Deliverable Phase 1 – Climate risk assessment

Strategies for Mitigating the Urban Heat Island (UHI) Effect in Antalya (Türkiye): Integrating High-Resolution Local Data for Enhanced Climate Resilience (MUHIR)

Türkiye, Antalya / Antalya Metropolitan Municipality

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	This deliverable presents the Phase 1 outcomes of the MUHIR project, developed under the CLIMAAX framework, focusing on assessing climate-related risks—particularly heatwaves and urban heat island (UHI) effects—in the city of Antalya, Türkiye. The work was carried out entirely by the internal team of Antalya Metropolitan Municipality without external consultancy support, using the open-access methodologies provided by the CLIMAAX Handbook.
Project name	Strategies for Mitigating the Urban Heat Island (UHI) Effect in Antalya (Türkiye): Integrating High-Resolution Local Data for Enhanced Climate Resilience
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Abbreviations and acronyms

Abbreviation / acronym	Description
ABB	Antalya Büyükşehir Belediyesi
AFAD	Disaster and Emergency Management Authority (Türkiye)
AOI	Area of Interest
API	Application Programming Interface
CDS	Copernicus Climate Data Store
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolbox
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRA	Climate Risk Assessment
CSV	Comma-Separated Values (data file format)
ESRI	Environmental Systems Research Institute
EU	European Union
EURO	Europe-wide (prefix often used in climate projects like EUROHEAT)
EUROHEAT	A European project for heat-health risk analysis (WHO/EU-wide)
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information Systems
IRAP	Integrated Risk Assessment Plan (AFAD-led national document)
LST	Land Surface Temperature
METEO	Meteorological (Data or Services) - Türkiye
MLGP	Multi-Level Governance Platform (EU4ETTR project context)
MUHIR	Strategies for Mitigating the Urban Heat Island Effect in Antalya
NASA	National Aeronautics and Space Administration
PDF	Portable Document Format
RCP	Representative Concentration Pathway (climate scenario)
ROI	Region of Interest
RS	Remote Sensing
SCADA	Supervisory Control and Data Acquisition
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
TIFF	Tagged Image File Format (geospatial image file format)
UHI	Urban Heat Island

Executive summary

This deliverable presents the Phase 1 outcomes of the MUHIR project, developed under the CLIMAAX framework, focusing on assessing climate-related risks—particularly heatwaves and urban heat island (UHI) effects—in the city of Antalya, Türkiye. The work was carried out entirely by the internal team of Antalya Metropolitan Municipality without external consultancy support, using the open-access methodologies provided by the CLIMAAX Handbook.

The motivation behind this deliverable is the increasing severity and frequency of extreme heat events in Antalya, which have posed significant risks to public health, infrastructure, and urban resilience. Recent events—such as the destructive flood on 12 February 2024 and record-breaking heatwaves in summer 2024—have further emphasized the urgency of data-informed climate adaptation planning.

Four structured workflows were selected and implemented:

- Two hazard workflows (EUROHEAT and Xclim) for analyzing historical and projected heatwave trends,
- Two risk workflows combining satellite-derived land surface temperature data and population vulnerability information to map current and future risk intensity across the city.

Key findings show that:

- The frequency and duration of heatwaves in Antalya are expected to increase significantly, especially under the RCP8.5 scenario by 2046–2075.
- Elderly populations, particularly in urban districts like Muratpaşa and Kepez, are at greater risk due to higher exposure to land surface temperatures and limited access to climate-adaptive infrastructure.
- The workflows helped reveal spatial hotspots and validate the need for more granular, in-situ data collection—potentially through drone-mounted thermal imaging.
- Local METEO and mortality datasets are expected to be integrated in future phases to build localized early warning systems and support health-based threshold calibration.

The first phase has contributed significantly to building institutional capacity, improving cross-departmental collaboration, and initiating stakeholder engagement processes—such as the Environmental Board meeting, which welcomed the early findings and emphasized the importance of developing a local heatwave action plan.

The deliverable concludes that the MUHIR project, supported by the CLIMAAX methodology, has laid a strong foundation for future phases. It demonstrates the feasibility of using open-source tools for climate risk analysis at the municipal level and highlights the importance of continued investment in localized data, stakeholder coordination, and science-based policy development.

1 Introduction

1.1 Background

Antalya is a rapidly growing metropolitan city located on the southern Mediterranean coast of Türkiye. With a population exceeding 2.6 million, it stands as one of the most urbanized and economically dynamic cities in the country. Antalya also serves as a major national and international tourism destination, with significant seasonal population fluctuations. The city's rapid urban expansion, increasing energy demand, and intense development pressure pose serious sustainability and climate resilience challenges. In recent years, Antalya has experienced alarming climate-related events, including the **severe flood on 12 February 2024** and the **record-breaking temperatures in the summer of 2024**. These events have brought the **urgency of climate adaptation** into sharp focus for both the municipality and the local community. As a coastal city, Antalya is particularly vulnerable to the combined effects of **urban heat island (UHI)** and **heatwaves**. While the city is home to important green areas like **Zeytinpark**, and new green corridors are beginning to emerge, existing green infrastructure is not yet fully designed or distributed to address UHI impacts effectively. UHI-reducing landscape strategies are still in their early stages and require data-driven expansion. The CLIMAAX project, through the MUHIR initiative, has provided the municipality with a structured opportunity to assess climate-induced heat risks using standardized methodologies while incorporating local context. This work aims to support targeted adaptation actions and build the foundation for long-term climate resilience strategies in Antalya.

1.2 Main objectives of the project

The MUHIR project aims to assess and address the increasing risks of **heatwaves** and **urban heat island (UHI)** effects in Antalya by applying standardized workflows provided in the CLIMAAX Handbook. The main objective is to build a data-driven understanding of heat-related risks and to translate this knowledge into **localized, evidence-based climate adaptation actions**. Antalya, as a coastal city with dense urban settlements, aging population groups, and strong seasonal tourism dynamics, faces intensifying climate pressures. Despite its dynamic growth, the city had not yet developed a structured methodology for assessing heat-related risks. The MUHIR project fills this gap by equipping the municipality with practical tools and spatial analysis methods to identify vulnerable areas, quantify hazard trends, and support early planning of adaptation interventions.

The project also aims to:

- Develop Antalya's internal technical capacity for climate risk assessment using open-access tools,
- Enable cross-departmental collaboration by building a common language around climate risks,
- Provide the basis for a **future local Heatwave Action Plan**,
- Serve as a reference for integrating heat risk analysis into **urban planning, public health, and disaster management**.

By following the CLIMAAX Handbook, the municipality was able to run **four structured workflows**—two for hazard and two for risk analysis—while tailoring them to local conditions. The use of EURO-CORDEX datasets, satellite-derived risk indices, and vulnerability layers (e.g. elderly population segments) allowed the city to visualize both **current hotspots and future risk zones**. The methodology was flexible and modular, which enabled the local team to revise codes, solve data integration issues, and interpret results with support from local experts. Ultimately, the project is expected to bring long-term benefits by building institutional experience, triggering policy discussions (e.g. heatwave-specific planning), and paving the way for further collaboration with academia and health institutions. The methods developed here will also guide similar work in other Turkish municipalities with limited resources but high climate exposure.

1.3 Project team

Antalya Metropolitan Municipality is overseeing this project with its own internal analysis team based on CLIMAAX methodologies. All stages of the project, from the application and proposal stage to the execution of the project, have been actively involved by an in-house team of the municipality. There has been no paid consultancy or paid technical input from outside organizations in the project. Core Municipal Team: The project team of MUHIR is made up of experts from different municipal departments led by the Climate Change and Zero Waste Department. Table 1-1 shows the composition of the project management and core team of Antalya Metropolitan Municipality.

Table 1-1 Project Management and Core Team of Antalya Metropolitan Municipality

Name	*Department*	*Expertise*	*Assignment in MUHIR*	*Working Frequency*
Fulya Kandemir	*Climate Change and Zero Waste Dept.*	*Dr. Senior Researcher (GIS-RS, Climate Change, Modelling & Data)*	*Project Manager (Contact Person), overseeing administrative work, climatological training, result interpretation, and reporting.*	*Very High*
Abdulkadir Yıldız	*Disaster Management Dept.*	*Geology Engineer (GIS-RS, Coding, Data)*	*CLIMAAX workflows' operations, workflow code adjustments, data transfer, and output analysis.*	*Very High*
Mustafa Kaynarca	*IT Dept. - GIS Branch*	*Mapping Engineer (GIS-RS, Coding, Data)*	*Local data collection, UHI analysis, heatwave indices processing using GIS tools.*	*High*
Esra Aksoy	*Climate Change and Zero Waste Dept.*	*Public Administration (PhD Student)*	*Administrative work, scheduling meetings, official documentation, policy preparation.*	*High*
Volkan Sepetci	*IT Dept. - GIS Branch*	*Mapping Engineer (GIS, Coding)*	*Local data collection, UHI analysis, mortality data collection.*	*Moderate*
Mehmet Doğan	*IT Dept. - GIS Branch*	*Mapping Engineer (GIS)*	*Initial studies on health models and literature review.*	*Moderate*
Özlem Kılıçarslan	*Climate Change and Zero Waste Dept.*	*Environmental Engineer*	*Staff management, budget documentation, policy pre-studies.*	*Moderate*
Güliz Yaman	*Foreign Relations Dept. - EU Project Branch*	*Project Specialist*	*EU Project Support & Coordination*	*Regular Follow-up*
Melike Kireççibaşı	*Climate Change and Zero Waste Dept.*	*Environmental Engineer*	*Head of Department - Administrative Oversight*	*Regular Follow-up*
Lokman Atasoy	*Mayor's Office*	*Environmental Engineer (MSc.)*	*Mayoral Representative & Oversight*	*Regular Follow-up*

External Stakeholders & Contributors: Besides the in-house staff, MUHIR works with institutional and academic stakeholders who contribute either voluntarily or officially to the project. The stakeholders' roles and contributions are shown in Table 1-2.

Table 1-2 MUHIR's External Stakeholders and Contributors (processes in this period).

Name	*Institution*	*Contribution to MUHIR*	*Contribution Frequency*
Prof. Dr. Murat Türkeş	*Boğaziçi University, Climate Policy & Research Center*	*Interpretation of CLIMAAX outputs, guidance on climate data for Antalya.*	*High*

Name	Institution	Contribution to MUHIR	Contribution Frequency
Assoc. Prof. Dr. Nusret Demir	*Akdeniz University, Space Sciences Dept.*	*Technical consultancy on CLIMAAX workflow stages.*	*Moderate*
Assoc. Prof. Dr. Çağdaş Kuşçu Şimşek	*Akdeniz University, Space Sciences Dept.*	*Technical consultancy on UHI effects.*	*Low*
Daiva Matonienė	*EU4ETTR Multi-Level Governance Platform*	*Dissemination and outreach support for MUHIR.*	*High*
Environmental Board	*Antalya Metropolitan Municipality*	*Participating in discussions and providing feedback on MUHIR outputs.*	*High*

Capacity-Building Approach & Municipality's Role: MUHIR has been conducted fully utilizing the existing capacity and experience of the municipality, without external technical or administrative consultancy. This strategy is a response to one of the most prevalent issues municipalities encounters—a shortage of capacity for the implementation of research-based projects. As a difference from other urban projects, CLIMAAX has developed municipality capacity through active engagement of municipality personnel in every step, from writing proposals to implementation of workflows. Team member motivation in Table 1 has been opportunity for professional growth and greater capability for Antalya to manage climate risk. In addition to this, diversity and gender equality have also been given importance at the team's composition, while the participation of a PhD student in municipal work indicates the facilitation of scientific research at government institutions. Inputs of academic as well as dissemination have also begun to be attracted for the project, which confirms long-term engagement in climate adaptation work.

1.4 Outline of the document's structure

This document is structured according to the CLIMAAX Phase 1 Deliverable guidelines. It begins with an overview of the regional context and project objectives, followed by a detailed **Climate Risk Assessment (CRA)** for the city of Antalya. The CRA is divided into several key sections:

- **Scoping**, which defines the goals, governance context, stakeholder participation, and initial risk screening.
- **Hazard and Risk Workflows**, where four selected CLIMAAX workflows (EUROHEAT, Xclim, Satellite-derived risk, and Climate projection-based risk) are described in detail, including methods, data sources, and results.
- **Preliminary Risk Findings**, highlighting severity, urgency, and institutional capacity in responding to heat-related risks.
- **Monitoring and Evaluation**, capturing the lessons learned, encountered challenges, stakeholder feedback, and data needs for future work.
- **Scenario Reflection**, which summarizes assumptions used for climate and socio-economic projections relevant to Antalya.
- **Conclusions**, which wrap up key insights from Phase 1 and indicate how the findings will support the next steps of the project.

Supporting documentation, references, and annexes are provided at the end of the report.

2 Climate risk assessment – phase 1

2.1 Scoping

The main goal is to determine heatwave risks, estimate their effect on cities and suggest adaptation measures according to CLIMAAX workflows. Antalya is already faced with an enhancement of the frequency and intensity of heatwaves and additionally with UHI impacts. The most vulnerable populations are elderly people, outdoor workers, and individuals with chronic diseases. There is a lack of regulative policies for mitigation of extreme heat in Türkiye.

2.1.1 Objectives

This CRA focuses on heatwave processing as one of the four core components of the CLIMAAX infrastructure—two dedicated to hazard processing and two to risk processing. Our approach uses EURO-CORDEX climate projections (12 km resolution) to estimate the frequency and severity of heatwaves under current and future climate conditions. These projections enable the assessment of heatwave recurrence under varying Representative Concentration Pathways (RCPs), supporting better understanding (Lin and Colle, 2025) and planning by local decision-makers. The results help identify populations and areas at greatest risk by integrating high-resolution heatwave data (30 m) with vulnerable population distribution data (100 m). This facilitates informed, data-driven decision-making in key sectors such as:

- Urban planning: Promoting heat-resilient infrastructure and urban greenery,
- Public health: Enabling early warning systems and targeted interventions,
- Disaster risk management: Enhancing preparedness and response efforts,
- Energy and water planning: Anticipating the impact of heat stress on utilities (Perkins-Kirkpatrick and Lewis, 2020; Yasdıman, 2023).

This methodology strengthens the translation of climate forecasts into actionable knowledge. Our **CRA outputs are designed to be directly integrated into municipal policies and have already contributed to discussions on a local heatwave action plan during the Environmental Board meeting. They also guide green infrastructure planning, protection of vulnerable groups, and climate-resilient investments.**

Implemented entirely by the municipal team using open-source tools and local knowledge, this study offers a replicable model for other municipalities, particularly those with limited resources. The MUHIR project's adaptable framework also enables alignment with other national and international projects, contributing to a cohesive climate resilience strategy. Despite its value, the CRA faced several challenges. **Technical issues with the CLIMAAX JupyterHub platform, especially early on, slowed progress. Additionally, some code modules required adaptation to suit local needs. The lack of Türkiye-specific datasets—such as a national heatwave definition—limited policy alignment. Tools like RsLab proved effective only in small areas, and staff had to juggle project duties with daily responsibilities.** Stakeholder engagement was strong in some stages, but partnerships with health authorities remain a key area for growth. Future efforts will focus on improving tool usability, expanding stakeholder involvement, and integrating more localized data sources such as METEO records and mortality data from the Cemetery Information System for deeper analysis.

2.1.2 Context

In recent years, several climate hazard and risk assessments have been conducted by Antalya Metropolitan Municipality and its partners. In 2021, the Antalya AFAD Provincial Disaster Risk Reduction Plan (IRAP) (https://antalya.afad.gov.tr/il-planlari) included a wildfire risk analysis in collaboration with the municipality. Additionally, as part of the technical assistance initiative aimed at enhancing AFAD's capacity for adaptation and mitigation of disaster risks associated with climate change in Turkey, which started in 2021, studies were carried out to identify risk areas for heat waves (https://www.antalya.bel.tr/YarinlardaBizVariz/Documents). This project was also a study in which our municipality directly participated. In 2022, the Sustainable Energy and Climate Action Plan (SECAP) prioritized both heatwaves and Urban Heat Island (UHI) effects, scoring 4.37 out of 5 in risk prioritization (https://www.antalya.bel.tr/YarinlardaBizVariz/Documents). More recently, Cittaslow initiatives led to localized UHI assessments in a neighborhood of Döşemealtı district. The MUHIR project was launched to address rising heatwave and UHI risks in Antalya, driven by rapid urbanization, population growth, and limited green infrastructure. Although prior policy documents like SECAP and IRAP highlighted these issues, no spatially detailed, health-focused heat risk assessment had been done locally. MUHIR fills this gap using open-access tools and municipal capacity. It directly supports national goals under Türkiye's Climate Change Adaptation Strategy and Action Plan (2024–2030) (https://iklim.gov.tr/eylem-planlari-i-19), including climate-health integration and early warning systems. MUHIR also aligns with CLIMAAX by translating complex climate models into locally relevant risk outputs. Antalya's CRA is guided by several municipal strategies, including SECAP (2022), the Disaster Risk and Climate Adaptation Plan, the 2025–2029 Strategic Plan (https://www.antalya.bel.tr/Institutional/Strategic-Plan) and National Climate Change Strategy. The Climate Change and Zero Waste Department coordinates climate activities, while the Environmental Board enables stakeholder collaboration. Nationally, Antalya aligns with Türkiye's updated climate strategies, the draft Climate Law, and international agreements like the Paris Agreement and the Covenant of Mayors. Multiple sectors are impacted by climate change:

- **Health:** Heatwaves affect vulnerable populations, including the elderly, children, and outdoor workers.
- **Energy:** Increased demand for cooling during summer months.
- **Agriculture:** Altered rainfall and drought threaten crops and irrigation.
- **Water:** Growing demand and reduced supply stress peri-urban and tourism-heavy areas.
- **Tourism:** Disruptions due to thermal discomfort and extreme weather.
- **Transport/Infrastructure:** Damage to roads and public systems due to extreme heat.

External drivers such as regional climate patterns, national strategies, and international initiatives (e.g. CLIMAAX, EU4Energy, Covenant of Mayors) shape the city's response capacity. Antalya's location in the Eastern Mediterranean further exacerbates exposure to heat extremes and biodiversity loss. Adaptation interventions by our municipality already underway include:

- **Urban greening** (2.3 million+ trees planted)
- **Smart water systems** and greywater reuse (Rainwater harvesting, greywater reuse systems, smart irrigation, and SCADA-based water monitoring, nearly **3,754** km of water pipelines have been renewed, and water-saving tariffs for households)
- **Climate-resilient agriculture** (Closed irrigation systems, drought-resistant crops, agroecological practices, and renewable energy support for farmers, **climate-smart agriculture technologies and** digital tracking systems in greenhouse production)
- **Early warning systems**
- **Awareness campaigns** and **zero waste education**
- **Low-carbon transport** (EV fleets, bike lanes, light rail expansion)

Together, these actions aim to build a resilient and future-ready Antalya. MUHIR plays a central role by linking data, stakeholders, and strategy into a locally tailored climate risk response.

2.1.3 Participation and risk ownership

From the beginning, Antalya Metropolitan Municipality designed the climate risk assessment process to be participatory and inclusive. One of the earliest steps was the organization of a Local Environmental Board meeting, which brought together key stakeholders from various sectors, including agricultural chambers, the Provincial Directorate of Environment and Climate Change, academic experts, and relevant municipal departments. These initial discussions laid the groundwork for building stakeholder engagement and shared ownership of the risk assessment process. Internally, several municipal units such as the Climate Change and Zero Waste Department, the Disaster Management Department, IT/GIS teams, and the Foreign Relations Department were actively involved. In addition, academic advisors—most notably Prof. Dr. Murat Türkeş—provided critical input in interpreting climate data and improving technical aspects of the workflow (Türkeş, 2008; Erlat et al., 2021).

In identifying vulnerable groups, the municipality used demographic overlays and spatial data of WorldPop (https://www.worldpop.org/) to prioritize elderly citizens (aged 65 and over), outdoor workers, socio-economically disadvantaged populations, and residents of densely populated areas like Muratpaşa, where land surface temperatures are already high and green space is not totally suitable for resilience to UHI. Responsibility for managing these risks is coordinated by the Climate Change and Zero Waste Department but is shared across all related municipal departments to ensure institutional learning and collaborative planning. While the community recognizes that it is impossible to eliminate all risk, the aim is to achieve a manageable level through proactive measures such as early warning systems, informed planning, and effective communication strategies (IPCC, 2023). Reducing heat-related illness and mortality is viewed as a moral and operational imperative (Khasnis and Nettleman, 2005; Laaidi et al., 2012). The results of the climate risk assessment are intended to inform local decision-making, guide sectoral authorities such as AFAD and regional health institutions, support academic research and local model development, and raise public awareness through accessible materials and outreach campaigns. Moreover, Antalya's MUHIR's participation in the EU4ETTR Multi-Level Governance Platform has enabled the municipality to present its work during the SECAP Masterclass event, where the CLIMAAX framework and the MUHIR project were introduced to peer cities, contributing to national and international knowledge exchange and capacity-building.

2.2 Risk Exploration

Relevant climate-related hazards and risks: Antalya, as a major coastal city in Türkiye, is increasingly affected by climate change, especially through the Urban Heat Island (UHI) effect and the growing frequency and intensity of heatwaves. The UHI phenomenon results from factors like dense urban surfaces, low vegetation, and limited air circulation, leading to elevated urban temperatures (Fu et al., 2024). This intensifies thermal stress, particularly during heatwaves, and poses serious risks to public health, energy infrastructure, and environmental quality (Ya-ping et al., 2020). **Current situation and affected populations:** According to the GFDRR’s Think Hazard tool (Figure 2-1) (https://thinkhazard.org/en/report/3024-turkey-antalya). Antalya faces a high risk of extreme heat, expected to occur at least once in the next five years. Heatwaves are especially severe from May to September, impacting vulnerable groups such as the elderly, children, pregnant women, and those with chronic illnesses. Outdoor workers—including road and sanitation staff—are also highly exposed, as there are currently no national regulations offering protections such as heat-related leave (Ngwenya, 2018). This leads to increased morbidity, mortality, and economic loss due to reduced labor productivity (Denghan et al.,2020). **Observed and expected hazards in the region**: Key climate-related hazards in Antalya include:

- **Urban Heat Island and Extreme Heat:** Increasing urbanization intensifies UHI, worsening heatwave impacts and increasing health risks. Vulnerable populations in dense, low-income areas are particularly affected (Kum ve Çelik, 2014; Maharjan et al., 2021; Kahraman and Polat, 2022).
- **Flash Floods:** Due to heavy rainfall and impermeable surfaces, flash floods are a recurring risk, exacerbated by inadequate drainage infrastructure (Yılmaz, 2015; Molina et al., 2020).
- **Drought and Water Scarcity:** Reduced precipitation and rising temperatures have lowered groundwater levels, threatening agriculture and water supply (Sukanya and Joseph, 2020).
- **Forest Fires:** Hot, dry summers have led to destructive wildfires, with 2021 as a recent example. Climate change is expected to lengthen and intensify fire seasons (Aydin-Kandemir and Demir, 2023).
- **Sea Level Rise and Coastal Erosion:** Antalya's coastline is vulnerable to erosion and saltwater intrusion, jeopardizing coastal infrastructure and tourism assets (Brown et al., 2012).

Main hazards covered in this CRA: This CRA focuses on the **heatwave phenomenon**, examined through the CLIMAAX “Urban Heatwaves” workflow. The study includes UHI interactions and their combined effects on public health and urban systems. **Available and needed data**: In this phase, the CRA utilized open datasets via the CLIMAAX platform, including:

- EURO-CORDEX climate projections (12 km resolution)
- Satellite-based land surface temperature (30m)
- Population and demographic data (100m), with a focus on elderly segments
- EUROHEAT's health-based heatwave definition
- Xclim indicators for heat threshold exceedance

Local datasets, such as meteorological records and mortality data, were not yet integrated but are planned for future use. Limitations include the lack of a Türkiye-specific heatwave threshold, restricted access to health data, and insufficient spatial detail for neighborhood-scale analysis. A proposed drone-based thermal mapping solution was not implemented due to funding constraints. Despite these challenges, the CRA lays a solid foundation for local climate risk understanding and will be strengthened through future collaborations with academia and technical experts.

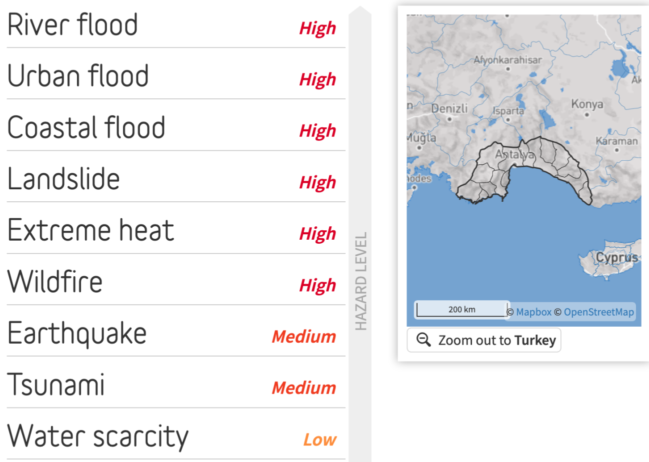

Figure 2-1 The overview of the hazards in Antalya and the risk levels.
Figure source: https://thinkhazard.org/en/report/3024-turkey-antalya

2.2.1 Workflow selection

For our chosen climate hazard—heatwaves—we used each of the four workflows provided by the CLIMAAX framework (https://handbook.climaax.eu/notebooks/workflows/heatwaves.html) to provide a multi-aspect and integrated climate risk evaluation. By applying all four workflows, our CRA ensures both **spatial resolution and temporal depth** in assessing heatwave risks. Each workflow addresses a different layer of the risk chain—**hazard detection, exposure mapping, vulnerability integration, and future scenario modeling**—creating a robust foundation for **urban adaptation strategies, public health planning, disaster risk management and policy development in alignment with national frameworks (e.g., SECAP). Special and detailed studies were carried out during the execution of these workflows; all analysis and visualizations were performed on Jupyter Hub. No other software was required as requested in the CLIMAAX ecosystem. Some initial code-based issues were resolved, and the analysis was performed on Jupyter Hub from the beginning to the end. Antalya's Note: In general, an error was encountered in some codes. All code string corrections were given at Zoledo with document (Yildiz and Kandemir, 2025).**

2.2.1.1 Workflow #1: EUROHEAT – Hazard Assessment

This workflow is based on the EURO-CORDEX climate projections (12 km spatial resolution) and will evaluate heatwave frequency under historical and future climate conditions. In our instance, we used only the health-based heatwave definition given in the CLIMAAX methodology since Türkiye is not among the country-specific definitions given in the workflow. The health-based threshold provides a consistency with regard to identifying those heat events that are likely to have considerable consequences for susceptible groups. Key outputs are: Frequency, duration, and severity of heatwaves; and spatial and temporal patterns of extreme heat events by health risk levels. Targeted areas/groups: Urban areas and densely populated settlements with restricted availability of cooling equipment; and old persons, patients suffering from chronic conditions, and workers exposed to heat and sun.

2.2.1.2 Workflow #2: Xclim – Custom Hazard Assessment

This approach employs the Xclim Python library, with normalized climate index analysis and percentile-based thresholding. It is customizable and provides more advanced statistical analysis of temperature anomalies. Key outputs: Threshold exceedance analysis (e.g., TX90p, warm spell duration); and calculation of climatological extremes relevant to regional norms. Target populations/areas: Best suited in determining how the future climate environment differs from historical normal; and sensitive sectors (public health, agriculture, energy).

2.2.1.3 Workflow #3: Risk Assessment – Satellite-Derived Data Workflow

This process utilizes high-resolution satellite images (e.g., Landsat) to map existing heatwave exposure and UHI impacts at a spatial scale of 30–100 meters. Key outputs are: Urban heat maps with high resolution; and local exposure at the neighborhood and infrastructure levels. Targeted groups: older persons, outdoor workers, and residents of informal settlements; and low vegetation cover areas or high-density built-up areas. This workflow is important because it facilitates very localized interventions, e.g., placement of cooling centers or green infrastructure.

2.2.1.4 Workflow #4: Risk Assessment – Climate Projections Workflow

Workflow combines hazard projections and exposure and vulnerability information and facilitates anticipatory risk assessment. Deliverables are scenario-based risk maps linking climate and socioeconomic factors; and risk evolution with time in relation to vulnerable people and main sectors. Ranked priority areas/populations: Long-term strategic planning expanded Antalya region; and supports consistency with national and city adaptation plans.

2.2.2 Choose Scenario

In Antalya, scenario assumptions are shaped by both climate projections and socio-economic dynamics. Ongoing trends—such as population growth, expanding tourism, and urbanization—intensify the Urban Heat Island (UHI) effect and increase vulnerability to heatwaves. In the short term (next 5 years), priorities include strengthening institutional capacity, preparing a heatwave action plan, and piloting interventions in identified hotspots. In the medium to long term (20–50+ years), adaptation strategies must address continued migration, demographic changes (e.g., aging population), and increased energy demand due to prolonged heat seasons. For projection-based analysis, RCP8.5 was selected as the primary scenario due to its strong alignment with local vulnerability trends and the precautionary principle, as advised by our climate science advisor. Although both RCP4.5 and RCP8.5 were assessed via EUROHEAT and Xclim workflows, RCP8.5 provided clearer guidance for policy development. EURO-CORDEX data (12 km resolution) supported city-wide planning, while future integration with higher-resolution neighborhood data is planned. CLIMAAX's population projections also informed local risk analysis, especially for vulnerable age groups (65+, 75+), helping define priority adaptation zones. Together, these workflows will form the scientific and visual basis for Antalya's local adaptation planning.

2.3 Risk Analysis

2.3.1 Workflows: EUROHEAT – Hazard Assessment and Xclim – Custom Hazard Assessment

Table 2-1 Data overview workflow: EUROHEAT – Hazard Assessment and Xclim – Custom Hazard Assessment

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
EUROHEAT - CDS (Heat waves and cold spells in Europe derived from climate projections)	*Not directly used in this workflow (used in risk workflows later)*	*Not directly used in this workflow (city-level mapping only)*	*Provides baseline hazard maps and trend graphs for frequency and duration of heatwaves (e.g., 2046–2075), used as input for risk modeling in later workflows*
Xclim - CORDEX regional climate model data on single levels	*Not directly used in this step (planned to be linked with age-sensitive risk mapping)*	*Not directly used in this step (to be aligned with population layers later)*	*Produces spatial and temporal maps showing number of threshold exceedance days, which support local risk interpretation and refine later vulnerability-focused analyses*

2.3.1.1 Hazard assessment

<u>EUROHEAT – Hazard Assessment (https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview)</u>

This workflow, adapted from the CLIMAAX Handbook, applies the EuroHEAT methodology using EURO-CORDEX climate projections (12×12 km resolution) to assess heatwave occurrence in Antalya. It defines the hazard component of climate risk by estimating the frequency, duration, and spatial extent of heatwaves under present and future scenarios. The analysis uses pre-processed data from the Copernicus Climate Data Store (CDS), covering the period from 1986 to 2085. Since Turkey lacks a national heatwave definition, the study adopted the EU-wide health-based threshold: two or more consecutive days where both the maximum apparent temperature (Tappmax) and the minimum temperature (Tmin) exceed their respective monthly 90th percentiles. This combined day/night criterion enhances relevance for public health planning. The workflow's strengths include the availability of pre-calculated indicators, extended temporal coverage, and the use of both maximum and minimum temperatures to better reflect severity. However, it also has limitations—such as fixed thresholds, year-binned output, and exclusion of the Urban Heat Island (UHI) effect—which may lead to underestimating urban heat stress. The analysis covered the whole Antalya region and its urban settlements. Key outputs include annual projections of heatwave frequency and duration, time-series trends for all RCP scenarios, and spatial risk maps. Although UHI effects were not included, EUROHEAT provided a standardized, health-oriented hazard baseline that informed the exposure and vulnerability phases of the CRA. In practice, the following steps were completed:

- Required packages were imported.
- Heatwave occurrence data were retrieved from the CDS.
- Health-related heatwave datasets were downloaded for RCP4.5 and RCP8.5.
- Interactive maps were created (Figure 2-2).
- Plot results based on EU-wide health thresholds were generated (Figure 2-3).

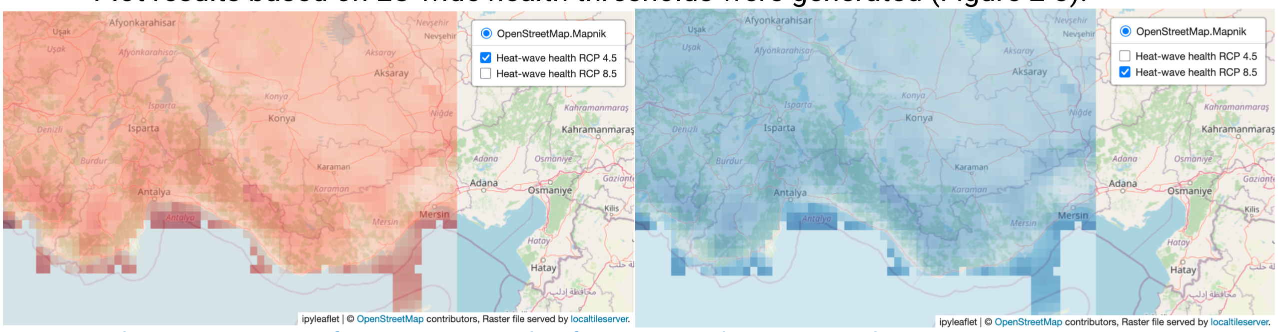

Figure 2-2 The interactive maps from EuroHeat studies for RCP4.5 and RCP8.5, in order.

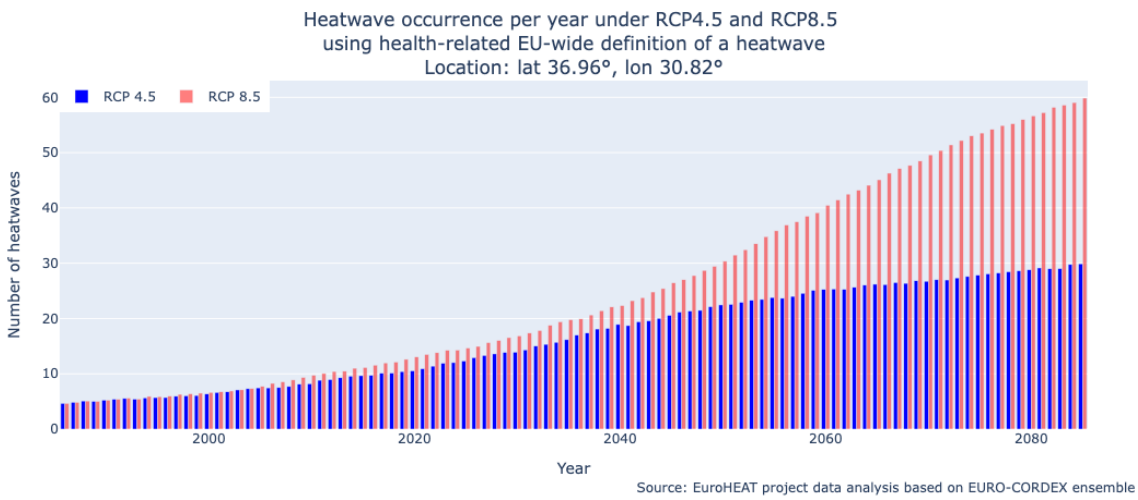

Figure 2-3 Antalya's city center plot results for heatwave data defined based on EU-wide health-related thresholds (for location from Fig 2-2).

Xclim – Custom Hazard Assessment (https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview)

The second workflow used in our study applied the Xclim Python package to conduct a tailored hazard analysis based on EURO-CORDEX climate projections. This approach allowed for the creation of custom heatwave indices aligned with Antalya's climatic and public health needs. Data at 12 km resolution were retrieved from the Copernicus Climate Data Store (CDS) for historical (1971–2005) and future (2006–2050) periods under RCP4.5 and RCP8.5 scenarios. A bounding box was defined to focus the analysis on Antalya.

Heatwaves were defined as 2 or 3 consecutive days exceeding a temperature threshold—typically 29.4°C—based on epidemiological studies in Mediterranean cities (Baccini et al., 2008). Using Xclim, various indices such as frequency, cumulative exposure, and a composite heatwave index were calculated. This enabled more granular examination of year-on-year variation and improved local adaptability compared to the standard EUROHEAT workflow.

Although the Urban Heat Island (UHI) effect was not directly simulated, the flexibility in threshold selection allowed for a better approximation of urban heat risk. The workflow enabled full control over index creation and scenario-sensitive projections, offering a second layer of hazard analysis. In this workflow:

- Climate datasets were downloaded from CDS including daily maximum and minimum 2m air temperatures.
- Heatwave occurrence was calculated based on the Xclim methodology.
- Temperature thresholds initially followed CLIMAAX recommendations, with plans to define
- Antalya-specific values in future reporting periods using national meteorological data (The temperature threshold for the Mediterranean given here was found to be sufficient for the sub-analyses to be conducted for the first six-month reporting period to determine whether the CRAs are working or not. In the next reporting period, in order to find the threshold value specific to our city, a calculation will be made with the data received within the framework of our protocol with the General Directorate of Meteorology of Türkiye and the threshold values of the model will be found by us).
- An interactive map was produced for the selected location (Figure 2-4). Key indices -Heatwave Index, Heatwave Frequency, and Heatwave Total Length- were calculated and visualized (Figure 2-5).

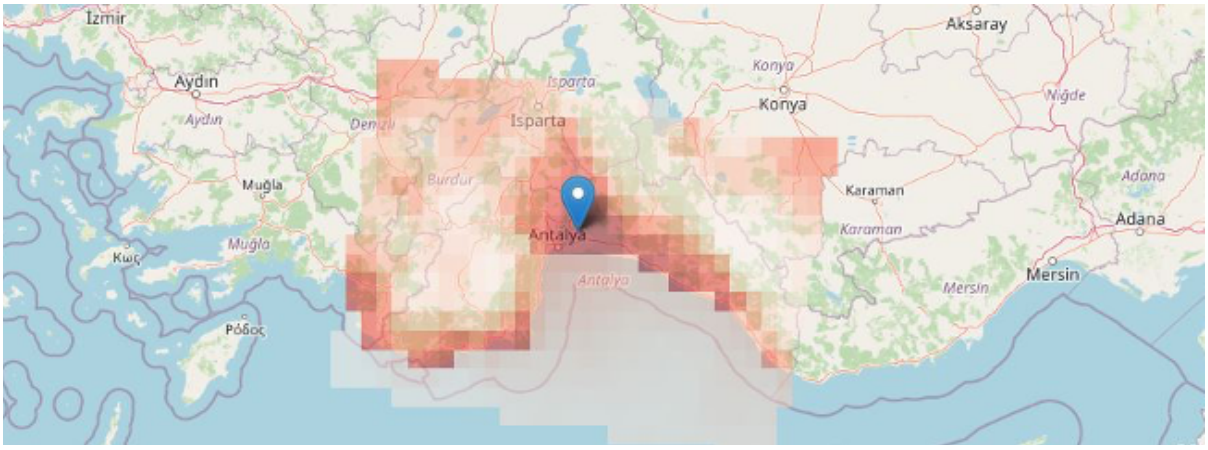

Figure 2-4 The interactive maps from XClim studies (Lat: 36.95, Lon: 30.70). The shown data is based on the calculated heatwave index. This visual comparison is intended to help understand which locations in your selected area will suffer more from heat (dark red will be most affected).

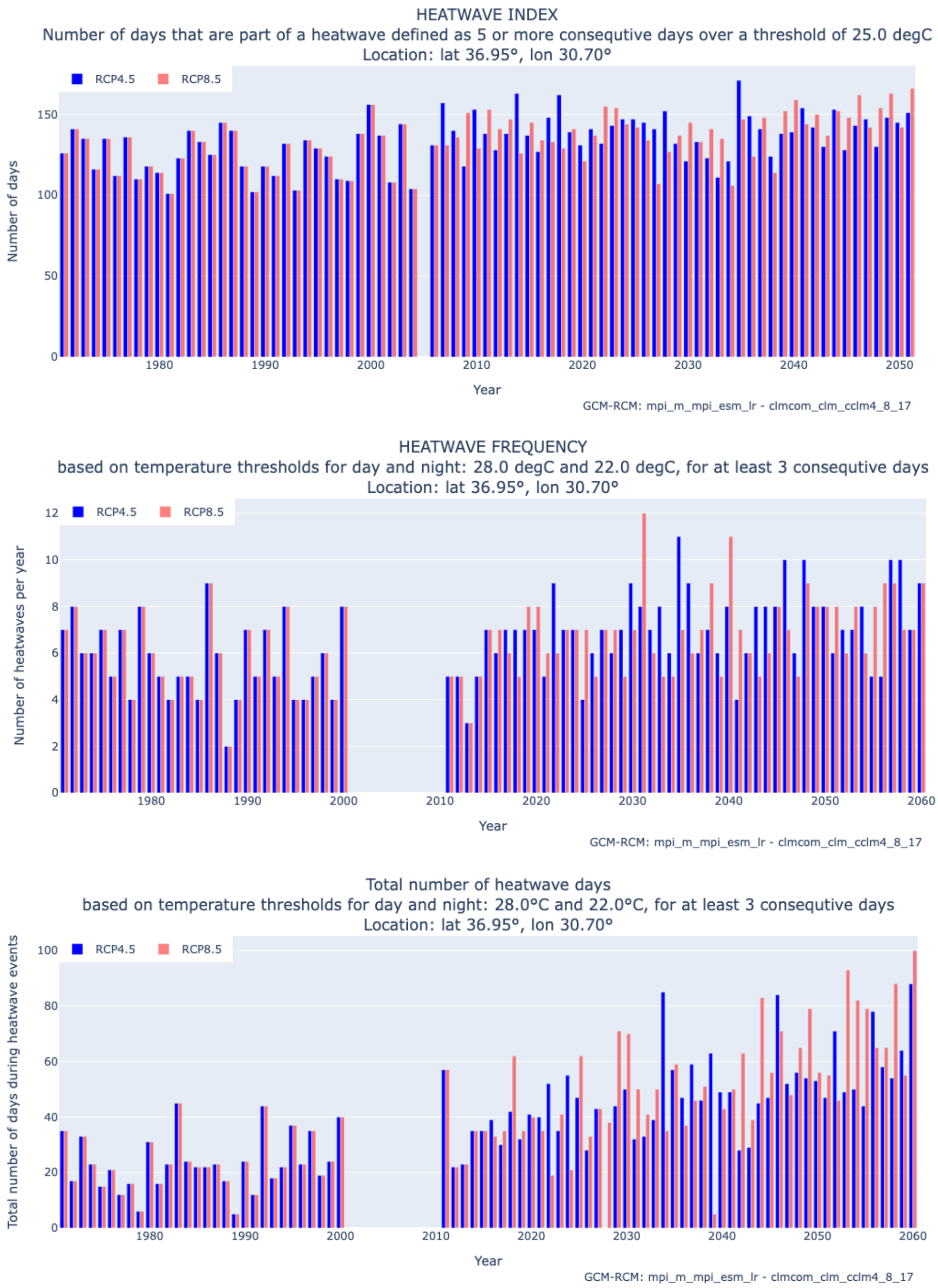

Figure 2-5 Heatwave index, Heatwave frequency, and Heatwave total length of the selected location (Antalya's city center).

2.3.2 Workflows: Satellite-Derived Data Workflow and Climate Projections Workflow

Table 2-2 Data overview workflows: Satellite-Derived Data Workflow and Climate Projections Workflow

Risk data	*Vulnerability data*	*Exposure data*	*Risk output*
RSLab heatwave risk index data (based on remote sensing; 30m resolution)	*WorldPop Turkey 2020 population data (age groups 65+, 70+, 75+, 80+)*	*High-resolution population distribution data aligned with LST maps.*	*Heatwave risk intensity maps for Antalya; hotspots identified (e.g., Muratpaşa); used for prioritizing adaptation planning at neighborhood scale*
EURO-CORDEX projections under RCP4.5 and RCP8.5, processed through CLIMAAX workflows	*WorldPop Turkey 2020 + custom demographic classification*	*Spatial exposure derived from population maps and scenario overlay*	*Projected risk maps for 2046–2075 showing increased vulnerability in urban areas under RCP8.5; supports long-term planning and targeted heatwave action strategies*

2.3.2.1 Risk assessment

Satellite-Derived Data Workflow

This procedure was developed to assess heatwave hazards at fine spatial resolution by integrating satellite-derived Land Surface Temperature (LST) data with layers representing vulnerable populations. The analysis focused on Muratpaşa, a densely populated and heat-exposed district in Antalya (Figure 2-6). Unlike climate projections, this method relies on observed, high-resolution thermal data, offering actionable insights for local planning.

LST data were obtained from Landsat 8 via the RSLab Portal (Parastatidis et al., 2017), covering June, July, and August from 2013 to 2024, with a spatial resolution of 15–30 meters and 8–16 day intervals. A total of 126 raster files were processed. After filtering out cloud-contaminated imagery, the remaining data were stacked to form a multi-annual average. These surface temperatures were then classified into five major categories—Very Low (<25°C), Low (25–35°C), Medium (35–45°C), High (45–55°C), and Very High (>55°C)—and further refined into 10 sub-classes using Jenks natural breaks to better capture urban heat hotspots (Figure 2-7).

In parallel, high-resolution population data from WorldPop (2018; DOI: 10.5258/SOTON/WP00646) were used to identify vulnerable groups, focusing on male and female populations aged 5, 65, 70, 75, and 80. The data, representing the year 2020, were processed and classified into 10 vulnerability categories using the same classification method to ensure compatibility and sensitivity in urban settings (Figure 2-8).

These two layers—thermal exposure and demographic vulnerability—were then merged into a 10×10 spatial risk matrix to generate a composite heat risk index. This index highlighted areas where high surface temperatures and vulnerable populations intersect, revealing urban heat risk hotspots (Figure 2-9). Technical adjustments were made to the code throughout the process, such as correcting variable names (e.g., replacing band_data with rxr.open_rasterio) and improving file-handling routines to ensure accurate analysis.

The results were plotted interactively (Figure 2-10), providing stakeholders with a user-friendly tool to visualize heat exposure and vulnerability spatially. While the workflow does not rely on future projections, it serves as a real-time baseline that complements model-based assessments. Cross-validation with EUROHEAT outputs helped confirm current risks and detect deviations from long-term trends. This high-resolution, satellite-based approach has been instrumental in identifying priority intervention zones and informing locally specific strategies—such as cooling center placement, green infrastructure design, and urban planning adaptations.

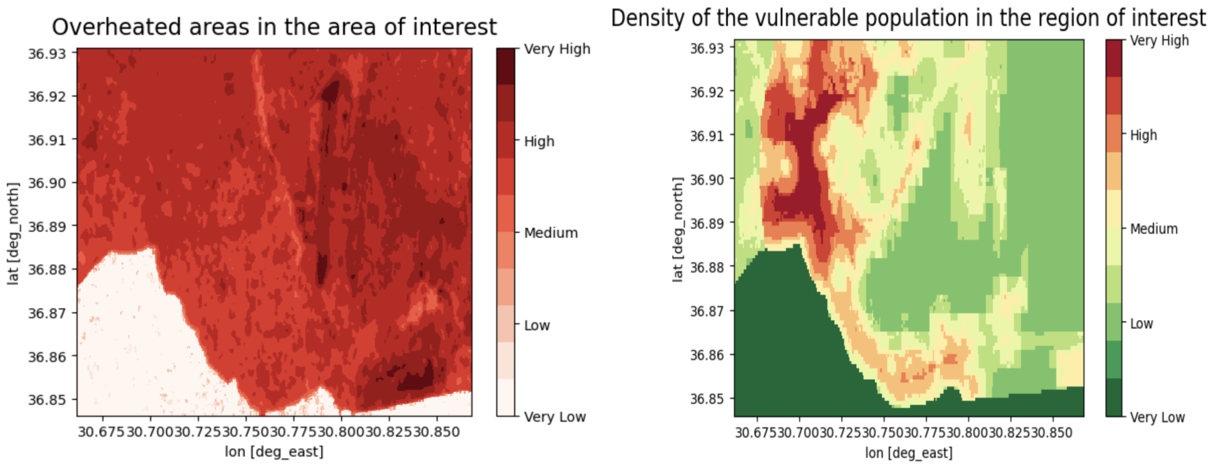

Figure 2-6 Identifying overheated areas in the urban environment of Antalya (left). Density of the vulnerable population in the ROI (Muratpaşa District is included) (right).

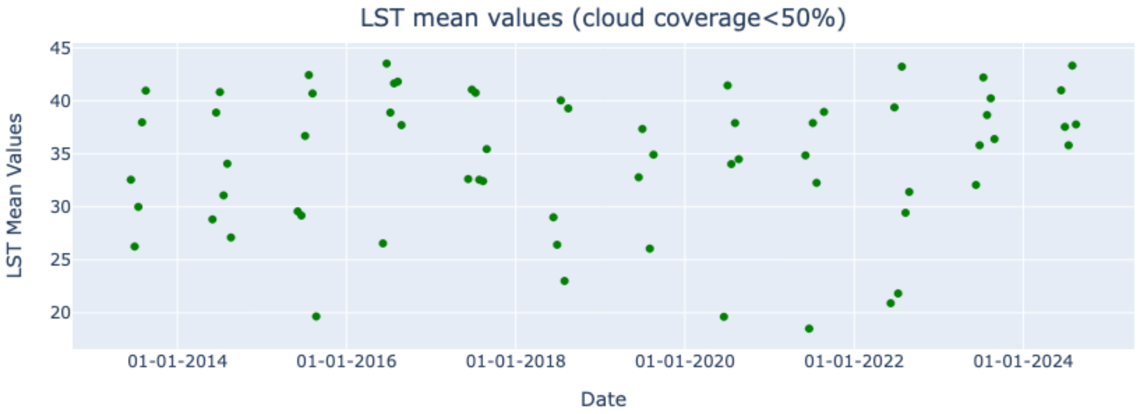

Figure 2-7 Plot-based information about land surface temperature mean values for the selected area, per Landsat8 image. Only the days corresponding to the LST pictures with cloud coverage lower than 50% are plotted.

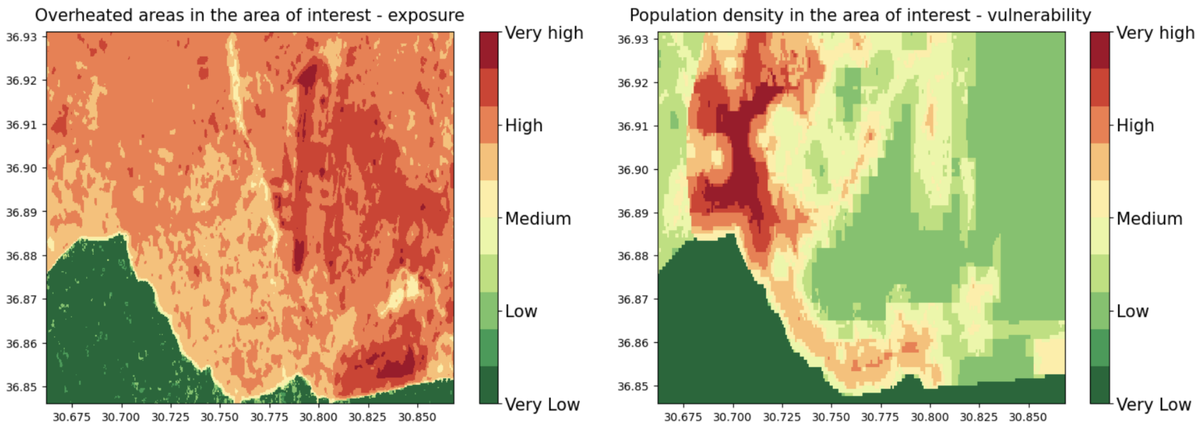

Figure 2-8 Overheated areas in the AOI-exposure (included Muratpaşa District, city center) (left). Population density in the AOI-vulnerability (right).

Risk matrix 10+10

Heat exposed areas based on the LST	1	2	3	4	5	6	7	8	9	10
10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19	Very high 20
9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19
8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18
7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17
6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16
5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15
4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14
3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13
2	Very low3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12
1	Very low 2	Very low 3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11

Vulnerable population density

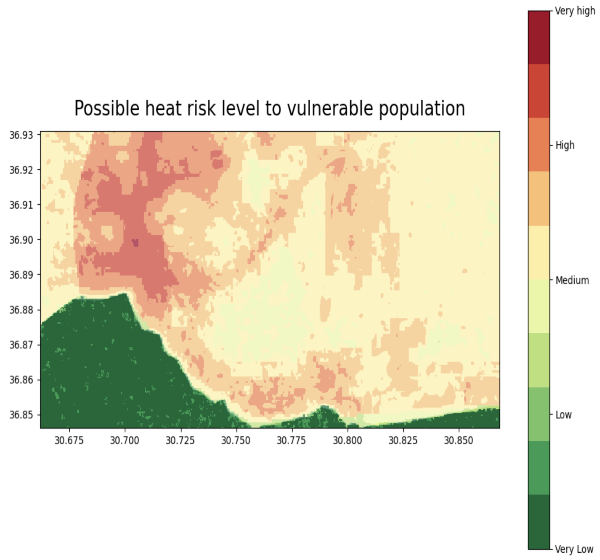

Figure 2-9 Risk matrix between heat exposed areas based on the LST and vulnerable population density (left). Risk interpretation map for Muratpaşa District (Antalya's city center) (right).

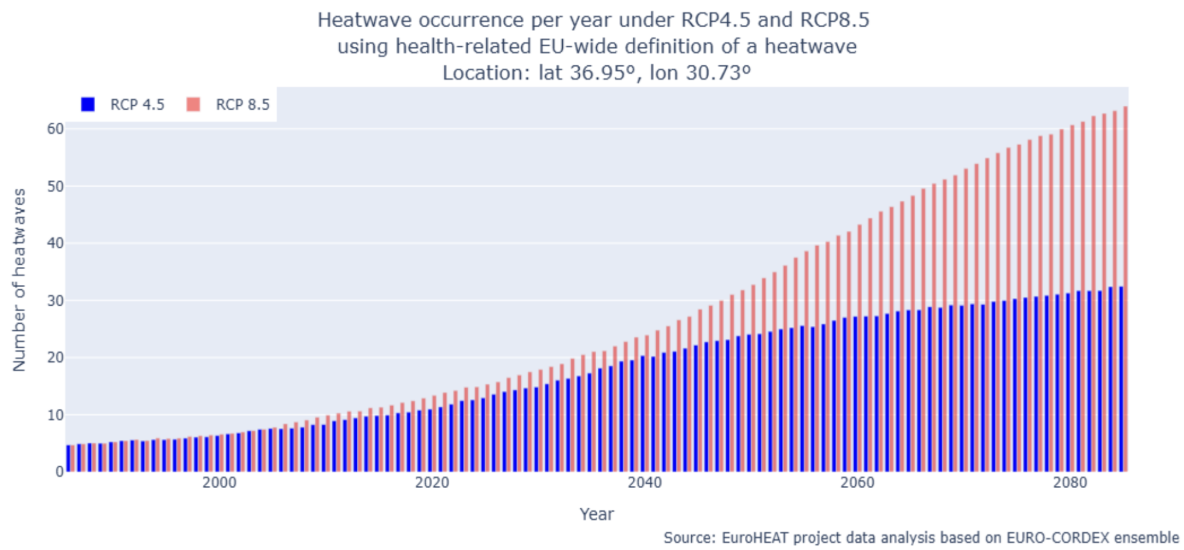

Figure 2-10 Plot for risk data for Lat: 36.95 and Lon: 30.73.

The results of the risk workflow help us identify the places that are the most exposed to the effects of heat in combination with the map of areas with high density of vulnerable groups of population (based on age). Antalya's note: In the existing codes, it does not work due to the error of small file names, the location of the file names should be paid attention to. The most important shortcoming is the lack of the "rioxarray" library; without it, the whole algorithm crashes and no results are obtained. The variables in the data should be well defined and defined accordingly (example "band_data" variable).

Climate Projections Workflow

This process assesses future heatwave risk in Antalya by integrating EUROHEAT hazard projections with demographic vulnerability data through a spatially explicit, matrix-based risk model. Two future periods—near future (2016–2045) and far future (2046–2075)—were compared to a baseline historical period (1986–2015) to evaluate projected changes in heatwave frequency. The EUROHEAT data were accessed via API, clipped to Türkiye's administrative boundaries, and reclassified into ten categories ranging from "very low change" to "very high change" to enable spatial analysis and integration with population data. Vulnerability was assessed using age-segmented population datasets (65+, 70+, 75+, 80+), filtered for the Antalya region and also classified into ten density-based groups. The combination of hazard and vulnerability layers produced a 10x10 risk matrix (Figure 2-9), yielding high-resolution spatial outputs that highlight areas where intensifying heatwave patterns coincide with vulnerable populations (Figure 2-11, Figure 2-12, Figure 2-13).

Several preprocessing and technical adjustments were required to handle inconsistent TIFF files and ensure compatibility, including setting coordinate systems, filtering time series, and adapting code (e.g., removing obsolete variables like band_data). The resulting maps visualize relative change in heatwave occurrence (Figure 2-12), population vulnerability (Figure 2-13), and the spatial distribution of projected risk (Figure 2-14). These outputs offer critical insights for long-term adaptation planning, particularly in older urban areas, and support localized decision-making for infrastructure, public health interventions, and early warning systems.

Note: The workflow of the process also involved technical and preprocessing operations, including registration of a coordinate system, filtering of the time series, and recoding of matrices. Because TIFF files are inconsistent, certain code was created to fetch and prepare respective data variables so that a compatible hazard and vulnerability layer setup is possible.

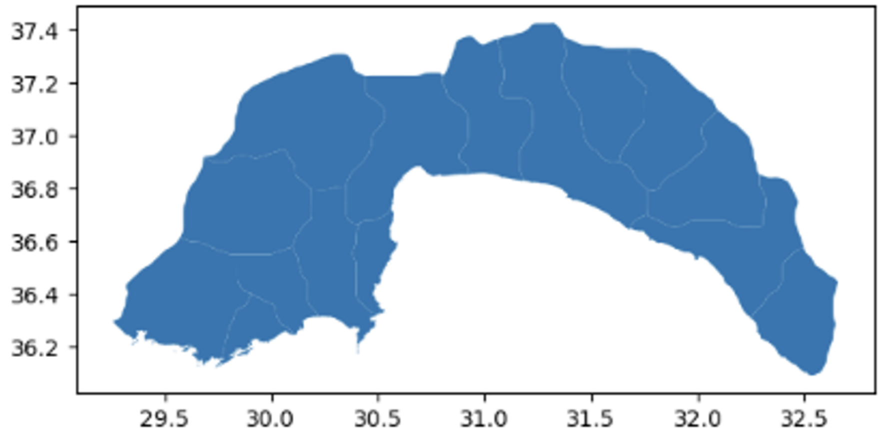

Figure 2-11 Antalya city from the whole country layer.

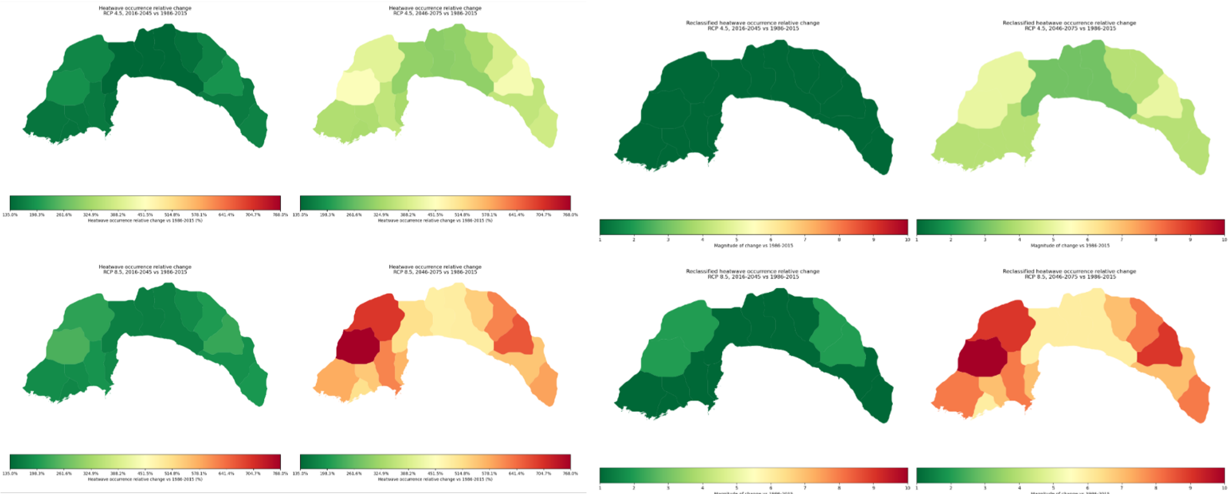

Figure 2-12 These results represent the relative change in heatwave occurrence for the selected region against heatwave occurrence for the reference period 1986-2015 (left). The image above represents the magnitude of the projected potential increase in the occurrence of heatwaves across selected regions on a scale of 1 to 10 (1-very low change, 10-very high change) (right).

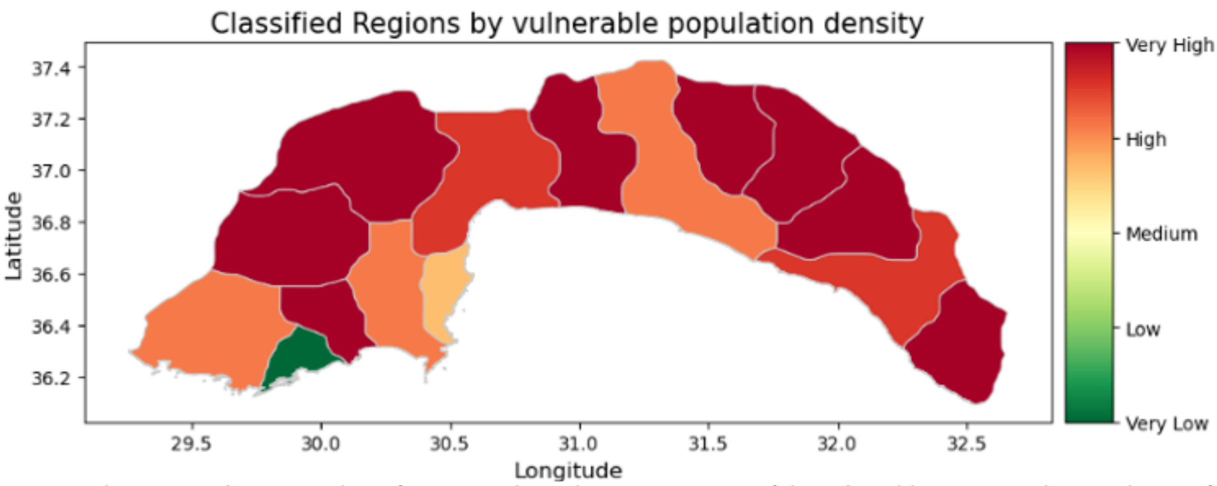

Figure 2-13 The picture above provides information about the concentration of the vulnerable groups in the population of Antalya.

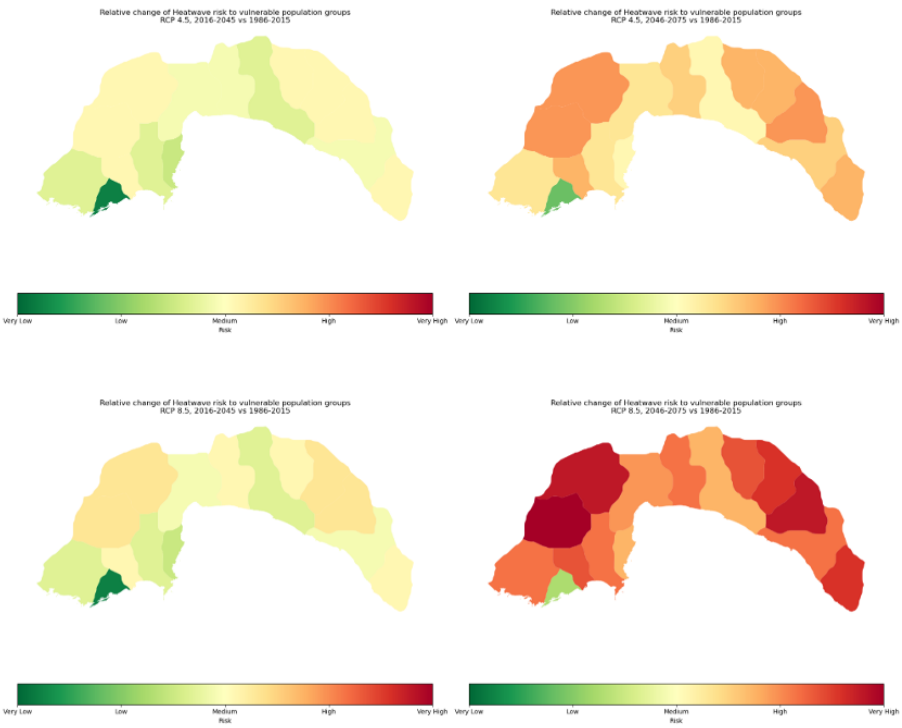

Figure 2-14 The picture above shows the potential projected increase of the heatwave risk to vulnerable population groups for Antalya. This result is based on the combination of the projected magnitude of change in the heatwave occurrence with the distribution of the vulnerable groups of the population.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

Our assessment clearly shows that **heatwaves are becoming one of the most serious and growing climate-related risks in Antalya**. As Türkiye's most urbanized Mediterranean coastal city, Antalya is increasingly vulnerable to extreme heat events. The analyses we conducted using historical climate patterns and EURO-CORDEX projections (through the EUROHEAT and Xclim workflows) confirm that **heatwaves will become more frequent and longer-lasting**, especially under the RCP8.5 scenario. In discussions with our climate advisor, we agreed that **focusing on RCP8.5 offers a more realistic picture of Antalya's future**, especially considering recent trends. Even under moderate scenarios, the number of heat stress days is expected to rise significantly in both urban and peri-urban areas. Our Xclim-based analysis allowed us to define thresholds based on Mediterranean conditions—like 29.4°C—and showed that **these critical thresholds are now being exceeded more often**. This signals a clear shift toward a longer and more intense heat season in Antalya, particularly during the summer months. For this first phase, we used the standard threshold suggested by CLIMAAX, as our goal was to test and optimize the tool and code structure. In the next phase, we plan to define custom thresholds based on **Antalya's own METEO data** and expert input, so that the entire workflow is tailored to local conditions. Still, even without local thresholds, the results already point to **a high level of heatwave risk** for the region. Our satellite-based analysis focused on **Muratpaşa**, a densely populated district in the city center. The area is already experiencing **consistently high land surface temperatures**, worsened by dense buildings, limited vegetation, and a high proportion of elderly residents. When combined with demographic vulnerability data, these areas clearly emerge as **high-priority zones for action**. Finally, our risk maps combining future heatwave trends with vulnerable population groups (65+, 70+, 75+, and 80+) show that **heat-related risk will intensify, especially between 2046 and 2075**. Several neighborhoods along the coastal corridor and inner city will likely face **overlapping environmental and social pressures**, increasing the risk of heat-related health issues unless targeted adaptation strategies are implemented.

2.4.2 Urgency

The findings of the climate risk analysis show that **heatwaves have already begun to affect Antalya**, and in the coming years, they are expected to become significantly more intense. While our projections highlight a sharp increase in heat-related risks between **2046 and 2075**, recent satellite observations reveal that **districts like Muratpaşa are already facing high surface temperatures**. This makes it clear: **the time for action is not tomorrow—it is now**. Heatwaves are **rapid-onset hazards** that can escalate within days, but their underlying causes—such as rising mean temperatures and urbanization—develop over much longer periods. This duality makes them particularly dangerous, requiring **both immediate early-warning systems and long-term infrastructure adaptation** to build resilience. Short-term responses must prioritize **preparedness and early warning systems**, especially for vulnerable groups like **elderly residents and outdoor workers**. Simultaneously, long-term strategies should focus on **urban greening, heat-resilient infrastructure, and the integration of localized climate data**, especially as Antalya-specific thresholds are developed using **national METEO datasets**. The work carried out within the CLIMAAX project has shown how vital **data-driven heatwave assessments** are—and how **urgent** this issue is becoming. Based on the findings from this initial phase, it will be necessary to develop a **heatwave action plan** within the jurisdiction of our municipality. Currently, **there is no heatwave-specific action plan in Türkiye**, and even scientific studies on **heat-related mortality are limited**. Deaths are often recorded under primary causes such as heart attacks or strokes, with no reference to heat exposure as a contributing factor. This highlights an urgent need to **develop a heatwave-mortality model** tailored to local health data. Considering both the projected models and current exposure levels, **timely intervention is essential**. The earlier adaptation measures are implemented, the more effective they will be in reducing long-term impacts, protecting public health, and enhancing climate resilience in Antalya.

2.4.3 Capacity

Antalya Metropolitan Municipality has demonstrated a strong institutional foundation for managing climate-related risks, particularly through the work conducted during the CLIMAAX project. One of the most notable aspects of this capacity is the establishment of a **fully in-house technical team** comprising experts in climate science, GIS, satellite data processing, and municipal governance. The project was carried out **without any external consultancy**, reflecting a growing confidence and competence within the municipality's departments. Another innovation in the project team is the motivation for academic support, which is not so strong in other municipalities. In this period of increasing youth unemployment in our country, a PhD student has been recruited as project staff, especially to support the internal administration of the project. This may even pave the way for the permanent employment of a young woman scientist candidate who has been trained in our municipality through this project. This situation makes us very proud. Another situation that increases the capacity of the project is that the municipal contact person of the project is a NASA and ESRI award-winning woman scientist who specializes in climatology, GIS-RS and CDS data. The project team therefore works with confidence and constantly renews their knowledge. The well-known climatologist Prof. Dr. Murat Türkeş, who is also among our project advisors, gives us great strength and guides us on the results. The team has successfully implemented four distinct workflows—two for hazard and two for risk assessment—by customizing open-access CLIMAAX tools, interpreting results using regional knowledge, and incorporating feedback from academic advisors. This internal capacity is supported by the municipality's active participation in national and regional policy frameworks, including the **SECAP**, **AFAD's IRAP**, and the **National Climate Change Adaptation Strategy and Action Plan**. In terms of opportunities, the experience gained through CLIMAAX will lay the groundwork for the development of a **local heatwave action plan**—a first for any Turkish municipality. Furthermore, the integration of local METEO data, cemetery information system data and demographic analysis opens the door to pioneering a **heat-related mortality model**, which could fill a critical data gap in Türkiye's climate-health nexus. In addition, scientific publications will be made from the results obtained within the scope of CLIMAAX framework and rules. The first studies for this have started with the beginning of the reporting period. This project has also fostered cross-departmental collaboration and inspired a high level of institutional motivation. Several technical improvements were made to existing workflows, not just for analysis but also for potential **open-source sharing**. This means Antalya is now well-positioned to **lead by example** in building urban resilience through science-based and socially inclusive climate planning.

2.5 Preliminary Monitoring and Evaluation

The first phase of our climate risk assessment has been a strong learning process for our municipal team. While CLIMAAX tools provided a solid technical foundation, we realized that adapting them to Türkiye's context requires local thresholds and a high level of technical customization. For example, EUROHEAT does not include national heatwave definitions for Türkiye, which made it necessary to use health-based default thresholds in our early analyses. We faced several technical challenges along the way. One of the most critical was the instability of the CLIMAAX JupyterHub, especially during the first months. System crashes and platform slowdowns created delays, and the provided code strings often needed debugging and revision to work properly. In the RsLab workflow, we also had limitations—particularly because it only worked effectively for very small areas. Since this is a fully in-house project, our team members also had to juggle their regular responsibilities, which made consistent scheduling difficult. Still, we made major progress. We held a well-attended **Environmental Board meeting**, where we presented our first findings to key stakeholders, including the Provincial Directorate of Environment and Climate Change, agricultural chambers, university professors, and other municipal units. Their feedback was extremely positive, especially about the idea of creating a local heatwave action plan. We also received strong academic support. Our advisor Prof. Dr. Murat Türkeş helped us interpret the results, and our project contact person—an award-winning climatologist—guided the team with scientific clarity. We now have access to new datasets, including **local METEO data** and the **Cemetery Information System**, which we plan to use for creating a **heatwave-related mortality model** in the next phase. Overall, even though we faced technical and institutional limitations, we gained valuable skills, built momentum, and established trust in both our methods and results. This gives us the confidence to move forward with stronger coordination, improved tools, and broader stakeholder engagement in the next round. However, **moving forward will require ethical data access protocols, partnerships with academic researchers, and potentially, medical institutions** to better understand and act on heatwave-related health risks.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the MUHIR project under the CLIMAAX framework provided Antalya Metropolitan Municipality with the opportunity to conduct a comprehensive climate risk assessment focused on heatwaves and urban heat island (UHI) effects. This phase was essential not only for learning how to use open-access CLIMAAX tools but also for adapting them to our own local context.

A key achievement of this phase was the successful implementation of four separate workflows (two for hazard assessment and two for risk assessment), using EURO-CORDEX climate projections, satellite-derived data, and demographic vulnerability layers. All workflows were carried out by our internal team without any external consultancy, reflecting the municipality's growing technical capacity and cross-departmental collaboration. Through these workflows, we were able to study both present-day urban heat hotspots and future high-risk areas based on climate scenarios (especially RCP8.5).

Several important challenges were addressed during this phase:

- Technical adaptation of workflows was accomplished by revising some of the code strings and overcoming compatibility issues in the CLIMAAX JupyterHub platform.
- Stakeholder engagement was initiated through the Environmental Board meeting, which included representatives from public institutions, academia, and civil society.
- Vulnerability mapping was tailored to elderly populations and enabled spatial prioritization for local interventions.

However, some challenges remain:

- Due to technical instability in the CLIMAAX platform in the early stages, workflow testing was delayed.
- Lack of Turkey-specific heatwave definitions made it necessary to rely on EU-wide health thresholds.
- In-situ validation of urban heat hotspots was not possible due to limited access to field equipment (e.g., thermal drone).
- Health and mortality data could not yet be fully integrated due to data ethics and access issues.

Despite these limitations, the first phase laid a strong scientific foundation for future planning. Key findings include:

- Clear increase in heatwave frequency and persistence in Antalya under RCP8.5 between 2046–2075.
- Urban districts like Muratpaşa already show alarming land surface temperatures.
- Vulnerable population segments (especially elderly) are expected to be more exposed in the coming decades.

The outputs of this phase are already being considered in the design of a local heatwave action plan, which will be the first of its kind in Türkiye. In the next phase, integration of local METEO and mortality data will further improve the accuracy of risk models and help define context-specific thresholds for early warning systems.

Note: All the results lay outs were made using CLIMAAX Jupyter Hub environment. No other GIS software was used.

4 Progress evaluation and contribution to future phases

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
One (1) of workflows (Heatwave" hazard assessment using EURO-CORDEX climate data (EuroHeat and Xclim)) successfully applied on Deliverable 1	*Completed*
Four (4) of potential stakeholders involved in the activities of the project – 4 completed	• *Antalya Science Forum was attended. Prof. Dr. Murat Türkeş, Assoc. Prof. Dr. Nusret Demir and Assoc. Prof. Dr. Çağdaş Kuşçu Şimşek attended the forum. (Nov 6-8, 2024).* • *SECAP Masterclass online event was attended and a presentation on CLIMAAX was made. We came together with MLGP Platform more than 200 participants (Feb 11, 2025).* • *Environmental Board meeting was held. At least 70 board members attended the meeting. (Feb 21, 2025).* • *Cities meet Cities" program organized by the Global Covenant of Mayors in cooperation with Türkiye MLGP4Climate platform (Daiva Matonienė) (EU4ETR) and with Antalya Metropolitan Municipality (Feb 29, 2025)*
Three (3) of communication actions taken to share results reaching at least 200 citizens – 2 completed	• *One of the Environmental Board meetings was held. At least 70 board members attended the meeting. (Feb 21, 2025).* • *SECAP Masterclass event was attended and a presentation on CLIMAAX was made. We came together with MLGP Platform more than 200 participants (Feb 11, 2025).*
Three (3) Antalya Metropolitan Municipality Environmental Board's stakeholder meetings, workshops, or consultations – 1 completed	*One of the Environmental Board meetings was held. At least 70 board members attended the meeting. (Feb 21, 2025).*
Six (6) of articles in regional media mentioning the project – 2 completed	• *ABB Press: First Environmental Council meeting of 2025 was held (https://www.antalya.bel.tr/Haberler/HaberDetay/7780/2025-yilinin-ilk-cevre-kurulu-toplantisi-gerceklestirildi)* • *ABB Press: 2nd Antalya International Science Forum started (https://www.antalya.bel.tr/Haberler/HaberDetay/7470/2-antalya-uluslararasi-bilim-forumu-basladi)*

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Test of the workflow "Heatwave" hazard assessment using EURO-CORDEX climate data (EuroHeat and Xclim)	*Completed*
M2: Initial introductions of CLIMAAX project in Antalya International Science Forum (6-8 Nov 2024, Antalya, Türkiye) to explain the projects importance for the city of Antalya.	*Completed*
M3: Initial Risk Assessment using CLIMAAX tools completed.	*Completed*
M10: Introduction of CLIMAAX project to the stakeholders from Multi Level Governance Platform (MLGP) of EU4ETTR Western Balkans and Türkiye, which Antalya Metropolitan Municipality is a member of this platform, as possible contributor of MUHIR.	*Completed* *SECAP Masterclass event was attended and a presentation on CLIMAAX was made. We came together with MLGP Platform more than 200 participants (Feb 11, 2025).*

5 Supporting documentation

All outputs produced must be shared in the Zenodo repository.
For clarity and consistency, arrange the list of outputs in the same order as in Zenodo.

Main Report: ABB_CLIMAAX_Deliverable_template_FSTP_final.docx: 10.5281/zenodo.15106923

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CLIMAAX is a 4-year Horizon Europe project that will provide financial, analytical, and practical support to improve regional climate and emergency risk management plans. CLIMAAX is designed to contribute to the harmonization and consolidation of the practice of climate risk assessment, leaving a legacy for upcoming European initiatives. The project started in January 2023 and runs until December 2026.