindergarten	Ľudová 27	yes	≥ 40 °C
Kindergarten and primary school	Vančurova 38	no	≥ 40 °C
Kindergarten	Markovičova 1	unspecified	≥ 40 °C
Kindergarten and primary school	Halenárska 45	unspecified	≥ 40 °C
Hospital	Starohájska 2	no	≥ 40 °C
Health care centre	Mozartova 3	no	≥ 40 °C
Children's integration center	Čajkovského 55	no	≥ 40 °C

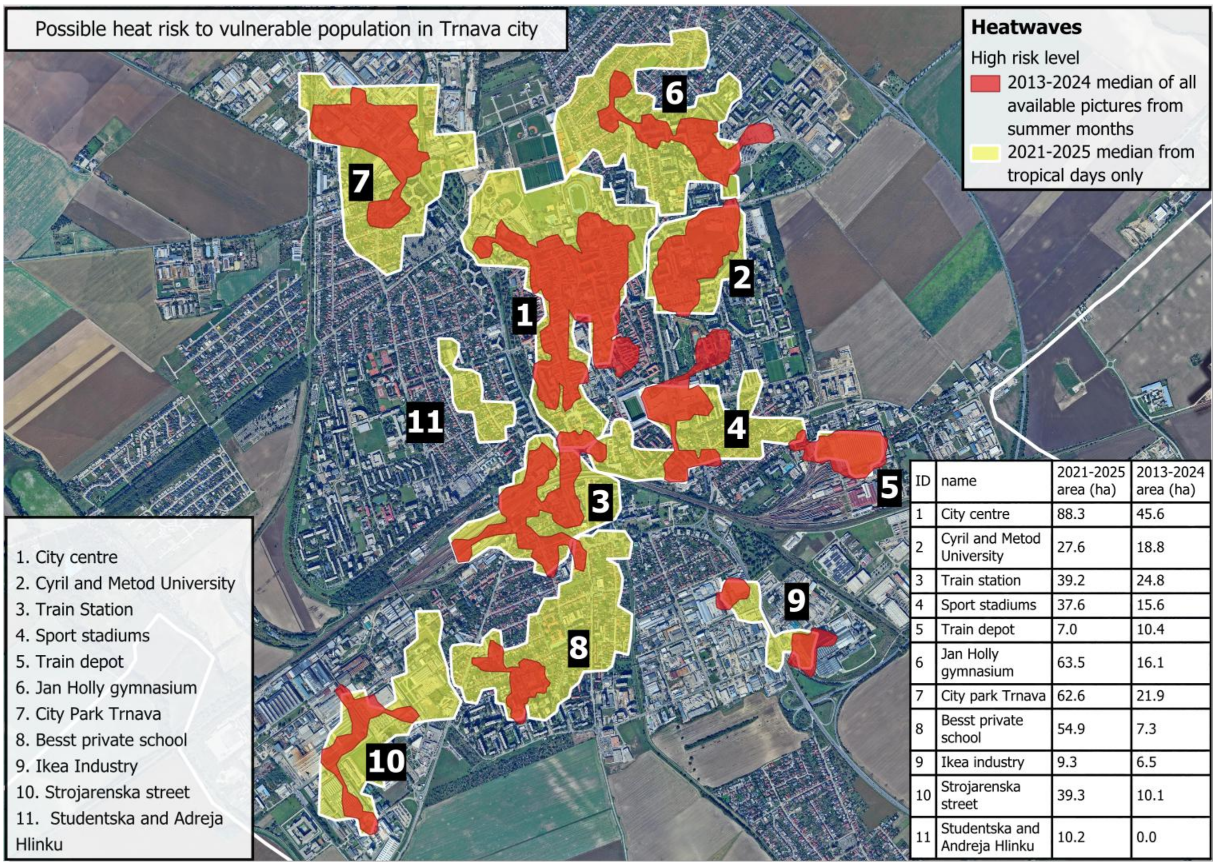

Figure 2-8 Heat risk to vulnerable population within the city of Trnava based on comparison of LST from all available Landsat 8 images from the summer months 2013-2024 and LST from only from Landsat 8 and Landsat 9 images during tropical days (above 30°C) in 2021–2025.

Table 2-6 Estimated area from the zones with the high and very high-risk level based on the 2013-2024 all summer days and 2021-2025 tropical days only (above 30°C).

ID	Name of the area	2013-2024 area (ha)	2021-2025 area (ha)
1	City centre	45.6	88.3
2	Cyril and Metod University	18.8	27.6
3	Train station	24.8	39.2
4	Sport stadiums	15.6	37.6
5	Train depot	10.4	7.0
6	Jan Holly gymnasium	16.1	63.5
7	City park Trnava	21.9	62.6
8	Besst private school	7.3	54.9
9	Ikea industry	6.5	9.3
10	Strojarenska street	10.1	39.3
11	Studentska and Andreja Hlinku	NA	10.2

The new heatwave risk matrix results highlighted several changes in the identification of the most urgent zones in terms of vulnerable population exposure. Zone 1 – City Centre, Zone 6 – Ján Hollý Gymnasium, Zone 7 – Trnava City Park, and Zone 8 – BESST Private School showed an increase in high-risk areas. In addition, a completely new high-risk area, Zone 11 – the crossroads of Študentská Street and Andreja Hlinku Street, was identified.

Based on the Phase 2 results for the heatwave hazard and risk assessment, selected parts of the city of Trnava show very high heat exposure and risk potential. The LST maps and Figure 2-8, based only on tropical days during the period 2021–2025, defined as days with maximum daily air temperature above 30 °C, highlight the importance of LST image selection and show how this selection can affect the estimation of heat risk. The heat risk assessment for vulnerable buildings shows that 50% of these buildings, representing 17 out of 34 buildings, are located in areas with LST values above 40 °C. The heat risk assessment for the vulnerable population highlights the most urgent areas across the city, as shown in Figure 2-8 and Table 2-6. The heatwave days hazard scenarios further emphasize the urgency of implementing possible adaptation measures. The projected heatwave occurrence for the mid-term period 2021–2050 and the long-term period 2071–2100 indicates a potential doubling of heatwave day occurrence in the future.

2.3.3 Hazard #2 Agricultural drought - finetuning to local context

Table 2-7 Data overview for workflow #2.

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m, including daily maximum and minimum air temperature, relative humidity, wind speed, potential evapotranspiration and solar radiation, for 1981–2100	Local map of irrigation availability (RPI, 2025)	Local crop production and crop distribution maps for 2018–2025 (PPA, 2025)	Estimated yield loss and potential revenue loss for maize, wheat, rapeseed and barley [CLIMAAX, methodology]

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
under selected SSP scenarios, mainly SSP2-4.5 and SSP5-8.5			

2.3.3.1 Hazard assessment

The main objective of Phase 2 was to introduce locally downscaled and bias-corrected CMIP6 climate scenarios and apply them within the CLIMAAX agricultural drought hazard and risk workflow. The Phase 1 results were based on European-scale EURO-CORDEX (CDS Drought, 2019) data. Other factors expected to improve the quality of the results included the use of a local irrigation availability map and local crop distribution and production maps for the period 2018–2025.

In the first step, the CLIMAAX Bias and Uncertainty Tool was applied to select the most suitable GCM–RCM combination for comparison with the original EURO-CORDEX-based Phase 1 workflow (Table 2-8). The locally downscaled CMIP6 scenarios were then used as the main input for the refined Phase 2 agricultural drought assessment.

Table 2-7 the GCM and RCM selection for the EURO-CORDEX comparison and local climate scenarios analysis, based on the CLIMAAX bias and uncertainty tool.

GCM	RCM	Temperature (C)	Precipitation (%)
ncc_noresm1_m |	geric_remo2015	1.21	20.19
mpi_m_mpi_esm_lr	smhi_rca4	0.49	32.73
cnrm_cerfacs_cm5	knmi_racmo22e	-2.54	25.51
cnrm_cerfacs_cm5	cnrm_aladin63	-0.93	31.74
ncc_noresm1_m	**smhi_rca4**	**0.28**	**16.20**

In the next step, the four most frequently cultivated crops in the Trnava area during the analysed period were selected based on the crop production table for the period 2018–2025 (Table 2-9). Maize, wheat, rapeseed, and barley together represent almost 86% of the cumulative planted crop area recorded in the Trnava area during the analysed period, based on local crop production statistics (PPA, 2025). The remaining share of the total analysed cumulative planted crop area was grouped as other crops and was not further analysed in the agricultural drought workflow.

Table 2-8 The cumulative planted area of the crop fields within the Trnava area for the period 2018-2025, including the share of selected crops and other crops in the total analysed crop area.

Crop	Cumulative planted area 2018–2025 [ha]	Share of total analysed crop area [%]
Wheat	6073.3 ha	32.2%
Maize	5358.6 ha	28.4%
Rapeseed	3436.3 ha	18.2%
Barley	1356.9 ha	7.2%
Other crops	2641.3 ha	14.0%
Total analysed crop area	18866.4 ha	100%

Subsequently, the first step of the agricultural drought hazard workflow was run using both EURO-CORDEX data, with an approximate spatial resolution of 12 × 12 km, and locally downscaled CMIP6 data, with a spatial resolution of 500 × 500 m. The hazard workflow provided an estimation of crop-specific yield loss caused by precipitation deficit (Figures 2-9 and 2-10). The results enabled a clear visual and analytical comparison (Table 2-10).

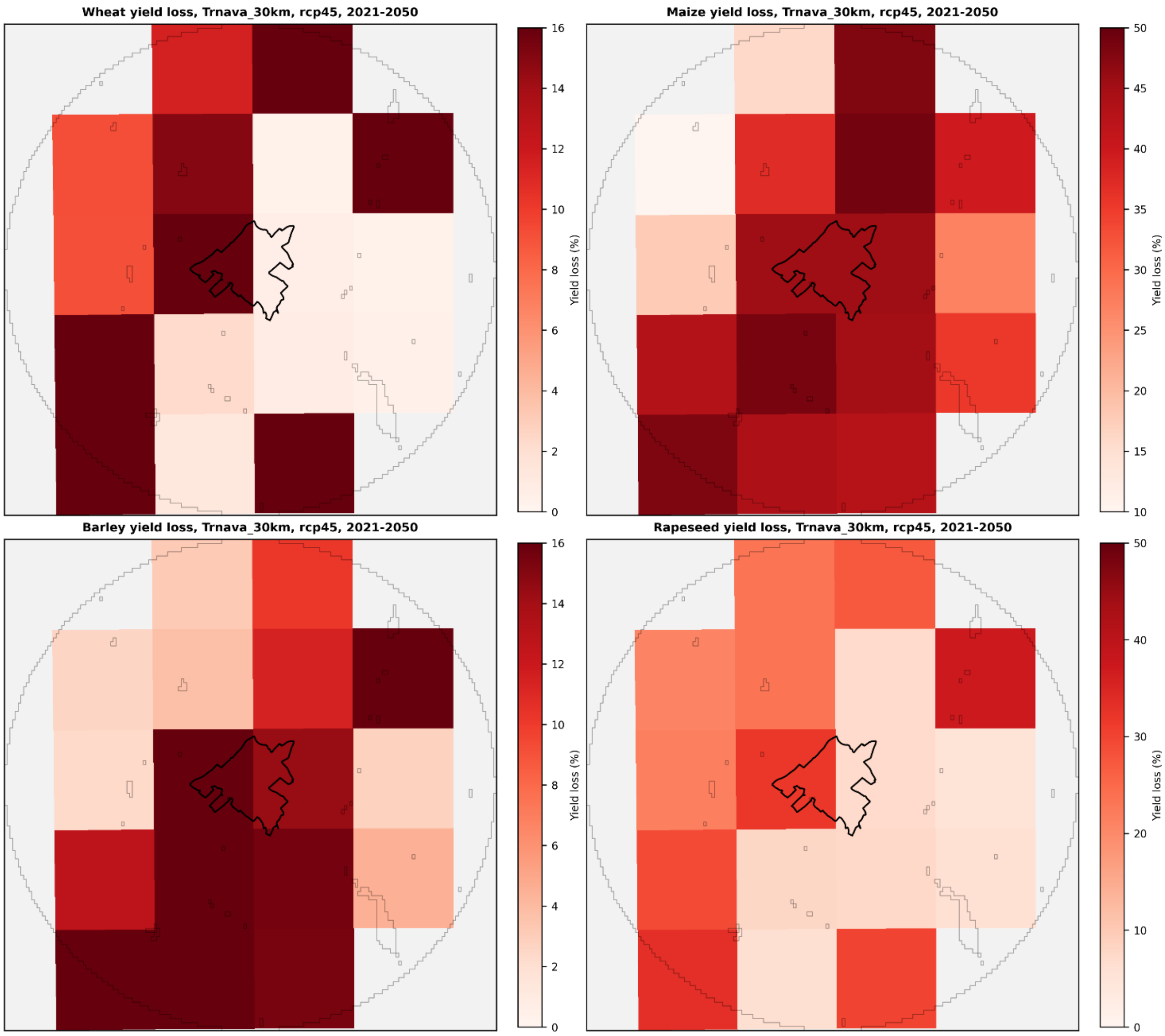

Figure 2-9 Projected yield losses for selected crops based on EURO-CORDEX (CDS drought, 2019) climate scenarios with an approximate spatial resolution of 12 × 12 km for the Trnava area, RCP 4.5, period 2021–2050.

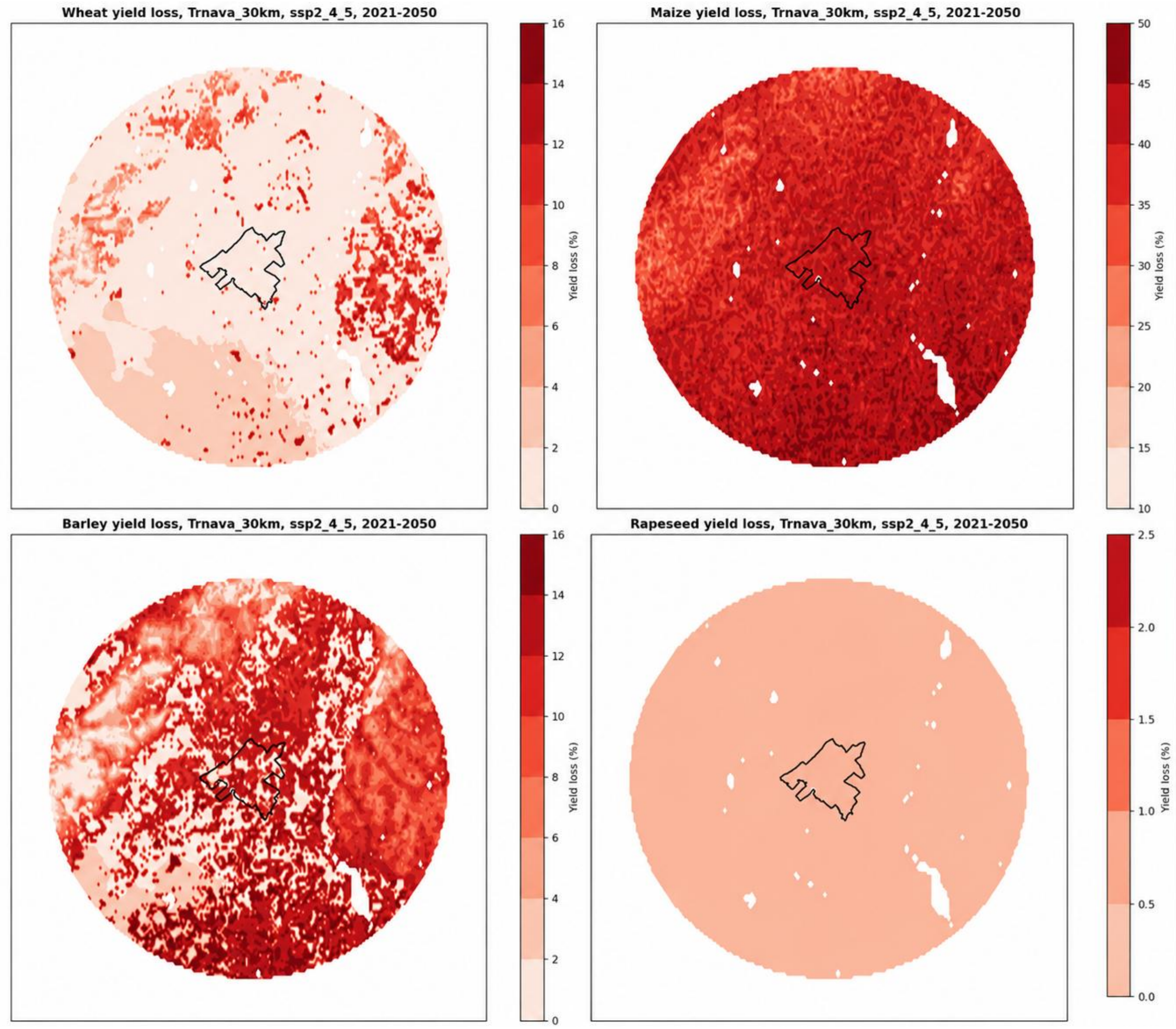

Figure 2-10 Projected yield losses for selected crops based on locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m for the Trnava area, SSP2-4.5, period 2021–2050.

The comparison shows that differences in the results may be partly explained by the different spatial resolutions of the EURO-CORDEX data (Figure 2-9) and local data (Figure 2-10), as well as by differences between the climate model datasets and scenario frameworks used in Phase 1 and Phase 2. The Phase 1 EURO-CORDEX results are based on CMIP5-driven regional climate model simulations under RCP scenarios, while the refined Phase 2 assessment uses locally downscaled and bias-corrected CMIP6 climate scenarios under SSP pathways. Therefore, the differences in the results should not be interpreted only as an effect of spatial resolution, but also as a combined effect of climate model generation, scenario framework, bias correction and the local suitability of the input climate data for the agricultural drought workflow. The most significant yield loss is projected for maize, reaching 41.6% in the mid-term future period 2021–2050 under the selected scenario.

Based on the visual and analytical comparison of the results, the decision was made to use the locally downscaled CMIP6 scenarios to estimate yield and revenue loss for the mid-term and long-term future periods under selected SSP scenarios, mainly SSP2-4.5 and SSP5-8.5.

Exposure and vulnerability

To improve the quality of the results, local exposure and vulnerability data were used. For the exposure assessment, it was necessary to select the most appropriate crops for the analysis. For this purpose, detailed local maps of crops planted within the Trnava area were used. Based on the cumulative area of planted crops during the period 2018–2025, the four crops with the largest cumulative planted area were selected: wheat, maize, rapeseed, and barley. Together, these crops represented 86% of the total analysed cumulative planted crop area during the period 2018–2025.

Another important factor is vulnerability, which is represented in the CLIMAAX agricultural drought risk workflow by irrigation availability. Figure 2-11 below shows the spatial distribution of the selected crops in 2025 together with the areas covered by irrigation infrastructure. Irrigation availability in the surroundings of the city of Trnava is relatively high. In total, 57% of the cropland area is covered by irrigation infrastructure. However, the presence of irrigation infrastructure, such as irrigation canals and hydrants, does not necessarily mean that it is regularly operational. This is an important factor that needs to be considered in future adaptation planning.

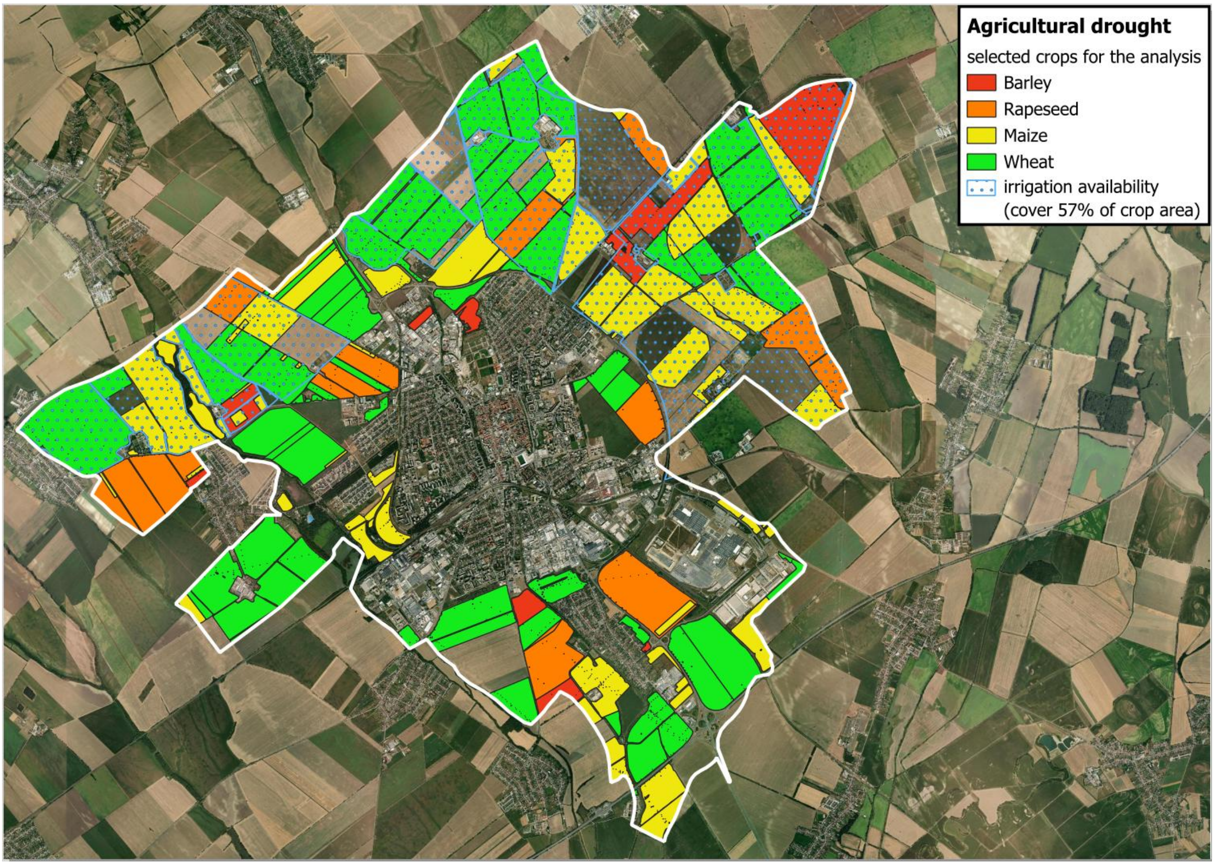

Figure 2-11 Spatial distribution of selected crops in 2025 and irrigation availability within the Trnava area (RPI, 2025).

2.3.3.2 Risk assessment

For the risk assessment, the CLIMAAX agricultural drought risk workflow was selected with the aim of estimating potential revenue loss for the selected crops. In the first step, the influence of the local high-resolution climate scenarios was tested by comparing the results with the Phase 1 EURO-CORDEX-based (CDS Drought, 2019) results.

The results presented in Table 2-10 and Figure 2-12 show that the differences can be significant. These differences may be caused by spatial resolution, which is a crucial factor for the relatively small area of Trnava. The difference in spatial resolution is shown in Figures 2-9 and 2-10.
While Figure 2-10 shows the locally downscaled CMIP6 outputs with a spatial resolution of 500 × 500 m, Figure 2-9 shows the coarser EURO-CORDEX outputs with an approximate spatial resolution of 12 × 12 km.
Another factor may be the quality and generation of the climate scenario itself. The new locally downscaled product is based on CMIP6 and SSP scenarios, while the Phase 1 EURO-CORDEX scenarios were based on CMIP5 and RCP scenarios. In addition, the downscaling level and the parameters used for downscaling may better capture local climate conditions and phenomena. Therefore, the observed differences should not be interpreted only as an effect of spatial resolution, but also as a combined effect of climate model generation, scenario framework, bias correction, downscaling approach, input variables and local suitability of the climate data used in the agricultural drought workflow.
The largest estimated difference was detected for rapeseed, reaching almost 20% in the tested period. The yield loss plots shown in Figure 2-10 indicate that this difference may be partly caused by grid size. The Trnava polygon is smaller than one EURO-CORDEX grid and lies on the border between two EURO-CORDEX grids with significantly different values. Therefore, one grid or the other can have a strong influence on the final result, potentially leading to misleading values. This is particularly visible for rapeseed, where the locally downscaled CMIP6 output indicates almost no yield loss, while the coarser EURO-CORDEX (CDS Drought, 2019) output indicates substantially higher losses. This result should therefore be interpreted with caution and mainly as an example of the sensitivity of the workflow to spatial resolution and input data.

Table 2-9 Yield reduction and revenue loss comparison between the refined Phase 2 local CMIP6 dataset with a spatial resolution of 500 × 500 m and the Phase 1 EURO-CORDEX dataset with an approximate spatial resolution of 12 × 12 km, GCM noresm2_mm, SSP2-4.5 / RCP 4.5 equivalent, period 2021–2050.

GCM	Mean projected yield losses [%] (maize/wheat)				Mean projected revenue losses per [€/km^2]			
SSP2-4.5/RCP 4.5 equivalent 2021-2050	maize	wheat	barley	rapeseed	maize	wheat	barley	rapeseed
Local CMIP6 (500x500m)	41.60	1.09	8.89	0	13502	227	877	0
EURO-CORDEX (12x12km)	44.04	10.56	7.05	19.52	14734	2049	747	1300

Based on the visual and analytical comparison of the results, the decision was made to use the locally downscaled CMIP6 scenarios to estimate yield and revenue loss for the mid-term and long-term future periods under selected SSP scenarios, mainly SSP2-4.5 and SSP5-8.5. The resulting spatial distribution of projected revenue losses for the selected crops under SSP2-4.5 for the period 2021–2050 is shown in Figure 2-12.

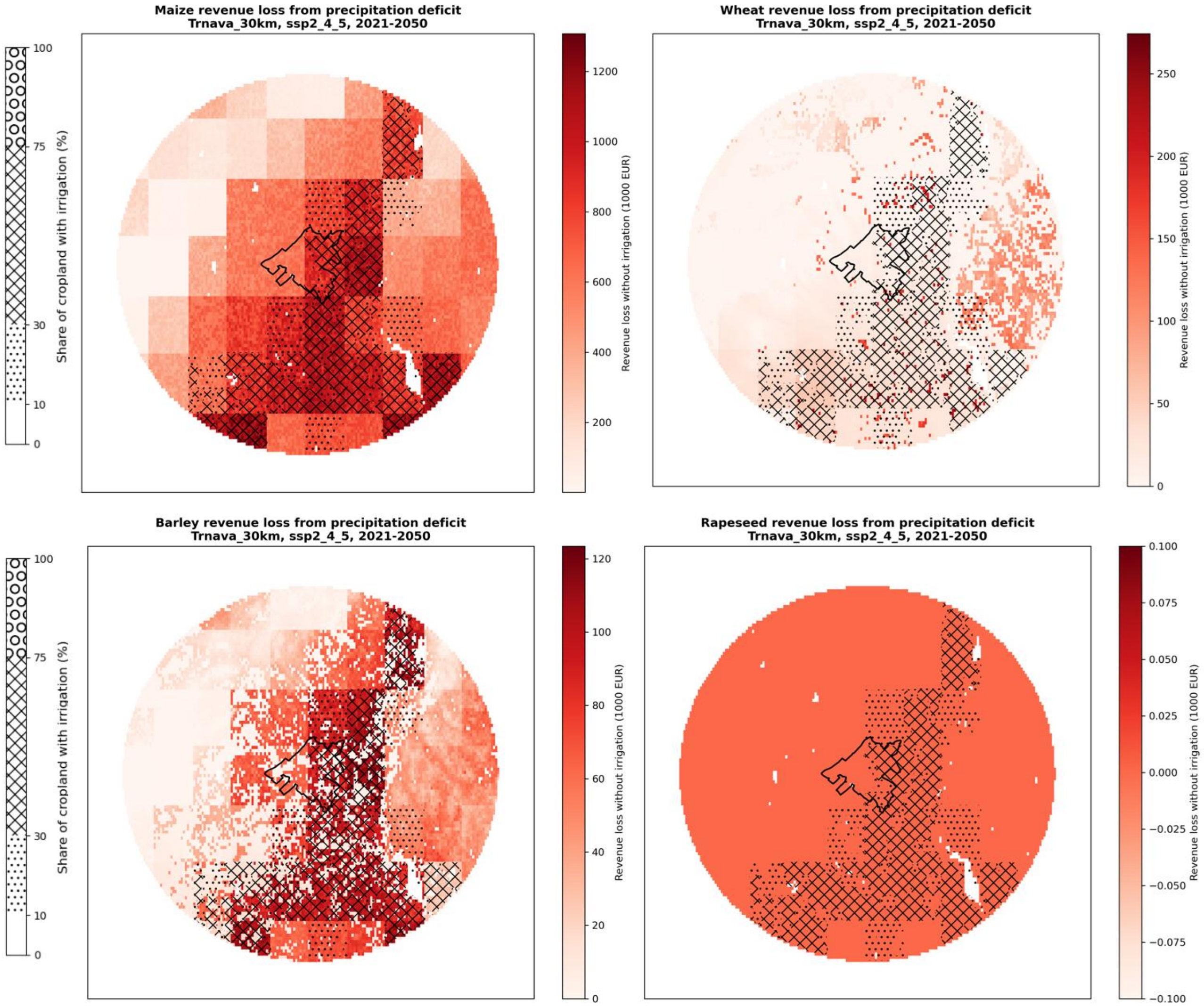

Figure 2-12 Projected revenue loss from precipitation deficit for selected crops based on locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m for the Trnava area, SSP2-4.5, period 2021–2050, GCM noresm2_mm. The hatching indicates the share of cropland with irrigation availability.

Table 2-10 Projected mean yield losses [%] and mean revenue losses [EUR/km²] for selected crops under SSP2-4.5 and SSP5-8.5 for the periods 2021–2050 and 2071–2100, based on locally downscaled CMIP6 climate scenarios with a spatial resolution of 500 × 500 m.

Local 500x500m noresm2_mm	*Mean projected yield losses [%]*				*Mean projected revenue losses [€/km²]*			
crops	*maize*	*wheat*	*barley*	*rapeseed*	*maize*	*wheat*	*barley*	*rapeseed*
SSP2-4.5 2021-2050	41.60	1.09	8.89	0	13 500	227	877	0
SSP5-8.5 2021-2050	45.66	1.39	7.46	0.06	14 800	286	793	4.21
SSP2-4.5 2071-2100	46.81	0.05	3.75	1.98	15 200	18.3	407	140
SSP5-8.5 2071-2100	**54.11**	**6.36**	**15.18**	**2.75**	**17 500**	**1 297**	**1 606**	**196**

The revenue loss results show potential losses for the four crops with the largest cumulative planted area in Trnava. The highest projected yield losses were estimated for maize, ranging from 42% to 54%, depending on the SSP scenario and time period. This is reflected in estimated revenue losses of 13,000–17,500 EUR/km². Such significant projected losses pose a major threat to maize production and should be considered in future agricultural planning.

The second-highest losses were projected for barley, ranging from 877 to 1,606 EUR/km². Wheat losses were generally lower, although they increased under the long-term high-emission scenario. Rapeseed showed very low projected losses in the local CMIP6 outputs, which should be interpreted with caution because of the strong difference compared with the coarser EURO-CORDEX results. The total projected losses for the selected eight-year period 2018–2025, based on the planted crop area, are presented in Table 2-12. These values represent total estimated revenue losses in EUR for the analysed crop areas, not mean losses per km².

Table 2-11 Total projected revenue losses estimated based on the observed planted crop areas during the period 2018–2025, using revenue loss information derived from the locally downscaled CMIP6 dataset with a spatial resolution of 500 × 500 m.

Category	Area sum 2018–2025 [km²]	SSP2-4.5 2021–2050 [€]	SSP5-8.5 2021–2050 [€]	SSP2-4.5 2071–2100 [€]	SSP5-8.5 2071–2100 [€]
Wheat	60.7 km²	13 779	17 360	1 111	78 728
Maize	53.6 km²	723 600	793 280	814 720	938 000
Rapeseed	34.4 km²	0	145	4 816	6 742
Barley	13.6 km²	11 927	10 785	5 535	21 842

The agricultural drought risk estimated through the CLIMAAX workflow poses a serious threat to the agricultural sector. However, the Trnava region is not unprepared. The sophisticated irrigation system, which covers 57% of the cropland area, provides a solid basis for adaptation. Nevertheless, the workflow results show that awareness is important, and that proper maintenance and further improvement of the irrigation system will be needed in the future. At the same time, the presence of irrigation infrastructure does not automatically mean that the system is fully operational or regularly used, which should be verified in future planning and monitoring. The results also indicate that maize production may be particularly vulnerable to future precipitation deficits, and should therefore be considered a priority crop in drought adaptation planning.

2.3.4 Additional assessments based on local models and data

The additional assessments were based on the integration of local datasets, purchased high-resolution climate scenarios, and locally adapted processing steps within the CLIMAAX workflows. In Phase 2, the original European-scale inputs were supplemented and refined by locally downscaled and bias-corrected CMIP6 climate scenarios with a spatial resolution of 500 × 500 m, measured air temperature data from SHMÚ stations, selected Landsat 8 and Landsat 9 LST images, local vulnerable building data, crop distribution maps, and irrigation infrastructure data. These additional assessments did not represent separate standalone workflows, but rather a local refinement of the original CLIMAAX workflow logic using more detailed and locally relevant input data.

For the heatwave workflow, the additional local assessment focused on the improved selection of LST images using measured air temperature data and the identification of urban heat islands and cooling spots during tropical days in 2021–2025. This enabled a more realistic spatial identification of exposed urban areas, and vulnerable buildings and priority locations for heat mitigation measures.

For the agricultural drought workflow, the additional local assessment focused on the use of local crop distribution data for 2018–2025 and irrigation availability data to refine the estimation of potential yield and revenue losses for the main crops in the Trnava area. The integration of local crop maps and irrigation infrastructure data made it possible to better reflect the actual agricultural exposure and vulnerability conditions around Trnava.

2.4 Key Risk Assessment Findings

The dashboard summarises the final qualitative evaluation of the two selected risk workflows. Severity was assessed separately for current and future conditions, while urgency and capacity were evaluated based on the expected need for action and the existing resilience and climate risk management capacity (Table 2-13).

Table 2-12 CLIMAAX evaluation dashboard for selected risk workflows

Risk Workflow	**Severity**		**Urgency**	**Capacity**	**Risk Priority**
	Current	Future		Resilience/ CRM	
Heatwaves	3	4	4	2	Very high
Agricultural Drought	2	3	3	3	Moderate

2.4.1 Mode of engagement for participation

The engagement process for the key risk assessment builds on the stakeholder activities described in Section 2.1.5. During Phase 1 and Phase 2, project goals, workflow selection, intermediate and final Phase 2 results, and possible applications of the project outputs were communicated through online workshops, expert discussions, conferences, on-site stakeholder meetings, dissemination activities, online media outputs, and the CLIMAAX SK group.

For the key risk assessment, the preliminary evaluation dashboard was prepared using the Phase 2 heatwave and agricultural drought results. The dashboard includes severity, urgency, resilience capacity, and overall risk priority. These preliminary scores were discussed and validated with stakeholders during the on-site meeting on 17 June 2026.

The discussion focused on whether the identified risk levels are locally relevant, understandable, and useful for adaptation planning, especially for the update of the Trnava Climate Adaptation Strategy (Trnava, 2015). Stakeholder feedback was used to confirm the practical relevance of the proposed scoring and to support the interpretation of the final risk priorities.

2.4.2 Gather output from Risk Analysis step

The key risk evaluation was based on the main quantitative outputs from the Phase 2 heatwave and agricultural drought risk analyses. These outputs were selected because they provide direct evidence for assessing severity, urgency, resilience capacity, and final risk priority.

For heatwaves, the evaluation used the projected occurrence of heatwave days based on locally downscaled climate scenarios. The results show that the mean number of heatwave days is projected to increase from 17.62 days in 2021–2050 to 28.32 days in 2071–2100 under SSP2-4.5, and from 25.2 days in 2021–2050 to 49.7 days in 2071–2100 under SSP5-8.5. These values are higher than the Phase 1 EURO-CORDEX-based results (CDS Heat, 2019), which are estimated to be 11.2 and 18.3 days for RCP 4.5 and 12.8 and 37.5 days for RCP 8.5. This indicates that the use of local climate scenarios provides a more critical assessment of future heatwave conditions in Trnava.

The heatwave risk evaluation also used the LST map from tropical days during 2021–2025, urban heat island areas above 40 °C, cooling spots below 35 °C, and vulnerable buildings located in high-temperature zones. The results show that 17 out of 34 vulnerable buildings, representing 50%, are located in areas with LST values above 40 °C. In addition, the estimated area of high and very high heat risk zones increased from 177.1 ha in the Phase 1 approach to 439.5 ha in the Phase 2 approach. The largest increases were identified in the City Centre, Ján Hollý Gymnasium area, Trnava City Park, and the BESST Private School area. A new high-risk area was also identified at the crossroads of Študentská Street and Andreja Hlinku Street.

For agricultural drought, the evaluation used projected yield losses, revenue loss estimates, local crop distribution data, and irrigation infrastructure availability. The four selected crops, wheat, maize, rapeseed, and barley, represent approximately 86% of the total analysed cumulative planted crop area in the period 2018–2025. The highest projected yield losses were estimated for maize, ranging from 41.6% to 54.11%, depending on the SSP scenario and time period. This corresponds to estimated revenue losses of approximately 13,500–17,500 EUR/km². The second-highest revenue losses were projected for barley, ranging from 877 to 1,606 EUR/km².

The total projected revenue losses calculated for the observed planted crop areas from 2018–2025 (PPA, 2025) range from approximately 0.75 million EUR under SSP2-4.5 for 2021–2050 to approximately 1.05 million EUR under SSP5-8.5 for 2071–2100. At the same time, the assessment shows that 57% of the cropland area is covered by irrigation infrastructure (RPI, 2025), which provides an important basis for adaptation but also highlights the need for future maintenance and improvement. However, the presence of irrigation infrastructure does not automatically mean that the system is fully operational or regularly used, which should be verified in future planning and monitoring.

These quantified outputs were used as the main evidence base for evaluating heatwaves as a very high-priority risk and agricultural drought as a moderate-priority risk in the Phase 2 key risk assessment.

2.4.3 Assess Severity

The severity of the selected risks was assessed using the four categories described in the Key Risk Assessment Protocol: limited, moderate, substantial, and critical. The assessment considered current evidence, future projections, exposed sectors, vulnerable groups, and the potential for cascading or irreversible impacts.

For heatwaves, the current severity was assessed as substantial. As shown in Phase 1, heat-related collapses are already repeatedly recorded during summer seasons in the Trnava Self-Governing Region. Phase 2 further confirmed that vulnerable buildings and population groups are exposed to high LST values, especially in densely built-up areas. The future severity was assessed as critical, because locally downscaled climate scenarios project a significant increase in heatwave day occurrence, especially under SSP5-8.5. Heatwaves therefore represent a direct and potentially severe threat to human health, public buildings, emergency services, and urban livability.

For agricultural drought, the current severity was assessed as moderate. The Trnava area is already exposed to drought, but the existing irrigation infrastructure reduces current vulnerability. The future severity was assessed as substantial, because Phase 2 results indicate significant projected yield and revenue losses, especially for maize and barley. Drought may affect crop production, farmer income, irrigation demand, urban greenery, and long-term agricultural planning.

Overall, heatwaves were assessed as the more severe risk because of their direct link to human health and vulnerable groups. Agricultural drought was also considered important, but its severity is partly reduced by the existing irrigation infrastructure. These preliminary severity levels were discussed with stakeholders during the on-site meeting on 17 June 2026 and were considered relevant for local adaptation planning.

2.4.4 Assess Urgency

The urgency of the selected risks was assessed using the four categories described in the Key Risk Assessment Protocol: no action needed, watching brief, more action needed, and immediate action needed.

For heatwaves, the urgency was assessed as immediate action needed. As described in the previous sections, heatwaves already affect vulnerable population groups in Trnava, and future climate scenarios indicate a significant increase in heatwave day occurrence. Since heatwaves can cause acute health impacts during individual summer events and may repeatedly occur every year, adaptation measures should be planned and implemented as soon as possible. Priority should be given to vulnerable buildings, densely built-up areas, and high-risk zones identified by the heatwave risk matrix.

For agricultural drought, the urgency was assessed as more action needed. Drought is a slower-onset and cumulative hazard, but the results indicate increasing future impacts on crop production, irrigation demand, and agricultural revenue. Existing irrigation infrastructure reduces the immediate urgency compared to heatwaves, but it does not remove the need for action. Maintenance, modernization, assessment of future water availability, and adaptation of crop selection will be needed to reduce future losses.

Overall, heatwaves were evaluated as the most urgent risk because of their direct link to human health and vulnerable groups. Agricultural drought was evaluated as a medium- to long-term urgent risk. The final urgency levels were discussed with stakeholders during the on-site meeting on 17 June 2026 and were used to support the final evaluation dashboard.

2.4.5 Understand Resilience Capacity

The resilience capacity was assessed using the categories low, medium, substantial, and high. The assessment considered existing measures, institutional capacity, available infrastructure, stakeholder awareness, and known weak points.

For heatwaves, the resilience capacity was assessed as medium. Trnava already has an adaptation strategy, experience with climate-oriented projects, and several implemented or planned measures, such as urban greening, shading, blue infrastructure, sponge city measures, and green roof requirements for large industrial halls. Short-term warnings for heat-related hazards are provided at the national level by SHMÚ, while the city is responsible for local response through infrastructure management, emergency services, and municipal planning.

However, several weak points remain. The existing adaptation strategy is partly outdated, and the city does not have a dedicated climate adaptation department. Some vulnerable buildings, including hospitals, social care facilities, and kindergartens, are in poor technical condition or are not sufficiently adapted to current and future heat stress. Therefore, although important measures and awareness already exist, the current capacity is not sufficient to fully address the projected increase in heatwave risk without further action.

For agricultural drought, the resilience capacity was assessed as substantial. The Trnava agricultural area has long-term experience with drought periods, and irrigation infrastructure is

already present across 57% of the cropland area. This provides an important physical basis for adaptation and reduces the immediate vulnerability of the agricultural sector compared to areas without irrigation infrastructure.
At the same time, this capacity depends on the future maintenance, modernization, and functionality of the irrigation system, as well as on future water availability. Additional measures, such as improved irrigation efficiency, drought-resilient crop selection, and better use of drought monitoring information, will be needed. Therefore, the current capacity for agricultural drought is relatively strong, but it should be further developed to remain effective under future climate conditions.

2.4.6 Deciding on Risk Priority

The final risk priorities were assigned based on the evaluation dashboard, using the previously assessed severity, urgency, and resilience capacity for each risk.
Heatwaves were assigned to be a very high-risk priority. This is mainly because they represent a direct threat to human health, especially for vulnerable population groups, and the climate scenarios indicate a significant future increase in heatwave day occurrence. Although adaptation activities already exist in Trnava, the current capacity is not sufficient to fully address the projected increase in heat risk without further action.
Agricultural drought was assigned a moderate risk priority. The risk is important for crop production, agricultural revenue, and irrigation planning, but it represents a more indirect and slower-onset threat compared to heatwaves. Existing irrigation infrastructure provides an important adaptation capacity, although further maintenance and improvement will be needed under future climate conditions.
The proposed risk priorities were discussed with stakeholders during the on-site meeting on 17 June 2026. Their feedback was used to confirm whether the assigned priorities reflect local experience, institutional capacity, and practical adaptation needs. The final evaluation therefore identifies heatwaves as the most urgent and highest-priority risk for Trnava, while agricultural drought remains an important moderate-priority risk requiring continued adaptation planning, irrigation-system maintenance, and monitoring of future crop-production impacts.

2.5 Monitoring and Evaluation

The second phase of the climate risk assessment showed that the integration of local data significantly improves the quality and usefulness of the results. The main lesson learned was that European-scale datasets are useful for initial screening, but they are often too coarse for detailed local planning in a relatively small area such as Trnava.
The greatest difficulties were related to gathering high-quality local and national climate-related datasets. Freely available data often lacked the required spatial resolution, temporal resolution, or climate variables needed for direct integration into the selected CLIMAAX workflows. Therefore, some key datasets, especially locally downscaled and bias-corrected climate scenarios and measured air temperature data, had to be purchased. This confirmed that local climate risk assessment requires not only methodological guidance, but also access to sufficiently detailed and locally relevant datasets.
Stakeholders play an important role in the Monitoring and Evaluation process by validating whether the mapped hotspots, identified risk priorities, and proposed interpretations of the Climate Risk Assessment correspond to local experience, institutional knowledge, and practical planning needs. Their feedback is used to check the plausibility of the heatwave and agricultural drought outputs,

identify missing local information, and refine the interpretation of results before they are translated into concrete adaptation measures in Phase 3.

The June 2026 stakeholder meeting and training activity represented an important step in this process. The event was attended by approximately 17 online participants and around 10 participants in person. After the presentation of the project results and CRA outcomes, stakeholders raised several questions and comments. The discussion focused mainly on the visibility of climate adaptation measures in the city, whether the project will also support practical implementation, and how precipitation amounts falling over the Trnava area were considered in the assessment. There was also interest in strengthening cooperation with relevant water-management actors, including SVP and the operators of the Trnávka watercourse.

Overall, the feedback confirmed that stakeholders are interested not only in the analytical results of the CRA, but also in their practical use for adaptation planning and policy support. The comments highlighted the need to clearly communicate how the assessment results can support future decision-making, prioritisation of adaptation measures, and cooperation between the city, water-management institutions, and other local actors. This feedback will be considered in Phase 3, particularly during the identification, discussion, and prioritisation of potential adaptation measures.

Learning was ensured through cooperation between the Trnava City Office and STU. Selected members of the Trnava City Office were introduced to the CLIMAAX tools and Handbook (CLIMAAX, Handbook) and guided on how local datasets can be incorporated into the workflows to produce climate risk assessment results.

This process helped to strengthen local technical capacity and improve the understanding of how CLIMAAX outputs can be interpreted and used for future adaptation planning.

New data became available during Phase 2 and significantly improved the understanding of both heatwave and agricultural drought risks. The locally downscaled climate scenarios provided new results for future heatwave days and agricultural drought impacts. In addition, measured air temperature data from SHMÚ and the availability of Landsat 9 LST data from RSLab (Parastatidis et al., 2017) improved the selection of relevant LST images for tropical days.

Further improvements would require updated data on the technical condition of vulnerable buildings, more detailed health impact data related to heatwaves, regular updates of land-use and crop distribution data, and information on the operational condition and future water availability of the irrigation infrastructure. Additional technical capacity within the city office would also help to maintain and update the assessment in the future.

As mentioned above, the final outcomes were communicated through conferences, online webinars, social media, the City of Trnava website, online media outputs such as the Trnavské rádio article and related podcast/interview published, and the CLIMAAX data repository. The results will also be summarized in a final document that will support and supplement the existing Trnava Climate Adaptation Strategy.

A dedicated monitoring system for the analysed risks is not yet fully in place. However, the preparation of a heat monitoring system will be considered as part of the updated adaptation planning process. This system should focus on the identified high and very high heat risk areas and vulnerable buildings, especially those exposed to LST values above 40 °C.

The monitoring system could support the regular evaluation of heat risk, help prioritize adaptation measures, and provide evidence for future updates of the Trnava Climate Adaptation Strategy.

In terms of agricultural drought, local agricultural companies will be encouraged to join the SHMÚ drought monitoring and prediction service for local reporters, known as Intersucho (Trnka et al., 2015). Through this service, they can contribute local observations and receive drought prediction information free of charge. This could help improve the local interpretation of drought conditions and strengthen the link between regional monitoring and farm-level adaptation decisions.

Stakeholder communication has worked well so far, although it will be important to see whether this cooperation continues after the end of the project. The cooperation between the Trnava City Office and the subcontracted team of experts from STU has also worked well.

The main challenge was the availability of suitable local and national climate-related datasets. Some freely available datasets did not provide the required quality, spatial resolution, temporal resolution, or variables needed for the Phase 2 workflows. Therefore, key datasets had to be purchased to improve the quality and local relevance of the results. This challenge was already partly addressed during Phase 2, but it remains relevant for future updates of the assessment.

The available resources were used according to the plan presented in the project proposal. The only delay was related to the purchase of locally downscaled climate scenarios. The initial price offer from SHMÚ was significantly higher than the planned budget, so an alternative data provider had to be identified.

Despite this delay, the resources were used efficiently, as the purchased datasets were directly integrated into the Phase 2 workflows and significantly improved the quality and local relevance of the results. The efficient use of resources had a positive impact on the CRA process. Although the purchase of local climate data was delayed during Phase 2, the results were still prepared on time. This was possible due to effective cooperation between the Trnava City Office and the STU expert team, as well as the direct integration of the purchased data into the selected CLIMAAX workflows. The delay had only a limited negative impact, mainly by reducing the time available for additional testing and interpretation of the final results. However, it did not prevent the preparation of the Phase 2 outputs or their use in stakeholder communication and dissemination activities.

The CRA has had a positive impact on improving the understanding of climate risks in Trnava. The project results need to be disseminated as effectively as possible to reach the wider community, stakeholders, and decision-makers, and to help them understand the potential impacts of climate change.

It is especially useful that the results were expressed through clear and understandable indicators, such as the increase in high-heat-risk areas and the estimation of potential agricultural monetary losses. These types of results are easier to communicate and can help increase public awareness, strengthen stakeholder engagement, support institutional capacity, and provide evidence for future funding and investment decisions. In this sense, the Monitoring and Evaluation process confirmed that the Phase 2 results are not only technically relevant, but also suitable for communication, strategic planning, and the preparation of concrete adaptation measures in Phase 3.

2.6 Work plan Phase 3

Phase 3 will focus mainly on the dissemination, practical use, and long-term sustainability of the Phase 2 climate risk assessment results. The main objective will be to communicate the key findings on heatwave and agricultural drought risks to local stakeholders, decision-makers, and the wider public in a clear and targeted way.

The results will be disseminated through several channels, including the City of Trnava website, social media platforms such as Facebook and Instagram, conferences, online communication activities, and stakeholder meetings. The CLIMAAX data repository will also be used to support transparent data sharing and long-term access to project outputs.

A key activity in Phase 3 will be the preparation of a final document that will support and supplement the existing Trnava Climate Adaptation Strategy. This document will focus on the selected workflows, heatwaves and agricultural drought, and will summarize the main risk findings, priority areas, and possible adaptation measures. Special attention will be given to the very high heatwave risk and the need for targeted heat mitigation measures in vulnerable areas and buildings, as well as to the agricultural drought results related to irrigation, crop selection, and revenue loss.

The CLIMAAX SK group will also be used as a platform for exchanging experience, inspiration, and good practices with other Slovak regions and cities involved in CLIMAAX and related projects. This will help to identify suitable dissemination approaches, improve the practical use of the results, and support the maximum targeted reach of the project outcomes.

3 Conclusions of Phase 2- Climate Risk Assessment

Phase 2 confirmed that heatwaves and agricultural drought remain the most relevant climate risks for Trnava within the scope of the TRACAP project. The refined assessment demonstrated that the use of locally downscaled and bias-corrected CMIP6 climate model data, measured air temperature data, recent Landsat LST information, local vulnerable building data, crop distribution data, and irrigation infrastructure data substantially improves the local relevance of the CLIMAAX outputs compared with the initial European-scale screening performed in Phase 1.

For heatwaves, the assessment identified high-risk urban areas, vulnerable public buildings and population groups exposed to elevated land surface temperatures. The results indicate that heatwaves should be treated as a very high priority risk because of their direct impact on human health, vulnerable groups, public services, and urban liveability. The Phase 2 results showed that 17 out of 34 vulnerable buildings without additional heat insulation are located in areas with LST values above 40 °C. In addition, the area classified as high and very high heat risk increased from 177.1 ha in the Phase 1 approach to 439.5 ha in the refined Phase 2 approach. The LST threshold of 40 °C provides a practical local indicator for identifying areas where targeted cooling, shading, greening and building-level adaptation measures should be prioritised.

For agricultural drought, the refined assessment quantified potential yield and revenue losses for the crops with the largest cumulative planted area in the Trnava area. The results show that drought risk is strongly linked to crop type, irrigation availability and future climate conditions. The highest projected yield losses were estimated for maize, ranging from approximately 42% to 54%, depending on the SSP scenario and future time horizon. Total projected revenue losses for the observed planted crop areas from 2018–2025 ranged from approximately 0.75 million EUR under SSP2-4.5 for 2021–2050 to approximately 1.05 million EUR under SSP5-8.5 for 2071–2100. Existing irrigation infrastructure provides an important resilience capacity, but its long-term effectiveness will depend on maintenance, modernisation, water availability, and the selection of more drought-resilient crops. The presence of irrigation infrastructure should therefore be understood as potential adaptation capacity, not as a guarantee of full operational functionality.

The main challenge of Phase 2 was the availability and cost of suitable high-resolution climate and local vulnerability datasets. This was addressed by purchasing locally relevant climate model data and by combining them with available local and national datasets. The main unresolved needs include more detailed health impact data, updated information on the technical condition of vulnerable buildings, regular crop and land-use updates, and better information on the future operational capacity of irrigation infrastructure. These data gaps should be considered in future updates of the assessment and in the design of local monitoring activities.

The results provide a direct evidence base for Phase 3, in which the focus should move from risk assessment to adaptation options, communication, integration into Trnava’s adaptation strategy, and the preparation of practical recommendations for urban greening, cooling spots, vulnerable buildings, irrigation planning and drought-resilient agriculture.

4 Progress evaluation

The Phase 2 deliverable directly builds on the Phase 1 climate risk assessment by refining both selected workflows with local data and higher-resolution climate model inputs. The main planned Phase 2 activities were achieved: high-resolution climate data were selected and purchased, the Heatwave and Agricultural Drought workflows were refined, selected representatives of the Trnava City Office were trained, and the results were communicated through scientific events, stakeholder communication and project dissemination outputs.

These outputs prepare the basis for Phase 3, which will focus on translating the refined risk assessment into adaptation priorities, improved risk-management planning, and practical recommendations for the City of Trnava. Particular attention should be paid to documenting the June 2026 training, the stakeholder meeting outcomes, public dissemination outputs, and the final list of datasets and maps uploaded to the CLIMAAX repository or Zenodo.

Table 4-1 Overview of key performance indicators.

Key performance indicators	***Progress***
2 CLIMAAX toolboxes successfully applied due M6 of the project (Heatwave, Drought) - Phase 1	**Done** – During Phase One, the Heatwave and Drought workflows were successfully applied, and initial results were prepared and visualized using QGIS software to meet the needs of the Trnava City Office.
At least 6 stakeholder groups involved in the activities of the project (Municipality, NGOs, first responders, representatives of the vulnerable population, healthcare system representatives, water management institutions). Phase 1, Phase 2 and Phase 3	**Done** – A group of stakeholders were created, informed and invited to the project workshops. In total, people from more than 10 different initiatives were involved in the First phase. (Trnava self-governing region, SVP, SHMU, SRZ Trnava, TAVOS, Ministry of Interior, 15 Mayors of surrounding cities and villages, ZZS SR, Local environmental initiatives Baterkaren and Youth for reality)
2 workshops (First in Phase1 and second in Phase3) executed throughout the project (presenting planned activities upon the start of the project, presenting achieved outcomes of the project). Phase 1 and Phase 3	**Done** – The first online workshop for stakeholders was held on 6 August 2025. The second on-site stakeholder meeting/workshop/dissemination activity was carried out on 17 June 2026, focused on the presentation and discussion of the refined Phase 2 results. Invitations and attendance lists for these activities were uploaded to Zenodo. Further dissemination and stakeholder communication activities are planned for Phase 3.
Disseminate the project results on Trnava city webpage, Facebook or Instagram. Phase 1, Phase 2 and Phase 3	**Done** – Information (press release) about the project was published on the City of Trnava's website, the city's social media, and through online media outputs, including the Trnavské rádio article and related podcast/interview – the recordings were uploaded to Zenodo. A project poster was created to inform the public and stakeholders about the project's implementation – it was published on the city's website and displayed in the premises of the City Hall accessible to the public and visitors.

At least one representative from the Trnava City Office trained to use the CLIMAAX toolbox. Phase 2	**Done –** Representatives of the Trnava City Office were trained to use and interpret the CLIMAAX workflows and outputs during the dedicated training activity held on 9 June 2026. In total, 7 participants attended the training: 2 representatives of the City of Trnava, 4 representatives of STU, and 1 representative of KAJO, a consortium member of the CLIMAAX project.
At least two workflows refined using local data and CLIMAAX tools in Trnava City. Phase 2.	**Done –** High-resolution, locally downscaled and bias-corrected climate scenario CMIP6 data were applied in the heatwave and agricultural drought workflows, and the results were successfully produced.
2 conference posters and 2 scientific publications of the project's outcomes. Phase 2 and Phase 3	**Done –** The project results were presented at scientific conferences, namely EGU 2026 and HydroCarpath 2025. A project poster was also presented at the 32nd SAV Poster Day. Further scientific outputs and publications may be prepared and documented during Phase 3.
2 presentations made at local events, regarding climate adaptation or municipality events. Phase 2 and Phase 3	**Done –** The project results were presented at local and public dissemination events, including the stakeholder meeting organised by the Trnava City Office on 17 June 2026, the Poster Day of the Slovak Academy of Sciences on 12 November 2025, and a live non-commercial interview on Trnavské rádio on 23 June 2026, which communicated the main CLIMAAX/TRACAP findings to the wider public

Table 4-2 Overview milestones.

Milestones	***Progress***
M1: Reviewing the original adaptation strategy. Hire a team of experts, selecting from scientific partners involved in previous projects. Phase 1	**Done –** The Trnava adaptation strategy were studied by the Trnava city office and STU, the findings (mainly about vulnerability mapping) were applied in the phase 1 or will be applied in the Phase 2 or 3
M2: Utilize the CLIMAAX toolboxes, focusing on droughts and heatwaves, and generate initial Climate Risk Assessment results based on European data. Phase 1	**Done –** The Trnava adaptation strategy was studied by the Trnava City Office and STU. The findings (mainly concerning vulnerability mapping) will be applied in Phase 2 or 3.
M3: Participate in the CLIMAAX workshop in Barcelona. Phase 1	**Done –** One representative of the Trnava City Office and one representative of STU actively participated in the CLIMAAX workshop in Barcelona.
M4: Select and purchase high-resolution local data to enhance the performance of the toolboxes and improve the quality of CRA results. Phase 1 and Phase 2.	**Done –** the locally downscaled high-resolution climate CMIP6 scenarios were purchased and incorporated in the workflows and measured air temperature data were purchased from SHMÚ for the selection of the LST images.
M5: Integrate high-resolution data into the CLIMAAX toolboxes and prepare refined results. Phase 2 and Phase 3	**Done –** High-resolution local climate scenarios were applied to the selected heatwave and agricultural drought workflows, and the results were successfully produced. The outputs provide the basis for Phase 3, where they will be translated into adaptation priorities, recommendations and strategy-supporting materials.

5 Supporting documentation

Dataset register used for the Trnava climate risk assessment

Main Report:

- CLIMAAX_M16_Deliverable_template_FSTP_TRACAP_vFinal.doc

Agricultural droughts

Exposure:

- trnava_agri_drought_exposure_crops_area_2025_hu2025_20250912.gpkg

Hazard:

- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp2_4_5_2021-2050_rapeseed_barley.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp2_4_5_2021-2050_wheat_maize.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp2_4_5_2071-2100_rapeseed_barley.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp2_4_5_2071-2100_wheat_maize.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp5_8_5_2021-2050_rapeseed_barley.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp5_8_5_2021-2050_wheat_maize.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp5_8_5_2071-2100_rapeseed_barley.nc
- agridrought_hazard_yield_loss_noresm2_mm_local_30km_500m_ssp5_8_5_2071-2100_wheat_maize.nc

Vulnerability:

- trnava_agri_drought_vulnerability_irrigation_infrastructure_availability_2025.gpkg

Risk:

- trnava_agri_drought_risk_30km_ssp2_4_5_2021_2050_barley_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2021_2050_maize_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2021_2050_rapeseed_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2021_2050_wheat_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2071_2100_barley_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2071_2100_maize_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2071_2100_rapeseed_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp2_4_5_2071_2100_wheat_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2021_2050_barley_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2021_2050_maize_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2021_2050_rapeseed_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2021_2050_wheat_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2071_2100_barley_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2071_2100_maize_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2071_2100_rapeseed_revenue_loss_1000eur.tif
- trnava_agri_drought_risk_30km_ssp5_8_5_2071_2100_wheat_revenue_loss_1000eur.tif

Heatwaves

Exposure:

- trnava_multiple_exposure_trnava_city_borders.gpkg

Hazard:

- trnava_heat_hazard_cool_down_spots_based_on_lst_tropical_days_2021_2025_selected.gpkg
- trnava_heat_hazard_heat_islands_based_on_lst_tropical_days_2021_2025_selected.gpkg
- trnava_heatwaves_hazard_heat_days_occurrence_2021_2050_ssp2_4_5_noresm2_mm.tif
- trnava_heatwaves_hazard_heat_days_occurrence_2021_2050_ssp2_8_5_noresm2_mm.tif
- trnava_heatwaves_hazard_heat_days_occurrence_2071_2100_ssp2_4_5_noresm2_mm.tif
- trnava_heatwaves_hazard_heat_days_occurrence_2071_2100_ssp2_8_5_noresm2_mm.tif
- trnava_heatwaves_hazard_lst_tropical_days_median_2021_2025.tif
- trnava_heatwaves_hazard_air_temperature_measured.xlsx

Vulnerability:

- trnava_heatwaves_vulnerability_hospitals_and_social_care_without_heat_insulation.gpkg
- trnava_heatwaves_vulnerability_kindergartens_without_heat_insulation.gpkg
- trnava_heatwaves_vulnerability_vulnerable_population_worldpop_2020.tif

Risk:

- trnava_heatwaves_risk_vulnerable_pop_vs_lst_tropical_days_2021_2025.gpkg

Local high-resolution climate scenarios:

- CMIP6 Trnava 500m metodicka sprava Pecho.docx
- noresm2_mm_historical_trnava_30km_500m.nc
- noresm2_mm_ssp2_4_5_trnava_30km_500m.nc
- noresm2_mm_ssp5_8_5_trnava_30km_500m.nc

Dissemination materials:

- climaax_tracap_Barcelona_poster_vFinal.pdf
- egu_bohumelova_et_al_tracap_8_5_2026.pdf
- egu_kuban_et_al_tracap_8_5_2026.pdf
- hydrocarpath_tracap_4_12_2026.pdf
- sav_32nd_posterday_tracap_12_11_2026.pdf
- tracap_online_presentation_to_stakeholders_8_6_2025.mp4
- tracap_online_toolbox_trainning_webinar_to_stakeholders_9_6_2026.mp4
- tracap_podcast_Trnavske_radio_Trnava_horuce_dni_06_24_2026.mp3

Publicita projektu Climaax:

- climaax_publi_fb.png; climaax_publi_ig.png; climaax_publi_wa.png; TTkraj-článok.doc; web mesta Trnava - 2.faza.pdf

Odborna prednaska Climaax - 2. faza:

- CLIMAAX - odborna prednaska k II. etape projektu TRACAP – pozvanka.msg
- POZVANKA NA PREDNASKU_2.faza.doc
- Prezencka online ucastnikov - odborna prednaska k II. etape projektu TRACAP.pdf
- prezencna listina _odborna prednaska CLIMAAX - 17.06.2026.pdf
- TRACAP - prezentacia II. ETAPA.vlc
- TRACAP_CRA_Faza_2.pptx

FOTO:

- foto1.jpg, foto2.jpg, foto3.jpg, foto4.jpg, foto5.jpg, foto5.jpg, foto6.jpg, foto7.jpg, foto8.jpg

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