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

Deliverable Phase 2 – 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

Version 1.0 | July 2025

Funded by
the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101093864. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	This document provides the Phase 2 Climate Risk Assessment (CRA) for Antalya within the CLIMAAX project, centered on heatwave and urban heat risks. It consolidates province-wide hazard and risk analyses (current and future), documents the localization of workflows using local thresholds and datasets, and summarizes stakeholder engagement results used for key risk evaluation (severity, urgency, and resilience capacity). The deliverable also outlines how Phase 2 findings will be used to prioritize adaptation measures and inform Phase 3 planning outputs.
Project name	Strategies for Mitigating the Urban Heat Island (UHI) Effect in Antalya (Türkiye): Integrating High-Resolution Local Data for Enhanced Climate Resilience (MUHIR)
Country	Türkiye
Region/Municipality	Antalya
Leading Institution	Antalya Metropolitan Municipality
Author(s)	• Fulya Kandemir (Antalya Metropolitan Municipality)
Deliverable submission date	17/01/2025
Final version delivery date	dd/mm/yyyy
Nature of the Deliverable	R – Report
Dissemination Level	PU - Public

Version	Date	Change editors	Changes
1.0	17.01.2025	Antalya Metropolitan Municipality	Deliverable submitted
2.0	…	CLIMAAX's FSTP team	Review completed
5.0	…		Final version to be submitted

Table of contents

List of figures

List of tables

Abbreviations and acronyms

Abbreviation / acronym	Description
AFAD	Disaster and Emergency Management Authority (Türkiye)
AMM	Antalya Metropolitan Municipality
C3S	Copernicus Climate Change Service
CCLM4-8-17	COSMO-CLM regional climate model configuration (v4.8.17)
CDS	Copernicus Climate Data Store
CINEA	European Climate, Infrastructure and Environment Executive Agency
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
COSMO-CLM	Consortium for Small-scale Modelling - Climate Limited-area Modelling
CRA	Climate Risk Assessment
CRM	Climate Risk Management
CSV	Comma-Separated Values
DRM	Disaster Risk Management
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EU	European Union
EU4ETTR	EU4ETTR Multi-Level Governance Platform
EURO-CORDEX	European domain of CORDEX (EURO-CORDEX)
FSTP	Financial Support to Third Parties
GCM	Global Climate Model (General Circulation Model)
GIS	Geographic Information System
HadGEM2-ES	Hadley Centre Global Environment Model v2 - Earth System
HWD	Heatwave Days (total heatwave days)
HWF	Heatwave Frequency
HWI	Heatwave Index
HWN	Heatwave Number (count of events)
IT	Information Technology
JJA	June-July-August
KRA	Key Risk Assessment
LST	Land Surface Temperature
MGM	General Directorate of Meteorology (Türkiye)
MPI-ESM-LR	Max Planck Institute Earth System Model - Low Resolution
MUHIR	Strategies for Mitigating the Urban Heat Island (UHI) Effect in Antalya (Türkiye): Integrating High-Resolution Local Data for Enhanced Climate Resilience (MUHIR)
NASA	National Aeronautics and Space Administration
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
PDF	Portable Document Format
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RCP4.5	Representative Concentration Pathway 4.5
RCP8.5	Representative Concentration Pathway 8.5
SCI	Science Citation Index
SECAP	Sustainable Energy and Climate Action Plan
SSP	Shared Socioeconomic Pathway
TR-dizin	Turkish Academic Database (TR Dizin)
UHI	Urban Heat Island
UHRHO	Urban Heat Risk Hotspot Overlay
USGS	United States Geological Survey
XClim	Python library for climate indices (xclim)
Zenodo	Open-access research repository (used for project outputs)

Executive summary

This deliverable presents the Phase 2 Climate Risk Assessment (CRA) for Antalya with a focus on extreme heat/heatwaves. It was developed to provide a province-wide, decision-ready understanding of heat risk and to support the prioritization of adaptation measures through the CLIMAAX Key Risk Assessment approach. Phase 2 particularly aimed to move beyond pilot-level analysis and produce outputs that are spatially explicit and directly usable for planning. A central achievement of this phase of MUHIR is the scale-up from a single-district focus in Phase 1 to a province-wide application across all districts of Antalya (~20,177 km²), enabling risk interpretation not only through general trends but also through district patterns and urban concentration centers.

Phase 2 strengthened the CRA workflow in two complementary directions: current risk and future risk change. Current risk was operationalized through satellite-based LST/UHI analysis combined with vulnerable population density (ages 0–5 and 60+) and CLIMAAX risk-matrix logic, producing risk classifications that identify present-day hotspots. This was further enhanced with the Urban Heat Risk Hotspot Overlay (UHRHO), which intersects Medium/High/Very High risk pixels with ESA built-up areas to highlight intervention-ready zones in living environments. Future risk was assessed through climate-projection-based changes in heatwave occurrence and derived risk-change mapping for vulnerable groups, providing a structured view of how the hazard and related risks are expected to intensify over near- and far-future periods under RCP4.5 and RCP8.5. In addition, Phase 2 improved local relevance by integrating locally derived threshold approaches (e.g., MGM and NASA NEX-GDDP-based thresholds for indices where applicable) and by updating vulnerability inputs from WorldPop 2022 to a WorldPop 2025 projection with plausibility checking against TÜİK 2024, resulting in more realistic vulnerability and risk classifications.

The Key Risk Assessment step combined technical CRA outputs with stakeholder feedback collected through the workshop and survey process. Heatwave risk was evaluated across severity, urgency, and resilience capacity categories. Current severity was assessed as Substantial (3), reflecting that present-day risk reaches high classes but is spatially concentrated in urban hotspots. Future severity was assessed as Critical (4), as projection-based outputs indicate strengthening heatwave signals and expanding high-risk conditions for vulnerable groups. Urgency was classified as “immediate action needed,” since the transition from current to future risk shows a clear escalation and heatwaves represent a recurring seasonal hazard with persistent impacts, particularly when interacting with urban heat island conditions. Resilience capacity was assessed as Medium, acknowledging that institutional capacity is increasing, and data-driven products now enable more operational planning, while also recognizing that sustainable financing, systematic cross-institutional coordination, technical continuity, and routine integration into planning instruments still require strengthening.

Overall, Phase 2 provides Antalya with a multi-layer, action-oriented CRA package consisting of a comprehensive technical report and map set, dashboard-ready summaries, and stakeholder-informed scoring that together improve risk communication and prioritization. The work also clarified key needs for improving future assessment and monitoring, including higher-resolution health indicators where feasible (e.g., emergency admissions/ambulance calls), metrics that incorporate humidity and night-time heat, additional urban layers such as building stock and green infrastructure, and durable inter-institutional data-sharing protocols. In the final phase (Phase 3), the outputs and priorities from the Key Risk Assessment will be translated into a draft Heat Action Plan for Antalya, using hotspot-based targeting, stakeholder inputs, and good-practice evidence; the plan will define responsibilities, coordination mechanisms, and an implementable timetable, with the aim of completing a draft aligned with the COP31 Antalya window (9–20 November). A realistic monitoring approach will be adopted, combining an annual minimum monitoring set for key indicators and dashboards with periodic (e.g., every 2–3 years) renewal of data-intensive spatial products such as LST/UHI and UHRHO as capacity allows.

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 is among the country's most urbanized and economically dynamic provinces. Antalya is also a major national and international tourism destination, leading to significant seasonal population fluctuations and increased summer-time pressure on services, energy demand, and urban infrastructure. Rapid urban expansion and development pressure pose serious sustainability and climate resilience challenges, while recent climate-related extremes (including record-breaking summer temperatures and episodic high-impact events) have further intensified the need for targeted climate adaptation.

As a coastal city, Antalya is particularly exposed to the combined effects of urban heat island (UHI) and heatwaves. Although the city hosts valuable green assets (e.g., Zeytinpark) and emerging green corridors, green infrastructure is not yet sufficiently planned or distributed to mitigate UHI impacts at scale. UHI-reducing landscape and planning strategies are still at an early stage and require data-driven prioritization and expansion across districts.

Within this context, the CLIMAAX project—through the MUHIR initiative—provides a structured and standardized opportunity to assess climate-induced heat risks while integrating local context, local datasets, and stakeholder knowledge. The Phase 2 work aims to translate risk evidence into actionable, spatially explicit inputs that can support prioritized adaptation measures and strengthen the foundation for long-term climate resilience strategies in Antalya.

1.2 Main objectives of the project

The primary objective of Phase 2 was to scale up the CLIMAAX heatwave/urban heat risk approach, which was tested only at the Muratpaşa scale in Phase 1, to **the entire city of Antalya (20,177 km²)**, thereby establishing a **comparable, spatially consistent, and actionable** Climate Risk Assessment (CRA) framework for the entire province. This scaling up has produced an analytical infrastructure that can show not only **where the risk is high, but also in which districts it is concentrated, where it intersects with vulnerable groups in urban hotspots, and where intervention should be prioritized**. Phase 2 thus produced a "provincial-scale risk set" that enables comparing risk patterns across different districts of Antalya, conducting hotspot-based targeting, and providing direct input to policy/implementation processes such as heat action plans.

The second critical objective of Phase 2 was to integrate **local data, thresholds, and model diversity** into the analysis in a way that strengthens the local context while maintaining the standard workflow outlined in the CLIMAAX Handbook. In this context, heatwave hazard indicators were conducted using two methods: EuroHEAT outputs provided the long-term and scenario context within a standard framework, while XClim-based analyses were enhanced with **local thresholds** (based on MGM and NASA NEX-GDDP) and extended to the district level (with HadGEM) in Phase 2. In the risk component, satellite-based LST/UHI was combined with vulnerable population density (WorldPop 2025) to produce **current state risk maps**; additionally, the spatial pattern of risk increase for the near and distant future was revealed using a **risk change** approach based on climate projections. One of the most important innovations strengthening the action link in Phase 2 is the "Urban Heat Risk Hotspot Overlay (UHRHO)" module, which overlays **medium/high/very high** risk pixels with built-up areas and identifies intervention-ready urban hotspots.

The use of the CLIMAAX Handbook has provided three concrete benefits in Phase 2: (i) ensuring that methods remain **standardized and comparable**, (ii) enabling analyses to be conducted in a **repeatable/transparent** manner via JupyterHub workflows, (iii) supporting the translation of risk logic (hazard–exposure–vulnerability and risk matrix) into a language that **speaks to decision-makers**. The inclusion of local data and models (such as MGM thresholds, district-level output generation, WorldPop 2025 update, satellite LST/UHI, and local health data for pre-validation) significantly increased the **credibility and usability** of the results in the context of Antalya. As a result, Phase 2 produced a CRA output that addresses the risk of extreme heat in Antalya in both its **present** (urban heat island + vulnerable population overlap) and **future** (scenario-dependent increase and risk change) dimensions; it also directly provides a basis for discussions on **prioritization and adaptation options** through stakeholder participation and a scorecard approach.

1.3 Project team

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
Mustafa Kaynarca	IT Dept. - GIS Branch	Mapping Engineer (GIS-RS, Coding, Data)	Local data collection, UHI analysis, heatwave indices processing using GIS tools.	Very 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.	High
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.	High
Güliz Yaman	Foreign Relations Dept. - EU Project Branch	Project Specialist	Head of Branch-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
Assoc. Prof. Dr. Nusret Demir	Akdeniz University, Space Sciences Dept.	Technical consultancy on CLIMAAX method stages.	High
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.	Medium
Environmental Board	Antalya Metropolitan Municipality	Participating in discussions and providing feedback on MUHIR outputs.	Medium

1.4 Outline of the document's structure

This document summarizes the climate risk assessment (CRA) studies conducted for Antalya under CLIMAAX Phase 2, including the methodology, findings, and decision support outputs. The first section presents the context of Antalya and the Phase 2 objectives; then, based on the CLIMAAX

Handbook, the hazard and risk assessment methodologies adapted to local data and local thresholds are explained. Subsequently, the findings on heatwave and urban heat risk in Antalya are interpreted based on the generated maps and risk outputs; the results are supported by additional analyses such as local health data. The next section reports on the “Key Risk Assessment” steps (severity–urgency–capacity and risk priority) using stakeholder participation and survey findings, and summarizes the scorecard approach. The document concludes with monitoring and evaluation, the Phase 3 work plan, Phase 2 results, and progress assessment (KPI/milestone).

2 Climate risk assessment – phase 2

2.1 Scoping

The climate risk assessment presented in this section was conducted following the steps defined in the CLIMAAX Framework. The following subsections explain the methods used, data sets, outputs produced, and the meaning of these outputs in the context of Antalya, based on the guiding questions in the CLIMAAX Handbook. While some sections may be like the Phase 1 deliverable in the template, the work carried out in Phase 2 **has expanded and deepened the scope of Phase 1 in terms of scale, data, methods, and participation. Note:** In this report, 'hazard assessment' refers to indicators of heatwave hazards, while 'risk assessment' refers to prioritized impact areas along with vulnerability/exposure layers.

In this context, the main innovations of Phase 2 can be summarized as follows:

- Scaling up the risk assessment from the Muratpaşa district to the entire province of Antalya (at the district level),
- Continuation of the EuroHEAT methodology in heat wave assessment; enhancement of the XClim methodology with local threshold values,
- Derivation of local temperature threshold values from two independent sources (General Directorate of Meteorology station data (MGM) + NASA NEX-GDDP),
- Using HadGEM outputs as the main climate model and producing indicators such as HWF, HWN-HWD, HWI for all Antalya districts (In this report, **HWN/HWD** refers to the same metric and is used to mean **total heatwave days**),
- Running the MPI model at the Muratpaşa scale with local thresholds for comparability with Phase 1,
- In the risk component, conducting LST analyses for all of Antalya using USGS Landsat data; not preferring the RsLab approach due to its data/processing load and small area-focused structure at the provincial scale,
- In the vulnerability/exposure component, WorldPop 2022 rasters were projected to 2025 using an analog method for the under-5 and over-60 age groups, and vulnerability analyses were performed for the entire Antalya region using these layers,
- Integrating the land use reading–statistics generation and risk overlay steps into the automated workflow on CLIMAAX JupyterHub; thus, making the output more repeatable and operational (Urban Heat Risk Hotspot Overlay-UHRHO addition) (see also Zoledo supplementary documents; Kaynarca, 2026),
- Overlaying risk outputs in UHRHO with land use/land cover; specifically, spatially separating "medium + high + highest" risk classes in built-up (urban) areas and generating priority focus areas.
- Inclusion of 2018–2024 district-based mortality data (especially circulation + respiration) obtained with special permission from the Antalya Provincial Health Directorate as an additional evidence set in the analysis and interpretation focused on the summer season (JJA).
- **Conducting a stakeholder workshop (≈149 participants) and integrating ≈84 survey outputs into the evaluation process,**

Initiating work on the Local Heat Action Plan to transfer findings into policy processes **and strengthening coordination at the provincial level, including informing the Governor's Office.**

2.1.1 Objectives

The main objective of this climate risk assessment (CRA) **is to spatially visualize** the current situation and possible changes based on climate projections of **heatwaves and urban heat island (UHI)** effects in Antalya **at the district level**, to **reveal risk patterns for vulnerable population groups (0–5 and 60+)**. The study was conducted based on the CLIMAAX "Heatwaves" workflow, prioritizing **repeatability, methodological transparency, and actionability**.

Phase 2 aims to broaden the scope of the objective beyond merely identifying risk; it targets **indicators reinforced with local thresholds, consolidation through model diversity, scaling up to the province level, and a hotspot approach that generates urban intervention priorities**. Within this framework, the Phase 2 objectives and expected outputs are summarized below:

- **Scaling up:** Expanding the analysis conducted at the Muratpaşa scale in Phase 1 to the **entire Antalya (19 districts)** level to produce a comparative spatial distribution of hazards and risks.
- **Local threshold and indicator development:** Strengthen XClim-based heatwave indicators (HWI/HWF/HWN-HWD) with local thresholds sourced from **MGM and NASA NEX-GDDP**; reduce threshold uncertainty and increase traceability.
- **Model diversity and comparability:** Produce indicators across the province using **HadGEM**; conduct comparative sensitivity readings with **MPI** in Muratpaşa for inter-phase consistency.
- **Spatialization of risk with UHI/LST:** Conduct **LST-based thermal exposure** analysis across the province using USGS/Landsat data.
- **Vulnerable population layer update:** Update the vulnerability pattern across the province **by projecting** WorldPop vulnerable population layers (0–5 and 60+) **to 2025**.
- **Action-oriented urban prioritization:** Produce **Urban Heat Risk Hotspot Overlay (UHRHO)** output by overlaying risk classes with **land use (especially built-up)** and identify urban focal areas with high intervention priority.
- **Participation and local knowledge integration:** Document risk perceptions, priorities, and feasible adaptation options using stakeholder workshop and survey outputs (≈149 participants; ≈84 surveys); support assessment steps with local knowledge.
- **Policy integration:** Present outputs in a format that will serve as input for **Local Heat Wave Action Plan** preparations, early warning/prevention measures, and relevant planning processes (SECAP, strategic plan, disaster risk management); strengthen coordination at the provincial level.

Limitations and constraints of the study: shaped by **data access (especially sensitive data such as health/mortality), differences in data set resolution, computational load at the provincial level**, and uncertainties in exposure patterns caused by rapid socio-economic changes (urbanization/migration). Main bottlenecks in Phase 2: Method change for LST (RsLab → USGS/Landsat), reduction of threshold uncertainty using two independent sources (MGM+NEX-GDDP), MPI comparison for model sensitivity, and clear notation in the report of the uncertainty of the population projection (2022 → 2025). It is desired that these outputs be used for targeted early warning, especially during the summer season, for spatial prioritization of urban cooling/green infrastructure investments, and for social support mechanisms for vulnerable groups.

2.1.2 Context

In Antalya, climate hazards and risks have so far been addressed primarily within the scope of municipal strategic plans, sustainable energy and climate action plans, disaster risk reduction, and adaptation-focused studies. However, a significant portion of these studies have remained at the "strategic framework" level; they have had limited capacity to address the hazard-exposure-vulnerability components together, make inter-district comparisons, and produce repeatable and numerical/spatial risk outputs. CLIMAAX Phase 2 studies aim to strengthen this gap with analyses scaled to the entire province of Antalya based on the Heatwaves workflow.

This project aims to demonstrate, in an **evidence-based and action-oriented** manner, the combined effects of rising temperatures, the frequency/intensity of heat waves, and the urban heat island (UHI) effect in Antalya on public health, energy demand, water management, tourism, and urban quality of life. The methodological infrastructure established in the Muratpaşa pilot area in Phase 1 was expanded to cover the entire city of Antalya (at the district level) in Phase 2, thereby producing hazard and risk layers suitable for prioritization across the province.

Governance and policy context: The governance context of the study has become more critical considering current developments in climate policy at both the national and local levels. The strengthening of the new legal/institutional framework in Turkey requires local governments to address mitigation and adaptation agendas in a more systematic and measurable approach. At the local level, Antalya Metropolitan Municipality's planning/implementation frameworks in the areas of climate change mitigation and adaptation (adaptation actions, disaster risk reduction, early warning, etc.) form the institutional basis of this study.

Within Phase 2, the preparation process **for the Local Heat Action Plan** was also initiated to directly translate risk assessment outputs into action; coordination with relevant institutions was targeted to strengthen coordination at the provincial level.

Sectoral impacts and vulnerability

The main sectors expected to be affected by temperature increases and heat waves in Antalya are:

- **Public health** (heat stress, circulatory/respiratory effects),
- **Energy** (cooling demand, peak load),
- **Water management** (evaporation/demand pressure),
- **Urban planning and infrastructure** (UHI, public space comfort),
- **Tourism** (thermal comfort, worker health),
- **Agriculture** (heat stress and productivity losses) can be grouped under these headings. Combining the hazard indicators produced in Phase 2 (HWF/HWN-HWD/HWI, etc.) with LST and vulnerable population layers has produced spatial evidence that enables **prioritization at the district level** in these sectors.

External factors and window of opportunity: External factors affecting the study include the standardization approach of the CLIMAAX framework, the Copernicus-based climate data infrastructure, updates to national legislation/strategy, and the rapidly changing socio-economic dynamics in Antalya. In addition, **COP31**, **to be held in Antalya on November 9–20, 2026**, creates a powerful "opportunity window" that increases the visibility of the city's climate risks and adaptation preparations. This context makes it even more critical to transfer risk-based and traceable assessments into policy processes.

Adaptation interventions: Key adaptation interventions aimed at reducing risks associated with heatwaves and the urban heat island (UHI) effect include:

- early warning and risk communication (targeted at vulnerable groups),
- urban design measures such as shading–green infrastructure–cool corridors,
- cooling and energy efficiency applications at the building/street level,
- coordination of health and social services,

components of a "heat wave action plan" (triggers, role distribution, intervention protocols) can be summarized. The district-based hazard–exposure–vulnerability outputs produced in Phase 2 provide an evidence base for determining **where** and **to which groups** these interventions should be directed first.

2.1.3 Participation and risk ownership

Stakeholder participation in Phase 2 is designed to **align** climate risk assessment outputs **with local priorities**, **validate them with local knowledge**, and **link them to implementation (Heat Action Plan)**. Stakeholders include Antalya Metropolitan Municipality and district municipalities, provincial-level public institutions, academia/experts, NGOs/professional organizations, and, to a limited extent, private sector representatives.

While stakeholder participation in Phase 1 was mostly at the information/networking level, in Phase 2, participation has shifted to a structure focused on **active feedback and prioritization**. During this process, preliminary findings were shared at various meetings and events (see also Zoledo supporting documentsM16 folder; Aksoy, 2026); the main participant output was produced at the "**From Science to Action on Climate Change: Antalya's Vulnerability to Extreme Heat** Workshop." Approximately **149 participants** attended the workshop, and **≈84 surveys** were collected (participant profile: municipalities, public institutions, academia, NGOs/professional organizations, and a limited number of private sector representatives).

Institutions, responsibilities, and connections (organigram summary): The stakeholder structure is organized in a multi-level governance format along the line of "**analysis → prioritization → action/implementation**":

- **Antalya Metropolitan Municipality (coordination and execution):** data management, spatial analysis, indicator/map production, transfer of outputs to planning processes.
- **District municipalities (local verification and implementation):** verification of priority areas at the district level, identification of feasible adaptation measures, and integration into service processes.

- **Provincial-level public institutions (data/expertise and operations):** meteorology–early warning, health–vulnerable groups, disaster management–coordination, agriculture/forestry, etc. sector inputs.
- **Academia/experts (scientific support):** methodological verification, interpretation of uncertainties, contextualization of indicators within the local context.
- **NGOs/professional organizations/private sector (field knowledge and dissemination):** risk perception, applicability feedback, risk communication channels.

In Phase 2, the initiation of the Local Heatwave Action Plan preparation process and coordination contacts at the provincial level strengthened the multi-stakeholder approach to risk ownership.

How is risk ownership organized in Antalya? Risk ownership for heat waves and UHI-related risks is multi-stakeholder:

- **Identification:** threshold/indicator production and spatial analyses (municipal technical units + project team; data contribution from relevant institutions).
- **Assessment:** joint interpretation of hazard–exposure–vulnerability components (municipality + academia/experts + sector institutions).
- **Mitigation and response:** early warning and risk communication, cooling/green infrastructure applications, health/social support for vulnerable groups, operational response protocols (Metropolitan Municipality + district municipalities + health/social services + disaster management and relevant institutions).

Representatives of vulnerable groups and exposed areas (priority groups): Priority groups include the **0–5 and 60+ age** groups used in CLIMAAX, as well as subgroups such as **those with chronic illnesses, outdoor workers, low-income groups,** and **migrants**, as reinforced by workshop/survey inputs. In Phase 2, the updating of WorldPop population layers has improved the representation of vulnerability across the province.

Acceptable/tolerable risk level: Quantitatively defined "acceptable risk" thresholds for extreme heat are limited in Antalya. Therefore, in Phase 2, the tolerance approach was addressed in practice through **early warning triggers**, **protection of vulnerable groups**, **inter-agency coordination**, and **prioritization of feasible adaptation measures**. Workshop and survey outputs indicate that extreme heat is perceived as a high-priority risk at the local level and that capacity requirements (funding, technical infrastructure, data/analysis support, coordination) are prominent.

2.1.4 Application of principles

Social justice, equity, inclusivity: The principle of inclusivity and equity has been applied by assessing risk not only in terms of hazard level but also in terms of **exposure and vulnerability** components. The analysis focused on **vulnerable groups** defined within the CLIMAAX framework **(ages 0–5 and 60+)**; additionally, subgroups highlighted in stakeholder inputs (those with chronic illnesses, outdoor workers, low-income groups, migrants, etc.) were included in the discussions.

In Phase 2, inclusivity was strengthened to answer not only "who is at risk" but also **where and in which areas of life the risk** is **concentrated**: urban focus areas requiring priority intervention were identified by **cross-referencing** the "high + very high" risk classes **with built-up (urban) areas**. Thus, making the risk visible in areas where vulnerable populations live. Stakeholder participation enabled representation from different types of institutions through workshops and surveys and supported the validation of findings with local knowledge (details in 2.1.3 and 2.1.5).

Quality, methodological rigor, transparency: Quality and methodological rigor were ensured by following a CLIMAAX Heatwaves workflow-compliant and **repeatable** analysis pipeline. In Phase 2, transparency and robustness were enhanced through three critical steps:

1. Strengthening the local context by deriving **threshold values from two independent sources** (MGM observations + NASA NEX-GDDP),
2. Using **HadGEM** as **the main model** in province-wide analyses and conducting a **comparative** assessment **with MPI** at the Muratpaşa scale to maintain comparability with Phase 1,
3. Ensuring data-processing consistency in the risk component by using data sources appropriate for the provincial scale (USGS Landsat-LST, updated WorldPop 2025 projection) and clearly justifying method choices (e.g., RsLab not being suitable at the provincial scale).

Additionally, incorporating the land use layer into the workflow and (where possible) automating it on JupyterHub has strengthened **traceability and quality assurance** by facilitating the re-execution of the same steps in different periods.

Precautionary approach: The precautionary approach was applied by prioritizing early detection of risk and **preventive planning**, accepting that heatwaves carry high impact potential even in the presence of uncertainties. Multi-source threshold development and model comparison made uncertainties visible, providing a more secure basis for interpretation. Furthermore, the separation of "high risk + urban living area" intersections has produced a practical prioritization output for **early intervention and targeted applications**. In Phase 2, positioning the risk outputs to directly feed into the Local Heatwave Action Plan studies and calendar-based preparation aligned with the COP31 target strengthened the "actionability" dimension of the precautionary approach.

2.1.5 Stakeholder engagement

Stakeholder participation in Phase 2 was conducted **through multiple channels** with the objectives of (i) validating risk analyses with local knowledge, (ii) strengthening inter-institutional coordination to transfer findings into decision-making processes, and (iii) peer learning/dissemination. Compared to Phase 1, the approach in Phase 2 was transformed from an information-heavy structure to a **feedback-generating and action-oriented** framework.

Participants: The participant profile consisted of Antalya Metropolitan Municipality and district municipalities, provincial-level public institutions (meteorology, disaster management, health, etc.), academia/experts, NGOs/professional organizations, and a limited number of private sector representatives. The main local engagement activity of Phase 2 was the "From Science to Action on Climate Change: Antalya's Vulnerability to Extreme Heat Workshop" (Figure 2-1), which was conducted with approximately **149 participants** and collected **≈84 surveys**.

Sharing of project objectives and interim results: Communication was structured through simplified indicator/map presentations and sectoral discussion formats: The CLIMAAX methodology, the hazard/risk outputs produced, and inter-district comparisons were discussed at the tables; structured feedback was obtained through the survey. Additionally, during Phase 2 (after March 31), the methodological approach and interim findings were shared at City Expo 2025, the CLIMAAX Barcelona workshop, and related webinars/symposiums.

How were the results received by participants? The overall assessment was positive in terms of the study providing **evidence-based prioritization** and producing actionable outputs. The roundtable discussions contributed to different sectors addressing risks in their own contexts and to the emergence of common priorities.

Participant feedback (summary themes): Common themes in workshop and survey outputs:

- **Priority impact areas:** public health, energy demand, agriculture, tourism, and social impacts (vulnerable groups).
- **Main challenges:** rapid/unplanned urbanization, lack of green spaces, awareness gaps, capacity/resource constraints.
- **Capacity needs:** financing, technical training, data-analysis support, inter-agency coordination.
- **Recommended adaptation interventions:** early warning–risk communication, cool spaces/cooling center applications, shading and green infrastructure, building/energy efficiency, social/health support for vulnerable groups.
- **Process recommendation:** pilot applications, clarification of roles and responsibilities, regular data sharing.

How will stakeholders use the project outputs? Stakeholder interaction was carried out with the aim of not only reporting the results but also **increasing their applicability**. The outputs produced will be used to: (i) directly contribute to the Local Heatwave Action Plan studies, (ii) support municipal service planning with district-level prioritization, and (iii) clarify the inter-agency role sharing in early warning–response processes. The fact that COP31 will be held in Antalya creates **a time-critical policy window** for these outputs, strengthening the motivation for transitioning to implementation.

Challenges encountered:

- The need to convey the technical content of province-wide analyses in a manner understandable to different levels of expertise,

- The need to establish a common language/common course of action due to differences in priorities and capacities between institutions,
- Restrictions on access to sensitive data sets, particularly health-based ones,
- The need to increase the visible participation of certain groups (citizens, youth, tourism actors, etc.).

Figure 2-1 From Science to Action on Climate Change: Antalya's Vulnerability to Extreme Heat Workshop, November 21, 2026.

2.2 Risk Exploration

The risk exploration step aims to address the risks related to extreme heat in Antalya (along with their hazard-exposure-vulnerability components) at a broad screening level and to carry the most apparent/priority risks forward to subsequent steps. In Phase 2, this step has been enhanced in terms of scale (entire province), data timeliness, and local context, while maintaining the Urban Heatwaves focus established in Phase 1.

2.2.2 Screen risks (selection of main hazards)

Copernicus Climate Service products and indicators show that an increase in heatwaves/heat extremes is a significant risk area in Europe and the Mediterranean basin. For example, C3S's "heat waves and cold spells" dataset allows for comparative monitoring of heat wave days/intensity using different definitions (https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview).

Furthermore, Copernicus Sentinel-3 LST samples reveal that surface temperatures can reach very high values during intense heatwaves along the eastern Mediterranean and western Turkish coasts (note that LST differs from air temperature) (https://www.copernicus.eu/en/media/image-day-gallery/heatwave-greece-and-western-republic-turkiye).

Findings that the Mediterranean basin is a "hotspot" for climate change and that heat extremes are increasing are also supported by regional assessments (https://www.medecc.org/wp-content/uploads/2021/11/MedECC_MAR1_SPM_TR.pdf). Briefly, extreme heat in Antalya has a high potential impact on public health and urban quality of life, as well as on energy demand, tourism, and working conditions; stakeholder workshop/survey findings also indicate that local institutions view this risk as a high priority.

Project MUHIR's focus has been maintained on **HEATWAVES workflow of CLIMAAX** and also **the urban heat island (UHI)** effect, which increases the heat load in urban areas. However, the risk framework has been expanded beyond the Muratpaşa pilot **to cover all districts of Antalya**. Within the CLIMAAX Urban Heatwaves workflow, four sub-methods have been continued as follows:

- **Hazard:** EuroHEAT + XClim
    - In Phase 2, the XClim analysis was enhanced **with local thresholds**; additionally, using a **model diversity** approach, HadGEM (all of Antalya) was used as the main model and run at the MPI Muratpaşa scale for comparison purposes to maintain continuity from Phase 1.
- **Risk:** Satellite-based LST/UHI + Vulnerability (WorldPop)
    - In Phase 2, LST analysis was scaled to the entire province using **USGS Landsat**; the vulnerability layer was updated using **the WorldPop 2025 projection** (0–5 and 60+).

- Additionally, risk outputs were overlaid with **land use/land cover** (particularly **built-up** areas) to convert "medium + high + very high" risk classes into operational priority areas.

As the assessment scale has been expanded **from Muratpaşa to the entire Antalya province**, heat hazards and risks can now be addressed **at the district level**. In the risk component, **the UHI/LST layer** (urban surface temperature) was generated province-wide and integrated with land use via the UHRHO extension to identify hotspots.

Vulnerable groups (especially **those under 5** and **over 60**) were represented across the province using updated 2025 population rasters, providing a clearer spatial picture of who is most affected. As noted in the literature, both young children (especially those under 5) and older adults (especially those over 60-65 and the very elderly) face disproportionate health risks during heatwaves. As the intensity of heatwaves increases with climate change, it is crucial to take age-specific targeted measures, along with social support and urban planning that reduces exposure to heat, to reduce illness and mortality in these groups (Xu et al., 2014; Meade et al., 2020; Arsad et al., 2022; Oh et al., 2023; Brimicombe et al., 2024).

Current data/information (Phase 2)

- **Threshold determination:** MGM station data (see; some_datasetsM16 folder in Zoledo & permission-based access) + NASA NEX-GDDP (Precipitation, Tmax and Tmin) (https://ds.nccs.nasa.gov/thredds/catalog/bypass/NEX-GDDP/catalog.html) to strengthen local thresholds.
- **Hazard indicators:** XClim workflow; GCMs HadGEM2-ES (all of Antalya), MPI-ESM-LR (Muratpaşa comparison). For RCM, CLMcom-CCLM4-8-17 used in both GCMs.
- **UHI/LST:** USGS Landsat-based province-wide LST outputs.
- **Vulnerability:** WorldPop 0–5 and 60+; 2022 → 2025 analog projection.
- **Land use:** Risk overlay focused on built-up areas using ESA WorldCover21.
- **Local evidence set (new and critical):** Additional analysis for contextual validation of risk/hazard outputs using **2018–2024 district-level mortality data** (circulatory + respiratory focus) obtained with special permission from the Antalya Provincial Health Directorate (detailed in 2.3.3) (see; some_datasetsM16 folder in Zoledo & permission-based access).

Note-1: Phase 2's extra materials beyond standard workflows" → mortality data of Antalya + UHRHO (Urban Heat Risk Hotspot Overlay) ESA Landcover dataset's built-up overlay + workshop/ESRI Survey123's survey integration.
Note-2: NASA NEX-GDDP dataset including historical and future data-MPI-ESM-LR for compatibility.
Note-3: All spatial analysis were carried out via in JupyterHub environment, except Figure 2-17-QGIS.
Areas requiring data/data gaps are also (1) indicators such as morbidity/ambulance calls, etc., for the traceability of health effects (privacy compliant); (2) better representation of health-critical variables such as humidity/heat index and nighttime LST etc.; (3) exposure determinants such as building stock, shade/green infrastructure inventory, outdoor work intensity, seasonal population movements and (4) clarification of district-level capacity/resource information and inter-agency role sharing for the implementation of the Heat Action Plan

2.2.3 Choose Scenario

In Phase 2, future climate conditions were assessed using **EURO-CORDEX climate projections** to represent the heatwave risk in Antalya. Analyses were conducted covering the **RCP4.5 and RCP8.5** scenarios. **HadGEM-based runs** were taken as the main reference to produce district-level outputs across the province and enable spatial comparisons; comparative analysis with **MPI** was performed **at the Muratpaşa scale** to maintain Phase 1 continuity and observe model sensitivity. The use of HADGEM2-ES for Antalya is consistent and common in terms of capturing general patterns and trends; however, it is recommended that bias correction be performed with local observations in practice and, if possible, supported by a multi-model/RCM (e.g., CCLM) ensemble (Dosio et al., 2015; Mesta et al., 2025). Therefore, within the scope of MUHIR, an RCM addition was made, and the HADGEM2-ES/CLMcom-CCLM4-8-17 combination was used. This approach aimed to **make model uncertainty visible** and increase the robustness of the findings when assessing the possible future change in extreme heat risk.

In Phase 2, socio-economic developments were addressed not through official SSP scenarios, but through the updating of population layers representing the vulnerability component of risk. In this context, **WorldPop 2022** population rasters were **analogically** projected **to 2025** in line with the planning horizon, producing a more up-to-date representation of vulnerability, particularly for the **0–5** and **60+ age** groups. This approach has been evaluated as a **proxy** for capturing short-term changes in population distribution for district-level risk prioritization.
Climate conditions represented by heatwave hazard indicators (HadGEM-based; MPI comparative) have been spatially integrated with socio-economic components represented by vulnerable population segments (WorldPop 2025 projection). The risk assessment is further supported by **a Landsat-USGS-based LST/UHI exposure layer** to strengthen the "urban heat" component. **In Phase 2, this was supplemented by overlaying land use (Built-up) with risk outcomes**, enabling the differentiation of "medium/high/highest risk" hotspots for action planning, particularly in urban areas. The time horizons underlying the analyses also vary according to workflow components (Figure 2-2).

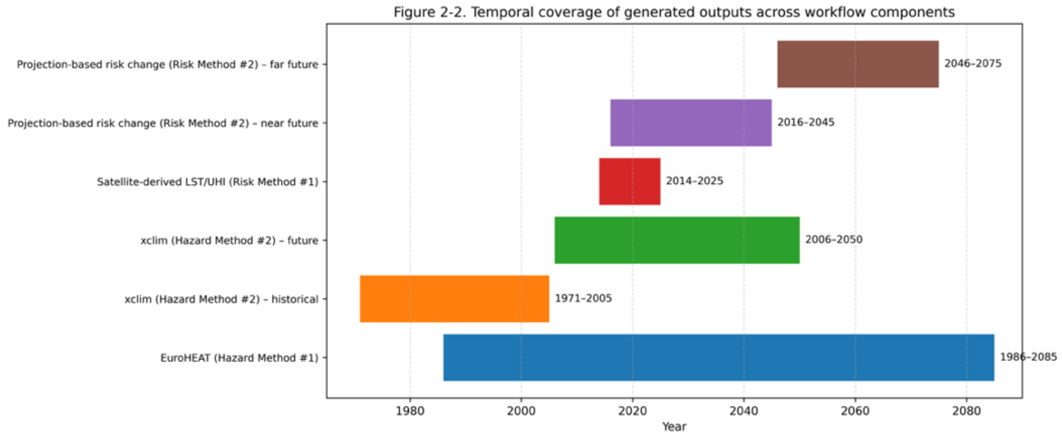


Figure 2-2 Temporal coverage of generated outputs across workflow components.

2.3 Regionalized Risk Analysis

In Phase 2, the *Heatwaves – Urban Heatwaves* workflow from the CLIMAAX Handbook was adapted to the Antalya context; it was expanded from the Muratpaşa pilot scale to the **entire Antalya** scale **(19 districts)**. Localization included (i) **local threshold derivation (MGM + NASA NEX-GDDP)**, (ii) **model diversity (HadGEM main; MPI comparison)**, (iii) **LST/UHI generation suitable for the provincial scale (USGS Landsat)**, (iv) **updating the WorldPop vulnerability layer ( ) to 2025**, (v) **separating hotspots using ESA land use** data (**"built-up × medium/high/very high risk")** (Figure 2-3).

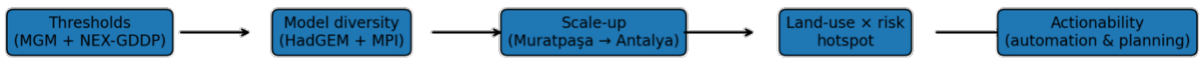


Figure 2-3 Workflow localization summary.

Tables 2-1 and 2-2 clearly present the data overviews and workflow components. These tables will not be repeated in the following sections, which will provide more detailed explanations.

Table 2-1 Data overview – Workflow component: Hazard (EuroHEAT & XClim)

Compon.	*Hazard data*	*Vulnerability data*	*Exposure data*	*Impact metrics / Outputs*
Hazard Method #1–EuroHEAT	EURO-CORDEX projections (CDS, ~12 km), **RCP4.5–RCP8.5**, period: **1986–2085** (https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview)	N/A (hazard-only)	N/A (hazard-only)	**Annual number of heatwaves** (EuroHEAT definition: Tappmax & Tmin monthly 90th percentile; ≥2 consecutive days)

Compon.	*Hazard data*	*Vulnerability data*	*Exposure data*	*Impact metrics / Outputs*
Hazard Method #2–XClim (localized)	EURO-CORDEX projections (CDS, ~12 km), **RCP4.5–RCP8.5**; period: **1971–2005 (hist)**, **2006–2050 (fut)**. **HadGEM2-ES** (all districts) + **MPI-ESM-LR** (Muratpaşa comparison). RCM for all scenarios: **CCLM4-8-17** (https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=download)	N/A (hazard -only)	N/A (hazard-only)	**HWI, HWF, HWN-HWD** (≥3 consecutive days; Tmin/Tmax). **Local thresholds:** MGM (1950–2024) + NASA NEX-GDDP (90th percentile approach)

Table 2-2 Data overview – Workflow component: Risk (Satellite-based LST/UHI & Climate projection-based risk change)

Compon.	*Hazard data*	*Vulnerability data*	*Exposure data*	*Impact metrics / Outputs*
Risk Method #1 – Satellite-derived LST/UHI	**LST**: Landsat 8 (USGS), **JJA**, period: **2014–2025** (cloud cover <50% scenes) (https://earthexplorer.usgs.gov/)	**WorldPop 0–5 and 60+** (https://www.worldpop.org/), **projected to 2025** (analog scaling factor **1.5**, plausibility checked vs **TÜİK 2024**, ~2.6% deviation).	**Urban exposure proxy (UHRHO)**: LST/UHI + (Phase 2) **ESA land use (built-up)** (https://worldcover2021.esa.int/)	(1) **Overheated areas** (average LST) (2) **Vulnerable population density** (3) **Possible heat risk level** (classification using CLIMAAX risk matrix) (4) **Urban Heat Risk Hotspot Overlay (UHRHO)**: **high/very high risk × built-up** (Kaynarca, 2026)
Risk Method #2 – Climate projections-based risk change	EuroHEAT heatwave occurrence outputs (reference: **1986–2015**; projection: **2016–2045 / 2046–2075**, **RCP4.5–RCP8.5**)	**WorldPop 0–5 & 60+, 2025 projection**	County-level administrative boundaries (Antalya shapefile)	(1) **Relative change in heatwave occurrence** (near/far; RCP4.5/8.5) (2) **Reclassified magnitude of change** (1–10) (3) **Vulnerable population density classes** (4) **Relative change in heatwave risk to vulnerable groups** (using risk matrix)

Phase 2 produced the **UHRHO (Urban Heat Risk Hotspot Overlay)** output. This output was developed by Mustafa Kaynarca, a member of the MUHIR team, in the form of a code sequence that can be used directly in JupyterHub and can also be utilized by other cities (The code script can be found in the Zoledo supplementary documents) and has the ability to distinguish high-priority urban areas for intervention in an "actionable" manner by overlaying the **medium/high/very high** classes in the *possible heat risk level* classification with **ESA built-up** areas.

Indirect effects (increased energy demand, loss of labor, healthcare burden, tourism comfort, etc.) **have not been also modeled quantitatively**, but have been evaluated as contextual input for risk prioritization within the **stakeholder workshop/survey** findings and the **Heat Action Plan** preparation process.

Future socio-economic conditions were not modeled directly with an SSP scenario; instead, in line with the decision horizon, the vulnerability component was updated using **an analog projection** of the **WorldPop 0–5 and 60+** population layers **to 2025** to represent "near-term" exposure/vulnerability dynamics. Furthermore, for the "urban context" of the risk, **Landsat-USGS LST/UHI (2014–2025)** and **ESA land use (built-up)** layers were used to identify urban hotspots with high intervention priority using the **UHRHO** output. **Limitations can be summarized as follows**: (i) EURO-CORDEX resolution (~12 km) may only capture microclimate differences within districts to a limited extent; (ii) LST is not a direct equivalent of air temperature and is sensitive to satellite pass time/cloud cover; (iii) The WorldPop 2025 projection is suitable for spatial prioritization but may contain uncertainties in rapidly urbanizing areas.

2.3.1 Hazard Methodologies #1 and #2 – EuroHEAT and XClim Methodology

2.3.1.1 Hazard assessment

Table 2-3 Hazard assessment methods description and developments in phase 2 of the heatwave workflow

Item	*Hazard Assessment Method #1 – EuroHEAT*	*Hazard Assessment Method #2 – XClim*
Purpose	Assess **heatwave occurrence** using a standardized EuroHEAT methodology for Antalya	Tailored hazard analysis and **custom heatwave indices** aligned with Antalya's climate & public-health needs
Climate projections & source	**EURO-CORDEX** climate projections; **pre-processed** data from **Copernicus Climate Data Store (CDS)**	**EURO-CORDEX** climate projections; data retrieved from **CDS** (defined bounding box for Antalya)
Spatial resolution	**12 × 12 km**	**12 km**
Temporal coverage of generated outputs	**1986–2085** (results reported for ~1985–2085 depending on plotting window)	Historical **1971–2005** and future **2006–2050**
Scenarios	**RCP4.5** and **RCP8.5**	**RCP4.5** and **RCP8.5**
Heatwave definition / thresholds	Turkey lacks a national heatwave definition → EU-wide health-based threshold adopted: **≥2 consecutive days** where both **Tappmax** and **Tmin** exceed their **monthly 90th percentiles**	HWF represents the number of heatwave events per year, using the report's threshold-based definition (≥3 consecutive days with daytime & nighttime thresholds); HWN-HWD represents the total number of heatwave days per year under the report's threshold-based definition (≥3 consecutive days with daytime & nighttime thresholds); HWI represents the number of days belonging to heatwaves defined as ≥5 consecutive hot days (daytime threshold), all reported for RCP4.5 and RCP8.5. **Phase 1 used Mediterranean thresholds from the CLIMAAX handbook (Baccini et al., 2008): Tmax=28°C and Tmin=22°C. Phase 2 added locally-derived thresholds (90th percentiles) from MGM (1950–2024) and NASA NEX-GDDP (see Figure 2-5) and re-ran indices accordingly.**
Main outputs	**Number of heatwaves per year** under RCP4.5/RCP8.5 (Figure 2-4)	**HWI (Heatwave Index), HWF (Heatwave Frequency), HWN-HWD (Heatwave Total Length)**
Spatial scope in Phase 1–2	Antalya (method applied consistently)	**Phase 1:** Muratpaşa (MPI-ESM-LR/CLMCom_CLM_CCLM4-8-17; Mediterranean thresholds) (Figure 2-5). **Phase 2: (i) Muratpaşa re-analysis with locally derived thresholds** (Figure 2-5) **+**

Item	*Hazard Assessment Method #1 – EuroHEAT*	*Hazard Assessment Method #2 – XClim*
		comparison vs Phase 1 thresholds (Figure 2-5), and **(ii) Antalya-wide district analysis using HADGEM2-ES/CCLM4-8-17 with locally derived thresholds** (Figure 2-6/Figure 2-8) (see details, some_datasetsM16 folder in Zoledo)
Phase 1 vs Phase 2 changes	**No change** (same method in Phase 1 and Phase 2)	**Major upgrades in Phase 2: local threshold derivation (MGM+NEX-GDDP), sensitivity/comparison against Phase 1 thresholds, model expansion (HADGEM2-ES for all districts), scale-up from Muratpaşa to all Antalya districts**

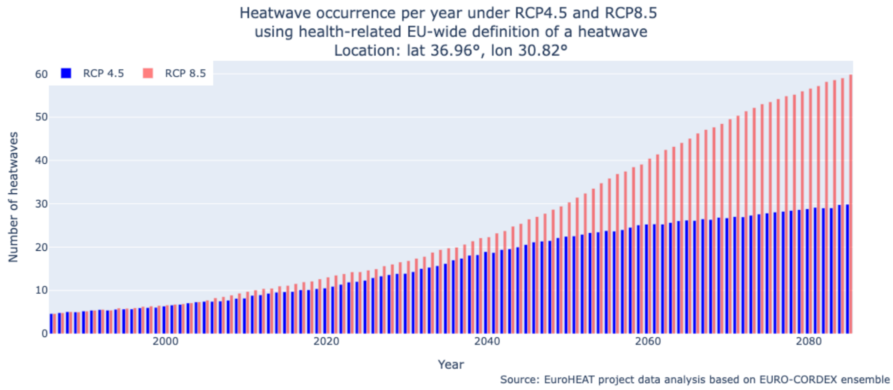


Figure 2-4 Antalya's city center plot results for heatwave data defined based on EU-wide health-related thresholds.

The EuroHEAT results in Figure 2-4 show that heatwave events in Antalya's city center have increased significantly, particularly **under RCP8.5**, starting from the middle of the century. This output provides a reference framework that confirms **the increasing regional-scale hazard signal**, independent of local thresholds.

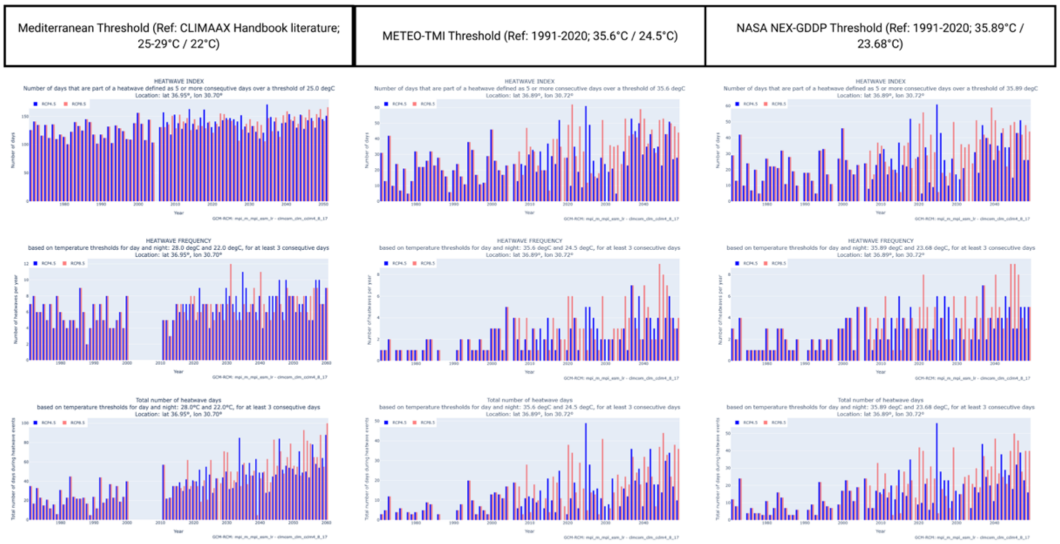


Figure 2-5 Threshold sensitivity comparison for the MPI-ESM-LR/CCLM4-8-17 run in Muratpaşa: HWI, HWF, and HWN-HWD outputs (RCP4.5–RCP8.5) based on the Handbook/Mediterranean threshold and local thresholds based on MGM and NASA NEX-GDDP (1991–2020). For MGM and NEX-GDDP, temperature thresholds for Tmax and Tmin are provided above each set of graphs. Thresholds were calculated based on the 90th percentile within the given reference period.

As shown in Figure 2-5, a threshold sensitivity analysis was performed using the MPI-ESM-LR/CCLM4-8-17 run specifically for Muratpaşa; CLIMAAX Handbook/literature-based Mediterranean thresholds were compared with local thresholds based on the General Directorate of Meteorology (MGM; 1991–2020 reference) and NASA NEX-GDDP (1991–2020). HWI, HWF, and total heatwave days (HWN-HWD/total heatwave days) metrics were generated for the RCP4.5 and RCP8.5 scenarios under three threshold sets. Local sets with higher day/night thresholds (MGM and NEX-GDDP) offer a more selective heatwave definition by reducing absolute event/day counts, while preserving the projected increase trend, with intensification becoming more pronounced, especially **under RCP8.5**. The similarity of patterns derived from MGM and NEX-GDDP thresholds supports the consistency of the threshold determination approach using two independent data sources in Phase 2.

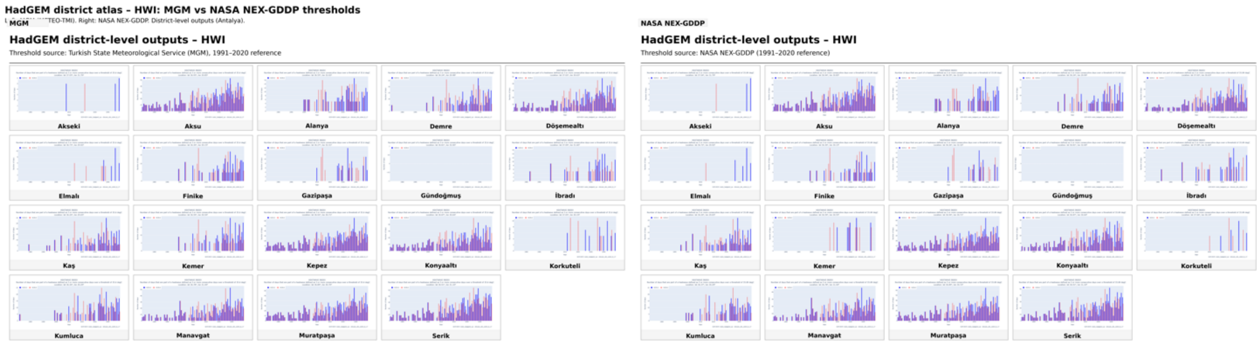


Figure 2-6 HadGEM district atlas–HWI (Heatwave Index) for Antalya (MGM-based local thresholds) (600 dpi resolution images are available on Zoledo; figuresM16 folder).

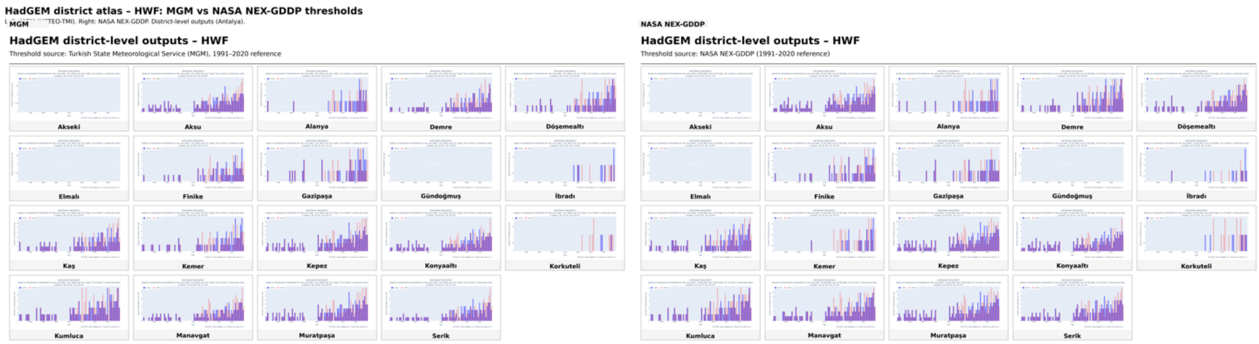


Figure 2-7 HadGEM district atlas–HWF (Heatwave Frequency) for Antalya (MGM-based local thresholds) (600 dpi resolution images are available on Zoledo; figuresM16 folder).

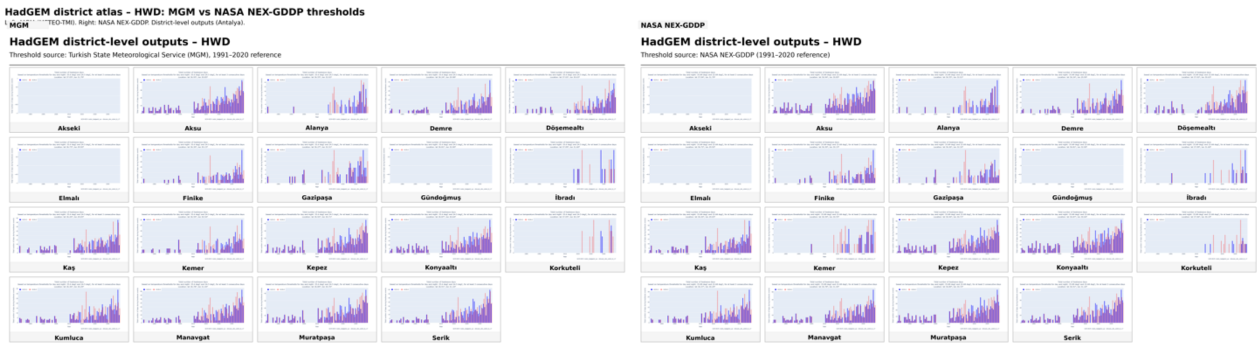


Figure 2-8 HadGEM district atlas–HWN-HWD (Total heatwave days) for Antalya (MGM-based local thresholds) (600 dpi resolution images are available on Zoledo; figuresM16 folder).

According to the results obtained in Figures 2-6/2-8, it is seen that **the risk is significantly concentrated in the urban core of Antalya (central districts)**. This concentration means that the heatwave burden varies between districts, and it is necessary to examine the results obtained here in the following sections together with spatial patterns such as LST/UHI exposure and vulnerable population density in urban (built-up) areas. Furthermore, these results indicate that **early warning, cooling infrastructure, risk communication, and protective services for vulnerable groups** should be planned primarily in these urban focal points within the scope of the Heat Action Plan, as they have the potential to increase the effectiveness of interventions. These priority areas emerging at the district level point to multiple hazard accumulation in some districts, beyond the single-hazard (heat-only) perspective. For example, in districts such as Kepez, local assessments indicate that flood/flooding hazards are high alongside temperature-related risks. This situation demonstrates that climate hazards can create combined pressure on service continuity, critical infrastructure, health, and social support capacity through simultaneous or cascading impacts. Therefore, the project outputs provide a strong initial evidence set for developing a "cascade" approach that addresses multi-hazard and compound risks (such as heat & flood) with the same spatial prioritization logic, in addition to action plans.

2.3.2 Risk Methodologies #1 and #2 – Satellite-based LST/UHI and Climate projection-based risk change

2.3.2.1 Risk assessment

Table 2-4 Risk assessment methods description and developments in phase 2 of the heatwave workflow

Item	*Risk Assessment Method #1 – Satellite-derived LST/UHI (Landsat 8 + WorldPop)*	*Risk Assessment Method #2 – Climate projections-based risk change (EuroHEAT + WorldPop + risk matrix)*
Purpose	Map **present-day urban heat exposure** and identify **risk hotspots** by combining satellite-derived **LST/UHI** with **vulnerable population density**	Quantify **relative change** in heatwave occurrence and the resulting **risk change for vulnerable groups** by comparing future periods against a reference baseline and applying the CLIMAAX risk matrix
Core data & source	**Landsat 8 LST** from **USGS Portal** + WorldPop projected rasters 2025 (**0–5** and **60+**)	**Antalya shapefile** + **EuroHEAT outputs (1986–2085)** + WorldPop rasters (**0–5** and **60+**, 2025 projection)
Spatial resolution	Landsat 8 LST: typically, **30 m**; WorldPop: product-100m	EuroHEAT / EURO-CORDEX-based grids: typically, **~12 km**; vulnerability integrated as density classes
Temporal coverage of generated outputs	**June–July–August (JJA), 2013–2024**; only scenes with **cloud coverage <50%** plotted/used in the LST time series	Risk-change computed relative to **Reference (1986–2015)** for **Near future (2016–2045)** and **Far future (2046–2075)**; outputs produced under **RCP4.5** and **RCP8.5**
Scenarios	Not scenario-based (satellite observations; recent past & present)	**RCP4.5** and **RCP8.5**
Key parameters / variables	LST mean values per Landsat image + vulnerable population density (0–5 and 60+)	(1) relative change of heatwave occurrence vs reference, (2) reclassified magnitude-of-change (1–10), (3) vulnerability density classes (1–10), (4) risk matrix combining magnitude-of-change × vulnerability density
Main outputs	(1) **“Overheated areas in the area of interest”**: map of LST-based overheated areas derived from the Landsat LST raster stack (JJA scenes) (Figure 2-9). (2) **“Density of the vulnerable population in the region of interest”**: vulnerability density maps for **0-5** and **60+** based on WorldPop 2025 rasters integrated into the workflow (Figure 2-9). (3) **“Possible heat risk level to vulnerable population”**: final **risk classification map** produced by reclassifying both LST and vulnerability layers into **10 classes** and	(1) **Relative change of heatwave occurrence** maps (Near/Far vs reference) for **RCP4.5 & RCP8.5** (Figure 2-12) (2) **Reclassified heatwave occurrence relative change** (1–10): “**magnitude of change in heatwave occurrence**” (Near/Far; RCP4.5 & RCP8.5) (Figure 2-13) (3) **Classified regions by vulnerable population density** (1–10 classes; **not scenario-specific**) (Figure 2-14) (4) **Relative change of heatwave risk to vulnerable population groups** (Figure 2-15) using

Item	*Risk Assessment Method #1 – Satellite-derived LST/UHI (Landsat 8 + WorldPop)*	*Risk Assessment Method #2 – Climate projections-based risk change (EuroHEAT + WorldPop + risk matrix)*
	combining them through the CLIMAAX risk matrix (Figure 2-10), resulting in a mapped risk level product (Figure 2-10). (4) **"Urban Heat Risk Hotspot Overlay (UHRHO) – Kaynarca (2026)"**: **Phase 2 extension module** that integrates **ESA land-use (built-up)** for Antalya, extracts **High** and **Very High** risk pixels from the "possible heat risk level" output, and overlays them with **built-up areas** to identify **action-oriented emergency intervention zones** in living areas (province-wide) (Figure 2-11).	the risk matrix (Figure 2-14) (magnitude-of-change + vulnerability density; Near/Far; RCP4.5 & RCP8.5)
Spatial scope in Phase 1–2	**Phase 1: Muratpaşa only; LST sourced via RsLab; vulnerability based on WorldPop 2022.** **Phase 2: Province-wide application across Antalya (all districts; ~20,177 km²); LST derived from USGS Landsat 8 (RsLab not used due to limited suitability for province-scale processing); vulnerability updated to WorldPop 2025 projection; and UHRHO (Kaynarca, 2026) applied to extract Medium/High/Very High risk hotspots intersecting ESA built-up areas for action-oriented prioritization.**	**Phase 1:** Antalya; EuroHEAT unchanged; WorldPop **2022. Phase 2:** Antalya; EuroHEAT unchanged; WorldPop updated to **2025 projection**, which **changes output (3)** and therefore **substantially changes output (4)**
Population projection approach (WorldPop 2025)	**WorldPop 2022** → **2025** via an **analog projection** using a scaling factor of **1.5** (derived from 2022–2025 population ratios). Plausibility check performed by comparing projected **2024** with **TÜİK 2024**, showing **~2.6% deviation**	Same 2025 vulnerability projection used; the update affects the vulnerability classification (3) and consequently the risk-change maps (4)
Phase 1 vs Phase 2 changes	**Phase 2 upgrades: Antalya-wide scale-up; USGS Landsat 8 (instead of RsLab); WorldPop 2025 projection (validated vs TÜİK 2024); UHRHO (Kaynarca, 2026) built-up overlay for Medium/ High/Very High risk hotspots.**	**Key change in Phase 2:** vulnerability update **2022** → **2025** (validated vs TÜİK), leading to different vulnerability and risk-change outputs

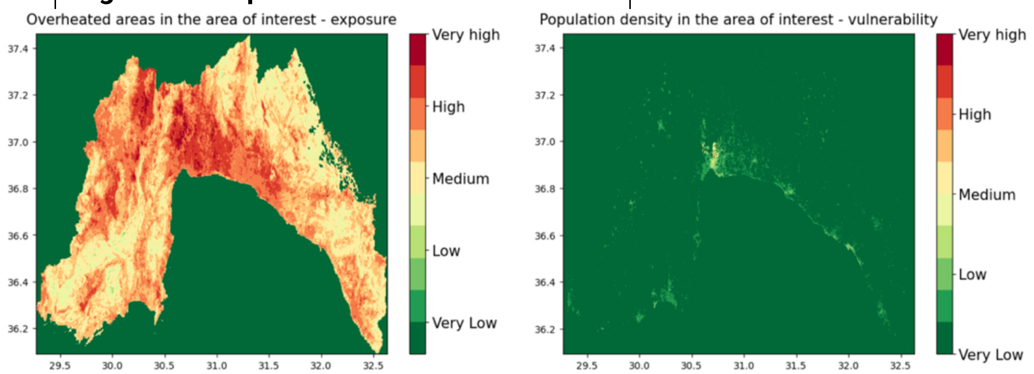


Figure 2-9 Inputs for Risk Method #1 (Landsat-based urban heat risk): (a) LST-derived overheated areas (JJA scenes, 2013–2024; cloud-filtered), and (b–c) vulnerable population density layers (WorldPop 2025 projection) for ages 0–5 and 60+.

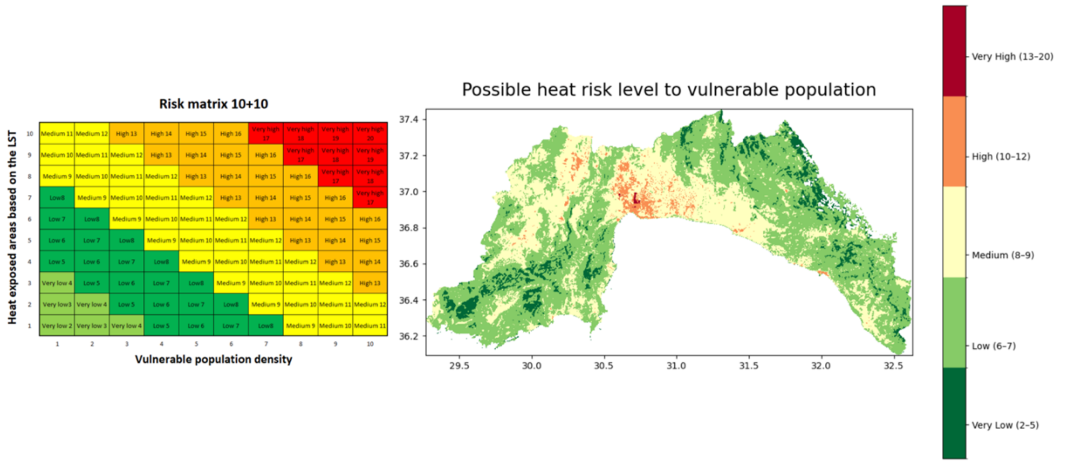


Figure 2-10 Possible heat risk level to vulnerable population (Risk Method #1): pixel-wise risk classification obtained by reclassifying LST and vulnerability into 10 classes and combining them using the CLIMAAX risk matrix logic (left side in the figure).

In Figure 2-9 and Figure 2-10, Figure 2-9 shows that overheated areas are more pronounced **in the coastal belt and central urban belt**; the pattern is more fragmented in the interior. The vulnerable population density map shows **distinct clusters in central districts** (urban core and densely populated areas). Accordingly, heat risk in Antalya is not "equal everywhere"; risk accumulates where **urban density and thermal exposure** overlap. This result shifts the question "where is it hot?" to "where and for whom?": **urban centers with high concentrations of vulnerable populations** are critical locations for monitoring and intervention. As seen here, the priority for the Heat Action Plan should be **hotspots with high concentrations of vulnerable populations** as much as the "hottest places" (targeted communication, cooling areas, shading, health/social support).

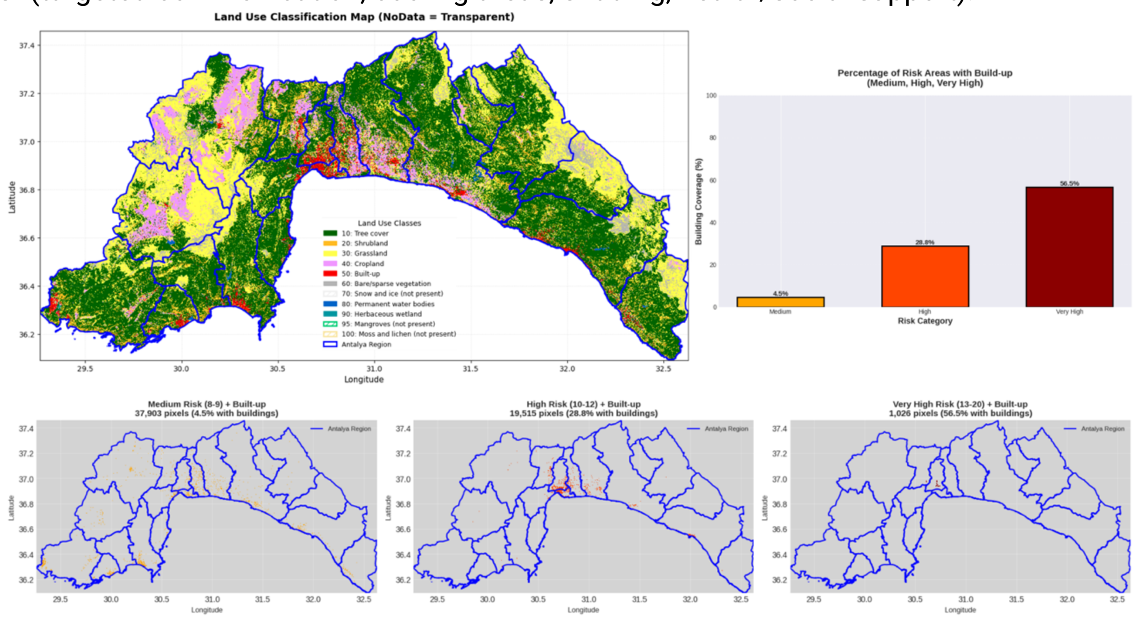


Figure 2-11 Urban Heat Risk Hotspot Overlay (UHRHO; Phase 2 extension): intersection of Medium/High/Very High heat-risk pixels (from Figure 2-10) with ESA built-up areas, highlighting intervention-ready hotspots in living environments across Antalya.

Figure 2-11 shows that in studies conducted in built-up areas, the "very high heat risk" level is more closely associated with urban areas. Antalya's built-up area constitutes 2.56% of the city's total area. However, a large portion of the population resides here (approximately 56% of the total population). Areas classified as "very high risk" (13-20 according to Figure 2-10; medium risk 8-9 and high risk 10-12) are concentrated in built-up areas at a rate of 56.5%. The most critical finding here is **that the "Very High Risk" level is increasingly within 'lived-in' areas.** In other words, the risk is not only technically high; it is **directly** embedded **in the living environment** (residential fabric, daily use areas).

This means "targets ready for intervention" for action planning. **The call to action** here **is very clear:** "Very High + built-up" areas **should be the top priority** in the Heat Action Plan: cooling centers, shading, cool corridors, green infrastructure, targeted communication with vulnerable groups, and field operations should be initiated in these areas.

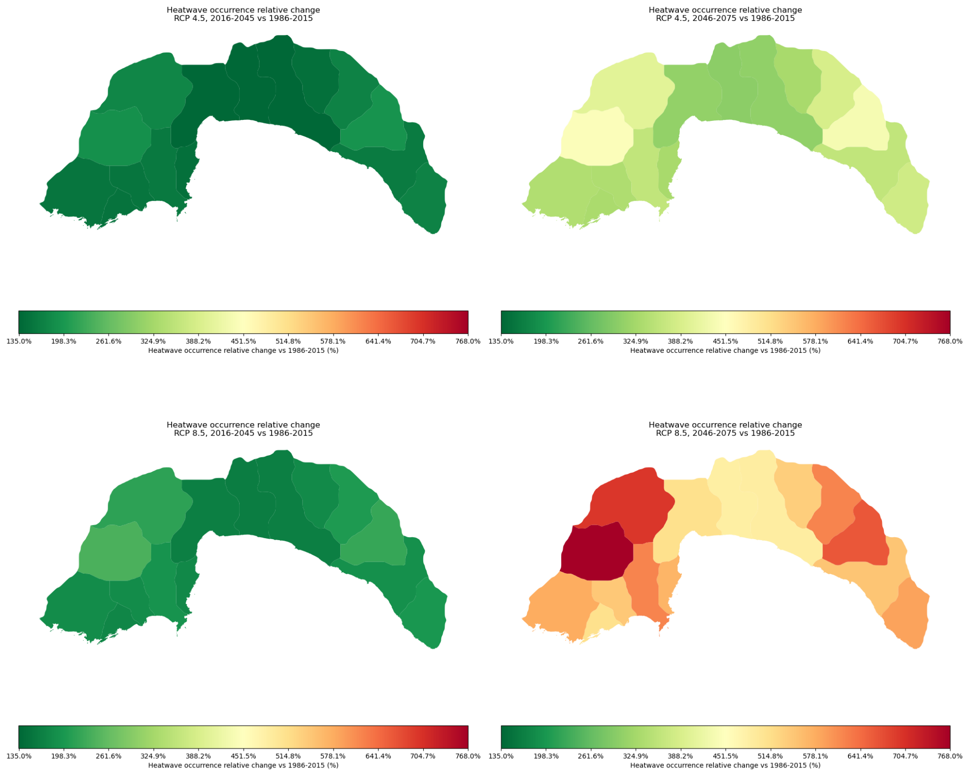


Figure 2-12 Relative change of heatwave occurrence (Risk Method #2): near future (2016–2045) and far future (2046–2075) compared to reference (1986–2015), under RCP4.5 and RCP8.5.

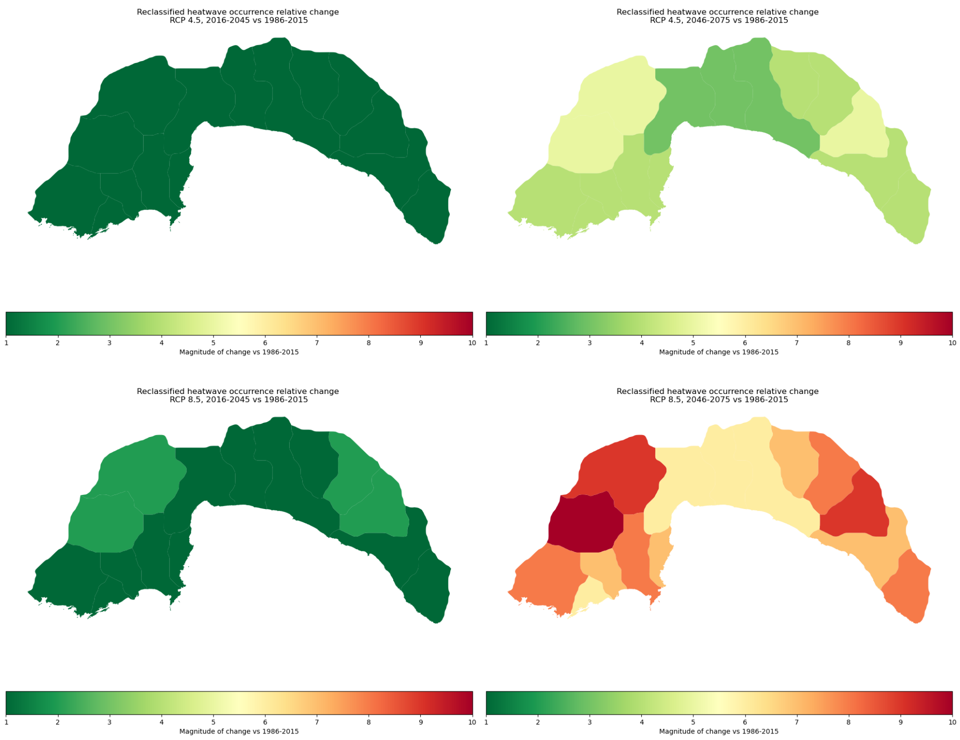


Figure 2-13 Magnitude of change in heatwave occurrence (1–10 classes): reclassification of relative change maps for near and far future under RCP4.5 and RCP8.5.

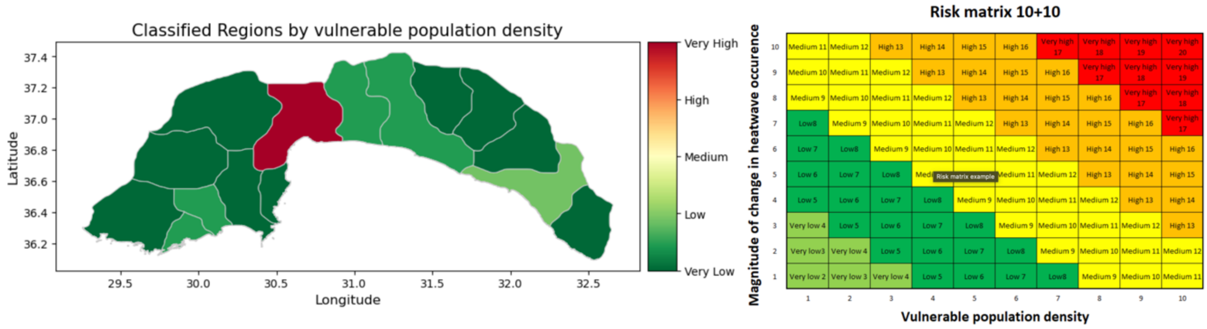


Figure 2-14 Vulnerable population density classes (1–10): WorldPop-based (2025 projection) density classification for ages 0–5 and 60+ (not scenario-specific) and also risk matrix (right side) for its axes to overlay.

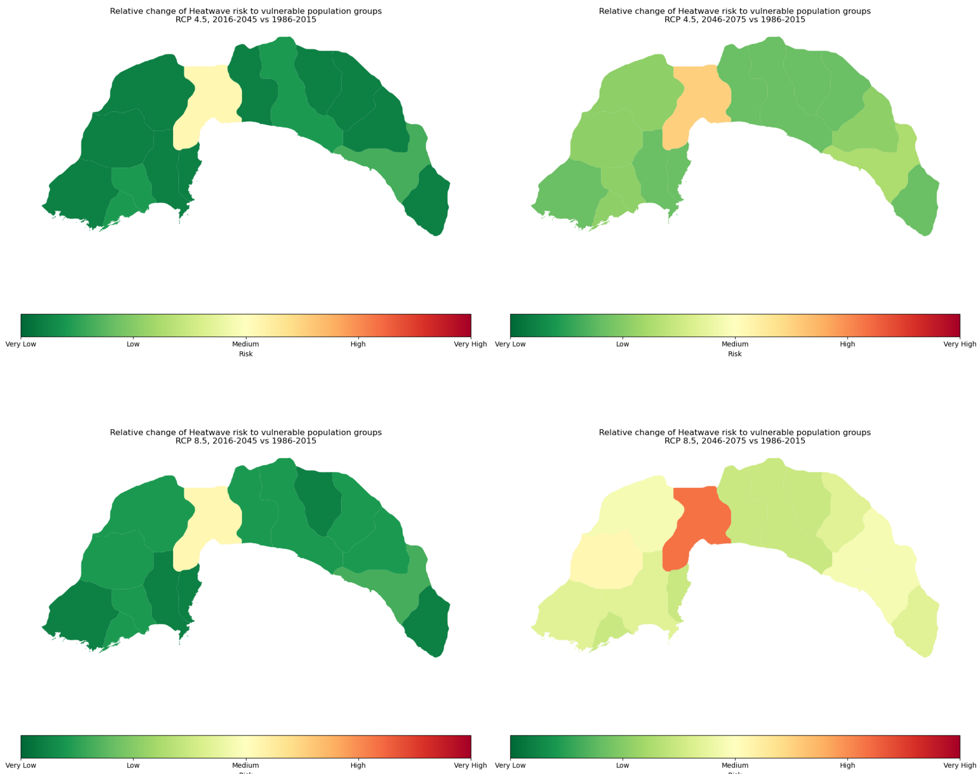


Figure 2-15 Relative change of heatwave risk to vulnerable population groups (Risk Method #2): risk matrix (Figure 2-14) output combining magnitude-of-change (Figure 2-13) with vulnerability density (Figure 2-14) for near/far future and RCP4.5/RCP8.5.

According to Figure 2-12 and Figure 2-13, the increase in risk is not equal across all districts; **a stronger rise** has been observed in some districts. Classifying the relative change on a scale of 1–10 facilitates inter-district comparison and decision-maker communication. Under RCP4.5, the relative change is more limited, while **under RCP8.5**, **the increase is particularly pronounced in the far future**. Particularly in the **RCP8.5 far future** scenario, the fact that some districts move to higher classes shows that the danger intensifies over time and that the "fastest growing" districts stand out more clearly. This supports the planning of adaptation measures not in a uniform manner but **differentiated at the district level**. Figure 2-14 **shows that** the concentration of vulnerable populations (0–5 and 60+) **is structurally concentrated in the metropolitan core**. As this layer is independent of the scenario, it provides **a stable basis** for answering the question "who is more vulnerable where?" and makes it possible to identify which districts will become more critical as the threat increases. Figure 2-15 presents the risk matrix approach. The risk matrix approach combines the increase in hazard (Figure 2-13) with the vulnerability population density (Figure 2-14) to show **where** the increase in risk **is most significant**. The results reveal that the areas with the strongest risk increase are generally concentrated **in districts with high hazard increase and highly vulnerable**

population density. This finding will support measures that will yield rapid gains in the metropolitan core in the short term and a phased adaptation strategy that will spread to other districts as the risk grows in the medium to long term.

2.3.3 Additional assessments based on local models and data

The CLIMAAX extreme heat risk assessment has been strengthened in the local context using **district-level mortality data (2018–2024)** obtained **with special permission** from the Antalya Provincial Health Directorate (see; Zoledo, some_datasetsM16 folder). The analysis focused on causes related to **circulation + respiration**, which have a strong correlation with heat in the literature (see also Zoledo supplementary documents, Doğan, 2026 for details) and was limited to **JJA (June–July–August)** for seasonal adjustment. During the 2018–2024 JJA period, these causes accounted for approximately half of all deaths in Antalya (**all ages 47.3%; 0–5 & 60+ 51.7%**; **50.3%** and **54.8%** respectively in 2024). This study is an innovative application in terms of assessing health impacts at the district level and with detailed mortality data within the context of Turkey and within the scope of CLIMAAX-MUHIR.

2.3.3.1 Hazard assessment

During the JJA period (2018–2024), circulatory & respiratory deaths constituted a significant proportion of total deaths in Antalya (**approximately 47% for all ages; approximately 52% for the vulnerable groups**). This finding provided a strong rationale for **contextualizing** hazard indicators with health impacts. Specifically, for Muratpaşa, observational summer season temperature metrics generated using **MGM-based thresholds** (**HWF/HWN-HWD: ≥3 consecutive days (daytime + nighttime thresholds)**; **HWI: ≥5 consecutive hot days (daytime threshold)**) were visualized together with the 2018–2024 JJA mortality changes (Figure 2-16). Muratpaşa was chosen because it had the highest number of deaths due to circulatory and respiratory causes (2266 deaths, ranked first; this ranking is based on absolute death numbers and should be evaluated separately as factors such as population size and age structure were not normalized). HWF, HWN-HWD, and HWI were additionally calculated for Muratpaşa for the years 2018-2024.

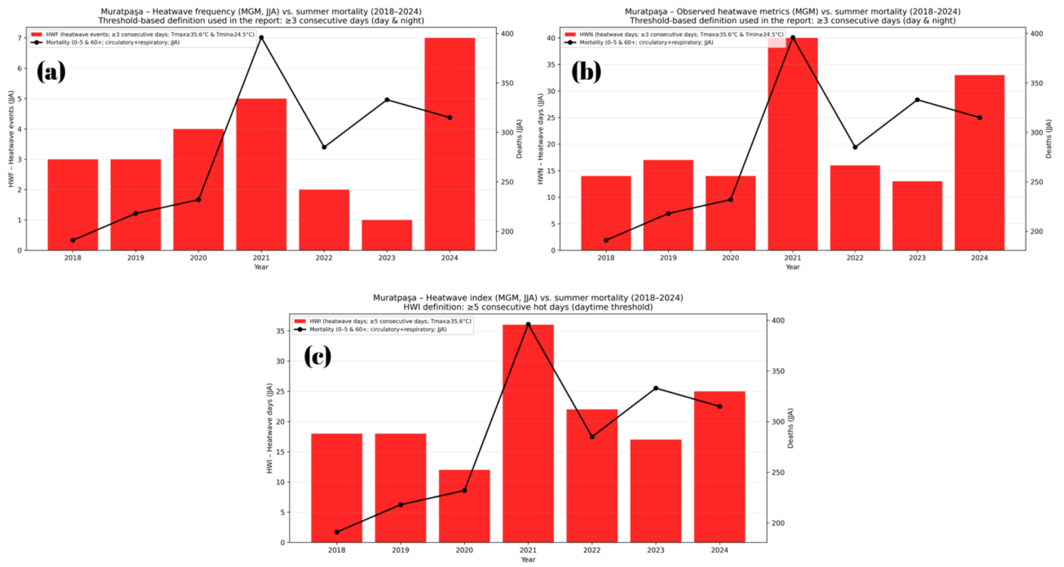


Figure 2-16 Concurrent display of observational summer season temperature metrics (MGM; JJA) and circulatory & respiratory mortality (0–5 & 60+) in Muratpaşa: (a) HWF vs mortality, (b) HWD-HWN vs mortality, (c) HWI vs mortality (2018–2024).

The observed summer mortality fluctuations in Muratpaşa during the period 2018–2024 can be interpreted in conjunction with the calculated changes in the heat wave metric during the same period; thus, a literature review has been conducted. This comparison does not aim to draw causal inferences; it is a contextual validation that tests whether the indicators carry a meaningful signal in the local context.

2.3.3.2 Risk assessment

As part of the preliminary validation, district-level mortality counts (total for women and men) due to circulatory and respiratory causes in the 0–5 and 60+ age groups for the summer of 2024 were combined (Figure 2-17) and compared at the district pattern level with the WorldPop 2025 vulnerable population density classes (Figure 2-14) used in Risk Method #2.

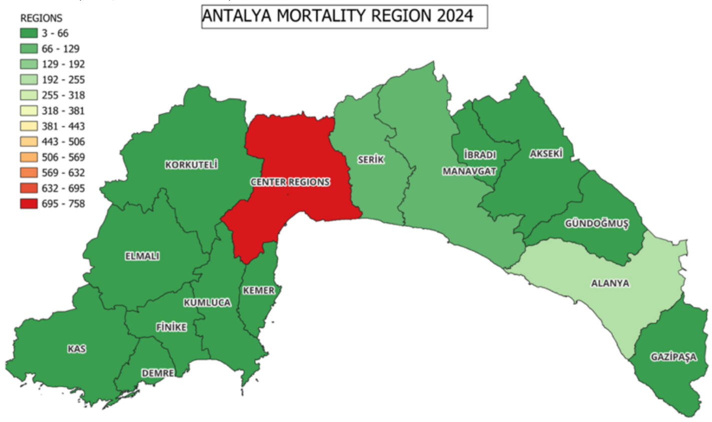


Figure 2-17 District-level distribution of JJA circulation & respiratory mortality (0–5 & 60+, total women/men) in Antalya (2018–2024). The map created in QGIS software shows a tendency for mortality to be concentrated in central districts, and when read together with the vulnerable population density layers, it provides contextual support for the consistency of risk outputs with the local context.

The marked concentration of mortality in central districts presents a generally consistent picture with vulnerable population density patterns, generating additional evidence at the local scale for risk prioritization and action plan targeting.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

In Phase 2, the Key Risk Assessment (KRA) process was conducted through the "From Science to Action on Climate Change: Workshop on Antalya's Vulnerability to Extreme Heat" and the participant survey conducted during the workshop, with the aim of having stakeholders evaluate risk outputs in terms of **severity, urgency, and response capacity**. The workshop and survey design were prepared by Dr. Fulya Kandemir, Özlem Kılıçarslan, and Esra Aksoy from the CLIMAAX-MUHIR team, with contributions from Prof. Dr. Murat Türkeş and Assoc. Prof. Dr. Nusret Demir. The questions for the application were transferred to the ESRI Survey123 environment by Volkan Sepetci from the CLIMAAX-MUHIR team, with support from Fatma Demiralay from the AMM GIS Department (see the survey questions template in Zoledo supplementary documents, Sepetci, 2026 for details). The participant profile consisted of Antalya Metropolitan Municipality and district municipalities, provincial-level public institutions (meteorology, disaster management/AFAD, health, agriculture/forestry, etc.), academia/experts, NGOs/professional organizations, and a limited number of private sector representatives (Figure 2-18). **149 people participated in** the workshop and **84 responded to the survey**.

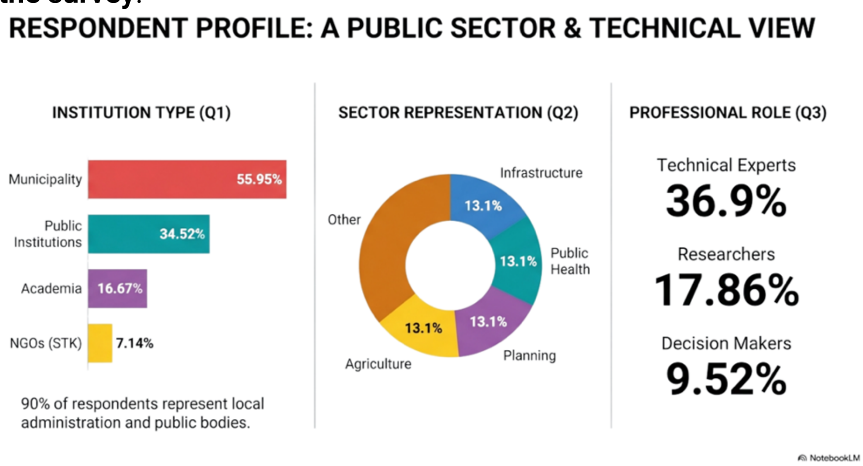


Figure 2-18 NotebookLM supported illustration of respondent profile from "From Science to Action on Climate Change: Workshop on Antalya's Vulnerability to Extreme Heat" (see supporting documents in Zoledo; Kılıçarslan, 2026 for details).,

Risk assessment feedback was collected through three channels (Figure 2-19):

- **workshop discussions** (interpretation of risk maps with local knowledge),
- **survey (self-report)** (severity–urgency–capacity ratings and needs),
- **action-oriented recommendations** (priority adaptation/intervention options and institutional needs).

Sample survey records showed that **severity and urgency scores** were **mostly high**, **while intervention capacity scores** were **moderate/lower** (the general framework of the stakeholder participation process is provided in Section 2.1.5; this section summarizes the feedback focus areas for the KRA). In addition to all this, a significant presentation was made, examining 12 cities, both their action plans and best practices, with the aim of serving as the basis for a Local Heat Action Plan, which will be discussed in detail in phase three and will support increasing the city's resilience to extreme heat before COP31 (Figure 2-20/Figure 2-21).

Figure 2-19 Round table discussions from the workshop.

Figure 2-20 Cities with different heat action plans or climate adaptation plans being examined to enter Phase 3 under CLIMAAX-MUHIR. Nine of the 12 cities examined have a dedicated "heat action plan" focused on extreme heat (illustration supported by ChatGPT).

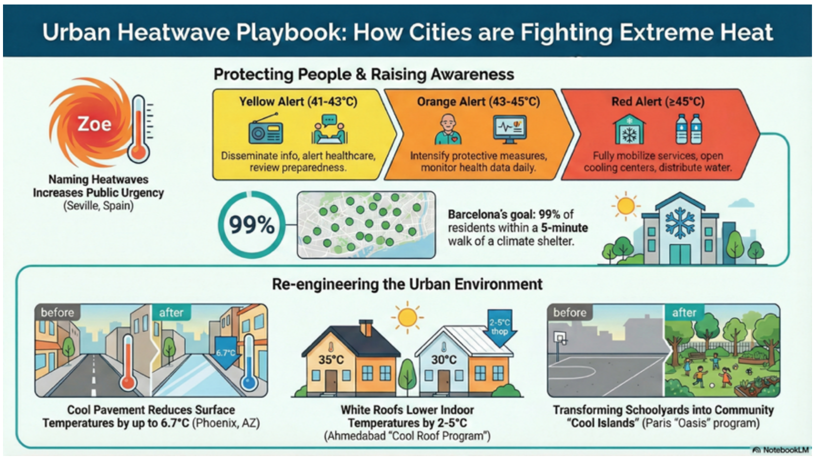


Figure 2-21 Some best practice examples included in the heat action plans of different cities. This infographic was created using NotebookLM.

2.4.2 Gather output from Risk Analysis step

For Key Risk Assessment, outputs generated in Phase 2 Risk Analysis step have been compiled to jointly evaluate **current risk patterns** (UHI/LST + vulnerability) and **future risk increase** (projection-based change) and grouped to serve as input for the evaluation dashboard:

1) Hazard-based outputs – heatwave indicators

- **EuroHEAT:** Heatwave occurrence frequency and long-term trends under RCP4.5/RCP8.5.
- **XClim:** HWI (Heatwave Index), HWF (Heatwave Frequency), **HWN–HWD** (total heatwave days/duration) indicators. In Phase 2, analyses were enhanced **with local thresholds** (MGM and NASA NEX-GDDP-based thresholds).

2) Risk outputs – Risk Assessment Method #1 (Satellite-based LST/UHI + vulnerable population)

- **LST-based overheated areas** derived from JJA scenes with cloud filter applied,
- **WorldPop 2025** vulnerable population density (0–5 and 60+),
- **Possible heat risk level** (risk classes) generated by the risk matrix,
- Phase 2 additional output: **UHRHO (Urban Heat Risk Hotspot Overlay)** – Overlaying **Medium/High/Very High** risk classes with ESA **built-up** areas (Kaynarca, 2026).

3) Risk outputs – Risk Assessment Method #2 (Projection-based risk change)

- **Relative change in heat wave formation** and classified magnitude maps for the near future (2016–2045) and distant future (2046–2075) relative to the 1986–2015 reference period (RCP4.5/RCP8.5),
- Vulnerable population density classes (WorldPop 2025),
- **Heat wave risk change** maps **for vulnerable groups** using a risk matrix (two-time horizons; two scenarios).

This output set aims to directly inform the identification of **priority intervention areas** within the Heat Action Plan by jointly visualizing **risk patterns concentrated in central districts** of Antalya and **the spatial direction of risk increase** under different scenarios.

2.4.3 Assess Severity

Severity assessment is based on the combined reading of the **current risk (LST/UHI + vulnerable population + risk matrix)** produced in Phase 2**, UHRHO,** and **future risk increase (heat wave increase and risk change with climate projections)**. and is further supported by participants' scoring of risks on the **severity–urgency–resilience capacity** axes in the workshop survey. The survey design used a separate scoring structure for risk topics based on "Severity/Urgency/Resilience Capacity" (Figure 2-22). In this way, the severity assessment was translated into "actionable" emergency response priorities.

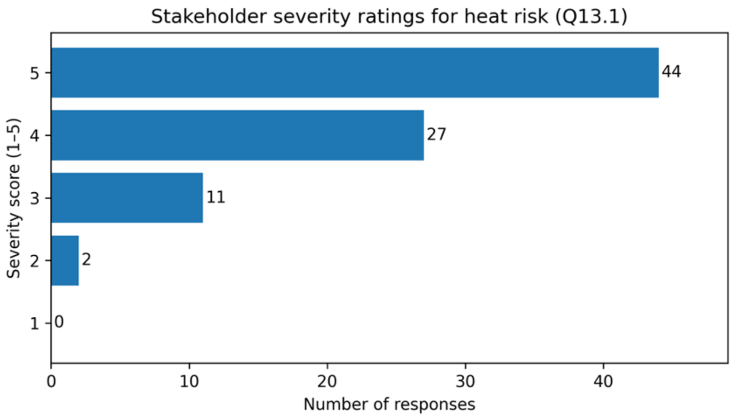


Figure 2-22 Results obtained from the workshop's surveys and roundtable discussions and identified with the city's inclusive stakeholders regarding the severity rating of heatwaves: 1-low; 5-highest.

The overlap of satellite-based LST/UHI layers with vulnerable population densities (0–5 and 60+) shows that heat risk is significantly elevated **in urbanized hotspots**. This situation transforms the impact from a "homogeneous risk across the province" into a risk **that is concentrated in hotspots** but has a high potential to produce significant consequences in terms of health and access to services. The clustering of heat risk scores towards the upper values in the workshop survey (e.g., 4–5 in sample records) supports the perception of current severity. For these reasons, the current

severity is classified as **Substantial (3)**: **high impact exists**, but **it is spatially concentrated in hotspots**.
Hazard/risk change outputs based on climate projections indicate that **the severity of impact will increase** through the upward trend in heatwave indicators and the increased risk to vulnerable groups. This means not only more frequent/longer hot periods, but also that "high risk" conditions for vulnerable groups will become more widespread **and persistent**. Therefore, future severity is classified as **Critical (4)**.
Extreme heat can trigger cascading consequences, including **increased energy demand**, **cost pressures**, **labor losses**, and **difficulties in service delivery**, in addition to direct health impacts. Stakeholders' open-ended responses also emphasized that the risk could extend to areas such as energy use and economic pressures. Therefore, an approach converging towards the upper category was adopted in the severity assessment; specifically, the "critical" class was justified for the future period. Stakeholders highlighted **energy use, ecosystems, and vulnerable groups/social impacts** as the areas most affected. This perspective strengthens the link between technical risk outputs and "field reality" thereby solidifying the severity classification. The understanding of climate risk and the level of preparedness among decision-makers/institutions **is not homogeneous**: some survey respondents stated that they had "education/experience," while others stated that they did not. This situation points to a "capacity gap" that could cause the severity of the same risk to be felt more acutely in the field and is a factor that pushes the severity classification upward (especially for future risks.

2.4.4 Assess Urgency

The urgency assessment was conducted by interpreting the current risk outputs (LST/UHI + vulnerable population + risk classes/UHRHO) together with projection-based risk increases, according to the four categories in the CLIMAAX protocol (**no action needed – watching brief – more action needed – immediate action needed**) and supported by stakeholder feedback. Currently, risk is concentrated in distinct "hotspots" in urban areas (with medium–high–very high risk clusters separating in built-up areas with UHRHO), while heatwave indicators (HWF, HWI, HWN/HWD) and risk-change maps for the near and distant future indicate that risk will emerge **in wider areas** and **at higher levels**. This indicates that the urgency should not remain at the "monitoring" level.
As extreme heat is a recurring threat in Antalya every summer season, the "window of action" begins before the next summer season. Therefore, critical steps for damage mitigation must be implemented **before the heat season (spring–early summer)** (early warning–risk communication, cool areas/cooling plan, social/health protocols for vulnerable groups, municipal service continuity). These critical steps were discussed in the survey and best practices were compared according to priority criteria (Figure 2-23).

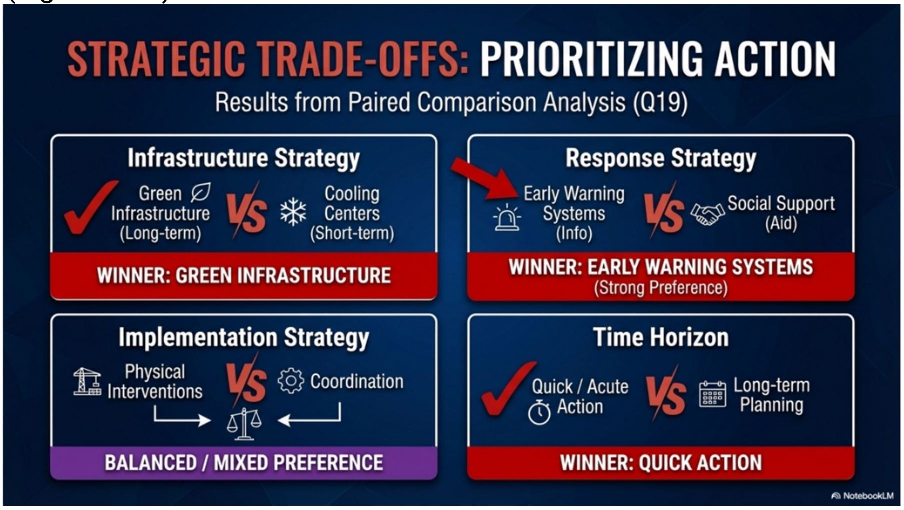


Figure 2-23 Results from the "prioritization study" based on the Analytic Hierarchy Process evaluated with stakeholders during the workshop's roundtable discussions; the applications here were identified from the best practices of the cities indicated on the map in Figure 2-20. During the workshop, the extent to which these applications are a priority for Antalya was discussed under the main headings (Illustration supported by NotebookLM).

Projections indicate an increase in the frequency/duration of heat waves and longer hot periods, so the risk is expected to grow even in the short term (near future), which raises the urgency score (Figure 2-24). Heat waves are not "one-off sudden events" but rather a process that **recurs seasonally and can rapidly intensify over a scale of several days to weeks**. This characteristic requires a high assessment of urgency, as the effects accumulate annually if no preparations are made. Combined with the UHI effect and urbanization dynamics, the impact of extreme heat is not merely a meteorological episode but creates a **persistent/recurring** risk framework at the city scale. Therefore, a "wait-and-see" approach is inappropriate. Workshop discussions and survey results showed a strong perception that the risk cannot be postponed and increased expectations for action-oriented measures.

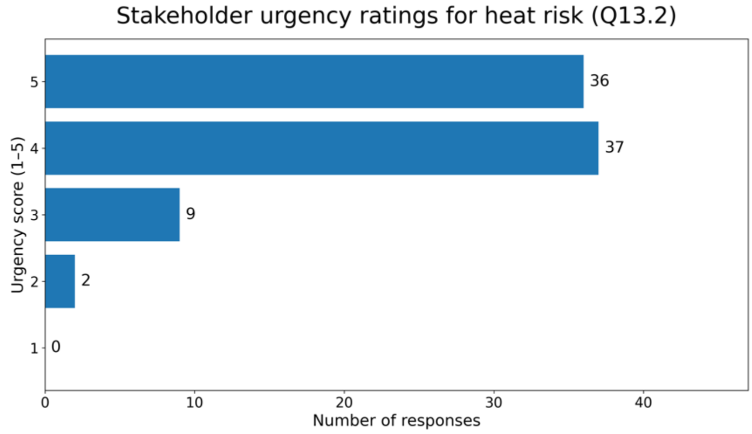


Figure 2-24 Results obtained from the workshop's surveys and roundtable discussions and identified with the city's inclusive stakeholders regarding the urgency rating of heatwaves: 1-low; 5-highest.

This feedback supported the upward assessment of urgency in line with technical findings. For all these reasons, the urgency level for extreme heat/heatwave risk was classified as "**immediate action needed**".

2.4.5 Understand Resilience Capacity

Resilience/response capacity; current climate risk management practices, institutional processes and resources, and data-driven risk products strengthened under Phase 2 were evaluated together and classified into **low–medium–substantial–high** categories. The assessment considered financial, human resource, physical/technical, social, and natural capacity components together.

Factors supporting the response capacity to extreme heat risk in Antalya include the increased interest of the municipality and relevant institutions in the issue, the expansion of the stakeholder network in Phase 2, and the production of outputs that enable the spatial concretization of the risk (LST/UHI, vulnerable population density, risk classification, and **UHRHO/built-up overlay**). These outputs lay the groundwork for the more operational design of interventions such as early warning–preparedness–targeting.

However, capacity needs to be strengthened in areas such as the requirement for widespread implementation across the province, sustainable financing of actions, systematization of inter-agency coordination, technical expertise, and data/analysis continuity. Workshop feedback and survey findings also indicate that application-focused needs (coordination, resources, training/capacity building, integration into plans, etc.) are prominent.

Therefore, the current resilience/response capacity to extreme heat/heatwave risks has been assessed as "**medium.**" Based on the workshop held in Phase 2 and within the scope of Phase 3, the initiation of the preparation process **for the Antalya Heat Action Plan/report** with the contributions of public institutions at the provincial level and the target of completing the draft action plan by the **COP31 Antalya** calendar (November 9-20) indicate that the resilience capacity can increase rapidly in the short term. This process has been assessed as an important lever in terms of strengthening inter-agency coordination, clarifying risk communication and early warning-response components, and prioritizing implementation (especially for vulnerable groups in urban hotspots). Therefore, while the capacity classification is maintained at the "medium" level, **the potential to approach the "substantial" level within the next 12 months** has also been noted.

2.4.6 Decide on Risk Priority

Risk priority is determined by reading the scores for **severity (current + future), urgency, and resilience/response capacity** together on the assessment board. Stakeholder assessments from the workshop and survey, along with Risk Analysis outputs (current: LST/UHI + vulnerable population + risk matrix + UHRHO; future: projection-based risk change), were evaluated within the same framework.

Dashboard scores for Heatwaves were compiled as **Severity (C)=3, Severity (F)=4, Urgency=4, Capacity=2**; it was concluded that the risk is unavoidable due to the combination of high severity and urgency with medium capacity. Therefore, the **Heatwaves risk priority was assigned as "High"**. The priority assignment, thanks to the UHRHO output and the identification of Medium/High/Very High risk focal points in built-up areas, also provides a basis for targeting interventions in action plans (Table 2-5).

Table 2-5 Key Risk Assessment dashboard summary for Antalya: risk prioritisation results for heatwaves (severity–urgency–capacity scoring and assigned risk priority)

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
Heatwaves	3	4	4	2	High

Severity	Urgency	Resilience Capacity	Risk Ranking
Critical	Immediate action needed	High	Very high
Substantial	More action needed	Substantial	High
Moderate	Watching brief	Medium	Moderate
Limited	No action needed	Low	Low

2.5 Monitoring and Evaluation

The most important outcome of Phase 2 is the establishment of a multi-layered CRA set that makes the risk of extreme heat/heat waves **visible and actionable**: (i) LST/UHI + vulnerable population + risk matrix + UHRHO for the current situation, (ii) projection-based heat wave increase and risk change for the future. Thus, risk has become readable across Antalya through **districts and urban centers of concentration**, and a structure has emerged that directly feeds into heat action planning.

The most challenging areas in the process were: the increased complexity of data/workflow when scaling up to the provincial level; the need to accurately reflect the consistent comparison of **different threshold sets**, such as MGM and NASA NEX-GDDP, in the report language and visuals; and the requirement to **simultaneously conduct technical analysis and stakeholder processes** under time constraints. However, the workshop and participant survey transformed the risk assessment from a purely technical output into a process **validated by local knowledge and institutional needs**; feedback indicated that the severity/urgency of risk was perceived as high, while coordination, resource, and training needs were highlighted on the capacity side.

Learning and continuity were ensured through the reproducible documentation of workflows, internal task sharing, and knowledge transfer. During the MUHIR process, the **JupyterHub capacity** within the municipality has significantly improved (2 full experts + 2 semi-experts), and the process was supported by a doctoral student at the university in the role of "facilitator + literature." Thanks to internal redundancy within the team, continuity was maintained by transferring outputs in the event of a member leaving.

New data layers were introduced to strengthen the local context (e.g., district-level mortality for pre-validation; stakeholder data; WorldPop 2025 projection). To better understand the risk going forward, more detailed indicators related to health impacts (emergency visits/ambulance calls, if possible), **humidity and nighttime LST**, as well as urban detail layers such as building stock–shading/green infrastructure and socioeconomic vulnerability, and protocols to institutionalize inter-agency data sharing are priority areas (in this context, a separate meeting is planned with the Akdeniz University School of Health Sciences).

Outputs: technical report and map set, dashboard and summary visuals, short policy notes for stakeholders, and communication through national/international dissemination channels (conference presentation, proceedings/book chapter, SCI publication target). (see also Zoledo supplementary documents; Aksoy, 2026) and will be further expanded in phase 3. Phase 2 findings have made the relationship between extreme heat and multiple disasters/cascading effects more visible; accordingly, a new **cascade-focused** project idea that will ensure continuity in Phase 3 and beyond has matured, and discussions have begun with some stakeholders. The holding of COP31 in Antalya (November 9–20) also presents an important opportunity to disseminate CLIMAAX outputs to institutional and public audiences.

Finally, Phase 2 outputs have enabled the establishment of a risk-based monitoring framework for Antalya: Updating heatwave indicators (HWF, HWI, HWN–HWD, etc.) during each heat season (JJA); monitoring urban interventions in LST/UHI and UHRHO hotspot areas; annual assessment of impacts on vulnerable groups; monitoring the performance (access, coverage, applicability) of early warning–preparedness–response components. This framework can be institutionalized in Phase 3 by pairing it with a heat action plan.

2.6 Work plan Phase 3

The objective of Phase 3 is to translate the climate risk assessment (CRA) outputs and Key Risk Assessment findings (particularly **extreme heat/heatwaves**) generated in Phase 2 into **actionable adaptation measures** and a **draft institutional Heat Action Plan**. This phase will focus on matching risk priorities (severity–urgency–capacity) with field applicability, responsibility sharing, and a timeline.

Main activities (what / why / how):

1. **Operationalization of risk priorities (monitoring and decision support):** Based on Key Risk Assessment scores and risk maps, a **list of priority districts/focus areas** will be compiled for Antalya. This output will be integrated into the dashboard and converted into a usable summary/monitoring format for decision-makers.
2. **Identification and packaging of adaptation measures (adaptation measure shortlist):** Using workshop/survey feedback and "best practice" documents, measures to reduce the risk of extreme heat will be shortlisted within the framework of **intervention type–target group–responsible institution–scale of implementation** (e.g., early warning and risk communication, cooling centers, shading and green infrastructure, social support for vulnerable groups, occupational health measures, etc.).
3. **Hotspot-based targeting and action planning:** Using the risk outputs generated in Phase 2 (LST/UHI + vulnerable population + risk matrix + **UHRHO**), **intervention-priority living areas** will be identified; measures will be spatially targeted to answer the question "where and for whom." The aim is to focus resources on high-impact interventions in **high/very high risk areas** rather than distributing them equally across the entire province.
4. **Drafting and institutionalization steps for the Heat Action Plan:** A plan structure will be created that includes an early warning–preparedness–response–recovery cycle; inter-agency role sharing, coordination mechanisms, communication protocols, and a feasible timetable will be clarified. As COP31 will take place in Antalya (November 9–20), presenting an opportunity for visibility, the goal will be to **finalize the draft plan** by that date.
5. **Realistic monitoring and updating approach:** Instead of reproducing all outputs from scratch each heating season, a sustainable model will be adopted: updating indicators/dashboards with an annual "minimum monitoring set"; more intensive spatial productions (LST/UHI, UHRHO, etc.) will be renewed periodically (e.g., every 2–3 years) or as data/capacity allows. Health impacts will be gradually integrated into the monitoring framework as accessible data becomes available.

Scopes not to be covered (reasons):

In Phase 3, **data- and time-intensive** analyses such as detailed building inventory, high-resolution energy demand modeling, and scope expansion for all hazards will not be conducted. The focus is on transforming the extreme heat risk into a prioritized action plan and establishing a feasible institutional structure. The multi-hazard/cascading risk approach (e.g., flood + heat together) will be addressed in the new project line (cascade) to be developed at the end of Phase 3.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 resulted in the establishment of a multi-layered Climate Risk Assessment (CRA) set that makes the risk of extreme heat/heat waves in Antalya "spatially visible and actionable." In this phase, two complementary outputs were produced: (i) combining satellite-based LST/UHI exposure for the **current situation** with vulnerable population density (0–5 and 60+) and classifying it with a risk matrix; (ii) the transformation of changes in heatwave formation based on climate projections for the **future period** (near/distant future, RCP4.5/8.5), integrated with vulnerability classes, into risk change maps. This structure has enabled the comparison of risk at the district level in Antalya and the creation of a framework that can directly contribute to policy/implementation processes such as the Heat Action Plan.

The main findings indicate that risk is not "equal everywhere"; it accumulates in centers where urban concentration and vulnerable populations overlap. When LST/UHI and vulnerable population patterns are read together, the question "where is it hotter?" practically becomes "**where and for whom is it riskier?**" This provides critical prioritization in terms of monitoring, targeted communication, and on-site intervention.

Phase 2's most powerful action-oriented innovation is the UHRHO approach, which **cross-references risk classes with built-up areas**. This layer directly highlights where high-risk classes intersect with the "lived environment" and concretely defines **where** intervention packages (cooling areas, shading, cool corridors, green infrastructure, targeted risk communication, field operations) should be focused.

In the future risk perspective, projection-based analyses show that the increase in heatwave indicators is continuing, and that the intensification is becoming more pronounced, especially under **RCP8.5**. Furthermore, the fact that the increase is not homogeneous across the province, with some districts showing stronger signals of increase, reinforces the need for targeted adaptation/intervention planning at the district level.

Significant progress has been made in Phase 2 in terms of local context adaptation and "contextual validation." To represent health impacts, the high proportion of circulation & respiratory-related deaths among total deaths in Antalya during the 2018–2024 JJA period was considered; this proportion was found to be approximately 47% across all ages, approximately 52% in the vulnerable group, and rising in 2024. In this context, reading mortality fluctuations together with temperature metrics for Muratpaşa served as a "control" function, without claiming causality, indicating that the selected indicators could carry meaningful signals locally.

The main challenges addressed in this phase were the increased complexity of data/workflow at the province-wide scale, the consistent comparison and accurate reflection in the reporting language of different threshold sets (based on local MGM and NEX-GDDP), and the execution of technical production and stakeholder processes within the same timeline. Nevertheless, the process was made manageable through the reproducible documentation of workflows, internal task sharing/redundancy, and stakeholder participation. **However, there are areas that could not be fully resolved or were outside the scope of Phase 2**: the routine integration of higher temporal resolution indicators of health impacts (emergency visits, ambulance calls, etc.); finer disaggregation of risk with heat stress components (humidity, nighttime LST, etc.) and urban detail layers (building stock, shading/green infrastructure, socioeconomic vulnerability); protocols to institutionalize inter-agency data sharing and sustainable monitoring capacity. These topics are suitable for consideration in Phase 3, along with the technical annexes and monitoring framework of the Heat Action Plan.

In conclusion, Phase 2 has provided a CRA foundation that addresses heatwave risk in Antalya in its **current + future** dimensions, **generates spatial prioritization**, and is strengthened by stakeholder feedback. This foundation is a strong starting point for defining the target areas of the Heat Action Plan, designing early warning–preparedness–response packages, and establishing a "risk-focused governance" line that can be expanded in the future to a multi-hazard/cascading risk (e.g., heat & flood) approach.

4 Progress evaluation

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
One (1) of workflows (Heatwave" hazard assessment using local data successfully applied on Deliverable 2.	Achieved. The heatwave hazard workflow was successfully implemented using local thresholds and datasets; outputs, figures and methodological details are documented in this Deliverable 2 report.
Three (3) multi-risk assessments (UHIs, heatwaves, and vulnerability analysis) completed by Month 16.	Achieved. UHI/LST-based risk mapping, heatwave hazard indicators, and vulnerability layers were produced and integrated for multi-risk interpretation at provincial/district scale; full outputs are reported in Deliverable 2.
Four (4) of potential stakeholders involved in the activities of the project	Achieved / ongoing engagement. Core stakeholders engaged include Antalya Governorship, Akdeniz University (Health Sciences), Antalya Provincial Directorate of Health, Antalya Provincial Directorate of Meteorology, and Chamber of Surveyors and Cadastral Engineers. Engagement is ongoing via data exchange, technical consultations, and workshop participation (for details, in Zoledo-supporting documentsM16, Stakeholders_List)
Three (3) of communication actions taken to share results reaching at least 200 citizens.	Achieved (exceeded). Dissemination activities reached an estimated **~479 participants** via: City Expo 2025 (~150), "From Science to the Future: GIS for Climate & Environmental Resilience" Symposium (~100), Akdeniz University National GIS Day (~80), and the "Antalya's Vulnerability to Extreme Heat" Workshop (149) (for details, in Zoledo-supporting documentsM16, Aksoy, 2026)
Four (4) of notes for policy makers.	In progress. Policy briefs/notes have been shared with the Governorate and AMM Secretary General's Office, and additional notes are being drafted based on workshop priorities and Key Risk Assessment outputs.
Three (3) Antalya Metropolitan Municipality Environmental Board's stakeholder meetings, workshops, or consultations	In progress. One of them completed in Phase 1.
Four (4) of publications (two-2 of SCI-based scientific journals, others-2 of TR-dizin (Turkish academic database-based journal)) and three (3) main dissemination actions	In progress (partly achieved). A conference contribution was produced (in Zoledo-supporting documents, Kandemir, 2026) and a full paper was presented/submitted at **INECPAC 2025 (Demre)**. Key dissemination actions were implemented, including the **CLIMAAX Barcelona Workshop** participation and multiple national dissemination events (in Zoledo-supporting documents, Aksoy, 2026). Two SCI journal manuscripts are **under preparation** (to be submitted in Phase 3).
Six (6) of articles in regional media mentioning the project.	Achieved (exceeded). The dissemination tracker lists multiple media items. Examples include several links compiled in the tracker and additional media mentions (in Zoledo-supporting documents, Aksoy, 2026).
Three (3) adaptation strategies (focused on UHI, heatwaves, and nature-based solutions) finalized and integrated into Antalya's urban planning.	In progress. Antalya Heat Action Plan is being developed (review of international examples completed; stakeholder inputs collected). The plan is expected to provide the basis for operational integration of priority adaptation measures and enable follow-up project development (cascade/multi-hazard perspective) in Phase 3.

Key performance indicators	Progress
Integration of at least two (2) adaptation strategies into Antalya's Sustainable Energy and Climate Action Plan (SECAP).	In progress. Heat Action Plan measures are being aligned for integration into SECAP/Local Climate Action Plan frameworks; formal integration steps are planned for Phase 3.
At least two (2) cities or regions (in Türkiye or the Mediterranean region) express interest in adopting the project's methodologies and solutions.	In progress. Such as Pathways2Resilience session (in Zoledo-supporting documents, Aksoy, 2026) support replication potential; concrete adoption commitments will be targeted in Phase 3 just like preparation a replication proposal for a new Horizon call.

Table 4-2 Overview milestones

Milestones	Progress
M1: Test of the workflow "Heatwave" hazard assessment using EURO-CORDEX climate data (EuroHEAT and XClim).	Completed in Phase 1 (Workflow test and initial implementation were finalized during the initial CRA phase).
M2: Initial introductions of CLIMAAX project in Antalya International Science Forum	Completed in Phase 1. 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).
M3: Initial Risk Assessment using CLIMAAX tools completed.	Completed in Phase 1. Initial CRA outputs were produced using CLIMAAX tools and formed the baseline for Phase 2 refinement.
M4: Comprehensive Risk Analysis Report finalized	Completed in Phase 2 (Month 16). This deliverable corresponds to **D2-Comprehensive Risk Analysis Report** (refined regional/local multi-risk assessment including local data and comparison of results).
M5: Stakeholder meeting held to validate risk assessment results.	Completed in Phase 2. "From Science to Action on Climate Change: Antalya's Vulnerability to Extreme Heat Workshop" was held (**Nov 21, 2025**) with **149 participants**, and feedback was collected through roundtables and survey tools.
M6: Attend CLIMAAX workshop in Barcelona.	Completed in Phase 2. The CLIMAAX Barcelona Workshop was attended (**June 10–11, 2025**, CosmoCaixa, Barcelona); Antalya shared UHI/heatwave analyses and implementation roadmap with other regions.
M7: Pilot implementation of adaptation strategies initiated.	Planned for Phase 3 (in preparation). Phase 2 outcomes and stakeholder feedback already point to piloting targeted interventions in hotspot districts.
M8: Presentation of project results to local policy and decision-makers.	In progress (ongoing dissemination & dedicated briefings planned). Results have been communicated through high-visibility events and stakeholder platforms; the outputs are positioned for direct use in the Local Heatwave Action Plan and inter-agency early warning/response processes.
M9: Publications of MUHIR results in scientific journals	In progress. A scientific contribution was presented at **INECPAC 2025 (Demre, Oct 29–31, 2025)**, and journal manuscript preparation is ongoing (SCI-track planned).
M10: Introduction of CLIMAAX project to the stakeholders from Multi Level Governance Platform of EU4ETTR	Completed in Phase 1. 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).
M11: Attend CLIMAAX workshop in Brussels.	Scheduled after Phase 3.

5 Supporting documentation

Acknowledgement: Writing and editing support tools were used to improve the text (translation, rephrasing, style harmonization, and fluency) and to support some visual communication (some charts or figures). The tools did not replace expert judgment: all methodological decisions, data processing, results, interpretations and conclusions were produced and quality-checked by the author and project team. We would also like to thank Mekke Yıldız, the Antalya Met. Mun. (AMM) branch manager and our co-workers in the departments of AMM, because they facilitated this phase for MUHIR team.

List of Zoledo Documents (in order):

- Main Report: in Zoledo as word and pdf files “Antalya-MUHIR_CLIMAAX M16 Deliverable Phase 2”
- Visual Outputs (infographics, maps, charts): in Zoledo as “figuresM16 CLIMAAX-MUHIR_Antalya Phase 2.zip”
- Communication Outputs (Press release, media) and other additions: in Zoledo as “supporting documentsM16 CLIMAAX-MUHIR_Antalya Phase 2.zip”

  The documents contained in this zip file are listed below (note: The name of each document, except for the last one, begins with the last names of the MUHIR team members who contributed to that document);
  - Aksoy 2026-Dissemination Tracker after March 31_2025.pdf
  - Doğan 2026-Health and Heat Risk Literature Research.pdf
  - Kandemir 2026-INECPAC_Abstract.pdf
  - Kaynarca 2026-UHRHO Code Addition.pdf
  - Kaynarca 2026-UHRHO Codes. ipynb
  - Kılıçarslan 2026-Participant Profile to MUHIR Workshop.pdf
  - Sepetci 2026-Workshop Survey Questions.pdf
  - Stakeholders_List.pdf
- Datasets Outputs: in Zoledo as “some datasetsM16 CLIMAAX-MUHIR_Antalya Phase 2.zip”

Participations/ Disseminations in Phase 2 – CLIMAAX-MUHIR (details are in Zoledo; suppoting documentsM16 folder; Aksoy, 2026):

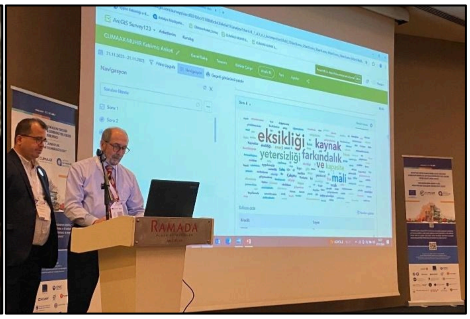
1. City Expo 2025 (April 18-20, 2025)
2. CLIMAAX Barcelona Workshop (June 10–11, 2025)


3. Pathways2Resilience (P2R) Knowledge and Data Innovation Application Group Session (October 24, 2025)
4. International Nature and Environmental Protection and Protected Areas Congress (INECPAC 2025) – Demre (October 29–31, 2025)

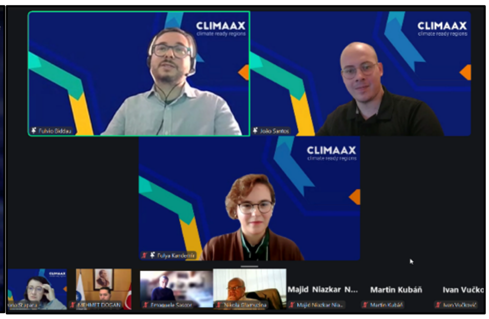
5. "From Science to the Future: Geographic Information Systems for Climate and Environmental Resilience" Symposium (November 6, 2025)
6. Akdeniz University National Geographic Information Systems Day Event (November 19, 2025)

7. From Science to Action on Climate Change: Antalya's Vulnerability to Extreme Heat Workshop: (November 21, 2025)



8. CLIMAAX Heatwaves Workflow – "Heatwave Risk Assessment: Learning from Regions" Session (November 27, 2025)



6 References

Arsad, F., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M., and Tangang, F.: The Impact of Heatwaves on Mortality and Morbidity and the Associated Vulnerability Factors: A Systematic Review, https://doi.org/10.3390/ijerph192316356, 2022

Brimicombe, C., Gao, C., and Otto, I.: Vulnerable to heat stress: gaps in international standard metric thresholds, https://doi.org/10.1007/s00484-024- 02783-6, 2024

Dosio, A., Panitz, H., Schubert-Frisius, M., and Lüthi, D.: Dynamical downscaling of CMIP5 global circulation models over CORDEX-Africa with COSMO-CLM: evaluation over the present climate and analysis of the added value, https://doi.org/10.1007/s00382-014-2262-x, 2015

Meade, R., Akerman, A., Notley, S., Mcginn, R., Poirier, P., Gosselin, P., and Kenny, G.: Physiological factors characterizing heat-vulnerable older adults: A narrative review, https://doi.org/10.1016/j.envint.2020.105909, 2020

Mesta, B., Kentel, E., Sasaki, H., and Nakaegawa, T.: Changes in surface air temperature for Mediterranean climate in Turkey, https://doi.org/10.20937/atm.53404, 2025

Oh, J., Kim, E., Kwag, Y., An, H., Kim, H., Shah, S., Lee, J., and Ha, E.: Heat wave exposure and increased heatrelated hospitalizations in young children in South Korea: A time-series study, https://doi.org/10.1016/j.envres.2023.117561, 2023

Xu, Z., Sheffield, P., Su, H., Wang, X., Bi, Y., and Tong, S.: The impact of heat waves on children's health: a systematic review, https://doi.org/10.1007/s00484-013- 0655-x, 2014

Related Links:

https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview

https://www.copernicus.eu/en/media/image-day-gallery/heatwave-greece-and-western-republic-turkiye

https://www.medecc.org/wp-content/uploads/2021/11/MedECC_MAR1_SPM_TR.pdf

https://ds.nccs.nasa.gov/thredds/catalog/bypass/NEX-GDDP/catalog.html

https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview

https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=download

https://www.worldpop.org/

https://worldcover2021.esa.int/

https://earthexplorer.usgs.gov/