Deliverable Phase 1 – Climate risk assessment

Sustainable Climate Outcomes for People of Eastern Slovakia (SCOPE)

Slovakia, Košice Region

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

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Table of contents

List of figures

List of tables

Abbreviations and acronyms

Abbreviation / acronym	Description
CDS	Climate Data Store (Copernicus)
CRA	Climate risk Assessment
EEA	European Environmental Agency
GCM	General Circulation Model
NAP	National adaptation strategy
OECD	The Organisation for Economic Co-operation and Development
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RP	Return period
SECAP	Sustainable Energy and Climate Action Plan
SHI	Slovak Hydrometeorological institute
VVS	Eastern Slovak Water Management Company

Executive summary

The document outlines the significant geographic, climatic, and socio-economic characteristics of Košice, Slovakia, with an emphasis on the city's commitment to climate resilience and sustainability. It asserts Košice's role as a metropolitan hub in Eastern Slovakia and its membership in the Convention of Mayors for climate action. The document details the city's efforts to decrease its carbon footprint by 40% by 2030 while adapting to the adverse effects of climate change, highlighting new adaptive strategies and the importance of localized climate risk assessment. Furthermore, it introduces the CLIMAAX project, emphasizing its potential benefits for the community by providing actionable solutions, enhancing resilience against climate variability, and improving the quality of life for residents. In the context of climate change, the adaptation measures proposed in Košice reflect a broader understanding of the interconnectedness between socio-economic factors and environmental conditions. By acknowledging the dynamic nature of climate-related risks and the necessity for comprehensive, adaptive strategies, Košice showcases the potential for cities to lead in sustainability efforts. The project's emphasis on localized climate risk assessments is an innovative approach, allowing for nuanced understandings of vulnerabilities that could otherwise be overlooked. In a region facing climatic changes that differ from broader national trends, this localized approach could yield tailored, effective responses that enhance community resilience. Furthermore, the synergy between urban planning, community engagement, and educational institutions puts Košice in a strong position to influence regional practices. Mobilizing local universities to research and implement adaptive strategies could serve as a benchmarking model for other cities facing similar challenges, fostering a culture of innovation grounded in local realities. The commitment to reduce CO2 emissions by 40% is ambitious yet attainable, signaling the city's dedication to contributing to global climate goals. If successful, it not only benefits the local environment but sets a precedent for collective action on a larger scale, demonstrating that cities can serve as pivotal agents in the fight against climate change. Lastly, the sustainable integration of the Hornád River within urban plans offers an example of how natural resources can be harnessed for urban development while attending to ecological integrity. By elevating the river's status in urban planning, Košice can promote recreational opportunities, enhance biodiversity, and reinforce the ecological framework of the region. In conclusion, Košice's proactive measures in addressing climate risks through the CLIMAAX project highlight the importance of targeted adaptation initiatives. By ensuring equitable practices, harnessing local knowledge, and focusing on sustainability, Košice is paving the way for a resilient future that prioritizes both community and environmental health.

1 Introduction

1.1 Background

Košice is the metropolis of Eastern Slovakia and together with 40 adjacent villages (Figure 1), it has 283 241 inhabitants (2021, of which 51,14 % are women and 49,3% are men), the second most populous city in Slovakia. The city of Košice and surrounding villages has 469 692 ha. With proximity to neighbouring countries (20 km to Hungary, 80 km to Poland, 90 km to Ukraine) the city is a natural regional social and cultural centre, as well as a centre for industry, business, and education (seats of three universities). The city plays a role in the East-West transport link, forming a connection between Eastern and Central Europe. The topography of the city is diverse. Its shape is formed by the Hornád river valley that it occupies. The hilly north is surrounded by massive city-owned municipal forests, while the south opens towards low-lying flatlands. Since 2019, the city of Košice has been a member of the Convention of Mayors and Mayors on Keys and Energy, within which it has set a goal of reducing CO2 emissions (and, if possible, other greenhouse gases) by 40% by 2030. share of better energy efficiency and wider use of renewable energy sources to increase the resistance of the managed territory to climate change. The City of Košice has developed the Adaptation Plan of the City of Košice for Environmental Change (2022-2030), SECAP (framework for combating the climate-changed path of supporting sustainable production and energy consumption in the city of Košice) is also part of the mission "Cities" 100 climate-neutral cities. Despite regional climate differences across Slovakia, an analysis of the average annual air temperature from 1991 to 2014 shows a clear upward trend. At the Košice-Airport station, the temperature increased by 1.1°C compared to the 1961–1990 period. The average annual temperature in Košice is 8.6°C, with the warmest areas (up to 9.11°C) in the southern districts and the coldest (6.29°C) in the northern mountainous regions. Annual precipitation ranges from 550 to 800 mm, depending on altitude. The Košice Basin is open and windy, with its north-south orientation influencing air circulation. The Hornád Valley acts as a ventilation corridor, and in summer, katabatic airflow from surrounding slopes plays a significant role. The coldest areas are valleys near watercourses. The prevailing winds come from the northeast and southwest, with northern winds reaching an average speed of 5.7 m/s. Annual wind speeds range from 2.4 m/s in the southern lowlands to 3.8 m/s in the northern highlands. Košice belongs mainly to the Hornád River basin and partly to the Bodva River basin. The Hornád River has ecological, recreational, and urban planning significance, but its potential remains underutilized. The city is working on integrating the river into urban development plans. Like much of Central Europe, Košice is experiencing above-average warming, expected to be evenly distributed throughout the year.

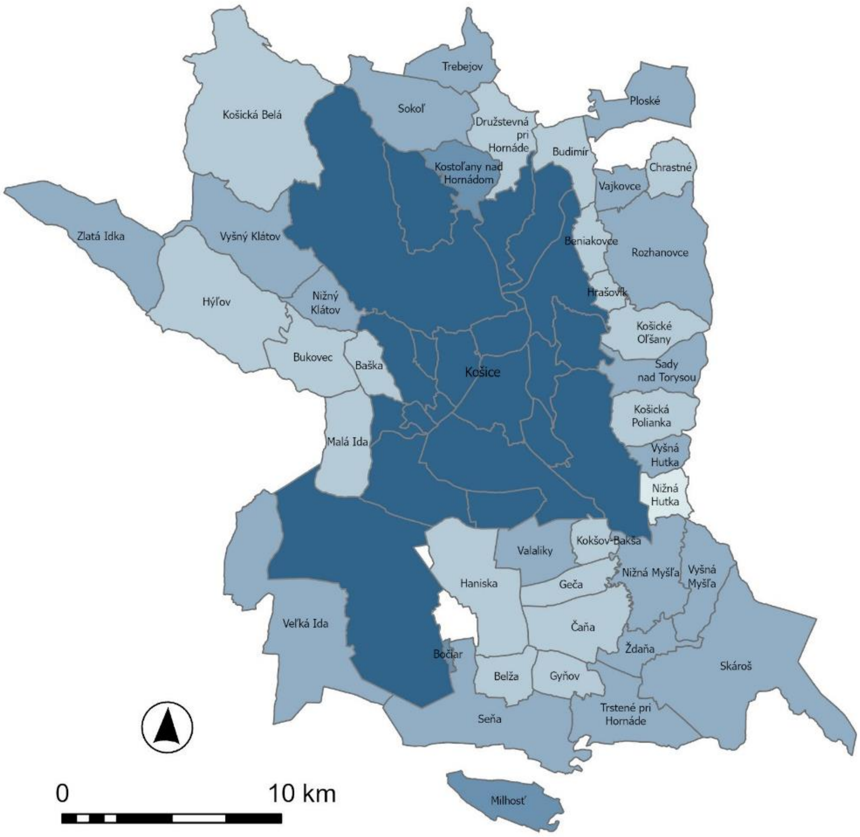


Figure 11 Analyzed area – Kosice region

1.2 Main objectives of the project

The project's focus on localized climate risk assessment and adaptation planning offers new opportunities to improve understanding and management of these risks. Building on city´s experience with the framework provided by CLIMAAX, local resilience and awareness of climate-related risks are expected to deteriorate. This approach will improve existing detailed assessments, identify vulnerable sectors and populations, and identify targeted adaptation strategies that are based on the latest science and best practices in resilience to change. It will also allow for ongoing updates with the latest available data. Integrating climate risk assessments with socio-economic data will map out the legacy of a given community and identify where and how it could exacerbate existing challenges or create new ones. This comprehensive analysis will include the development of adaptation measures that are effective and equitable, ensuring that no part of our community is left behind. With more available, more accurate data and more detailed analysis strengthening our region's resilience to climate change, we will also create a model for effective climate change adaptation that can be replicated in other regions facing similar challenges. The CLIMAAX project will bring specific and practical solutions to Košice and the surrounding area in the fight against climate change. Improve the city's and rural areas' preparedness for extreme weather, help obtain funding for green projects and improve the quality of life of residents. Thankfully Climaax handbook city and municipal authorities can plan preventive measures based on data from weather stations and climate models. Košice and municipal authorities gain more accurate data for local decision making, helpful for applying financing for adaptation measures.

1.3 Project team

The project was managed by the city's Strategic Development Department and the Data Policy and Analysis Department. Since the Strategic Development Department oversees the preparation and monitoring of the city's key climate policies and the Data Policy and Analysis Department is the data carrier in the city of Košice, work on the project began using existing experiences and partnerships. The core team intensified its work in January 2025, work on the project began with an assessment of existing goals and data available to the city. After a thorough analysis, preparations began for the collection of datasets not only within the competence of the city, but also of other organizations (SHI, district office, civil defense department). Based on the results generated through the workflow, hazards were identified.

1.4 Outline of the document's structure

Introduction provides an overview of Košice´s geographic, climatic and socio-economics significance, emphasizing its role in climate resilience.
Climate risk assessment detailed mapping and analysis of climate related risk specific to the Košice region. The analysis identified hazards - heat waves/ Urban heat islands and heavy rains/extreme precipitation. Relevant vulnerable groups and areas at risk have been identified for each of the risks, too. Hazard assessment presents a broader overview of hazard, exposure and vulnerability data sets according to the CLIMAAX manual.
Conclusions phase 1 provides a summary of the climate risk analysis for Košice and the surrounding area. The analysis indicates a significant increase in the frequency and intensity of torrential rainfall and heat waves, posing a major challenge to the city's infrastructure. The risks associated with heat waves have identified the most overheated areas and their impact on vulnerable populations, with projections for 2086 predicting even more frequent heat waves. Past climatic extremes, such as intense rainfall and uneven distribution of rainfall, have already caused serious problems. These trends are expected to become even more pronounced in the future, underlining the need for adaptation measures.

2 Climate risk assessment – phase 1

The Framework consists of a five-step process (Fig. 2) which forms an iterative cycle. The goal of the CRA Framework is to inform Climate Risk Management (CRM) strategies. The Framework is designed to estimate and contextualize Climate Risk that can be quantified through CRA workflows. It makes sure that the CRA process and its implementation are consistent with the highest standards and best practices as well as with state-of-the-art scientific findings.

The CRA framework identifies five operational steps – Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment and Monitoring & Evaluation – and corresponding sub-steps. The Scoping phase defines objectives, sets the context and identifies stakeholders and risk ownership. Risk Exploration is strongly informed by Scoping as it applies gathered knowledge, information and decisions and moves forward through more detailed hazard and risk exploration. This supports decisions on workflows and scenarios to use. After the risk workflow application in the Risk Analysis step, the individual risk outcome is evaluated and contextualised in the Key Risk Assessment step (severity and urgency of risk resulting in key and less urgent risks), thus identifying potential entry points for CRM and risk reduction. Monitoring & Evaluation puts emphasis on summarising the CRA process and surveilling climate risks while gathering knowledge and data that is relevant for improvements in the next iterations of the CRA.

Figure 11 The framework is based on established principles (related to social justice, equity, transparency), technical choices to be made (e.g., for parameters, climate scenarios, time horizons etc.), and participatory processes (learning, communication, consultation). Source: CLIMAAX Consortium.

2.1 Scoping

Over the years, the city of Košice has developed substantial experience in assessing vulnerability to climate change within its territory. This expertise is reflected in the city's vulnerability assessment, which evaluates climate-related risks and their impacts, as well as in the subsequent adaptation plan designed to address these challenges. Meanwhile, at the regional level, the Košice Regional Government has conducted a separate vulnerability assessment covering the entire region. However, this assessment was carried out using a different methodology, which makes direct comparisons or coordinated adaptation efforts more difficult. For both local and regional authorities, as well as decision-makers and some technical staff working in relevant departments, climate vulnerability assessment and adaptation planning are well-established topics. However, despite their experience, the differences in methodologies and the lack of coordination between these two levels of government present significant challenges. These discrepancies hinder the effective implementation of adaptation policies, particularly in areas that encompass both urban environment and their immediate rural surroundings. These areas collectively form a Sustainable Urban Development Area of the Functional Urban Region, a strategic development zone where climate adaptation strategies must be aligned across administrative and functional boundaries. The primary objective of this initiative is to establish a risk assessment process based on the latest methodologies provided by CLIMAAX and publicly available data. A key requirement is reproducibility—ensuring that the same approach and data sources can be applied in future years to track changes, measure progress, and improve climate adaptation policies. By implementing a standardized and transparent assessment framework and its workflows, with participatory approaches established to involve all identified institutions and related stakeholders during all phases of the process, a strong climate adaptation risk management to be introduced that lead to climate resilience. To achieve this goal, support and cooperation with identified stakeholders is essential. Due to the different expected outcomes of the project phases, different stakeholders were invited to participate in each phase. These are Municipalities - City Of Košice, 22 city districts of City of Košice, 40 smaller municipalities (villages and settlements) in Kosice County, which surrounds City of Košice, Košice Region, City owned organizations: Municipal forests, Greenery maintenance, Utility of housing, Creative Industry Košice, ZOO Košice, Institutions: Slovak Water Management Company, Botanical Garden Košice, Civic Associations: ETP Slovakia, DEDO foundation, Klima ta potrebuje/Climate needs you and Universities: Technical University Košice, UPJS University Košice.

2.1.1 Objectives

The main objective of SCOPE project is detailed mapping and analysis of climate related risks specific to the Košice region. By utilizing the advanced tools and methodologies provided by CLIMAAX, we will generate and reg regularly update localized climate risk data that is both accurate and actionable. The project builds on past efforts in local data gathering and processing, ensuring that previous findings inform future climate risk assessments. A revision of stakeholders and a co-design approach will help refine the local CRA workflow, enhancing collaboration and effectiveness.To align with regional needs, the CLIMAAX workflows and toolbox will be adapted, ensuring that methodologies remain relevant and practical. Additionally, the project will leverage an ongoing participatory approach to define viable adaptation strategies, while a communication and engagement campaign will foster awareness and involvement from key stakeholders. A crucial aspect of the initiative is to identify successful adaptation cases driven by CLIMAAX, which can serve as replicable models for other regions and sectors. Lastly, policy recommendations will be developed in critical areas, including adaptation strategy, civil protection, urban planning, and building regulations, ensuring that climate resilience is effectively integrated into governance and decision-making.

2.1.2 Context

In the Košice Region of Slovakia, climate hazards, impacts, and risks have been assessed and addressed through a combination of national and regional, and also local initiatives. But experiencing deficiency of more integrated approach, which prioritise data-driven, cooperation across levels of government and its policies. There is also a lack of understanding of the extent and complexity of climate risk issues among some of the region's residents, some key representatives and sector experts, leading to low levels of inclusion of adaptation measures and insufficient cooperation between sectors, resulting in insufficient climate resilience of society. The National Adaptation Plan (NAP) (MŽP SR, 2018) serves as the foundational document guiding these climate adaptation efforts. This strategy emphasizes the development of methodologies for comprehensive risk assessments at local, regional, and national levels. Also, Adaptation measurement: Assessing municipal climate risks to inform adaptation policy in the Slovak Republic (OECD, 2023) provides an overview of the country's adaptation policy context and presents a methodology – and the results of its application – for measuring climate change risks with respect to heat, drought, and extreme precipitation for each municipality in the country. At the regional level, the Adaptation Strategy for the Consequences of Climate Change in the Košice Region 2020 (KSK, 2020) has been developed. One of the benefits of our study will be the detailed mapping and analysis of climate-related risks specific to the Košice region. By utilizing the advanced tools and methodologies provided by CLIMAAX. Localized climate risk data will be generated and regularly updated that is both accurate and actionable. Additionally, Košice have already well-established participatory approach including organization of educational workshops and public forums which will be used to transfer knowledge and provide community feedback on the findings, ensuring that the knowledge permeates all levels of our community. By increasing awareness, we aim to foster a culture of preparedness and proactive adaptation among residents and stakeholders, empowering them to take informed actions to mitigate their vulnerability to climate impacts. Moreover, the study's results will support the integration of climate risk considerations into all aspects of local governance and planning. This holistic approach ensures that climate adaptation and risk management are not standalone efforts but are embedded within the broader framework of regional development, urban planning, and social welfare policies. In summary, the outcomes of our study under the CLIMAAX project will be instrumental in reducing our vulnerability to climate change. By enhancing risk knowledge and awareness and providing a solid evidence base for local policies, we will empower our community to navigate the complexities of climate adaptation with confidence and strategic foresight.

2.1.3 Participation and risk ownership

The first step was to map all relevant stakeholders who have an interest or influence on the project. In this phase of the project, this represents close cooperation with departments at the Košice City Hall (Strategic Development Department, Data Policy Department, Civil Protection Department, EU Projects Department, Environment Department) which, through their activities and activities, can contribute to achieving the goals of the project. Communication took place with each department personally. The aim of these meetings was to present the project and obtain feedback. The aim of the meetings was also to obtain the necessary data and documents to develop risks related to the city of Košice and the affected municipalities. In March, the first online meeting with stakeholders (Klíma ťa potrebuje, Poď na dvor, Prešovský samosprávny kraj, Creativ industry Košice) took place, where the project and the first phase of project implementation were presented to them. In the next phase of the project, specific stakeholders will be specified (mayors of municipalities, vulnerable groups of residents, non-profit organizations dealing with the given issue, universities ...). To ensure transparency and involvement, the results will be communicated to various audiences through adapted channels (media press, social media, participatory process).

2.2 Risk Exploration

Risk exploration started with a broad screening of the risks (their underlying hazards, exposures and vulnerabilities) that are most apparent or of significant concern to key stakeholders and the wider public of the city of Košice and surrounding villages.

2.2.1 Screen risks (selection of main hazards)

Košice region is increasingly experiencing climate-related hazards that pose significant risks to its community and environment. According to previous studies, vulnerability assessments and climatological analysis, as well as the experience of local stakeholders, it can be unequivocally stated that the city of Košice and its surroundings are mainly threatened by climate hazards such as heat waves, drought and also local flash floods. For example, the case study (Social vulnerability to heatwaves – from assessment to implementation of adaptation measures in Košice and Trnava, Slovakia) notes that the city has seen a notable rise in high-temperature events. Over the past two decades, the number of tropical days (temperatures exceeding 30 °C) has increased from 12 to 20 annually, with some years recording up to 37 such days. Increased air temperatures in Košice are additionally amplified by the influence of artificial surfaces and urban development, the so-called urban heat island. This escalation adversely affects urban residents, particularly vulnerable groups such as the elderly, children and socially disadvantaged groups. Also, with the increasing frequency of heat waves, rising average temperatures and irregularly distributed precipitation, the overall quality of green and blue infrastructure is likely to decline, ecological services, forestry and agriculture are at risk. Agricultural lands in and around Košice are increasingly susceptible to droughts. Unsustainable land management practices have diminished the soil's capacity to retain water, exacerbating the effects of prolonged dry periods. In recent years, there has also been an increased risk of forest fires in nearby urban forests during the summer months. Sudden temperature fluctuations, concretely sudden drops in temperature, are particularly problematic and have been repeated over the past years. The occurrence of absolute annual minimum air temperatures during the spring months poses a significant threat to farmers and fruit growers. The region has experienced more frequent torrential rains, leading to flash floods that impact both urban and rural areas in the area. These events disrupt daily life, damage infrastructure, and threaten the livelihoods of residents. Extreme weather events and heatwaves pose direct risks to human health, potentially increasing heat-related illnesses, even loss of life of the most vulnerable people.

2.2.2 Workflow selection

2.2.2.1 Workflow #1 Heavy rainfall / Extreme precipitation

The main vulnerabilities associated with extreme precipitation events include people, civil structures, and critical transportation routes located in terrain depressions, which are prone to flooding. Additionally, inadequate drainage systems can exacerbate urban flooding, leading to property damage and disruption of essential services. Historical flood-prone areas and poorly maintained sewage infrastructure further increase the risk.

According to a local study of stormwater runoff and local expirience, low-lying parts of the city near the Hornad River, which flows through the city from north to south, are at risk. However, during storms, some areas, especially roads or streets are often flooded, depending on many factors – for example, elevation, slope, local terrain characteristics, poor high vegetation cover, soil type, presence of impermeable surfaces, inefficient or blocked drainage. Problems often occur on busy streets, such as Vodárenská Street, several streets in the Džungla district, Štefánikova Street, Staničné námestie in the city center, also very busy underpass on Palarikova Street and many others. Regarding the peripheral urban areas and villages around the city, most vulnerable places were identified: Myslava, Druztevna pri Hornade, Košice-Krasna, Trstene pri Hornade, Cana, Geca and others. There are approximately 9,800 drainage devices and 1.7 kilometers of drainage channels in Košice that need to be regularly cleaned to prevent potential road flooding. This task is carried out by the Eastern Slovak Water Management Company (VVS). "The city of Košice has previously requested VVS to double its capacity, as the current pace of drainage system cleaning is insufficient from the city's perspective."

2.2.2.2 Workflow #2 Heatwaves / urban heat islands

The urban heat island (UHI) is present in the analyzed area, which represents a significantly higher occurrence of extreme temperatures compared to the surrounding natural landscape. The main cause is the covering of the original vegetation area with paved surfaces (roads and buildings). Asphalt and concrete have a greater tendency to absorb incident light and heat radiation and subsequently emit it into the environment. In the case of asphalt roads and sidewalks, heat absorption is further enhanced by their dark color. The main vulnerabilities related to heatwaves include vulnerable population groups, such as older adults, children, and individuals with pre-existing health conditions. Sensitive infrastructure, including hospitals, elderly care facilities, and public transportation systems, is particularly affected by extreme heat. The negative impacts of heatwaves also extend to vegetation health, leading to increased tree mortality and a decline in urban greenery, which exacerbates the UHI effect. Additionally, prolonged heatwaves can strain water supply systems and increase energy demand for cooling, posing further challenges for the city. Among the most temperature-stressed parts of the city are the Old Town – Stare mesto District, with the exception of the City Park and the Hornad river area; the Juh District, especially its northern part and industrial areas; the Dzungla District, a large part of which is occupied by shopping centers and parking lots; the Nad Jazerom District, mainly the industrial zone; and the southern part of the Sever District. The most vulnerable places were identified as the: KVP District, Sidlisko Tahanovce District and Lunik IX settlements in Košice city. Which is the biggest settlement in the Košice city with older infrastructure and high concetration of the vulnerable groups of people.

2.2.3 Choose Scenario

The Košice City Office is seeking “reliable” climate scenarios that can be used as input for urban planning and decision-making. Several projects operated by the Košice City Office are currently planned with a time horizon up to the year 2030. However, city planning should look much further than just five years ahead, so climate scenario results for the near future (2041–2070) and beyond will be considered. The aging population in Slovakia is a well-known fact and will be taken into account. Other scenarios, such as socio-economic developments and economic activities, are currently planned only for the short-term horizon of 2030.The heavy rain workflow provides scenarios illustrating changes in the magnitude and frequency of heavy rainfall events. Similarly, the heatwave workflow offers scenarios depicting changes in the occurrence of heatwave days and nights. These insights are crucial for urban planners and policymakers, enabling them to make informed decisions and implement effective adaptation strategies to better prepare for future climate extremes.

2.3 Risk Analysis

2.3.1 Workflow #1 Heavy rainfall

Table 2-1 Data overview workflow #1

Hazard data	Vulnerability data	Exposure data	Risk output
Expected precipitation for 3h event for 2041-2070, Return period 2, 5, 10, 20, 50, 100 years **[Climaax]**	Distribution of the Vulnerable population **[Climaax]**	Population density **[Climaax]**	The shift in the frequency and magnitude of the extreme precipitation rainfall thresholds for the selected points in Košice region. **[Climaax]**
Annual maximum precipitation for 3h 2041-2070 **[Climaax]**	Building materials and construction quality **[In preparation]**	Critical infrastructure-buildings, airports, schools, socio-economic facilities, sewage system, **[Košiče city office]**	DHI – flash flood analysis **[Košice city office]**
Precipitation 24h for 10, 25, 50, 100 years for 2041-2070 and relative change to the 1976-2005 base line **[Climaax]**	Socioeconomic indicators **[needs]**	Map of the areas susceptible to flash floods, based on hazard impact database and DHI flash flood analysis **[In preparation]**	Hazard-impact database classified by impact severity **[In preparation]**
Extreme precipitation days 1981-2100 rcp 4.5, 8.5	Institutional capacity e.g., early warning systems, emergency response plans **[needs]**	Landslides and slope deformations **[Košice city office]**	
Extreme precipitation totals 1981-2100 rcp 4.5, 8.5	Maps of the terrain depressions **[needs]**		
Maximum 5-day precipitation 1981-2100 rcp 4.5, 8.5			

2.3.1.1 Hazard assessment

The initial hazard assessment was performed based on Climaax extreme precipitation hazard assessment tool. Firstly, the climaax handbook for Extreme Precipitation: Local data requirements and interpretation for climate risk assessment was studied. The preparation of hazard impact-based tables depends on local data for past extreme precipitation events. However, the city of Košice does not have this type of data, and in Slovakia, it is not possible to obtain such data for free. Therefore, the Košice City Office has initiated the data preparation process, which involves compiling a list of extreme precipitation events from local papers, fire departments, and the crisis management office. This list will serve as the main input for requesting extreme precipitation accumulation data, which needs to be obtained from the Slovak Hydrometeorological Institute. Subsequently, the initial hazard assessment, based on freely available European data, was performed using the CLIMAAX heavy rainfall tools. The first step involved a subcontracted team of experts who handled the initial setup of the CLIMAAX tools, assisted with understanding the methodology, prepared an overview of the local CRA data, and provided additional open-source data. Since the spatial resolution of the Euro-CORDEX data is 12×12 km, and Slovakia is a relatively small country, we selected the entire country for the initial hazard assessment (for the bounding box, which is then refined in the next steps). The GCM = ICHEC-EC-EARTH and RCM = KNMI-RACMO22E models with RCP 8.5 were used. The first results provide information about the projected annual maximum precipitation for a 3-hour duration in Košice city (selected point) — see the picture below. This result provides great output for better imagination of the projected uneven distribution of the potential maximum precipitation amount with slightly increasing trend. As part of the hazard workflow, a selected point was required. Košice city was chosen due to its higher concentration of vulnerable areas and critical infrastructure elements.

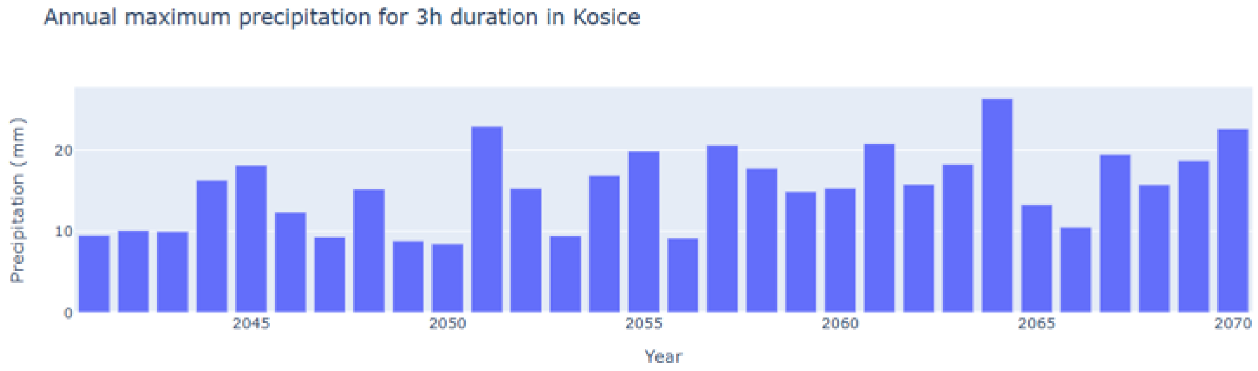


Figure 2.2 Annual maximum precipitation for 3h duration in Košice

The next step was the estimation of return periods for expected 3-hour precipitation events for the 2041–2070 period in Košice. Since the Košice City Office does not have information on extreme precipitation return periods, these results provide an excellent starting point for further analysis.

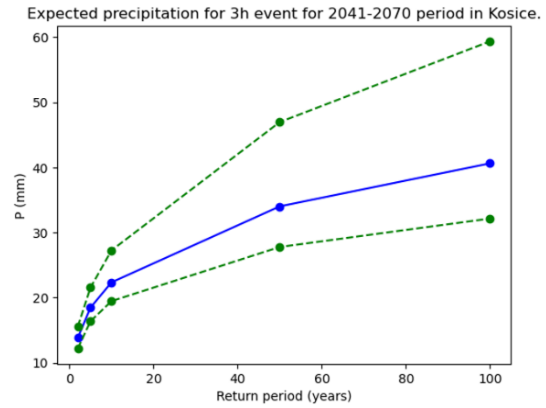


Figure 2-2 Expected precipitation for 3h event for 2041-2070 period in Košice (rcp8.5) based on the Euro-Cordex data.

Maps of precipitation changes (%) relative to defined periods were first prepared for the entire country of Slovakia to better capture regional differences and assess uncertainties related to data resolution. Maps for the 10-, 25-, 50-, and 100-year return periods were calculated and plotted (here we display only one example for 100 return period).

From these maps, it was evident that the Košice region is expected to be the most affected by changes in the magnitude of extreme precipitation compared to all other regions in Slovakia (based on the selected climate scenario).

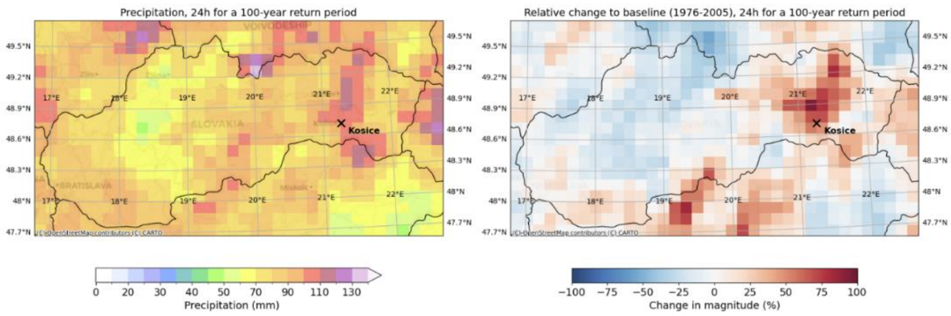


Figure 2-3 Preciptation for 24h for 100-year return period on left for 2041-2070 and relative change to baseline 1976-2005 on the right

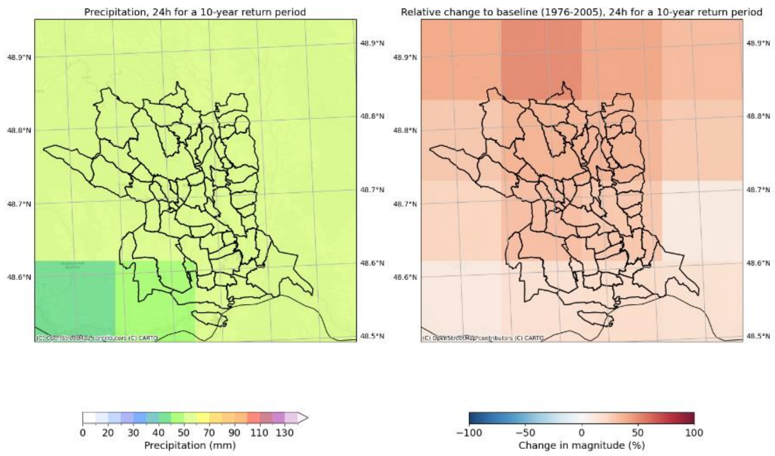


Figure 2-5 Preciptation for 24h for 10-year return period on left for 2041-2070 and relative change to baseline 1976-2005 on the right clipped for Interested area

For the estimation of mean precipitation vs. frequency curves, the entire workflow needed to be run again. This step initially estimated mean values for all of Slovakia, but we aim to obtain results specifically for the Košice region. The results show a significant shift in the projected extreme precipitation amounts between the historical 1976–2005 and 2041–2070 periods. This substantial increase in extreme precipitation magnitude is expected to lead to a dramatic rise in flash flood-related issues.

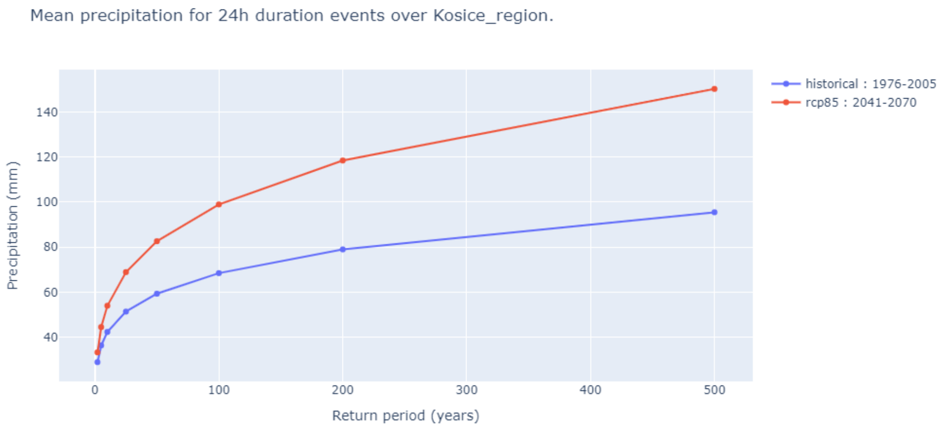


Figure 26 Mean precipitation for 24h duration events over Košice region nd given return periods based on the EuroCordex data.

2.3.1.2 Risk assessment

The extreme precipitation risk assessment Climaax tool was applied for the estimation of the shift in the rainfall intensity (Magnitude) and Frequency of the extreme precipitation events. For this analysis we used the Euro-Cordex bias-correct datasets precalculated in the hazard estimation. For this kind of data this workflow provides the information about projected changes in the magnitude and frequency of extreme precipitation events (see pic. below).

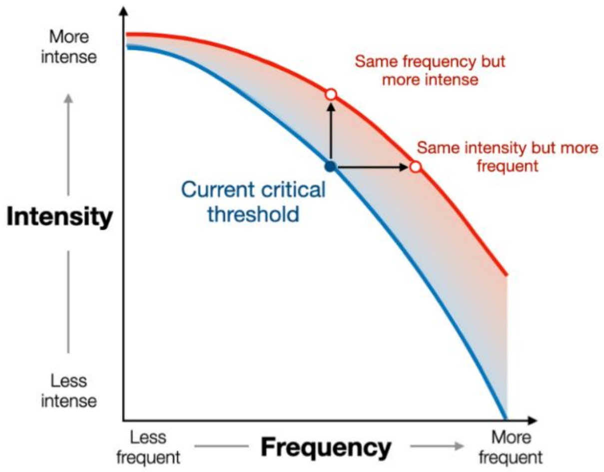


Figure 27 Possible changes in critical tresholds (CLIMAAX heavy rainfall)

The results of the risk workflow were summarized in the table below for better understanding. The selected critical rainfall thresholds were selected based on the 10 (42mm/24h) and 50 (60mm/24h) years return period obtained in the hazard workflow.

Table 2-2 Change in magnitude and frequency for the critical rainfall thresholds for 10 and 50 years return periods.

Košice city 2041-2070 change vs 1976-2005 (RCP 8.5)		
Critical rainfall threshold (based on 10 and 50years RP)	Magnitude change (mm)	Frequency change (return period years)
10y RP = 42mm/24hod	**25%**	**from 10 to 5 years**
50y RP= 60mm/24hod	**35%**	**from 50 to 14 years**

Table 2-3 Registered accumulations (local sources) and return periods based on the Euro-Cordex data with the impact severity scale

Date	Accumulations registered (mm/hrs)	Return periods associated	General description	Risk to people	Damage to buildings	Disruption of transport	Others or Comments	Impact severity scale
10-28.6.2020	**30 mm/24h (SHMU flood report)**	T 5	Local flooding caused by heavy rainfall	High river level pose a risk to people	Locally flooded basements	Locally flooded crosroads	At surrounding stations in the Košice region, more than 40 mm of rainfall was recorded within 24 hours.	Low impact (1)
5-6.2010	**50.0 mm/24h (SHMU flood report)**	T 25	Excesive flooding caused by heavy rainfall	1500 people were affected, due to owerflow of Hornad river which flood the surrouidings	Multiple houses were damaged	Flooded roads and crossroads	25 million euro aid package for the hardest hit regions in eastern Slovakia.	Medium impact (2)
20.7.1998	**100 mm/24h (Scientific paper)**	T 500	Excesive flooding caused by heavy rainfall	2471 Affected population, 10 people evacuated only 1 injured	575 overflow houses, 476 overflow sources of drinking water	22.8 km damaged roads, 32 damaged bridges	The floods also caused extensive property damage, with estimates reaching up to $25 million at the time. In the village of Jarovnice, located only 40 km from Košice, 50 people were killed by the flood.	High impact (3)
13-14.10.2020	...	...	Local flooding caused by heavy rainfall	High river level pose a risk to people	Only few houses were flooded	Locally flooded streets in Krásna and Súdky pri Hornáde	A state of emergency has been declared. Firefighters were needed in Krásna to build mobile dams and pump out water.	Low impact (1)
18.5.2023	...	...	Local flooding caused by heavy rainfall	No significant risk for people.	Dozens of houses were flooded	Streets in Malá Ida and Myslava were flooded	Firefighters were needed in Malá Ida and Myslava to build mobile dams and pump out water.	Low impact (1)
18.5.2021	...	...	Local flooding caused by heavy rainfall	No significant risk for people.	Dozens of houses were flooded	Streets in Družstevná pri Hornáde were flooded	Firefighters were needed in Družstevná pri Hornáde to build mobile dams and pump out water.	Low impact (1)
5.11.2023	...	...	Local flooding caused by heavy rainfall	No significant risk for people.	Only few houses were flooded	Streets in Myslava were flooded	Firefighters were needed in Myslava to build mobile dams and pump out water.	Low impact (1)
...	...	...	...	...	...	...	...	...

Next steps: The hazard-impact database classified by impact severity, which is currently in preparation, will enhance the risk assessment workflow with the real event based extreme precipitation thresholds. These are the initial results of the hazard-impact database. Data on accumulation and related flood events were gathered from available web sources. However, due to limited data accessibility and the scarcity of available records, it will be necessary to purchase data from SHMÚ. With only three samples, it is not possible to verify the quality of the results. Additionally, the data lacks information on return periods, which, for the purpose of this study, were estimated using Euro-CORDEX data. This process introduces a significant level of uncertainty. Additionally, data about past flood events from the news (local papers) were gathered, but these data lack information about rainfall accumulations. This list of recorded flash flood events will be increased with the recorded data from fire fighters and crisis management centre. In the next step, this data will be supplemented with accumulation values and return periods purchased from SHMU.

2.3.2. Workflow #2 Heatwaves

Table 2-4 Data overview workflow #2

Hazard data	Vulnerability data	Exposure data	Risk output
Heatwave occurrence per year under the rcp4.5 and rcp8.5 using the health-related EU wide definition for the Selected location in the Košice region for 1986-2085 **[Climaax]**	Distribution of the vulnerable population **[Climaax]**	Identification of the heat islands **[Climaax]**	Possible heatwave risk to vulnerable population **[Climaax]**
Land surface temperature maps for the Košice region 2013-(now) **[Climaax]**	Building materials and construction quality in terms of possible overheating **[In preparation]**	Critical infrastructure **[Košice city office]**	Possible heatwave risk to vegetation **[needs]**
Occurence of the hot days (30 deg treshold), 1981-2100 rcp 4.5, 8,5 **[Climaax]**	Heat feeling map **[Košice city office]**	Vegetation state during the summer months (NDVI) **[in preparation]**	
Tropical nights, 1981-2100 rcp 4.5, 8,5 **[Climaax]**	Institutional capacity e.g., early warning systems, emergency response plans **[needs]]**		
Warmest 3 day period, 1981-2100 rcp 4.5, 8,5 **[Climaax]**	Socioeconomic indicators **[needs]**		
Measured temperature data (air/surface) **[needs]**			

2.3.2.1 Hazard assessment

The hazard assessment was performed based on the Climaax heatwave hazard assessment tool. The EuroHEAT approach was selected for the initial hazard assessment. This approach was selected to provide robust data from the ensemble of the RCM. This result provides basic but useful information about possible projected heatwave occurrence frequency in the future.

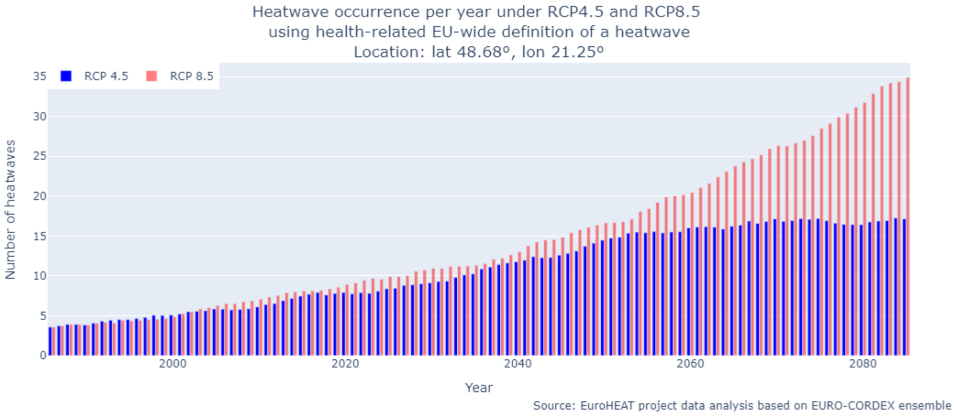


Figure 2-8 Heatwave days occurrence per year under RCP4.5 and 8.5 using health-related EU-wide definition of a heatwave for Kosice city

Then we continue with the additional sources provided from the heatwave description file. These sources from the EEA provide useful information about projected changes in the number of hot days (with a threshold above 30°C), and tropical nights (with threshold over 20°C) for the eastern part of Slovakia, where the Košice region is located.

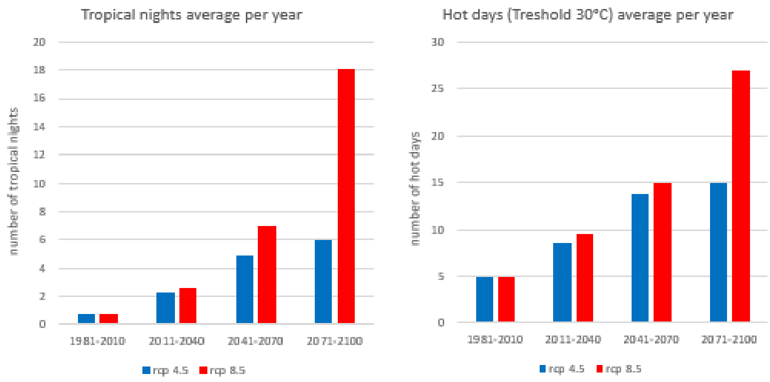


Fig. 2-9 Tropical nights (on the left) and hotdays (on the right) projected change from Euro-Cordex climate scenarios

The results of the hazard assessment indicate a significant projected increase in heat-related climate indices. This information serves as a strong starting point for raising public awareness about the impact of climate change on heatwave occurrence.

2.3.1.3 Risk assessment

The heatwave risk assessment followed the CLIMAAX heatwave risk workflow at the local level. Firstly, heat islands across Košice city and its surrounding areas were identified using land surface temperature (LST) data derived from Landsat 8 satellite imagery from RSLab. This approach was used to identify heat islands both within the city and in suburban areas (see the picture below). The method combines overheated areas with vulnerable population density. For the initial CRA, vulnerable population data from the open-source WorldPop dataset (recommended by the CLIMAAX toolbox) was used. These results highlighted the most problematic areas in terms of overheating, and provided methodological approach for the combining of the LST data with the distribution of the vulnerable population. In the next steps, the plan is to prepare data on vulnerable populations and vulnerable locations using local sources.

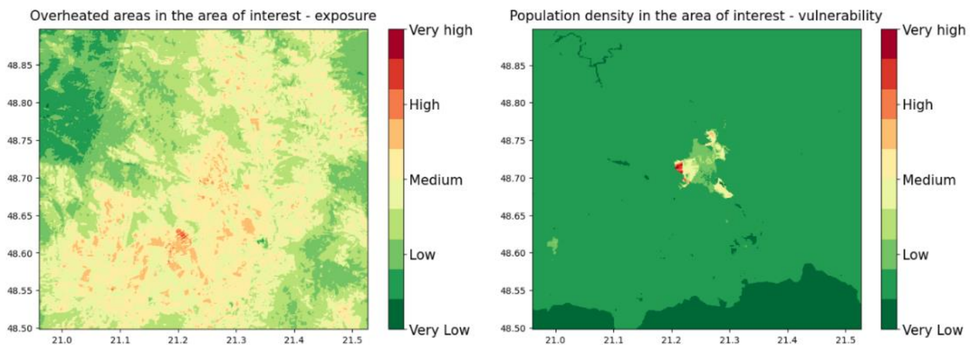


Figure 2-10 Overheated areas (on the left) and vulnerable population density (on the right) results based on Climaax heat wave toolbox for the interested area of Kosice UMR.

In the final step, this workflow combines the data using the risk matrix presented in the CLIMAAX heat wave workflow. This risk matrix integrates the data by summing Exposure and Vulnerability across the selected area. The main result of this workflow is shown in the picture below. These results highlight the most problematic areas based on the distribution of vulnerable populations and the most overheated locations. These areas should be prioritized for planning adaptation measures. These results provide a good initial assessment. However, there is room for improving the efficiency of the results by incorporating local vulnerability data, which will be collected in the second phase of this project.

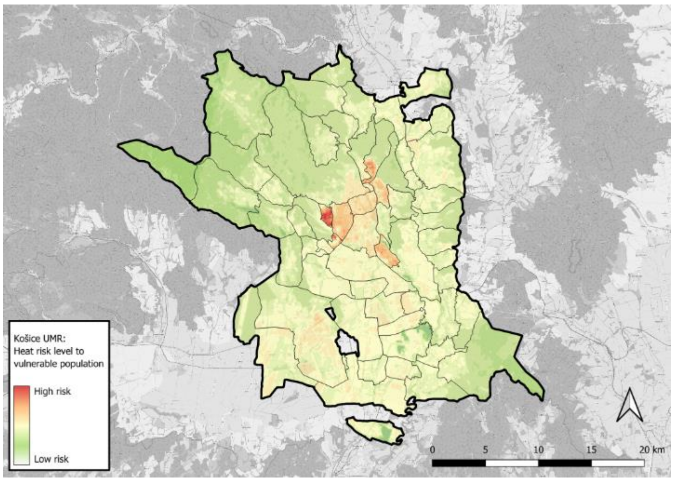


Figure 2-11Heat-risk level for vulnerable population in Košice UMR

Next steps: The vulnerability mapping in the heatwave workflow provides significant room for improvement. The next steps will follow the heatwave toolbox methodology, incorporating improved vulnerability maps prepared by the Košice City Office, drawing on local knowledge and experience. The goal is to focus on mapping vulnerable populations, such as children under 5 and adults over 65 years of age, buildings with a high potential for overheating, and critical infrastructure buildings such as hospitals. Another key objective is to identify locations with the greatest potential and need for implementing heat mitigation measures.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The risk analysis focused on heavy rainfall and heatwave risks. The results of the heavy rainfall CRA indicate a significant increase in the magnitude and frequency of heavy rainfall events (see the risk analysis). These projected changes will pose a major challenge for Košice umr infrastructure. The Heatwave risk analysis brings two important results based on the measured and projected data. The heatwave risk analysis at the local level identified the most overheated areas and demonstrated how to integrate this data with the distribution of the vulnerable population. The heatwave hazard analysis provides projections of heatwave occurrences until the year 2086, indicating a significant increase in the number of heatwave days. This trend will amplify heat-related challenges in the Košice city, where is a big space for the adaptation measures.
The Košice region has faced multiple climate risks in the past, with the most significant being extreme heat, intense rainfall, and uneven rainfall distribution. Heatwaves have repeatedly led to challenges such as impaired vegetation growth, health issues among residents, and reduced living comfort. Extreme rainfall events have triggered multiple flash floods, while irregular rainfall patterns have posed serious challenges for the agricultural sector. Each year, hundreds of people in Košice suffer from heat-related collapses during heatwaves and require medical assistance from paramedics. According to the results of the heatwave hazard assessment, heatwaves are expected to become more frequent and severe in the future. Over the past decades, massive flooding events triggered by heavy rainfall have forced the evacuation of hundreds of residents. These extreme rainfall events have also caused landslides, leading to the destruction of multiple structures. Projections indicate a significant potential increase in both the frequency and intensity of heavy rainfall events in the coming years.

2.4.2 Urgency

The risks identified in the CLIMAAX CRA for Košice Region, Slovakia, are expected to have a significant impact in the coming decades, with increasing intensity and frequency of heatwaves and heavy rainfall events. The projections indicate that by 2041-2070, heatwaves will occur more frequently, posing severe health risks to vulnerable populations. Similarly, heavy rainfall is expected to intensify, leading to an increased likelihood of flooding and infrastructure damage. These risks necessitate immediate planning, with short-term actions focused on improving drainage systems and public awareness, while long-term strategies involve climate-adaptive urban planning and infrastructure resilience. The modelled risks involve both slow-onset (e.g., gradual temperature rise can include heat waves) and sudden-onset hazards (e.g., flash floods from extreme precipitation). The urgency of response varies accordingly: slow-onset risks require continuous adaptation measures such as increasing green infrastructure, cooling through water elements, reducing the proportion of paved areas, shading, building cooling measures, while sudden-onset hazards demand early warning systems and emergency response plans, but also some land use changes including renaturation and protection of streams and wetlands or expanding the area of natural forests around the city, increasing the capacity of the sewerage system or measures against landslides. Given the increasing unpredictability of extreme weather, a proactive approach is essential to minimize damage and ensure the safety and resilience of the communities, especially the most vulnerable ones. Given that the city is surrounded by extensive urban forests, with the increasing risk of heat waves and an increase in average annual temperatures, the risk of drought and forest fires in the immediate vicinity of the city is likely to increase. This assumption would be appropriate to verify by Climaax CRA in the next phase of the project.

2.4.3 Capacity

Košice participates in international initiatives such as the Covenant of Mayors for Climate and Energy (2019), Green City Accord (2021) and Basque Declaration (2020) and other projects. Through these projects, it not only addresses the change of the city's governance in favour of sustainable development, but also works with other sectors and citizens to find solutions to climate change. It is also looking for solutions to specific situations of concern to its inhabitants, such as a possible slide into energy poverty. It is precisely the answer to avoid this threat that the city will be looking for together with the third sector in the implementation of the Building Power project (2024), supported by the Pilot Cities programm. In addition, the city has developed initial plans to reduce CO2 emissions. Over the last 8 years, the city has become more aware of the need for climate transformation and existing policies such as the Sustainable Mobility Plan (2015, update 2022) have been updated. Subsequently, the first GHG inventory (Baseline Emissions Inventory, 2018) and climate strategies such as the City's Climate Change Adaptation Plan (2022), the Climate and Sustainable Energy Action Plan (SECAP, 2022), the City's Master Plan Update 2022-2027, and others have been developed. Together with the forthcoming new master plan, these documents not only assess the current situation, but also define the city's steps towards its further transformation. The city's efforts are supported by various initiatives from the academic, private and civic sectors, which are not only directly involved in the city's activities but are also implementing their own projects to help citizens better understand the impacts of climate change. It also supports the decarbonization of large enterprises such as US Steel Košice, which is one of the largest air polluters in Europe, but also one of the largest employers in the city. Another major project that has come back to life after 30 years and is being strongly promoted from the city level is the introduction of geothermal energy into the central heating system of Košice, which supplies 75% of the households in Košice with heat.

2.5 Preliminary Monitoring and Evaluation

The first phase of the climate risk assessment in Košice easily identified heatwaves and heavy rainfall as the most pressing climate risks in the region. The initial analysis also showed that other hazards such as drought and forest fires could also affect the region and so application of appropriate workflows would be beneficial in the next steps. However, a significant challenge encountered during the process was the lack of detailed local hazard-impact data, particularly regarding past extreme weather events. These should be investigated in more detail in the next phase of the project, when meetings and surveys are planned with the crisis management department, which covers the tasks of local state administration in the areas of civil protection, integrated rescue system, crisis management and so on. To fully understand and mitigate risks, additional socioeconomic and infrastructure vulnerability data are needed, particularly to assess where and how different population groups and critical infrastructure will be affected. After interpretation of results and presentation to local stakeholders, their feedback emphasized the need for better collaboration between local government, institutions and communities to ensure an effective response to climate threats. They also highlighted the importance of public awareness and engagement. Also expressed interest in cooperating in the form of providing their experience with data gathering, processing and informing the public in a more effective manner.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the CLIMAAX has provided Košice and its surrounding region with a foundation for future climate resilience planning. Through the application of CLIMAAX workflows focused on heavy rainfall/extreme precipitation and heatwaves/urban heat islands, the region now has a clearer understanding of the key climate-related risks it faces and the methodological tools to address them in future adaptation planning.

Key Findings

- Projected Intensification of Climate Hazards: Both climate risk workflows confirmed that the frequency and intensity of heavy rainfall and heatwaves are projected to increase significantly by 2041–2070. In particular, rainfall events that previously occurred once in 50 years could become 3 to 4 times more frequent, while heatwaves are expected to occur almost every summer and extend in duration.
- Vulnerability Hotspots Identified: The combination of hazard and vulnerability data revealed specific high-risk areas within Košice. For heatwaves, densely built-up districts such as Staré Mesto, Juh, Nad Jazerom, Sidlisko KVP and Lunik IX are especially at risk due to the urban heat island effect and a high concentration of vulnerable populations. For flash floods and extreme precipitation, low-lying areas near the Hornád River and districts with inadequate drainage infrastructure were flagged as most vulnerable.
- Risk of Compound Events: The region is also exposed to compounding climate risks, including the potential for heat-related health emergencies coinciding with energy infrastructure stress, or flash flooding disrupting transportation and emergency response in high-density neighborhoods.

Challenges Addressed

- Establishment of a Data-Driven Climate Risk Assessment Framework: Košice successfully implemented the CLIMAAX workflows using openly available climate datasets and initial local inputs. This enabled the generation of first-generation climate risk maps for heatwaves and heavy rainfall.
- Stakeholder Engagement Initiated: Over a dozen stakeholders, including municipal departments, NGOs, and local institutions, were involved in the initial stages. This participatory approach has laid the groundwork for co-designed adaptation planning.
- Identification of Gaps in Hazard Impact Data: The project identified a clear lack of comprehensive local hazard-impact data, particularly regarding past rainfall accumulation and flood event severity. Work is already underway to address this gap by compiling event databases from newspapers, crisis management offices, and SHMÚ records.

Challenges Not Yet Fully Addressed

- Incomplete Vulnerability Mapping: While vulnerability hotspots were approximated using open datasets (e.g., WorldPop), locally verified and granular vulnerability data—particularly for socially marginalized groups and critical infrastructure—is still under development. This remains a top priority for Phase 2.

- Data Gaps in Socioeconomic and Institutional Capacity Metrics: Important factors such as emergency preparedness, building stock quality, and institutional response capacity have not yet been integrated into the workflows due to a lack of accessible data. Targeted data collection in these areas is needed for a complete risk picture.
- Disjointed Governance Context: Differences in methodologies and coordination between municipal and regional assessments present challenges for unified adaptation planning. The project recognized this issue and aims to address it by aligning future assessments with both city and regional strategies.

Outlook

Phase 1 has provided a solid technical and strategic starting point for developing a robust, locally relevant climate adaptation strategy. The Košice region is now better positioned to:

- Advance locally customized risk mapping using updated vulnerability and exposure datasets;
- Leverage the CRA results to guide urban planning, infrastructure investment, and public health strategies;
- Foster cross-sectoral and cross-level cooperation to ensure policy coherence and shared adaptation ownership.

Moving forward, the focus will shift to validating and refining the risk assessment through more precise local data, expanding stakeholder participation (especially involving community-based organizations), and ensuring the findings translate into actionable policies that can reduce the region's vulnerability to climate-related shocks.

4 Progress evaluation and contribution to future phases

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
12 stakeholders involved in the activities of the project	done
12 communication actions taken to share results with your stakeholders	Phase 2
4 publications and dissemination actions	2x (press release, FB post), Phase 3
4 notes for policy makers	Phase 3
2 of workflow successfully applied on deliverable 1	done
2 of workflow successfully applied on deliverable 2	Phase 2

Table 4-2 Overview milestones

Milestones	***Progress***
Mls 1 Stakeholder meeting in phase 1	done
Mls 2 Phase 1result presented	done
Mls 3 Stakeholder meeting and co-design in phase 2	prepared
Mls 4 Attend the CLIMAAX workshop held in Barcelona	prepared
Mls 5 Policy recommendation actions	prepared
Mls 6 Attend the CLIMAAX workshop held in Brussels	prepared

5 Supporting documentation

- ✓ *Main Report (PDF or Word)*

Submitted 31.3.2025

- ✓ *Visual outputs*

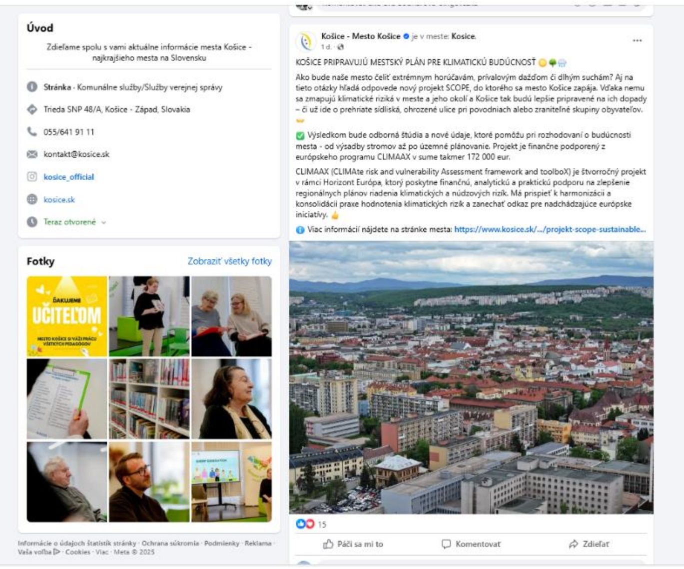
Submitted by Phase 1_results (heatwave_workflow, heavy_rainfall_workflow)

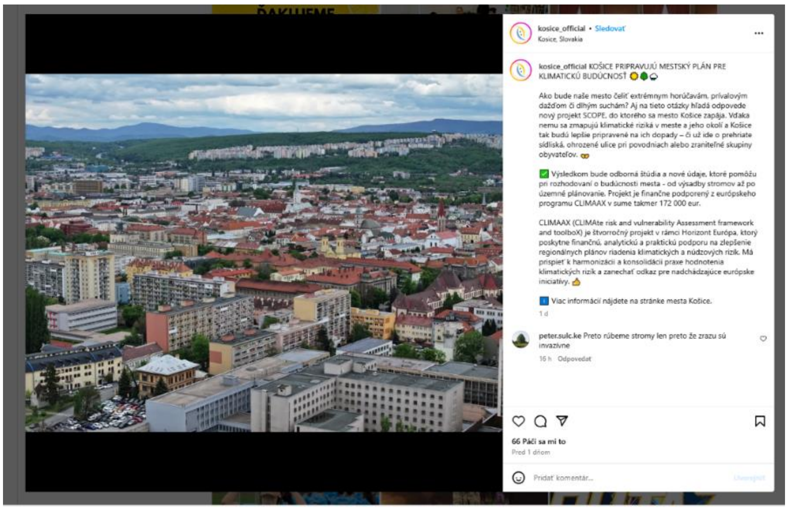
- ✓ *Comunication*

Press release:

[Projekt: SCOPE - Sustainable Climate Outcomes for People of Eastern Slovakia - Udržateľné klimatické účinky pre obyvateľov Východného Slovenska :: Oficiálne stránky mesta Košice]

FB post and IG post (posted 27.3.2025)





- ✓ *Datasets collected (Excel or CSV)*

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