CLIMAAX
climate ready regions

Deliverable Phase 1 – Climate risk assessment

Methodical Climate Risk Assessment for the Cluj Metropolitan Area (MECRA-Cluj)

Romania, Cluj Metropolitan Area

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

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Abbreviations and acronyms

Abbreviation/Acronym	Description
ACC	Adaptation to Climate Change
CMA	Cluj-Napoca Metropolitan Area
AIT	Austrian Institute of Technology GmbH
UBB	Babes-Bolyai University, Faculty ofGeography
CRA	Climate Risk Assessment
GCM	Global Climate Models
HW	Heatwave
JRC	Joint Research Centre
RCM	Regional Climate Model
UHI	Urban Heat Island

Executive summary (1 page)

This deliverable was developed as part of the Methodical Climate Risk Assessment for the Cluj Metropolitan Area (MECRA-Cluj), a critical component in addressing climate-related risks impacting key sectors, vulnerable communities, infrastructure, and ecosystems within the Cluj Metropolitan Area (CMA). Its main aim is to provide a comprehensive assessment using established methods and data processing tools to deliver clear, actionable outcomes. Readers will gain insights into climate hazards, the severity of risks, potential impacts, and necessary adaptation measures.

Main Results and Findings:

The climate risk assessment identified and evaluated two primary hazards—heatwaves and floods—utilizing European datasets and the CLIMAAX framework:

Heatwaves:

- Frequency, intensity, and duration are projected to increase, especially impacting densely populated urban areas such as Cluj-Napoca and neighboring localities (e.g., Florești).
- Risks are notably higher for vulnerable groups, including elderly and economically disadvantaged populations, especially in densely urbanized neighborhoods.

Floods:

- Economic impacts from riverine floods are significant, with potential damages estimated at approximately €481 million for moderate flood events (10-year return period), escalating to around €700 million for extreme events (500-year return period).
- Approximately 40,000 residents are directly exposed in moderate scenarios, increasing to 60,000 under extreme conditions.
- Critical vulnerabilities identified include densely populated and low-lying areas along the Someșul Mic River.

To accomplish these findings, the following key actions were undertaken:

- Application of the EuroHEAT methodology and Euro-CORDEX climate scenarios.
- Deployment of JRC flood hazard maps and economic impact assessments through depth-damage curves tailored to local land use.

Conclusions:

This initial phase established a foundational understanding of climate risks in the CMA, revealing significant vulnerabilities and urgent adaptation needs. Heatwaves and floods present considerable challenges, necessitating immediate and strategic interventions. Critical takeaways include:

- Heatwaves demand immediate urban adaptation measures, targeting vulnerable populations.
- Enhanced stakeholder engagement and improved data resolution are vital for future assessments.

Overall, these results provide essential guidance for policymakers and stakeholders in developing robust, informed, and community-supported climate resilience strategies.

1 Introduction(2-3 pages)

1.1 Background

The Cluj Metropolitan Area (CMA) is a partnership structure and public entity composed of Cluj-Napoca City and 19 communes, with a total population of 418,153 people. We are governed by the Metropolitan Zones Law, and our president is the Mayor of Cluj-Napoca. CMA has a mandate to do climate adaptation planning at the metropolitan level.

CMA is a part of the Climate City Contract Coalition. We have experience in implementing national and international research projects addressing climate mitigation (NZC Cluj), environment protection and systemic challenges (STARDUST), circular economy (Let's Go Circular Urbact IV), as well as protection, preservation and valorization of natural, cultural and historic heritage (proGireg, URBforDAN).CMA represents a vast network of public and private stakeholders, partners and collaborators from all segments of the economy: cities, municipalities, ministries, associations, universities, schools, and SMEs.

1.2 Main objectives of the project

The MECRA-Cluj project aims to enhance regional climate resilience through data-driven risk assessments and stakeholder engagement. Building on the CLIMAAX framework and toolbox, the project's key objectives are:

- To apply a standardized methodology for assessing climate risks tailored to local conditions.

The Climate Risk Assessment (CRA) aims to identify, quantify, and assess climate-related risks within the local/regional context of the CMA. Its primary goal is to analyze the extent, severity, and potential impacts of climate hazards on key sectors, vulnerable communities, infrastructure, and ecosystems by using existing tools that facilitate data processing and ensure reliable outputs.

- To develop actionable knowledge and tools that informs policy and decision-making.

The assessment aims not only to highlight the most critical climate risks, enabling informed decision-making and supporting the development of effective climate adaptation strategies, but also to improve public understanding and climate literacy.

- To improve awareness and capacity among local stakeholders in understanding and addressing climate threats.

Furthermore, by addressing mistrust towards authorities and increasing motivation for environmental monitoring, the project seeks to build stronger community engagement and enhance collaborative efforts in addressing climate challenges.

- To support the integration of climate risk analysis into strategic planning documents (e.g., Climate City Contract, Adaptation Plan, SIDU).

Since there is no climate change adaptation strategy or action plan in force at the metropolitan area or the settlement level, this primary information on risk assessment is of utmost importance to scientifically document such strategic approaches to be developed in the near future.

Thus, the objective is designed to directly inform regional and local policy and decision-making by equipping policymakers and stakeholders with solid evidence to guide climate action, optimized resource allocation, and embeds climate resilience into broader regional and local development strategies.

- To pilot the assessment with a dual focus on flooding and heatwaves—key climate threats to the Cluj Metropolitan Area.

The main benefits of the CLIMAAX Handbook consist of a detailed presentation of the conceptual framework to assess increasing risks associated with climate change, considering a multitude of hazard types addressed. A clear explanation of how to use the toolboxes, as well as a synthetic collection of freely available databases to be used for various hazards and associated risk assessment, are both very strong points of the handbook and make it a valuable resource for both scientists and practitioners in public administration and territorial planning.

1.3 Project team

Cluj Metropolitan Area IDA team:

Zoltan-Csaba CORAIAN, *General Director of the Cluj Metropolitan Area | Project Manager MECRA-Cluj.*Zoltan-Csaba Coraian is a senior executive with a degree in Mechanical Engineering and over 25 years of experience across the ICT, energy, and urban development sectors. As Project Manager of MECRA-Cluj, Mr. Coraián provides overall coordination and strategic direction, ensuring the alignment of project outcomes with metropolitan development goals and facilitating effective stakeholder engagement throughout the implementation process.
Adrian-Nicolae RĂULEA, *Programme Director ,Cluj Metropolitan Area | Implementation Expert ,* Currently serving as the Programme Director at the Cluj Metropolitan Agency, he leads the creation of governance frameworks for regional development, focusing on infrastructure projects and the promotion of the Cluj metropolitan area's economic interests. Adrian's experience includes coordinating key strategic documents like the Sustainable Urban Mobility Plan and the Integrated Urban Development Strategy, as well as coordinating externally funded projects related to renewable energy.
His career spans various prestigious roles, including State Secretary at the Ministry of Investments and European Projects, collaborations with institutions such as the World Bank, European Commission, and EBRD.

Paul IUHASZ, *Implementation Expert | Procurement Manager, Cluj Metropolitan Area*

Dipl. Eng. Paul Iuhasz is a seasoned engineer with over two decades of experience in technical coordination and procurement across both public and private sectors. As Procurement Manager at the Cluj Metropolitan Area, he plays a central role in the successful implementation of EU-funded projects, including Horizon and Interreg program.

He brings a strategic and analytical approach to managing technical workflows, ensuring quality, efficiency, and environmental sustainability throughout all stages of project delivery.

Melania BLIDAR, *Financial Manager*
Ms. Blidar is an economist with a Master's degree in Human Resources and over two decades of professional experience in finance and HR within the private sector (production, construction, services). Since 2019, she has managed financial planning, reporting, project implementation for various EU-funded programs including Horizon 2020, Erasmus+, Interreg Danube, and Urbact(project management).

The Austrian Institute of Technology GmbH - Competence Unit Cooperative Digital Technologies,(SUB1), is the international expert who, among others will assist the CMA and the local data/modeling experts in testing the CLIMAAX tools in the local context. The team consists of the following four people:

MSc Patrick KALETA completed his master's degree program in bioinformatics at the University of Vienna. As Research Engineer, previous and current work primarily focuses on the development of software solutions in the domains of Crisis & Disaster management and Climate change & climate adaptation. He has multiple years of experience working on EU-funded research projects, with main involvement in the conceptualization and development of web-based applications.

DI Ghazal ETMINAN, as Senior Research Engineer and Thematic Coordinator has a strong background in digital transformation and urban systems. She drives innovative projects that leverage advanced IT solutions to enable informed decision-making and enhance sustainability. Her expertise bridges technology and strategy, delivering impactful outcomes in areas like climate resilience, urban development, and community empowerment.

Dr Denis HAVLIK is a scientist with a PhD in Natural sciences and a long experience in designing and leading interdisciplinary research projects and helping the stakeholders to resolve societal challenges related to the environment and climate change. Current research interests arein the development of knowledge management & decision support systems that help stakeholders improve regional planning with respect to sustainability, resilience, and inclusive development.

MSc Refiz DURO is a scientist and project coordinator, specializing in Earth observation, data analytics, and decision support systems, and with experience in data analysis, software development, and research. Key projects include AI4Trees (AI-based, climate-sensitive tree growth models), ICARIA (climate impact and risk reduction), and digital-twin-oriented PED projects, integrating cross-sectional aspects of energy, economic, and circularity assessment methods.

Babeș-Bolyai University(SUB2) isthe local expert/technicalpartnersupportingthe Cluj Metropolitan Area (ZMC) in assessingandmanaging climate risks, adaptingto climate changeandprioritizinginterventionmeasures. Activitieswillaim at integrating local and regional climate data, usingadvancedtoolsprovidedby CLIMAAX andensuringtechnicalandscientificsupport. The team is composed of 3 persons as it follows:

Dr Csaba HORVÁTH is an experienced researcher member of the team with a wide range of expertise in the field of Geographic Information Systems (GIS) and Data Science. His contributions have significantly advanced various research initiatives, as evidenced by scientific publications and participation in national and international research projects (FMETPRO, M100CITIES, DAFE, INTEGRATE, SCEWERO). His work has contributed to a better understanding of the impacts of climate change and related hydro-climatic phenomena (floods, droughts, heat waves, landslides), facilitating the development of mitigation strategies at different spatial scales.

Relevant expertise for the project: Climate hazards - floods (hydrologist), Data handling

Prof Adina Eliza CROITORU is a Senior Researcher in Climatology, specialising in weather and climate hazards and their impact on society and the environment. She has published numerous books and articles in international scientific journals dealing with climate change as observed in extreme temperature and precipitation events. A significant focus of her research has been the analysis and evolution of heat waves and their impacts, as well as the detection of urban heat islands and associated hotspots. She has led numerous research projects as project manager/principal investigator or partner coordinator (FMETPRO, M100CITIES, DAFE, INTEGRATE, SCEWERO). She is also a technical expert for the World Bank, specialising in climate change mitigation.

Relevant expertise for the project: Framework assessment, Climate hazards - heatwaves (climatologist), Climate risk assessment

Dr Zsolt MAGYARI-SÁSKA is an experienced researcher and GIS expert with advanced data modeling and software development skills. He has conducted several research grants related to climate change as principal investigator ("Modelling and network-based analysis of long-term meteorological changes in major cities of Hungary for climate change monitoring and evaluation" / "The impact of climate change on the ideal period for outdoor tourism activities in different regions of the Carpathian Basin") and has been a research team member in the INTEGRATE and SCEWERO projects focusing on the detection and mitigation of climate change. He has developed an R software module called *ClimShift*(Magyari-Sáska et al., 2023) to detect climate change from a spatio-temporal perspective using climate analogues.

Relevant expertise for the project: Data handling, Programming/software engineering

1.4 Outline of the document's structure

The document follows the template guidelines provided by the Climaax Project team. It consists of three main sections: Introduction, Climate Risk Assessment, and Conclusion of Phase 1. An executive summary, a Progress evaluation and contribution to future phases, Supporting documentation, and References sections complement the main content sections.

Each of the main sections is divided into sub-sections, which detail the information about the project (Introduction), the scoping, risk exploration, risk analysis, preliminary key risk assessment findings, and preliminary monitoring and evaluation (Climate Risk Assessment—phase 1).

The most developed section is Climate Risk Assessment, which presents in detail the findings that will be further used for Deliverables 2 and 3.

2 Climate risk assessment – phase 1(12-15 pages)

This section outlines the steps taken in performing a first CRA using the CLIMAAX methodology and evaluating the initial findings.

2.1 Scoping

During the scoping phase, the following objectives and stakeholders have been defined and described in the subsequent sections.

2.1.1 Objectives

The objective of the Climate Risk Assessment (CRA) is to identify, quantify, and evaluate climate-related risks specific to the regional context. The primary purpose is to understand the scope, severity, and potential impacts of climate hazards on critical sectors, vulnerable populations, infrastructure, and ecosystems. The expected outcome is a clear identification of the most significant climate risks associated with heatwaves and floods at the CMA level, enabling informed decision-making and the development of targeted climate adaptation strategies and action plans at the regional level.

This objective aims to feed directly into regional policy and decision-making processes by providing policymakers and stakeholders with robust evidence to prioritize climate action, allocate resources effectively, and integrate climate resilience into broader regional and local development plans.

Limitations and boundaries of the CRA include the availability of high-resolution local climate (heatwaves, flash floods and urban floods) and socioeconomic data, potential gaps in historical hazard data, and constraints in stakeholder engagement due to resource limitations or limited awareness. Furthermore, the complexity of modelling socio-economic vulnerabilities at a fine spatial scale (communes) and the inherent uncertainties in future climate scenarios represent additional boundaries.

2.1.2 Context

In our region, climate hazards and their impacts have traditionally been assessed individually rather than systematically or holistically. Since no climate change strategy and/or action plan is in place at the CMA or the constituent settlements, previous assessments have often lacked integration of socio-economic vulnerabilities, typically focusing predominantly on physical hazard exposure, particularly flood and drought risk. The heatwave hazard or risk assessment has been done mainly by integrating a larger spatial scale (national) (Adina-Eliza Croitoru et al., 2018; Bogdan Antonescu et al., 2024; Croitoru et al., 2016; Piticar et al., 2018; Roxana Bojariu et al., 2015; Scripcă et al., 2022). Only one scientific study has been identified at the local scale to assess the impact of the combined impact of heatwaves and urban heat island effect on the local economy (Herbel et al., 2018). Similarly, the urban flood hazard or risk assessment in Cluj-Napoca has been primarily conducted at a broader spatial scale, focusing on hydrological and flood risk studies at the regional and national levels (e.g., (Bilașco et al., 2022; Bilasco& Csaba, 2016; Chendeş et al., 2014; Kocsis et al., 2022; Spachinger et al., 2008). These studies provide valuable insights into flood dynamics, surface runoff changes, and flood risk assessment methodologies. However, research explicitly assessing urban flood risks at the local scale within Cluj-Napoca and the surrounding area are limited (Gâlgău et al., 2023; Haidu & Ivan, 2016; Haidu & Kinga Ivan, 2016). Most available studies address hydrological hazards from a regional perspective, highlighting urbanization-induced runoff increases and flood susceptibility.

This CRA addresses the need for a comprehensive, integrated approach that considers multiple climate hazards focusing on local-specific vulnerabilities and capacities.

The project addresses the growing risks climate change poses to public health, critical infrastructure, local economies, and ecosystems, aligning with national climate strategies and regional sustainable development goals. Locally relevant sectors identified as particularly vulnerable to climate impacts include public health, water resources management, agriculture, infrastructure, and ecosystems.

Governance in our region is shaped by national climate adaptation strategies and sector-specific regulations (e.g., water management regulations, flood protection measures, and land use planning), but an integrating strategy and plan for ACC is still missing. While various local climate resilience initiatives exist, they are often fragmented, indicating a need for integrated risk management approaches. External influences such as national adaptation initiatives, EU-funded resilience projects (e.g., Pathways2Resilience), and transboundary issues related to water resource management could better frame the local strategies towards increased resilience of the communities.

Potential adaptation interventions include infrastructure upgrades (flash flood protection), nature-based solutions (green infrastructure, urban greening), strengthening water resource management systems, enhancing emergency preparedness and early warning systems, and capacity building for vulnerable groups to improve adaptive capabilities.

2.1.3 Participation and risk ownership

Initial steps towards stakeholder engagement included mapping relevant actors and defining participatory methods to ensure a broad representation of interests and local knowledge. Key stakeholders identified are local and regional government authorities, emergency response agencies, environmental and climate experts from academic institutions, public and private sector representatives, NGOs, and representatives of vulnerable or marginalized communities.

The MECRA-Cluj project benefits from the involvement of a wide range of stakeholders representing multiple sectors and governance levels. Stakeholders were initially mapped based on their relevance to climate adaptation, risk prevention, urban planning, water management, and vulnerable population support. The following key stakeholder groups participated or expressed interest in the project:

Cluj-Napoca City Hall – Local authority responsible for implementing climate adaptation actions and risk mitigation strategies.

Inspectorate for Emergency Situations Cluj (ISU) – Involved in disaster response planning and emergency preparedness.

Romanian National Meteorological Administration (MeteoRomânia) – Provides climate and weather data essential for evidence-based planning.

National Institute for Hydrology and Water Management – Supports flood risk modelling and hydro-meteorological analysis.

Someș-Tisa Water Basin Administration – Coordinates basin-level water resource management and flood defence infrastructure.

Someș Water Company – Ensures integration of urban water infrastructure into adaptation planning.

Academic representatives (e.g., Babeș-Bolyai University, Technical University Cluj) – Offer technical support and climate modelling expertise.

Private sector actors and investors – Interested in aligning sustainability goals with investment opportunities in climate-resilient infrastructure.

Civil society and citizens – Key beneficiaries and contributors to community-level resilience, especially those in flood-prone or heat-sensitive areas.

Stakeholders were invited to the project's kick-off event and have actively participated in discussions about local climate risks and adaptation measures. Their feedback helped shape the preliminary conclusions of the Climate Risk Assessment (CRA) Phase 1 and set the stage for more detailed collaboration in Phases 2 and 3.

Priority groups for engagement include residents in flood-prone or heat-sensitive areas (including those identified as hotspots associated with UHI's), elderly populations, economically disadvantaged communities, and minority groups disproportionately affected by climate impacts.

Risk ownership is regulated primarily through local and regional governance frameworks, with clearly defined responsibilities among municipal and regional administrative bodies. The level of risk considered acceptable to the community involves a consensus-building approach, with inputs from technical experts and local stakeholders, and aims at reducing risks to an acceptable minimum aligned with public safety standards and community resilience targets.

Results from the CRA will be communicated transparently to stakeholders through workshops, publicly accessible reports and online platforms.

2.2 Risk Exploration

Risk exploration for the CMA begins with an initial screening of the primary climate-related risks, notably heatwaves and floods, identified based on regional historical data and climate projections.In terms of floods, the future focus should be on urban flash floods, as due to Hydrotechnical works upslope the CMA, riverine floods risk probability is considerably lower. At the next stage, a higher-resolution flood map should be used, incorporating areas exposed to pluvial flash floods for a more comprehensive risk assessment.

Heatwaves have been increasingly frequent and intense, significantly impacting public health, urban infrastructure, energy demand, and ecosystem services. Floods, on the other hand, present a notable risk due to Cluj-Napoca's geography, urban density, and hydrological characteristics. They impact critical infrastructure, transportation networks, residential areas, and agricultural lands.

2.2.1 Screen risks (selection of main hazards)

For the CMA, the primary **climate-related hazards** identified during the proposal phase of this project are **heatwaves and floods**, both of which are expected to increase in frequency and intensity due to climate change.

Heatwaves:

Cluj-Napoca has been experiencing increasingly frequent and prolonged heatwaves, significantly impacting areas with intense UHI effects (hot spots). These impacts are especially prominent in densely populated neighborhoods such as Mărăști or villages (Floresti), where high-rise buildings, limited tree coverage, and extensive paved surfaces intensify heat exposure. Vulnerable groups, including the elderly, children, individuals with chronic health conditions, and outdoor workers in sectors like construction (and agriculture), are disproportionately affected. Additionally, residents of poorly ventilated housing and lower-income communities, especially those living in the countryside or older-built neighborhoods of Cluj-Napoca city, lacking adequate cooling solutions, face heightened risks during extreme heat periods.

Floods:

Cluj-Napoca is vulnerable to riverine and urban flooding, intensified by extreme rainfall events, increased urbanization, and inadequate stormwater management. Riverine flooding primarily occurs along the Someșul Mic River and its tributaries, significantly affecting low-lying areas. Urban flooding is prevalent in densely built central and residential neighborhoods characterized by extensive impervious surfaces, particularly neighborhoods with outdated drainage infrastructure. These flooding events have considerable impacts, including damage to critical infrastructure (roads, utilities, residential buildings), disruptions to transportation networks, significant economic losses for businesses and agricultural activities, and heightened demand for emergency services. Vulnerable populations living in flood-prone neighborhoods, businesses located in affected areas, and communities lacking robust flood defenses experience the most significant impacts during flooding incidents.

Both hazards pose significant risks to infrastructure, public health, and local economies, making them the focus of this CRA.

2.2.2 Workflow selection

For our region of interest, we selected two hazards, and consequently, two pre-existing risk workflows have been used for risk analysis. They were downloaded and used in their basic form for this first phase, described in this deliverable. Also, for this initial phase, we considered the datasets of pan-European hazard, exposure, and vulnerability data for the implementation of the different risk assessment methods corresponding to each toolbox as provided by the CLIMAAX team.

For further computation, we followed the guidelines provided by the CLIMAAX CRA Handbook to setup a local working environment and the Jupyter Notebooks for both workflows were downloaded, adapted, and used locally.

2.2.2.1 Workflow #1–HEATWAVES

The workflow dedicated to HWs has been used to assess the hazard and risk for CMA, considering both approaches presented in the CLIMAAX Framework and detailed in the dedicated Handbook.
Workflow #2 - FLOODS

The flood risk assessment for the Cluj-Napoca metropolitan area was conducted following the operational guidelines and tools provided in the CLIMAAX Framework and its accompanying handbook. The analysis started with mapping river flood hazards by employing European datasets, specifically the flood hazard maps from the JRC. Subsequently, potential climate change impacts on river flooding were qualitatively explored using Aqueduct Floods datasets, which illustrate how flood hazards may evolve under varying climate scenarios. The identified flood hazards were then integrated into the predefined risk workflow for assessing impacts on infrastructure. The assessment quantified risk primarily in terms of potential economic damages. The outcomes provided clear visualizations of hotspots where economic damages from floods could be most severe, thus highlighting the vulnerable areas.

2.2.3 Choose Scenario

For HWs, as Europe is the region experiencing the most accelerated warming, we identified as the most relevant climate change scenarios considering the moderate (RCP 4.5) and the pessimistic (RCP 8.5) ones for the medium- and long-term, depending on the data availability in the datasets selected. For the river flood hazard, we also analysed flood scenarios corresponding to multiple return periods (10, 20, 50, 75, 100, 200, and 500 years) and future projections in 2030, 2050, and 2080, when data availability permitted.

For this project's first phase, we followed the basic settings and recommendations from the Handbook. For vulnerability and exposure data, we used World Population datasets, which havea temporal coverage for 2000-2020 and thus, no scenario could be selected for future periods.

2.3 Risk Analysis

The next step was to apply the dedicated workflows and scenario decisions to estimate risk in our focus region (CMA). The risk workflows consider four main steps to calculate a region's individual Climate Risk: (i) preparation of the application, (ii) choosing and accessing data, (iii) estimating the hazard, and (iv) combining it with exposure and vulnerability data.
We downloaded the applications and selected the appropriate data for current and future climatic and socioeconomic conditions from the datasets recommended in the CLIMAAX CRA Handbook. The data used are presented in detail in the dedicated tables in each workflow section.

2.3.1 Workflow #1

Table 2-1 Data overview workflow #1

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
EURO-CORDEX regionalclimate model data; Type of data: Gridded data; Data calculation type: modelled; Horizontalresolution: European domain 0.11x0.11°; Temporalcoverage:Historical &future: 1951-2100; Experiments: RCP4.5 andRCP8.5; Temporalresolution: daily; File format:NetCDF; Global climate model: CNRM-CERFACS-CM5 (France) ……; Regional model: CLCcom-CLM-CCLM4-8-17(EU) ….; Parameters**:** Maximum and minimum 2m air temperature in the last 24 hours Provider: C3S CDS(host) Licence: CORDEX Available at: https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-	Category: Population; Dataset: WorldPop; Spatialresolution: 3 arcsec, 30 arcsec; Temporalresolution: 2000-2020; References: Pezzulo et al., 2017 Available at: https://hub.worldpop.org/doi/10.5258/SOTON/WP00646	Dataset: WorldPop; Spatialscale: Global; Temporalresolution: 2000-2020; Spatialresolution: 3 arcsec, 30 arcsec; Analysis type: Random Forestalgorithm; References: Bondarenko et al., 2020; Stevens et al., 2015 Available at: https://hub.worldpop.org/doi/10.5258/SOTON/WP00682	Heatwave risk level

Hazard data	Vulnerability data	Exposure data	Risk output
levels?tab=overview			

For this initial phase, we decided to access data on hazard, exposure, and vulnerability using pre calculated European/large-scale datasets available in the CLIMAAX Handbook about hazard (heatwave), exposure (population), and vulnerability (population).

The Hazard was estimated through pre calculated, large-scale European hazard maps.

2.3.1.1 Hazard assessment

For the HW hazard assessment, we applied both methodologies available: EuroHEAT methodology and the methodology based on Euro-Cordex dataset and Xclim library.

Based on the ***EuroHEAT methodology***, we haven't changed any part of the code and have used the standard data source. We executed all code cells in the Jupyter Notebook, selecting CMA as the location.

In this approach, we selected the option to use the health-related EU-wide definition because a national HW definition for Romania is not available: for the summer period of June to August, HWs were defined as days in which the maximum apparent temperature (Tappmax) exceeds the threshold (90th percentile of Tappmax for each month) and the minimum temperature (Tmin) exceeds its threshold (90th percentile of Tmin for each month) for at least two days. The apparent temperature a measure of relative discomfort due to combined heat and high humidity, developed based on physiological studies on evaporative skin cooling. It can be calculated as a combination of air and dew point temperature and contains values aggregated yearly.

The results for the historical and future decades (1986-2085), corresponding to the two RCPs selected, are presented in Fig 2-1. The difference between the two pathways gradually increases until 2055.After that, the HW occurrence seems to stabilize to values between 15 to 20 per year under the moderate scenario (RCP4.5), where as it continues to dramatically increase based on pessimistic scenarios data (RCP8.5), reaching an occurrence of a value of more than four times compared with the historical period.

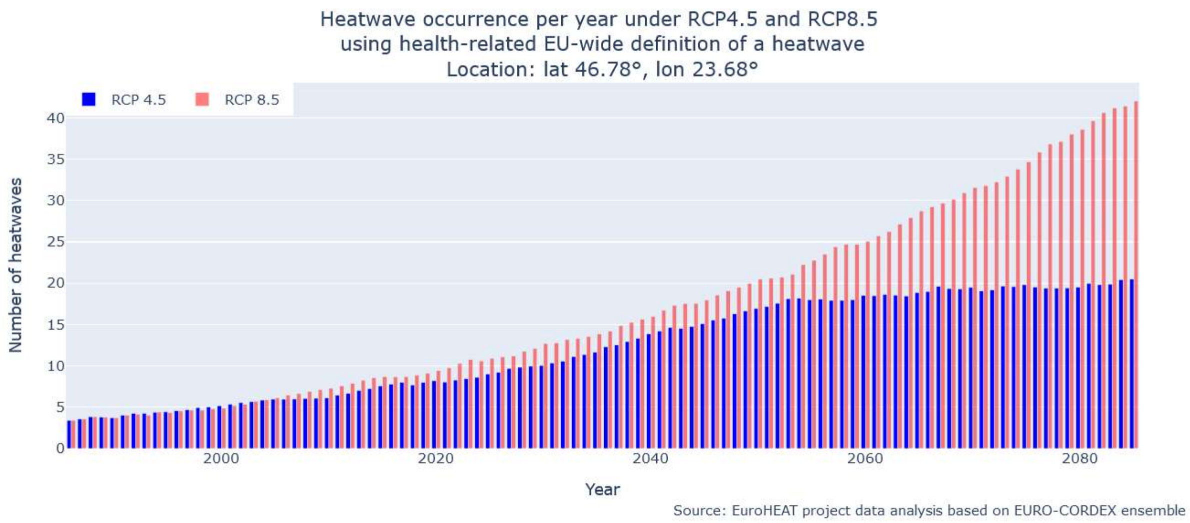

Figure 2-1HW occurrence per year based on EuroHEAT methodology (the location is Cluj-Napoca city center).

Based on the ***Euro-Cordex dataset and Xclim library***, we evaluated several GCM-RCM pairs (Table 2-2.):

Table 2-2Pairs of GCMs and RCMs used for HW hazard assessment

No	GCM	RCM
1	MPI	SMHI-RCA4
2	MPI	CLMCOM-CCLM4-8-17
3	MPI	MOI-CSC-REMO2009
4	CNRM-CERFACS-CM5	KNMI-RACMO22E
5	ICHEC-EC-EARTH	KNMI-RACMO22E

For both HW index, frequency and total length, we defined specific thresholds:

- HW index:
  - thresh_tempmax: 25 / thresh_window: 3
- HW frequency and heatwave total length:
  - thresh_tasmin: 18 / thresh_tasmin: 25 / thresh_window_hreq: 2
  - thresh_tasmin: 18 / thresh_tasmin: 25 / thresh_window_hreq: 3
  - thresh_tasmin: 20 / thresh_tasmin: 25 / thresh_window_hreq: 2
  - thresh_tasmin: 20 / thresh_tasmin: 25 / thresh_window_hreq: 3

The motivation for using two thresholds for HW frequency and length (2 days and 3 days) is that (i) usually, in international research studies, a minimum duration of 3 consecutive days is considered for HW (mainly based on Climpact HW definitions - https://climpact-sci.org/) and (ii) based on a study conducted for the most populated cities of Romania, including Cluj-Napoca, the relative risk of mortality increases from the first day in case of extreme high temperature; thus, we decided to decrease the length of the HW length.

We performed the hazard assessment analysis, considering the RCP4.5 and RCP8.5 for all GCM–RCM pairs presented in Table 2-1-1 and the results are presented as the averages of the ensembles of the models used for the period 1971-2050.

The results obtained for the HW index, in general, indicate almost similar values for both RCPs as average values over the period 2025-2050: 44.4 days for RCP4.5 and 43.3 days/yr for RCP8.5 (Fig. 2-2).

When the pair of TN18°C/TX25°C is considered, the frequency of 2-day HWs is estimated based on the RCM ensemble output to increase by three times considering RCP4.5 simulation and almost four times when RCP8.5 simulations were considered over the period 2021-2025 compared with the historical period (1971-2000) (Fig. 2-3 left, Table 2-3). In the case of 3-day HWs, the relative increase is expected to be even higher (five times) compared to the historical period. However, regarding real values, fewer3-day events are expected (less than 2) compared with 2-dayevents(Fig. 2-3 right, Table 2-3).

For the pair of TN20°C/TX25°C, due to the extremely low frequency of tropical nights (TN equal or higher than 20 °C) for both historical period and future decades, the HW frequency is considerably lower. However, it is worth noting that they have been very rare over the historical period, and they were lacking for most of the years before 2000 in case of 3-day events, but their number is expected to increase on mid-term (Fig. 2-4, Table 2-3).

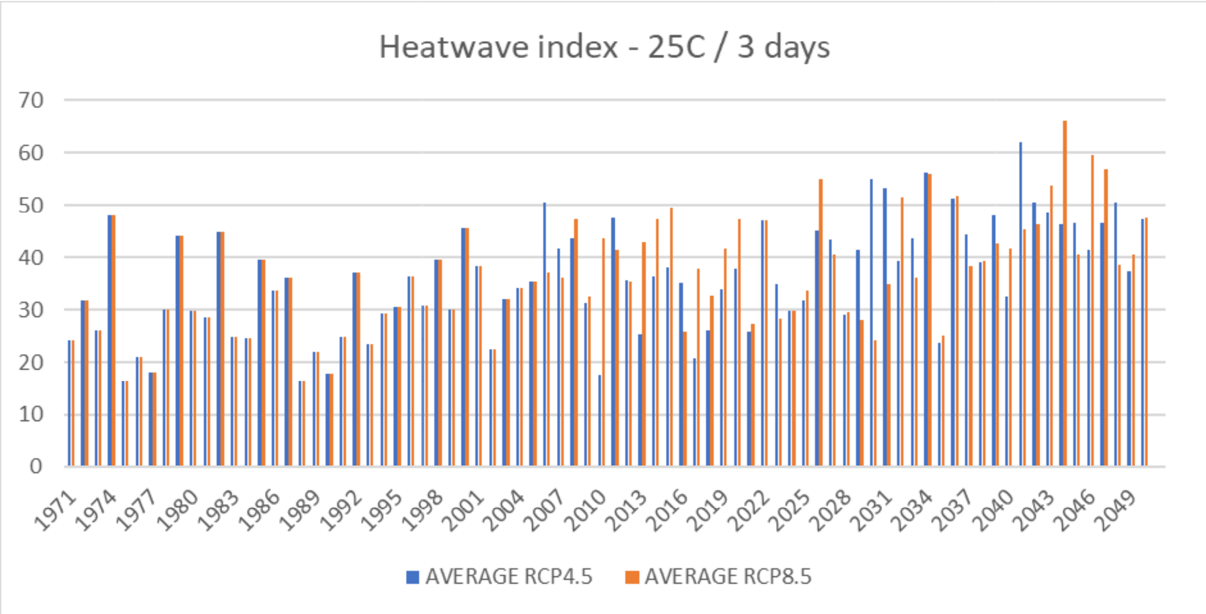

Figure 2-2HW index per year based on Euro-CORDEX data over the period 1971-2050

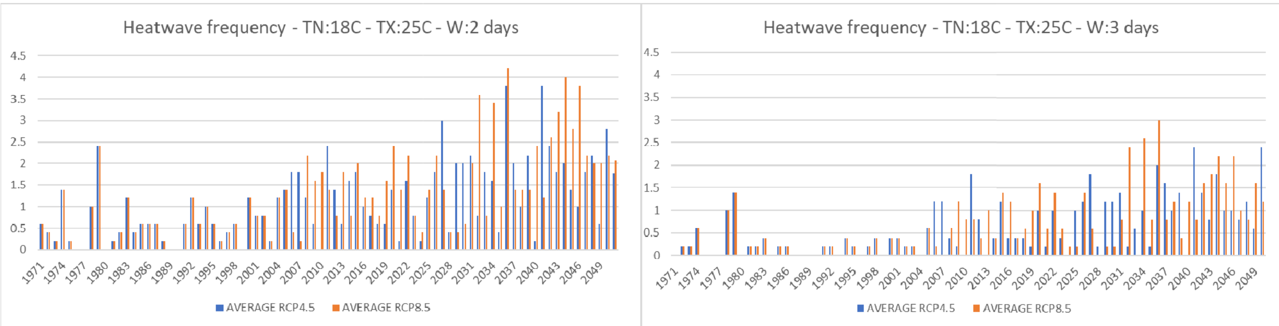

Figure 2-3. HW frequency for the threshold pair: TN – 18 °C and TX – 25 °C

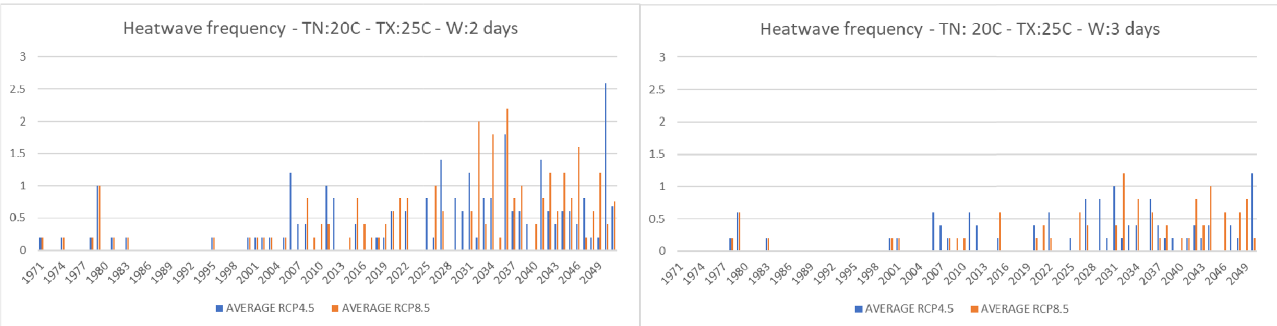

Figure 2-4. HW frequency for the threshold pair: TN – 20 °C and TX – 25 °C

HW length is estimated to increase considerably over the following decades, both for the 2-day and 3-day events. The average length of the events is also estimated to increase with their frequency over the next decades (Fig. 2-5 and 2-6, Table 2-3).

However, some of the GCM-RCM returned relatively low values for both frequency and length (CNRM-CERFACS-CM5/KNMI-RACMO22E; ICHEC-EC-EARTH/KNMI-RACMO22E), whereas some others indicated considerably higher values for both parameters considered (MPI/SMHI-RCA4; MPI/CLMCOM-CCLM4-8-17; MPI/MOI-CSC-REMO2009).

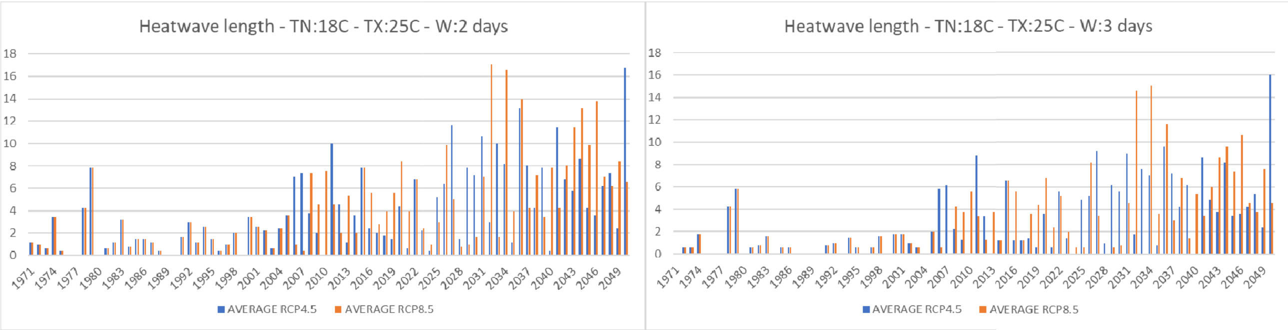

Figure 2-5. HW length for the threshold pair: TN – 18 °C and TX – 25 °C

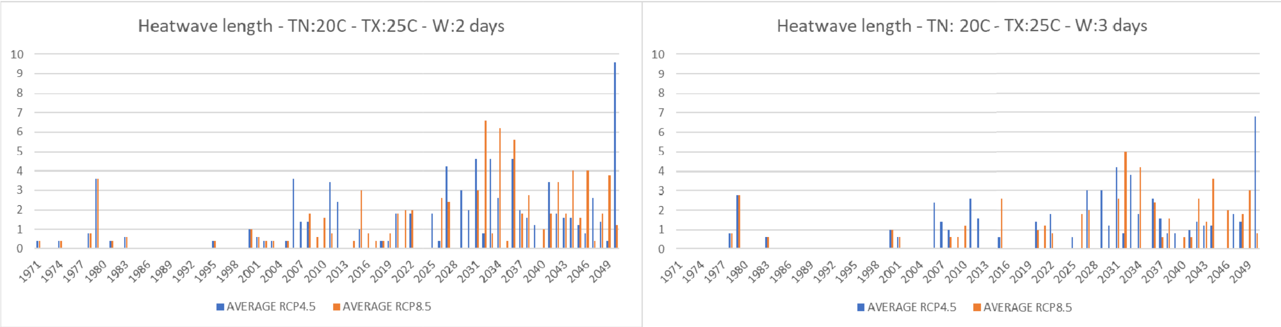

Figure 2-6. HW length for the threshold pair: TN – 20 °C and TX – 25 °C

Table 2-3Pairs of GCMs and RCMs used for HW hazard assessment

Parameter	Period	Scenario	Minimum length	Value	TN-18; TX-25	TN-20; TX-25
Index	1971-2000	Historical	3 days	30.2		
Index	2021-2050	RCP4.5.	3 days	44.4		
Index	2021-2050	RCP8.5	3 days	43.3		
Frequency	1971-2000	Historical	2 days		0.56	0.08
Frequency	2021-2050	RCP4.5.	2 days		1.78	0.69
Frequency	2021-2050	RCP8.5	2 days		2.08	0.75
Frequency	1971-2000	Historical	3 days		0.22	0.04
Frequency	2021-2050	RCP4.5.	3 days		1.13	0.33
Frequency	2021-2050	RCP8.5	3 days		1.18	0.36
Length	1971-2000	Historical	2 days		1.51	0.25
Length	2021-2050	RCP4.5.	2 days		6.90	2.22
Length	2021-2050	RCP8.5	2 days		7.41	2.19
Length	1971-2000	Historical	3 days		0.83	0.17
Length	2021-2050	RCP4.5.	3 days		5.61	1.50

Length	2021-2050	RCP8.5	3 days		5.61	1.41

2.3.1.2 Risk assessment

(a) Risk assessment under climate change conditions

For HW risk assessment under climate change conditions based on modeled data, we downloaded Romania's administrative boundaries from GADM, selecting Cluj as subregion_name.

The hazard and risk values were calculated based on EuroHeat Hazard Data for three periods: 1986-2015, 2016-2045, and 2046 – 2075. Using data downloaded from the WorldPop database, we considered individuals aged over 65 years to be vulnerable (Figs. 2.7-2.10).

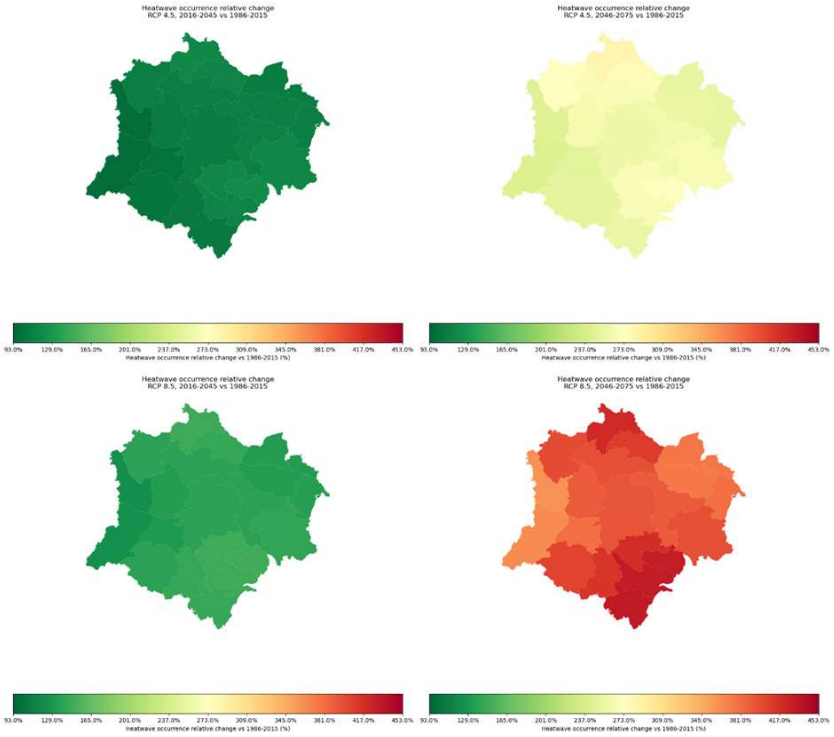

Figure 2-7Relative change of the heatwave occurrence

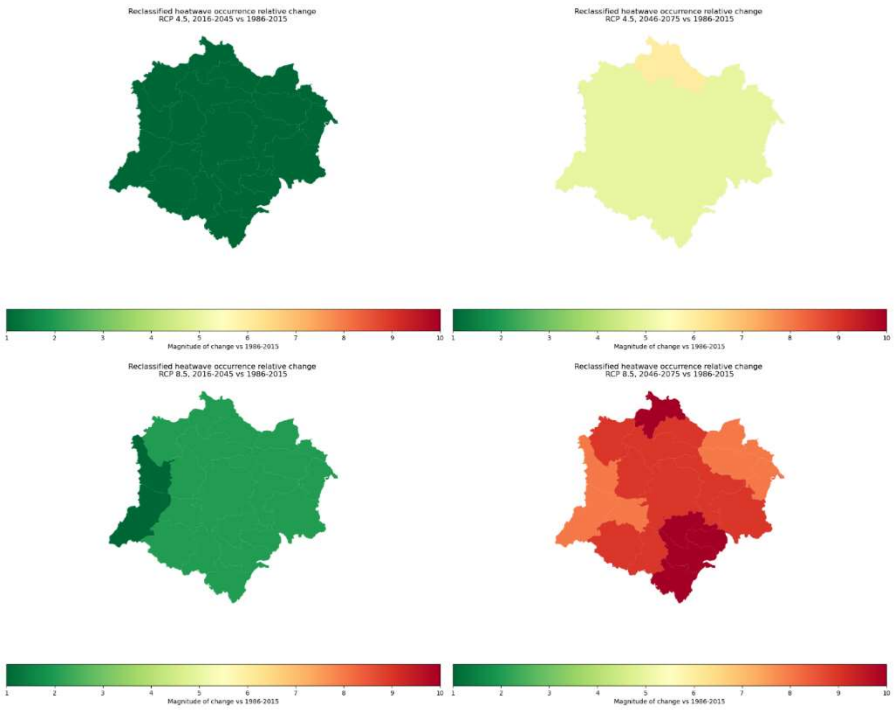

Figure 2-8Magnitude of change in the heatwave occurrence (reclassification)

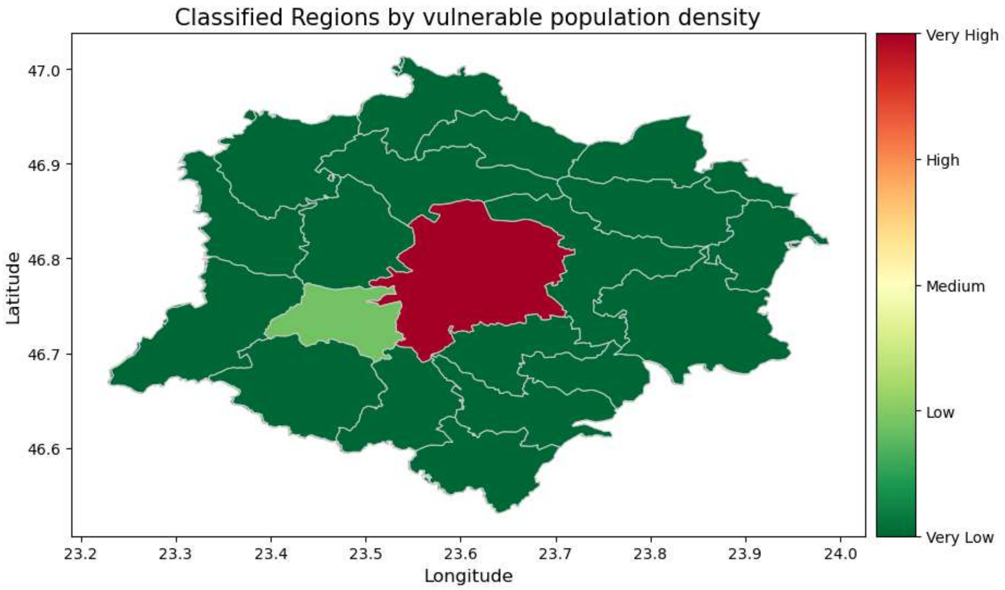

Figure 2-9Classified settlements by vulnerable population density

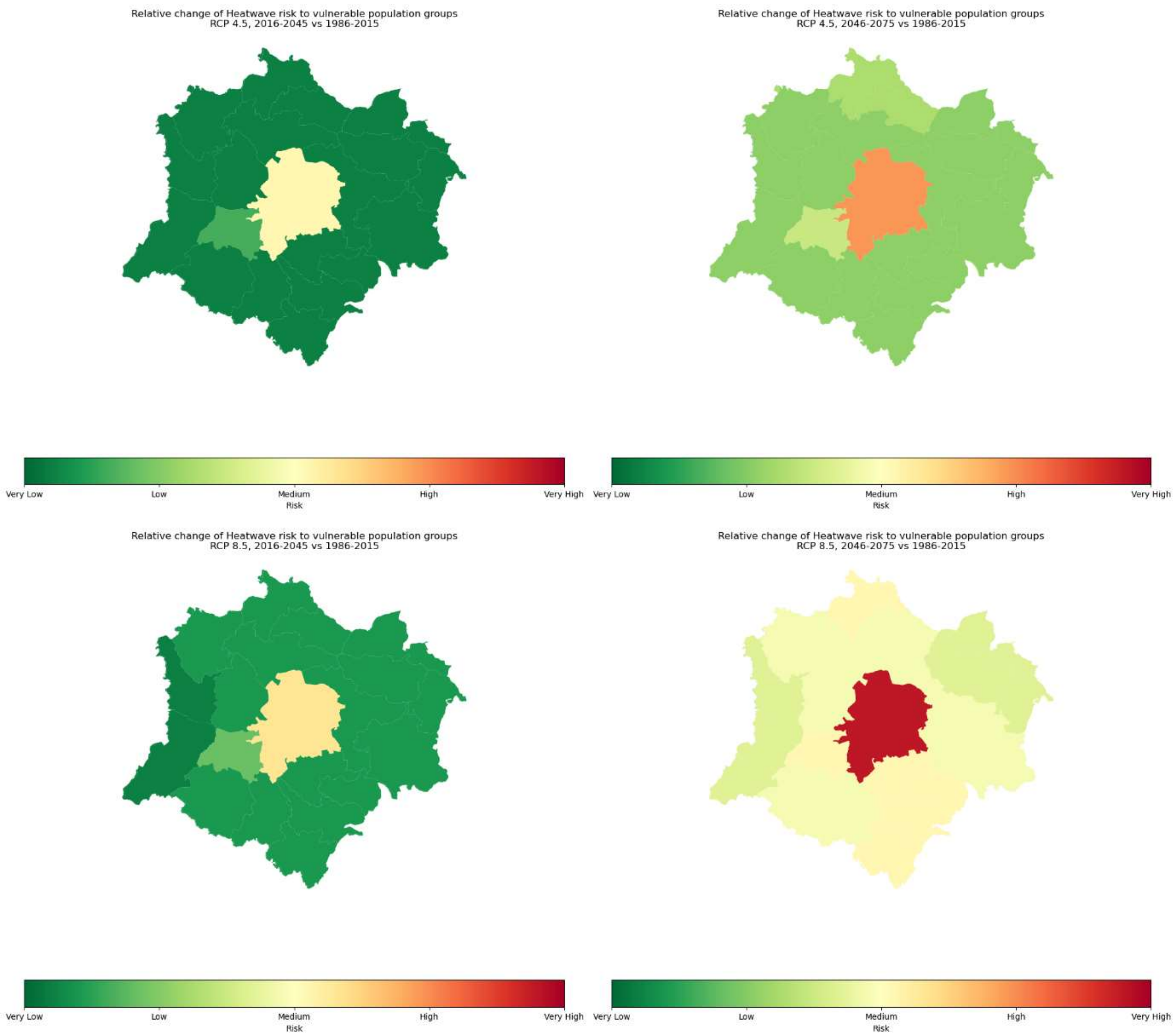

Figure 2-10Risk values based on the risk matrix

In terms of HW occurrence and well as in their magnitude, for the present and near future (2016-2046), very low to low changes are expected for the largest part of the focus region. The change analysis indicated a more accelerated change over the mid-to-late century (2046-2075), with medium-intensity change in the case of RCP4.5 and high and very high change in the case of the pessimistic scenario (RCP8.5) compared to the historical period (1986-2015) (Figs. 2.8-2.9).

Also, in terms of vulnerable population groups, Cluj-Napoca city seems to estimate the most intense change in the considered region, with medium risk in the nearterm and a severe situation with high and very high risk calculated for the long term, compared to the surrounding rural areas, where the risk remains low on medium on long term (Figs. 2.9-2.10) (High resolution images can be accessed on Zenodo).

(b) Risk assessment for heatwaves based on satellite-derived data

We applied the Jupyter Notebook as it is, without modifying any part of the code. The Landsat 8 satellite data to retrieve LST was downloaded using the RSLab portal for August 2024. Two usable images were selected (16 and 24 August) and employed for further processing.

Unfortunately, even though it is available as an option, and we attempted to upload the CMA as a KML file, the polygon did not appear. The onsite manual does not mention any aspects regarding the use, limitations, or constraints of KML uploads.

In order to get the results, we drew a rectangle to frame our study area (Fig. 2.11), but not the entire region could be covered by the satellite image. Under these circumstances, we selected the area mainly covering Cluj-Napoca city, which is the most critical due to high population density and heat stress intensification under UHI impact, especially in the associated hot spot areas (Fig. 2.12).As a vulnerable population group, we considered individuals aged over 65 years, using data from the WorldPop database. All other calculations were performed using the toolbox's predefined standard limits and classes. The heat risk level indicated the highest values corresponding to Cluj-Napoca city central and largest neighbourhoods. The surrounding villages, especially those in the western part, were detected with a low to very low heat risk level, mainly due to the combined consequence of high young population shares (not considered as vulnerable) and the cooling effect of the nearby forested areas (Fig. 2.13).

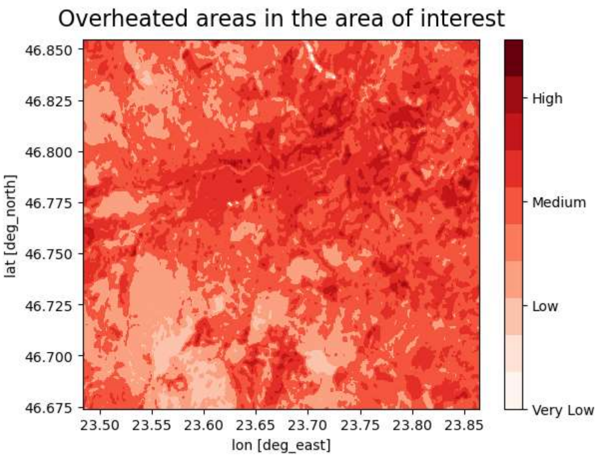

Figure 2-11. Overheatedareas in the CMA region

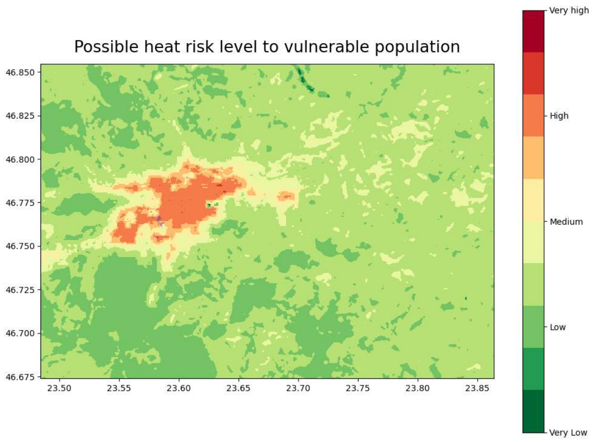

Figure 2-12. Possibleheatriskleveltovulnerablepopulation

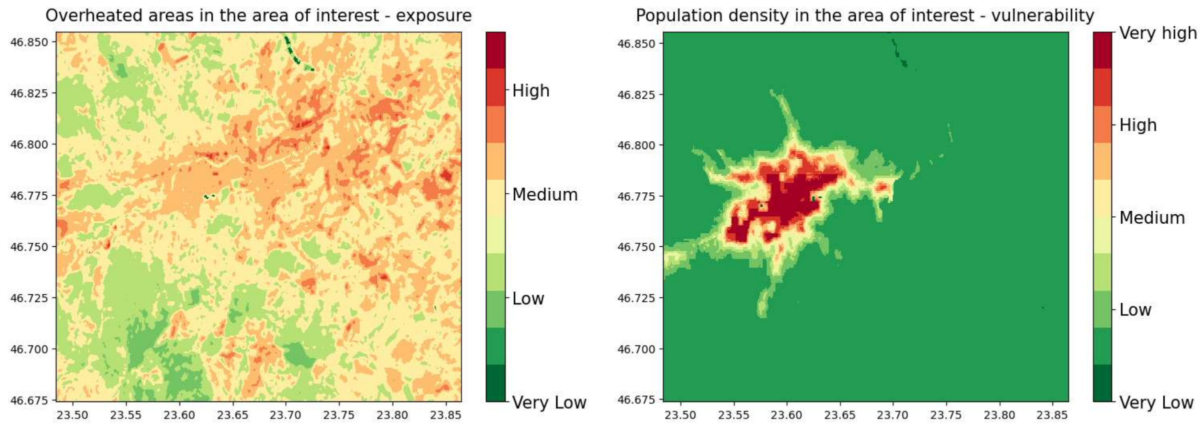

Figure 2-13Overheated areas – exposure (left) and vulnerability based on population density (right)

2.3.2 Workflow #2

Table 2-4 Data overview workflow #2

Hazard data	Vulnerability data	Exposure data	Risk output
River flood maps for historical climate River flood hazard maps for Europe and the Mediterranean Basin region Available at:**Flood maps:** **[“River flood](#)**	The land use map available from the Available at: [Copernicus Land](#)	Flood-damage curves for infrastructure expressed as relative damage percentage, available from JRC.	Flood inundation maps for the area of interest with different return periods based on European JRC dataset.

Hazard data	Vulnerability data	Exposure data	Risk output
hazard maps for Europe and the Mediterranean Basin region" dataset (Baugh et al., 2024)	Monitoring Service. Population density Available at:GHS-POP R2023A dataset (Carioli et al., 2023) Building data.Available at: OpenStreetMap	The economic value for different types of land use, which can be country/location specific.	Flood damage maps, expressed in economic value, for extreme events with different return periods based on available flood maps for the historical climate.
River flood maps for future climate scenarios **Aqueduct Floods coarse-resolution flood maps** **Aqueduct Floods is an online platform that measures riverine and coastal flood risks under both current baseline conditions and future projections in 2030, 2050, an 2080.** Available at: **https://www.wri.org/data/aqueduct-floods-hazard-maps**	...		Comparison of flood depth maps between the future and historical climates under two climate scenarios (RCP4.5 and RCP8.5) for different return periods.

2.3.2.1 Hazard assessment for river flooding

Hazard assessment for river flooding using flood maps

We performed the hazard assessment without modifying any part of the code and using the JRC maps. The necessary bounding box parameters were set accordingly to frame the Cluj Metropolitan Area. The predefined return periods for hazard calculations were used.

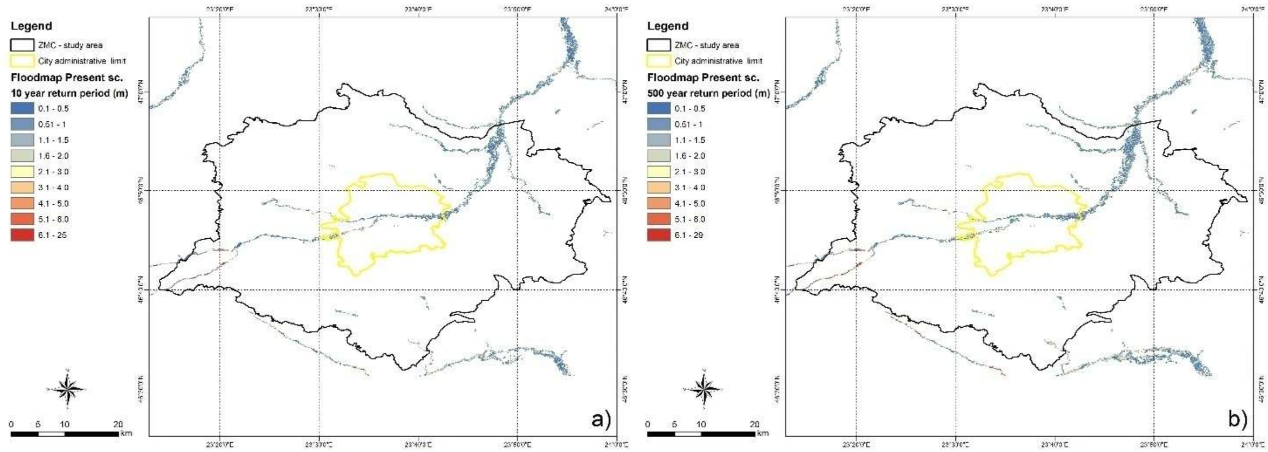

Figure 2-14Cluj-Napoca metropolitan area present climate scenario flood depth map (a- 10 year return period, b- 500 year return period)

We mapped the river flood hazard using the European and global datasets(Baugh et al., 2024).Initially, flood hazard mapping was done utilizing comprehensive the flood hazard datasets that include data for different flood return periods (12, 15, 20, 50, 75, 100, 200, and 500 years) (Fig. 2-14). Relevant subsets of these flood hazard datasets were retrieved and analyzed specifically for our targeted region to assess the current flood risks comprehensively (see Zenodo Floods_Maps_charts.zip).

In addition, we explored the projected impacts of climate change on river flood hazards under various climate scenarios. This was achieved by integrating datasets and projections from the

Aqueduct Floods coarse-resolution flood maps. These analyses allowed us to identify variations in flood risk patterns and severity, providing valuable insights into potential future challenges and informing the selection of targeted adaptation measures.

2.3.2.2 Risk assessment for river flooding

The entire analysis regarding risk calculation was performed using the existing code cells, without modifying any part of the code or data, based on the results obtained from the hazard assessment.

This analysis focused specifically on evaluating risks to built infrastructure, expressing flood risks primarily as **economic damages**. These economic damages were calculated using flood extent and depth data, combined with exposure and vulnerability information. The calculation method integrates **depth-damage curves**(Fig. 2-15) tailored to specific land-use categories and country-specific economic parameters, providing an approximation of the economic value associated with different land use types (Fig. 2-16) (see Zenodo Floods_Maps_charts.zip).

By overlaying flood inundation depth, land-use classifications, and economic vulnerability indicators, we generated detailed maps depicting **hotspots of potential economic damage** for different flood scenarios, corresponding to specific river discharge return periods.

These visual outputs effectively highlight spatial variations in flood risk, identifying critical areas most likely to experience significant economic losses due to river flooding events of various magnitudes. Hereby, stakeholders and decision-makers can pinpoint priority zones for adaptation measures and targeted flood risk management strategies.

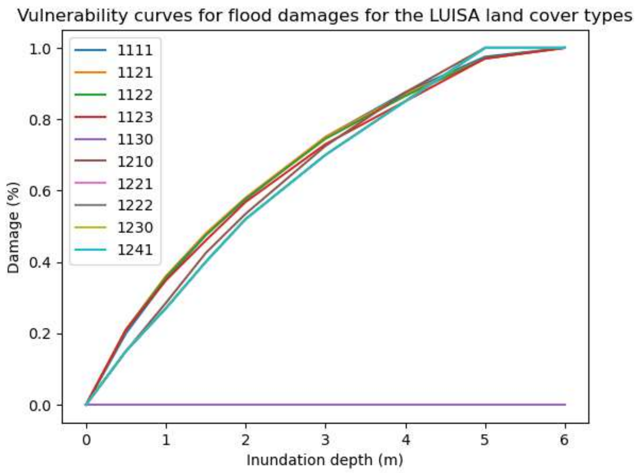

Figure 2-15. Vulnerability - damage curves for land use(CMA area)

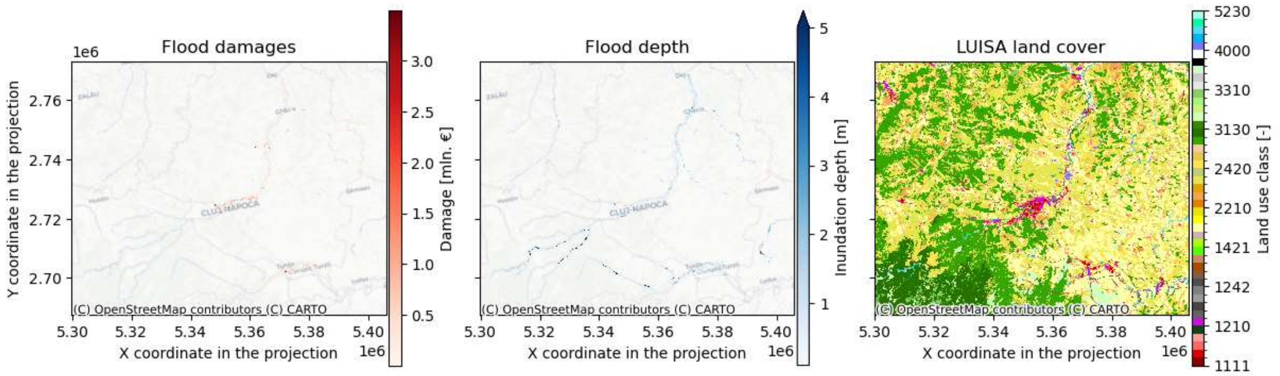

Figure 2-16. Maps of flood and associated damages for extreme river water level scenarios in current climate 1 in 100 year extreme event

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

Considering the risk outcome from workflow(s) application, it is encouraged to also involve stakeholders, experts and priority groups for collecting information on the perception of risks, finally resulting in an indication of risk severity.

Workflow #1Heatwaves. The HW occurrence and their magnitude, very low to low changes for the present and near future (2016-2046) are expected for the most significant part of the focus region. A more accelerated change is estimated over the mid-to-late century (2046-2075), with medium-intensity change in the case of RCP4.5 and high and very high change in the case of the pessimistic scenario (RCP8.5) compared to the historical period (1986-2015). Also, in terms of vulnerable population groups, Cluj-Napoca city seems to estimate the most intense change in the considered region, with medium risk in the near term and a severe situation with high and very high risk calculated for the long term, compared to the surrounding rural areas, where the risk remains low on medium on the long term.

Similar results have been obtained using satellite images, with the highest heat risk level corresponding to the central area and the most extended neighbourhoods of Cluj-Napoca city. The surrounding villages, especially those in the western part, were detected with a low to very low heat risk level, mainly due to the combined consequence of high young population shares (not considered as vulnerable) and the cooling effect of the nearby forested areas (Fig. 2-13).

Workflow #2 Floods. The risk analysis conducted for the CMA has revealed significant exposure to river flooding, particularly affecting built infrastructure and local populations. Utilizing European-wide flood datasets (JRC flood maps) and the Aqueduct Flood scenarios, the analysis provided quantitative estimates of economic damages and population exposure, here the two extremes are presented (Fig. 2-14):

- **10-year return period flood**: Potential economic damage is approximately €481 million, directly affecting an estimated over 40.000 residents, primarily those in low-lying neighbourhoods and near critical urban infrastructure.
- **500-year return period flood (extreme event)**: Potential economic damage escalates to about €700 million, with impacts extending significantly to essential services, critical infrastructure, economic activities, and potentially impacting 60.000 residents.

The MECRA-Cluj kick-off meeting served as an effective launchpad for joint climate resilience efforts in the Cluj Metropolitan Area. Stakeholders from various sectors welcomed the initiative and engaged constructively in the dialogue on regional climate vulnerabilities. The session confirmed the project's strategic focus on flooding and heatwaves, and highlighted the importance of strengthening cooperation between institutions for the next implementation phases.

2.4.2 Urgency

Workflow #1Heatwaves. Immediate actions are needed for Cluj-Napoca city in terms of adaptation to extreme heat stress, as the heat stress risk level has been calculated at a high level. The adaptation to climate change strategy and plan is a must, as the measures to be taken need to be designed in the long term as it is estimated to intensify even more by mid-century, considering the risk to vulnerable population groups and to extend to the rural areas.

Workflow #2 Floods. Climate projections indicate the severity and frequency of flooding will further escalate within the coming decades (2030-2050). Thus, proactive measures and strategic adaptations are urgently needed to minimize future losses. The timeframe for taking effective action to significantly reduce flood damages is within the **next 5-10 years**, given that existing infrastructure is currently insufficient for coping with projected increases in extreme precipitation.

2.4.3 Capacity

Workflow #1 Heatwaves. Since no ACC strategy or plan is in place, risk management measures currently derive from national regulations or specific measures in the case of each individual event adopted at the local level. They mainly consist of receiving early warnings for heat as established at the national level for much larger regions, establishing a first-aid network in the city/villages, and recommending individual or collective protection in case of heat events released by medical authorities. However, the first-aid network is not correlated with UHI hotspots identified in the city or based on vulnerable population density.

Due to the consistent increase in air temperatures, growing season length, and growing degree days, introducing thermophile species with a more intense cooling effect should be considered as a shift in green space design, especially in the urban area.

Workflow #2 Floods. In the first phase of the climate risk assessment, we gained significant insights into flood and heatwave hazards for the Cluj-Napoca metropolitan area. We learned that existing data sources, like the flood maps provided by the Joint Research Centre (JRC) and historical and projected meteorological data, represent valuable starting points for understanding current and future climate risks.

However, we also identified key limitations. Specifically, there is a critical need for improved local-scale data, particularly high-resolution climate data, detailed flood modeling, and more precise socioeconomic vulnerability mapping. The preliminary analyses clearly highlighted that, to accurately capture flood risks, future assessments must integrate enhanced data sources, including high-resolution flood hazard modeling at the urban scale. While JRC flood maps provide a useful baseline, further stages of assessment must include more detailed local flood modeling to accurately represent both riverine floods along the Someșul Mic River and urban flash floods, which currently remain underrepresented due to coarse spatial scales.

Additionally, the current assessment emphasized the urgency of addressing urban flooding in areas with high impervious surfaces, outdated drainage systems, and dense urban infrastructure, which amplify the vulnerability of residents and economic activities. The need to integrate local knowledge and engage stakeholders in continuous feedback loops was also recognized as vital for refining future climate risk assessments and aligning them closely with community priorities and adaptation strategies.

In the next phases, special attention should be given to detailed mapping of flash flood risks at high spatial resolution, as current European and global datasets within this first phase of assessment lack sufficient detail to effectively represent flash flooding and its impact within the urban context of Cluj-Napoca. This includes improving flood hazard maps and incorporating fine-scale urban topography and infrastructure characteristics. At the current stage, such detailed information is notably missing but essential for robust climate risk assessment and management in the urban context of Cluj-Napoca.

Overall, the first phase has clearly indicated valuable opportunities for future improvements, particularly in data accuracy and stakeholder participation, establishing a foundation for subsequent climate resilience and adaptation actions.

2.5 Preliminary Monitoring and Evaluation

In the first phase of the climate risk assessment, we gained significant insights into flood and heatwave hazards for the CMA. We learned that existing data sources, like the flood maps provided by the Joint Research Centre (JRC) and the existing historical and future modeled climate data, represent valuable starting points for assessing current and future risks. However, we encountered several challenges, including gaps in local-scale data, limitations in precise vulnerability mapping, and difficulties in integrating socioeconomic information at sufficiently detailed spatial resolutions. Moreover, the preliminary results underscore the urgency of addressing infrastructural vulnerabilities and critical hotspots where adaptation measures are necessary.

Some difficulties in manipulating or limitations of the Heatwave toolbox were encountered:

- For HW hazard estimation based on the Euro-Cordex dataset and Xclim library, even though the handbook mentions that a selection of the HW length can be made(2 or 3 consecutive days), in fact, the results return similar values for both length thresholds (corresponding for 3 days events); it seems that in the code, the value of 3 consecutive days is considered as the one valid for HW index parameter; we had to modify the code for obtaining valid results for the selection of two consecutive days events and to reprocess the datasets for all GCM-RCM pairs considered, which led to time-consumption;
- For the heat risk calculated based on satellite images, even though it is available as an option, and we attempted to upload the CMA as a KML file, the polygon did not appear on the figures generated. The onsite manual does not mention any information regarding the use, limitations, or constraints of KML uploads. Also, not the entire region can be visualized on the analysis based on satellite images and we had to select the most relevant area of the focus region to be analyzed.

The kick-off meeting of the MECRA-Cluj project marked a strong starting point for collaborative climate action in the Cluj Metropolitan Area. Local stakeholders responded positively to the invitation and participated actively in discussions on climate risks. The meeting helped validate the project’s dual focus on **flooding and heatwaves**, while also identifying shared priorities and opportunities for institutional cooperation in future project stages. Furthermore, continuous stakeholder involvement and feedback will be essential to refine and validate risk assessments and ensure alignment with community priorities and decision-making processes.

For the future steps, our goal is to involve more representatives of the civil society and local residents in the whole process.

For effective future monitoring and evaluation, we identified the need for improved data collection, particularly high-resolution climate data and flood models and detailed socioeconomic vulnerability indicators. Extra corrections for urban locations must include the increased temperatures within the built environment and land use.

3 Conclusions Phase 1- Climate risk assessment(1-2 pages)

This first phase of the CRA provided a systematic evaluation of climate-related hazards for the Cluj-Napoca metropolitan area, focusing on heatwaves and floods, in line with the methodological guidelines outlined in the CLIMAAX Framework and Handbook. The analysis was carried out using existing European and global-scale datasets provided in the CLIMAAX toolbox.
This phase successfully identified significant climate risks posed by HW and river flooding for the Cluj-Napoca metropolitan area (CMA). The main findings are listed below.

- HW Risks:
    - HW are increasing in frequency, intensity, and duration, particularly affecting densely populated urban neighborhoods such as Mărăști and some of the rural areas (Florești), characterized by limited vegetation cover and substantial impervious surfaces.
    - Results indicate medium to high risks for vulnerable population groups, particularly the elderly and low-income households residing in densely urbanized neighborhoods. Projections suggest that, without targeted adaptation, risk severity will escalate considerably by mid-century (2046-2075), particularly under the pessimistic climate scenario (RCP8.5).
- Flood Risks (Note: The actual numbers might differ, since the datasets used do not take existing man-made protections into account.):
    - Flooding represents a severe and immediate hazard, with economic damages potentially reaching approximately €481 million in a relatively frequent flood scenario (10-year return period) and escalating significantly to about €700 million in extreme flood events (500-year return period).
    - Approximately 40,000 residents are at risk of direct exposure in moderate flooding events, increasing up to 60,000 people in extreme flood scenarios.
    - The most critical areas are low-lying urban neighborhoods and central zones along the Someșul Mic River, highlighting the need for urgent infrastructure and drainage improvements.

During this phase, the assessment considered existing tools and recommended datasets for hazard and preliminary risk estimation. However, several key challenges were noted:

Resolution constraints: current assessments were limited by relatively coarse spatial resolution datasets, inadequate for precisely capturing detailed urban flash flood hazards, and small-scale inundation patterns.

Toolbox limitations: minor methodological issues and constraints in data manipulation were identified, particularly in:

- calculating the heatwave length (for the 2-day events):
  before determining the Heatwave Index, the maximum temperature (*thresh_tempmax*) and the duration (*thresh_window*) must be set. When calculating the Heatwave Frequency and Heatwave Total Length, the minimum and maximum temperatures (*thresh_tasmin* / *thresh_tasmax*) and the duration (*thresh_window_hfreq*) need to be specified.We found it strange and misleading that while the duration for Heatwave Frequency is defined by the *thresh_window_hfreq* variable, in the next step of the same process, the toolbox uses the previously set duration indicator (*thresh_window*) from the Heatwave Index calculation. Without a detailed review of the Python code, the user may mistakenly assume that the same duration is applied to both Heatwave Frequency and Heatwave Total Length. **We addressed this challenge by modifying the original code**.
- showing the focus area border– not addressed.

- effectively integrating satellite-derived heat-risk data for the entire focus area in a single figure – not addressed.

To enhance the quality and effectiveness of future climate risk assessments, it is essential to:

- ***Improve hydrological data resolution and detail***: develop high-resolution inundation maps for detailed representation of flash flood risks, particularly within urban contexts ~ for the future phases we identified the necessary resolution flood risk maps at the ~ *National Administration "Romanian Waters"*-"Flood hazard and risk maps"..
- ***Improved resolution climate data***: for upcoming analyses, a new historical climate dataset with a much higher horizontal spatial resolution (1 km), recently made available bythe *Romanian National Meteorological Administration*, will be employed; it is estimated to significantly enhance the accuracy in hazard mapping, particularly in densely populated urban zones.
- ***Integrating new methodology*** for UHI for the analysis based on LST derived from satellite images: it is also planned to integrate into the satellite-data approach the methods to identify SUHI hotspots recently developed by the SUB2 team (Magyari-Sáska et al., 2024). This increased resolution will enable more precise identification of affected areas, better vulnerability assessments, and targeted adaptation interventions.
- ***Engaging stakeholders actively*** is foreseen for the upcoming phases; we will continue to involve local communities, authorities, and key stakeholders throughout the risk assessment process, ensuring alignment with local priorities and targeting to facilitate adequate adaptation strategies through developing a dedicated strategy and associated action plan.

In summary, this initial project phase has laid a strong foundation by clearly defining the significant climate hazards and preliminary risks in Cluj-Napoca. The findings provide crucial insights for policymakers, urban planners, and stakeholders, informing targeted adaptation measures that can substantially mitigate future climate risks, thereby improving regional resilience and sustainability.

4 Progress evaluation and contribution to future phases(1-2 pages)

With this deliverable culminates the first phase of the project, where the CLIMAAX tools and methodology were successfully assessed in their existing form and validated against the already existing risk analyses for flooding and extreme temperatures (heatwaves), achieving the intended goals of phase 1. This evaluation provided a baseline understanding of the tools' applicability and serves as the basis for further improvements in the upcoming two phases of the project.

Furthermore, relevant stakeholders were engaged in the initial project phase and introduced to the project's intention and goals. Stakeholders from various sectors welcomed the initiative and engaged constructively in the dialogue on regional climate vulnerabilities. The first consultation session confirmed the project's strategic focus on flooding and heatwaves, and highlighted the importance of strengthening cooperation between institutions for the next implementation phases.

The common multi-risk methodology will motivate local environmental monitoring authorities to refine their work so that the information can continuously feed the European database and, in consequence, improve our understanding of the tendencies in weather changes and medium—to long-term forecasting.

Following the successful completion of this phase, the project's second phase will focus on downscaling available hazard data for flooding and heat waves. This refined data will be reintegrated into the CLIMAAX tools to assess whether it enhances their usability for developing prevention and intervention scenarios. Historical higher-resolution datasets for heat waves and floods have already been identified for use in this stage. Additionally, we aim to model pluvial flooding, particularly those related to flash floods. One challenge is that the data currently available in the CLIMAAX toolbox is at a regional scale, whereas flash flood assessment requires much finer, local-level data. We also hope to access precipitation intensity and frequency data to evaluate flash flood probabilities, similar to the approach used in the CLIMAAX Setúbal example. However, at this point, it remains uncertain exactly what data will be accessible for this purpose. We have already identified historical higher-resolution datasets for HW and floods to be used in the project's second phase. Any necessary modification to the existing CLIMAAX Jupyter Notebooks to accommodate the downscaled data will be implemented and documented in the second phase as well. Phase 2 of the project is expected to be finalized in January 2026.

The insights gained from the first two phases will serve as the basis for the third and final phase of this project, where the most effective adaptation measures will be selected and prioritized based on the results gained from the previous evaluations using the CLIMAAX methodology. This phase is scheduled to conclude in July 2026.

Table 4-1Overview key performance indicators

Key performance indicators	Progress
Two hazards assessment	HWs and riverine floods for the focus region were assessed during this phase.
Risk assessment forthe two hazards	HWs and riverine flood risk for the focus region werecalculated during this phase.

Key performance indicators	Progress
Two toolboxes to be tested as they are for the CMA	During the first phase, two CLIMAAX tools (Heatwaves and Floods) have been tested as they are, using indicated datasets and good results were obtained for the focus region. Difficulties on their use were presented in section 2.5.
One consultation with stakeholders.	One consultation with stakeholders to present the results of the first phase and get their feedback was organized. 16 persons participated representing Inspectorate for Emergency Situations Cluj (ISU), Romanian National Meteorological Administration (Meteo România), Someș Water Company, Technical University of Cluj-Napoca, Babes-Bolyai University of Cluj-Napoca, Institute for research in Circular Economy ”Ernest Lupan”, C-Edu Education Cluster.

Table 4-2Overview milestones

Milestones	Progress
Selection of the academic sub-contractors to perform hazard and risk analysis for HWs and RFs	The two subcontractors have been selected, namely the Austrian Institute of Technology, and Babes-Bolyai University.
Phase 1 results presentation to CMA representatives and stakeholders by SUB2	The SUB2 team presented the HW and RF hazard and risk assessment results to CMA representatives and stakeholders, collected their feedback, and integrated it into Deliverable 1.

5 Supporting documentation(1-2 pages)

- *Main Report (PDF or Word)*
- *Heatwaves Visual Outputs and Datasets(infographics, maps, charts, CSV)*
- *Floods Visual Outputs and Datasets(infographics, maps, charts, CSV)*
- *Communication Outputs (Press release, media)*
- *Stakeholders meeting(images)*

10.5281/zenodo.15100288

During this phase of the climate risk assessment for the Cluj-Napoca metropolitan area, the following outputs were generated and compiled:

- **Main Report**
- **GIS layers, maps and charts:**

Charts illustrating the heatwave (HW) index, frequency, and total length of heatwave events across the Cluj-Napoca metropolitan area.

Risk maps presenting relative changes and magnitude changes of heatwaves under different climate scenarios, highlighting areas particularly vulnerable to HW related hazards.

Charts presenting the vulnerability - damage curves for the land use, exposed people and damage values differentiated on return period.

Flood hazard maps depicting inundation extents for river flooding under various statistical return periods Joint Research Centre (JRC).Maps visualizing estimated economic damage hotspots associated with river flooding scenarios, illustrating areas with significant potential damage to critical infrastructure.

- **Analytical outputs (risk analysis results and tables):**

Tables and charts summarizing historical trends and future projections of HW frequency, intensity, and duration in Cluj-Napoca.

Summary tables detailing estimated economic damages and affected population numbers under different flood return periods.

- **Communication Outputs (Press release, media)**
  MECRA-Cluj project was promoted via multiple communication channels, ensuring visibility and engagement with the wider community:
  - Facebook (Cluj Metropolitan Area)
  A teaser post, announcing the kick-off and stakeholder meeting, highlighting the project's role.
  - Facebook (Cluj Metropolitan Area)
  A post presenting the Pilot MECRA-Cluj and summarizing the first stakeholders meeting.
  - Facebook (Ziua de Cluj)
  A link to the article (see below) also published on the Facebook page of the newspaper.
  - CMA Official Website (www.clujmet.ro)
  An article summarizing the objectives of MECRA-Cluj, the project's focus areas (flooding and heatwaves), and its alignment with European climate strategies will be published, along with event photos and stakeholder quotes.

- Article

An article in a local online newspaper (Ziua de Cluj) to inform local media about the project's scope and its alignment with Cluj's strategic development goals and Climate City Contract commitments.

Also a roll up with the official visual of the project has been produced and used at the events related to the project.

In person Kick off and stakeholder consultation meeting took place on the 19th of March 2025, where relevant stakeholder participated and were actively involved in discussions. For more details please see Table 41.

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