Deliverable Phase 2 – Climate risk assessment

Risk and Vulnerability Assessment in Municipality of Mantoudi–Limni–Agia Anna (RIVA)

Greece, Evia / Municipality of Mantoudi–Limni–Agia Anna

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

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1. Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	Refined regional/local multi-risk assessment integrating local data, with comparison to Phase 1 results and the addition of wildfire as a fully assessed third hazard
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2. Table of contents

3. List of figures

3. List of tables

4. Abbreviations and acronyms

Abbreviation / acronym	Description
RIVA	Risk and Vulnerability Assessment in Municipality of Mantoudi–Limni–Agia Anna
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
CMIP6	Coupled Model Intercomparison Project Phase 6
CRA	Climate Risk Assessment
CORDEX	Coordinated Regional Climate Downscaling Experiment
DEM	Digital Elevation Model
DRM	Disaster Risk Management
EAD	Expected Annual Damage
EFFIS	European Forest Fire Information System
EMS	Copernicus Emergency Management Service
FWI	Fire Weather Index
GEV	Generalized Extreme Value (distribution)
GIS	Geographic Information System
IDF	Intensity–Duration–Frequency
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
JJA	June–July–August
KAPI	Open Care Centres for the Elderly (Greek acronym)
LST	Land Surface Temperature
LUISA	Land Use-based Integrated Sustainability Assessment
MSL	Mean Sea Level
NOA	National Observatory of Athens
RCP	Representative Concentration Pathway
SLR	Sea-level rise
SME	Small and Medium Enterprises
SSP	Shared Socioeconomic Pathway
TN	Tropical Nights (Tmin > 20°C)
WUI	Wildland–Urban Interface

5. Executive summary

Phase 2 of the Climate Risk Assessment (CRA) for the Municipality of Mantoudi–Limni–Agia Anna refines the multi-risk screening conducted in Phase 1 by integrating higher-resolution local datasets, observed meteorological records, post-fire landscape evidence, and authoritative regional studies. The objective is to translate the strategic screening of Phase 1 into operationally relevant, municipality-scale risk information that supports civil protection planning and local adaptation. The most significant change relative to Phase 1 is the elevation of wildfire from a complementary annex analysis to a fully assessed third hazard, alongside heatwaves and river/coastal flooding.

Phase 1 identified heatwaves and river/coastal flooding as priority hazards and flagged wildfire as a growing concern, anchored on the catastrophic August 2021 northern Evia mega-fire. Phase 2 confirms these priorities, quantifies hazard evolution under future climate conditions (RCP4.5 as the central planning scenario, with RCP8.5 retained as a precautionary upper case), and explicitly integrates the compound interactions between the three hazards , most importantly the self-reinforcing loop in which post-fire loss of forest cover amplifies land-surface heating, which in turn dries fuels and lengthens the fire season.

Heatwaves.

- WorldClim v2.1 (Fick and Hijmans, 2017) indicates a historical (1970–2000) mean JJA Tmax of 28.55°C across the municipality, with strong local gradients from cooler mountainous/coastal zones to warmer inland valleys. Near-term SSP2-4.5 projections show an average JJA Tmax increase of about +1.15°C for 2021–2040, while CORDEX-derived indicators show a clear upward trajectory in tropical nights and days with Tmax >35°C.
- The loss of forest cover in the 2021 burn scar has amplified inland summer surface heating through reduced shading and evapotranspiration; the inland warming signal in the projected temperature fields coincides spatially with the burned area.
- Highest risk concentrates in inland, post-wildfire settlements (Mantoudi, Prokopi, Agia Anna) where reduced forest cover, sensitive populations, and limited cooling infrastructure overlap; coastal settlements (Limni, Rovies) remain comparatively moderated by sea breezes.

River and coastal flooding.

- River flooding along the Kireas basin remains the most historically destructive hazard. Phase 2 confirms the Phase 1 finding that coarse-resolution CLIMAAX river-flood products materially underestimate the flash-flood behaviour of the Kireas corridor, and adopts a precautionary, evidence-based characterisation built on observed rainfall, basin morphology, and documented events.
- Coastal flooding remains a localised but credible risk concentrated at the low-lying Agia Anna beachfront, with inundation depths up to ~0.7–1.0 m by 2050 under high return periods and sea-level rise, threatening port facilities, municipal car parks, and access roads.

Wildfire (new in Phase 2).

- The wildfire chapter combines the CLIMAAX FIRE ML and FWI workflows with the 2021 burn-scar evidence and the independent FireScope 2026 screening layer. These products show widespread high to very-high relative wildfire hazard/risk.
- Exposure is concentrated at the wildland–urban interface (WUI): settlements bordering pine, mixed forest, and post-fire regrowth , Rovies, Ahladi, Limni, Kerameia, Prokopi , where the Phase 1 firebreak proposals already signalled local concern.

- The 2021 burn scar is treated as both a vulnerability legacy (degraded forest resilience, increased erosion and post-fire flood potential) and a fuel condition (flammable regrowth), making wildfire risk demonstrably compound rather than isolated.

Synthesising hazard, exposure, vulnerability, and resilience capacity, the Phase 2 Key Risk Assessment prioritises the three hazards as follows: **river (and coastal) flooding** , highest priority (substantial-to-critical severity, immediate urgency, medium resilience capacity); **wildfire** , high priority (substantial severity, increasing urgency, low-to-medium resilience capacity, very high potential for catastrophic single-event loss as demonstrated in 2021); and **heatwaves** , high priority (substantial and rapidly intensifying severity, widespread and cumulative, low-to-medium resilience capacity).

By moving from European-scale screening to a locally grounded, higher-resolution, and prioritised three-hazard assessment, Phase 2 strengthens the municipality's capacity to manage current and future climate risks and provides a robust evidence base for updating civil protection plans, informing local adaptation strategies, and guiding future investment , particularly in integrated fire–flood–heat planning for the post-2021 recovery landscape.

1 Introduction

1.1 Background

The Municipality of Mantoudi–Limni–Agia Anna is a largely rural and semi-mountainous coastal region in northern Evia, Central Greece. Established through the 2011 Kallikratis reform, it covers approximately 584.8 km² and is home to around 12,230 residents, organised in three municipal units , Mantoudi, Limni, and Agia Anna. Its territory ranges from the Aegean coastline, with long sandy beaches and rugged cliffs, to inland mountainous terrain dominated by Mount Xiro and formerly dense pine forests. Mantoudi serves as the administrative and commercial hub; Limni is notable for its traditional architecture and maritime history; Agia Anna lies near one of the longest beaches in Evia and attracts significant seasonal tourism; Kymasi, the port of Mantoudi, links northern Evia to the mainland; and Prokopi, inland, is a year-round religious and cultural centre. Together these settlements form the social and economic backbone of the municipality and its principal zones of exposure to climate hazards.

Over recent years the municipality has faced escalating and increasingly compound climate risks. The defining event remains the catastrophic August 2021 northern Evia mega-fire, which destroyed vast forested areas within the municipality, forced large-scale evacuations, and inflicted long-lasting ecological and economic damage. The loss of forest cover has had cascading consequences that Phase 2 treats as central rather than incidental: reduced shading and evapotranspiration have raised land-surface temperatures inland, degraded slopes have increased post-fire runoff and erosion (elevating flash-flood potential along the Kireas system), and flammable post-fire regrowth has altered the local fuel regime. Alongside fire, the municipality has repeatedly experienced destructive hydrometeorological events, including Medicane “Zorbas” (2018), storms “Athina” and “Ballos” (2021), and storms “Daniel” and “Elias” (2023), which produced flash floods in low-lying communities. A further ecological stressor, the spread of *Ceratocystis platani* among riparian plane trees, continues to degrade riverbank vegetation, accelerate streamflow, and increase flood and erosion risk.

Local infrastructure is challenged by aging and partly inadequate flood-protection works, limited drainage capacity, and the legacy of constrained spatial planning. The prolonged effects of the Greek financial crisis, compounded by recurrent disaster damages, have strained municipal resources and limited proactive adaptation. Mantoudi–Limni–Agia Anna therefore requires a comprehensive, evidence-based resilience framework to protect its population, infrastructure, and the natural and cultural heritage on which its economy depends.

1.2 Main objectives of the project

Phase 2 builds on the harmonised, European-scale screening of Phase 1 and aims to refine risk understanding at municipal scale using higher-resolution local data and authoritative studies. The objectives of Phase 2 are to: (a) replace or complement European-scale proxy datasets with locally validated meteorological, hydrological, coastal, land-cover, and fire-weather data; (b) quantify and spatially refine the priority hazards , heatwaves, river/coastal flooding, and wildfire; (c) explicitly integrate projected climate-change signals and compound hazard interactions into the risk logic; (d) improve the representation of exposure and vulnerability at settlement and infrastructure level, including the wildland–urban interface; and (e) translate analytical outputs into operationally relevant inputs for municipal civil protection planning and the post-2021 recovery.

Phase 2 therefore moves from strategic hazard identification toward decision-oriented, spatially explicit, and forward-looking risk prioritisation across three hazards.

1.3 Project team

The RIVA is coordinated and led by the Municipality of Mantoudi–Limni–Agia Anna in collaboration with the environmental analytics and services company METEOME. METEOME is responsible for conducting the climate hazard analyses, implementing the CLIMAAX risk-assessment workflows, and ensuring rigorous scientific application of the framework. The project team works closely with municipal departments central to climate risk management , notably civil protection and technical/urban-planning services , whose local insight is instrumental in defining and evaluating regional risks. Phase 2 additionally emphasises broader stakeholder engagement, capturing input from emergency services, forestry and environmental actors, vulnerable-group representatives, and local economic actors, ensuring that outcomes are locally relevant and operationally usable.

1.4 Outline of the document's structure

Following this introduction, Section 2 presents the Climate Risk Assessment Phase 2: the refined scoping and stakeholder engagement (2.1), the risk-exploration and scenario choices (2.2), and the regionalised risk analysis for the three priority hazards , heatwaves (2.3.1), river and coastal floods (2.3.2), and wildfire (2.3.3) , followed by the Key Risk Assessment covering severity, urgency, resilience capacity, and risk prioritisation (2.4), monitoring and evaluation (2.5), and the Phase 3 work plan (2.6). Section 3 summarises the conclusions of Phase 2; Section 4 reports progress against KPIs and milestones; Section 5 lists supporting documentation; and Section 6 provides references.

2 Climate risk assessment – phase 2

2.1 Scoping

2.1.1 Objectives

The overall objective of CRA Phase 2 for Mantoudi–Limni–Agia Anna is to refine and operationalise the risk analysis conducted in Phase 1 so that the results are sufficiently detailed, accurate, and decision-relevant to support municipal civil protection planning and the post-2021 recovery. Whereas Phase 1 identified and prioritised risks using harmonised European-scale datasets, Phase 2 translates that screening into locally grounded knowledge through the integration of higher-resolution local data, authoritative studies, and context-specific information, in line with CLIMAAX guidance.

The specific objectives of Phase 2 are to:

- Improve the representation of climate hazards by incorporating local-scale processes (post-fire land-surface heating, flash-flood dynamics of the Kireas system, wildland–urban interface fuel conditions) that European-scale proxies cannot capture.

- Refine exposure and vulnerability analysis using detailed spatial information on population distribution, land use/land cover, settlements, critical assets, and the wildland–urban interface.
- Elevate wildfire to a fully assessed hazard with its own hazard–exposure–vulnerability–risk logic, building on the FWI analysis piloted in the Phase 1 annex and the documented 2021 burn scar.
- Make explicit the compound interactions between the three hazards, particularly the fire → heat and fire → flood cascades.
- Translate analytical outputs into operationally relevant inputs for civil protection preparedness, emergency response, evacuation planning, and recovery.

- Changes compared to Phase 1 scoping

Compared to Phase 1, the scope of Phase 2 has evolved in both depth and breadth. The priority hazards identified in Phase 1 remain valid, but Phase 2 introduces three substantive changes:

1. **Wildfire becomes a full hazard.** The FWI-based fire-danger analysis presented in the Phase 1 annex is promoted to a complete Regionalized Risk Analysis (Section 2.3.3), combining fire-weather projections, fuel/land-cover conditions, wildland–urban interface exposure, and the 2021 burn-scar legacy.
2. **Flood risk is re-characterised as flash-flood-dominated.** Consistent with the Phase 1 finding that coarse CLIMAAX river-flood products fail to reproduce Kireas flash-flood behaviour, Phase 2 adopts a precautionary, evidence-based hazard characterisation anchored on observed rainfall extremes, basin morphology, and documented events rather than on model inundation depths treated as quantitatively definitive.
3. **Compound risk is made explicit.** Phase 2 treats the post-2021 landscape as a coupled system in which fire, heat, and flood reinforce one another, rather than as three independent hazards assessed in parallel.

The scope remains subject to several limitations and boundary conditions, which are stated transparently in line with CLIMAAX guidance: variability in the availability, format, and temporal coverage of local datasets (in particular socio-economic vulnerability indicators and long-term local discharge measurements); the absence of calibrated local hydrometry for the Kireas system, which precludes fully dynamic hydraulic modelling; and the fact that the Fire Weather Index is a measure of fire-*weather danger* and not a probabilistic burn-probability model , full ignition-and-spread simulation remains a future-data need. Where information was insufficient to fully answer specific CLIMAAX guiding questions, this is acknowledged explicitly in the relevant sections.

2.1.2 Context

Historically, the assessment and management of climate hazards in Mantoudi–Limni–Agia Anna has been sectoral and largely reactive, focused on post-event response rather than proactive risk reduction. Flooding along the Kireas system, heatwaves, and wildfires have been recognised through individual studies, emergency plans, and civil protection actions, but were not previously integrated into a comprehensive, multi-risk framework. Phase 1 represented the first structured, harmonised attempt; Phase 2 builds on it by adding spatial detail, local specificity, operational relevance, and , critically , an explicit treatment of compound risk in a landscape reshaped by the 2021 fire.

The central problem addressed by the project is the increasing and increasingly interacting exposure and vulnerability of the municipality to climate extremes, driven by climate change, the legacy of the 2021 mega-fire, aging infrastructure, land-use pressures, and constrained municipal resources. Flood risk is strongly influenced by upstream catchment processes (now aggravated by post-fire slope degradation); heat stress is amplified inland by forest loss; and wildfire danger is rising under warming and drying trends while the protective and regulating functions of the forest remain diminished. These dynamics place Mantoudi–Limni–Agia Anna within a broader northern-Evia regional risk system in which local impacts are shaped by regional drivers and cumulative pressures.

The governance framework is shaped by EU, national, regional, and local instruments. At national level, Greece's National Climate Change Adaptation Strategy and civil protection legislation provide strategic direction and define responsibilities for preparedness, response, and recovery. At regional level, disaster-risk-reduction planning and resilience initiatives within the Region of Central Greece influence priorities, funding, and coordination. Locally, spatial and urban planning legislation, environmental regulation, and the municipal Civil Protection Plan (currently being updated to reflect newly assessed risks) determine how risk information can be operationalised. Phase 2 is explicitly designed to strengthen the link between refined risk analysis and this governance framework.

Sectors particularly relevant to climate risk in the municipality, and likely to be affected by climate change, include:

- Civil protection and emergency management, which must respond to more frequent and compound extreme events.
- Forestry, environmental management, and ecosystems, central to both wildfire risk and the regulating services (flood attenuation, microclimate) degraded by the 2021 fire.
- Urban infrastructure and housing, exposed to flooding, heat stress, and wildland–urban interface fire.
- Public health, especially regarding heatwaves and vulnerable groups.
- Transport and mobility, including Kymasi port and inland road corridors vulnerable to flood-induced isolation.
- Local economic activities , tourism, agriculture, forestry, and small-scale fishing , all highly climate-sensitive.

2.1.3 Participation and risk ownership

Stakeholder involvement in Phase 2 builds on the institutional network established in Phase 1 and broadens it toward the actors most relevant to the three priority hazards and the post-fire recovery. Engagement focused on stakeholders with direct responsibilities in risk management, emergency response, forestry, social support, education, and economic activity in exposed areas. Stakeholders were engaged primarily through targeted meetings and workshops in which Phase 1 results were presented and validated, refined flood, heat, and wildfire insights were discussed, and practical considerations for civil protection planning were collected.

The following stakeholders participated in CLIMAAX-related activities:

- Municipality of Mantoudi–Limni–Agia Anna, including technical and administrative services and the Civil Protection Office.
- Hellenic Fire Service (local), responsible for wildfire suppression, flood-related operations, and emergency response.

- Forestry Service / forest-management authorities, relevant to fuel management, reforestation, and post-fire recovery.
- Local Police, responsible for traffic management, public safety, and evacuation support.
- Port Authority (Kymasi), as a critical transport-infrastructure operator.
- Educational community (teachers from local primary and secondary schools).
- Open Care Centres for the Elderly (KAPI), representing elderly and socially vulnerable populations.
- Municipal social services and primary healthcare representatives, particularly regarding heat and smoke health impacts.
- Local businesses and SMEs from flood-prone and wildland–urban interface areas, and tourism operators.
- Environmental NGOs and civil-protection volunteer groups active in northern Evia.
- Regional-level civil protection representatives (Region of Central Greece), providing coordination and policy alignment.

Stakeholder roles can be conceptualised as an interconnected system centred on the municipality:

- The Municipality acts as the coordinating body for local preparedness, response, and recovery.
- The Fire Service and Forestry Service are the principal owners of wildfire prevention, suppression, and post-fire management, working closely with municipal civil protection.
- Emergency services (Fire, Police) operate in coordination with municipal structures across all three hazards.
- Social services, elderly care centres, schools, and healthcare act as intermediaries for vulnerable groups.
- Local businesses, tourism operators, and NGOs provide contextual knowledge and support awareness-raising and recovery.
- Regional authorities provide strategic coordination, guidance, and access to planning and funding mechanisms.

Risk ownership follows the institutional framework defined by national civil protection legislation and is shared across governance levels. Risk identification and assessment are supported by national authorities and research initiatives, while the municipality applies risk information locally. Wildfire prevention and suppression are owned primarily by the Fire Service and Forestry Service, with municipal support for prevention, evacuation, and recovery; flood risk management involves coordination with regional and national authorities given the scale of the Kireas catchment; and heatwave preparedness is guided by national protocols with local implementation. At municipal level, formal quantitative thresholds defining acceptable or tolerable climate risk are not explicitly established; risk acceptability is therefore implicitly defined through national standards, legal obligations, and operational practice. Phase 2 contributes by providing clearer spatial identification of high-risk areas, supporting prioritisation of intervention zones and vulnerable groups, and enabling more informed judgement on acceptable residual risk.

2.1.4 Application of principles

Phase 2 was conducted in accordance with the core principles of the CLIMAAX Framework, which guided both methodological choices and the interpretation of results.

Social justice, equity, and inclusivity.

The assessment recognises that climate risks do not affect all groups equally and gives particular emphasis to vulnerable and priority groups , elderly residents, children, low-income households, residents and businesses in flood-prone and wildland–urban interface areas, and seasonal users of the coast and port. Representatives of these groups were engaged directly or through institutional intermediaries (KAPI, schools, social services, local businesses). Where municipality-specific preparedness measures were absent , notably dedicated local heatwave and wildfire-evacuation protocols , the assessment identifies the gap and proposes locally adapted guidance complementing national frameworks, supporting more equitable protection of disproportionately exposed groups and areas.

Quality, rigour, and transparency.
Scientific rigour is ensured through systematic application of the CLIMAAX framework and the use of authoritative local data. All data sources, assumptions, and methodological choices are documented transparently. Where data limitations or inconsistencies were encountered , most importantly the inability of coarse river-flood products to resolve the Kireas system, and the distinction between fire-weather danger and burn probability , these are explicitly acknowledged and their implications discussed, preserving traceability and credibility for both technical and non-technical audiences.

Precautionary approach.
A precautionary approach was adopted throughout, recognising that climate change introduces significant uncertainty and that waiting for complete information may delay necessary action. Where quantitative data were limited or local thresholds undefined, the assessment prioritised risk awareness, transparency, and early action, focusing on areas and systems where impacts could be severe or irreversible , flash-flood-prone corridors, the wildland–urban interface, and vulnerable populations during compound heat–fire episodes. The principle is further reflected in the emphasis on strengthening preparedness, early warning, and civil protection capacity rather than relying solely on post-event response.

2.1.5 Stakeholder engagement

Engagement approach and activities. Stakeholders were engaged through targeted meetings and workshops, complemented by bilateral exchanges and follow-up communications, building on the Phase 1 network. Activities were structured around (a) presentation and validation of Phase 1 results, and (b) discussion of refined analyses and proposed measures developed during Phase 2, including the new wildfire assessment. Maps, summaries, and key messages were shared to support understanding and facilitate feedback.

Reception of results and feedback. Results were received positively. Stakeholders particularly valued the improved spatial detail of flood-risk information, the explicit treatment of wildfire as a standalone hazard following the 2021 experience, and the focus on practical implications for preparedness and response. Feedback emphasised the importance of locally adapted preparedness measures for heat and wildfire, clear prioritisation of intervention areas, and continued coordination between municipal services, the Fire and Forestry Services, and the Port Authority. This feedback informed the refinement of Phase 2 outputs and the formulation of proposed guidance.

Difficulties encountered. Engagement challenges included limited stakeholder availability due to operational responsibilities (acute for the Fire Service during fire season), variability in technical background among participants, and scheduling constraints. These were addressed through a flexible approach using targeted meetings rather than large events, and by providing follow-up explanations and materials.

2.2 Risk Exploration

2.2.2 Screen risks (selection of main hazards)

Phase 1 screened a broad set of climate-related hazards for Mantoudi–Limni–Agia Anna using harmonised European-scale datasets and stakeholder input, and identified heatwaves and river/coastal flooding as priority concerns, with wildfire flagged as a major and growing threat anchored on the 2021 mega-fire. In Phase 2 the screening conclusions are retained but refined in three ways:

Wildfire is elevated to a priority hazard assessed in full. The frequency, intensity, and 2021 realisation of fire in northern Evia, together with rising fire-weather danger, justify treating wildfire on equal footing with heat and flooding.

Flood risk is re-characterised as flash/pluvial-dominated, strongly driven by upstream catchment processes and post-fire slope degradation, based on observed evidence rather than coarse model inundation.

Heat risk is reframed as a compound public-health and preparedness issue, explicitly linked to post-fire land-surface heating and to wildfire danger through shared drivers (high temperatures, low humidity, dry fuels).

The hazards assessed in depth in Phase 2, and the rationale for each, are:

- **Heatwaves** , recurrent and intensifying, with direct public-health relevance and a documented post-fire amplification signal; selected for refinement using local LST and downscaled projections.
- **River and coastal flooding** , the most historically destructive hazard (Kireas flash floods; Agia Anna coastal inundation), selected because Phase 2 introduces local evidence that materially improves hazard representation where coarse products fail.
- **Wildfire** , realised catastrophically in 2021 and projected to intensify; selected because the municipality holds the key inputs (FWI run, LUISA land cover, documented burn scar) to assess it properly, and because the post-fire landscape couples it to both heat and flood.

2.2.3 Choose Scenario

Future climate conditions in Phase 2 are assessed principally under the intermediate pathway RCP4.5 (broadly equivalent to SSP2-4.5 in the CMIP6 framework), retained as the central planning reference, with RCP8.5 used as a precautionary upper case , consistent with the dual-scenario approach adopted in Phase 1. RCP4.5 represents a stabilisation pathway under moderate mitigation and is widely applied as a central scenario in European and Mediterranean climate risk assessments; the IPCC Sixth Assessment Report characterises SSP2-4.5 as a “middle-of-the-road” pathway broadly consistent with current global policy trajectories. The Mediterranean is a recognised climate-change hotspot, with warming exceeding the global average and pronounced sensitivity to heat extremes, hydrological variability, and fire weather; even under intermediate emissions, regional projections indicate substantial increases in the frequency and duration of extreme heat, intensification of heavy precipitation despite potential annual-total decreases, and lengthening fire seasons. The use of RCP4.5 as the central scenario, with RCP8.5 retained for the wildfire and heat upper bounds, is therefore scientifically robust and policy-relevant for municipal-scale adaptation planning in northern Evia.

2.3 Regionalized Risk Analysis

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

Table 2-1 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
EuroHEAT health-based heatwave definition;	Demographic structure (elderly 65–90, children 0–5); WorldPop / high-resolution population maps;	Settlements, schools, public buildings;	Heat-risk priority areas (10×10 risk matrix);
EURO-CORDEX / Med-CORDEX downscaled projections (RCP4.5 & RCP8.5)	critical facilities (schools, health, emergency)	Landsat-8 land-surface temperature (LST)	identification of population groups and settlements requiring targeted heatwave preparedness

2.3.1.1 Hazard assessment

The heatwave hazard assessment presented in this Phase 2 deliverable is based on three complementary datasets: WorldClim v2.1 for historical and projected mean JJA daily maximum temperature (Tmax), ISIMIP bias-corrected CORDEX-EUR-11 ensemble outputs for threshold-based indicators (tropical nights and days with Tmax >35°C), and local exposure layers (GlobalBuildingAtlas building footprints and critical infrastructure). EuroHEAT and land-surface-temperature analyses are useful complementary approaches, but the quantitative figures presented here are the WorldClim/CORDEX/exposure outputs shown in Figs. 2.3.1a–d.

The WorldClim historical baseline (1970–2000) shows a mean JJA Tmax of 28.55°C for the municipality, with values ranging from 23.90°C in cooler elevated zones to 30.10°C in warmer inland and lowland areas (Fig. 2.3.1a). Under SSP2-4.5, mean JJA Tmax increases by approximately +1.15°C in 2021–2040 relative to 1970–2000 (Fig. 2.3.1c), yielding a projected near-term mean of about 29.70°C across the municipality when overlaid with buildings and critical infrastructure (Fig. 2.3.1d).

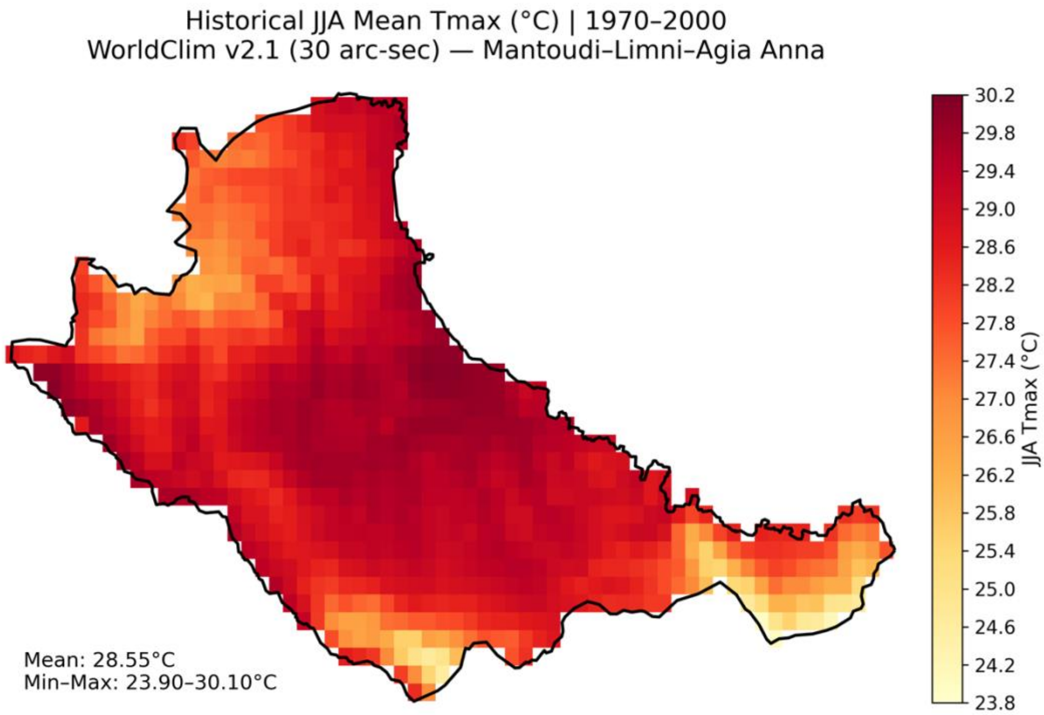
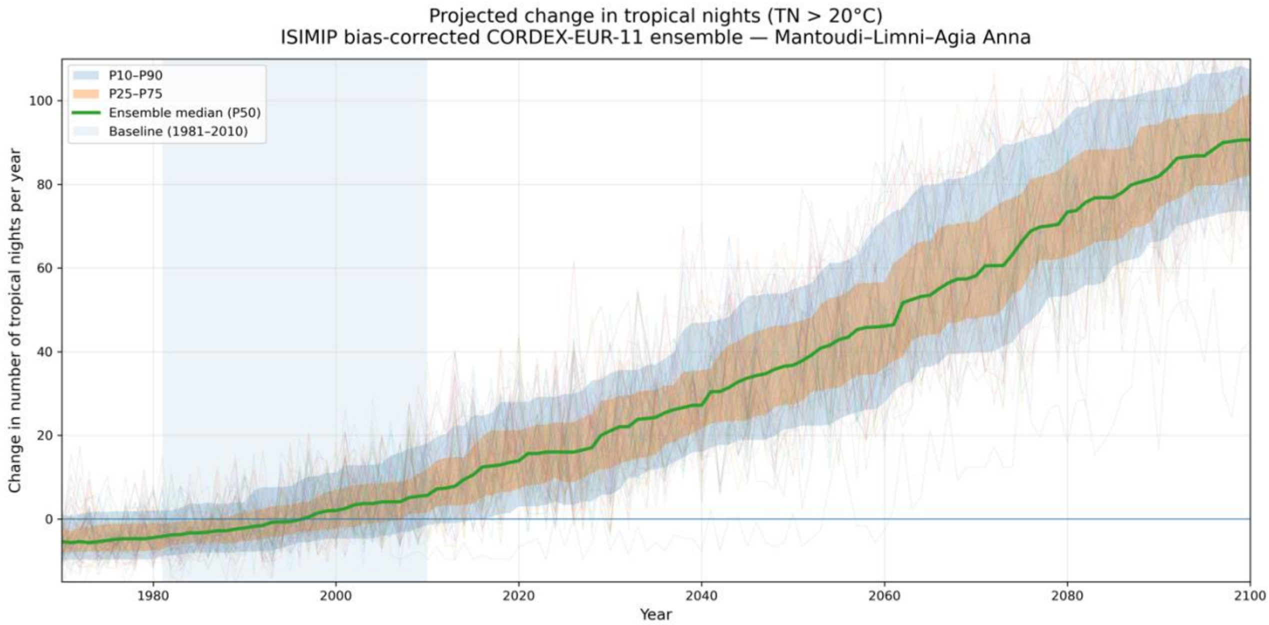


Fig. 2.3.1a Spatial distribution of historical mean June–July–August (JJA) daily maximum temperature (Tmax, °C) for 1970–2000, derived from WorldClim v2.1 at 30 arc-second resolution and clipped to Mantoudi–Limni–Agia Anna. The map represents the climatological average across CMIP6 ensemble means downscaled to approximately 1 km resolution.

The CORDEX-derived threshold indicators complement the mean-temperature maps by showing the temporal evolution of heat extremes. Both tropical nights (TN >20°C) and extreme hot days (Tmax >35°C) increase over the century, with a widening ensemble spread after mid-century (Fig. 2.3.1b). Because no dedicated LST map is included in the present figure set, specific numerical claims about post-2021 LST changes are not used as primary quantitative evidence in this deliverable, but the reader is encouraged to read more regarding LST in the RIVA Deliverable Phase 1.



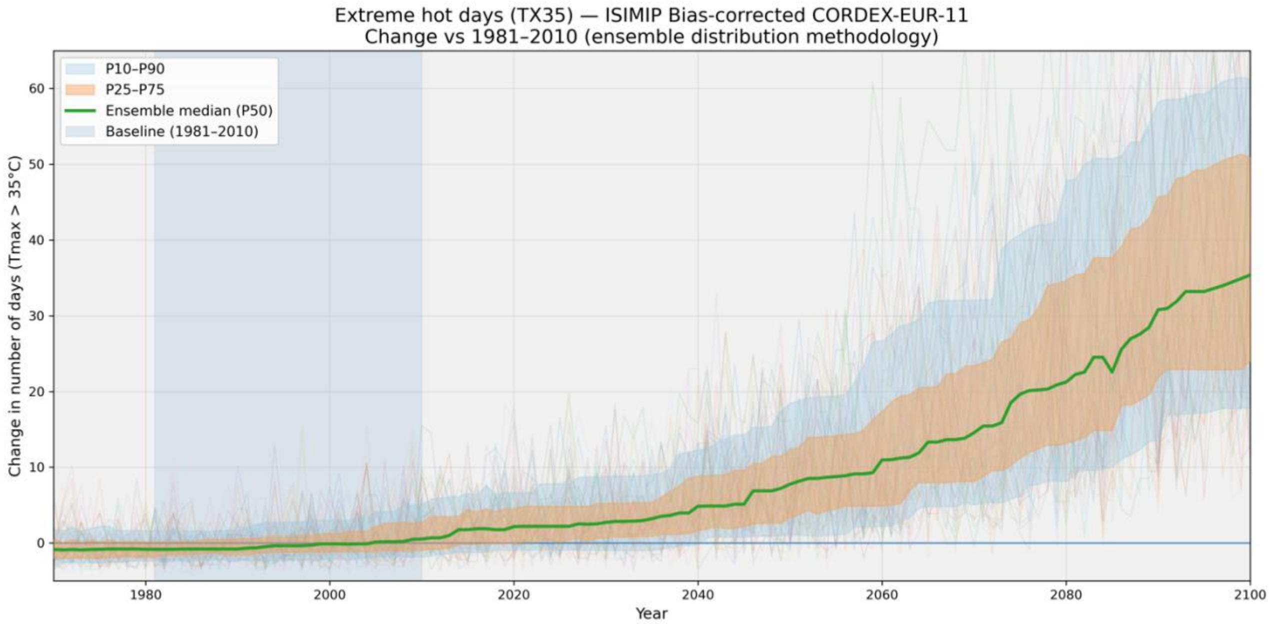


Fig. 2.3.1b Projected change in annual number of tropical nights (TN >20°C; top) and extreme hot days (Tmax >35°C; bottom) relative to the 1981–2010 baseline, derived from the ISIMIP bias-corrected CORDEX-EUR-11 ensemble. The green line denotes the ensemble median (P50), while shaded bands show inter-model uncertainty (P25–P75 and P10–P90).

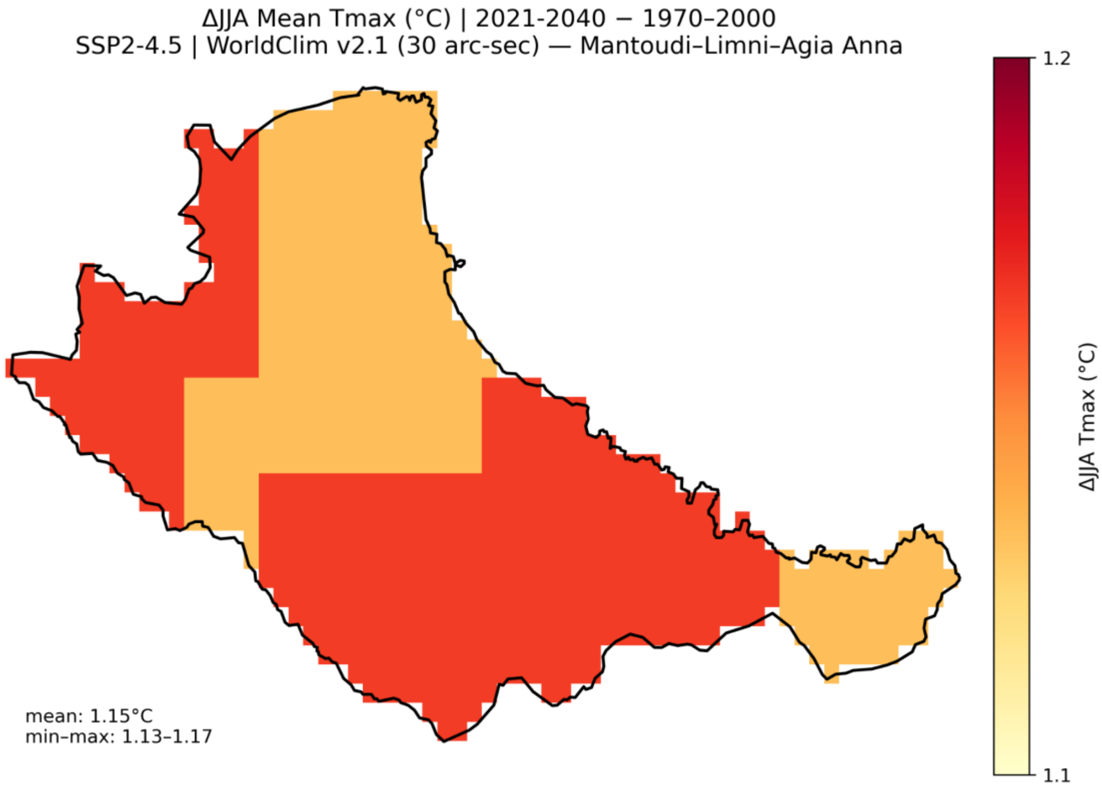


Fig. 2.3.1c Projected change (Δ) in mean JJA Tmax (°C) for 2021−2040 relative to 1970−2000 under SSP2-4.5, derived from WorldClim v2.1 (30 arc-second resolution). The municipal mean change is +1.15°C, with a narrow range of +1.13°C to +1.17°C.

Taken together, the WorldClim and CORDEX results indicate a transition toward higher baseline summer heat and more frequent threshold exceedances. The key quantified Phase 2 finding is the near-term upward shift of mean JJA Tmax (+1.15°C by 2021−2040 under SSP2-4.5), together with increasing tropical nights and extreme hot days. This provides a robust basis for treating heatwave risk as substantial and intensifying, particularly for inland settlements and facilities with limited cooling capacity.

Table 2.3.1 , Summary of observed and projected heat-hazard indicators (Mantoudi–Limni–Agia Anna)

Indicator	Historical baseline	Near-term projection	Interpretation / reference
Mean JJA Tmax (WorldClim v2.1)	28.55°C mean; 23.90–30.10°C range (1970–2000)	+1.15°C by 2021–2040 under SSP2-4.5; projected mean about 29.70°C	Spatial pattern and infrastructure overlay in Figs. 2.3.1a, 2.3.1c and 2.3.1d
Tropical nights (TN >20°C, CORDEX)	1981–2010 baseline used as zero-change reference	Increasing ensemble-median signal through the century	Trend and uncertainty shown in Fig. 2.3.1b
Extreme hot days (Tmax >35°C, CORDEX)	1981–2010 baseline used as zero-change reference	Increasing ensemble-median signal through the century	Trend and uncertainty shown in Fig. 2.3.1b

2.3.1.2 Risk assessment

Heat risk is understood as the interaction between increasing summer heat, exposed people and assets, and the vulnerability of sensitive groups. Exposure is municipality-wide but spatially differentiated: inland settlements and infrastructure experience higher projected daytime heat than some coastal zones, while critical facilities and buildings located in warmer grid cells require targeted preparedness. The exposure overlay in Fig. 2.3.1d should therefore be used as a screening map for prioritising local heat preparedness, rather than as a building-level thermal-comfort model.

Vulnerability is strongly age-dependent and socially differentiated. The most physiologically vulnerable groups are elderly residents, young children, low-income households with limited access to cooling, outdoor workers, and non-acclimatised tourists. In the present figure set, vulnerability is not mapped as a separate heat-risk matrix; therefore, the heat-risk interpretation is based on the spatial overlap between higher projected temperatures, settlements, buildings and critical infrastructure (Fig. 2.3.1d), combined with qualitative knowledge of vulnerable groups and municipal preparedness capacity.

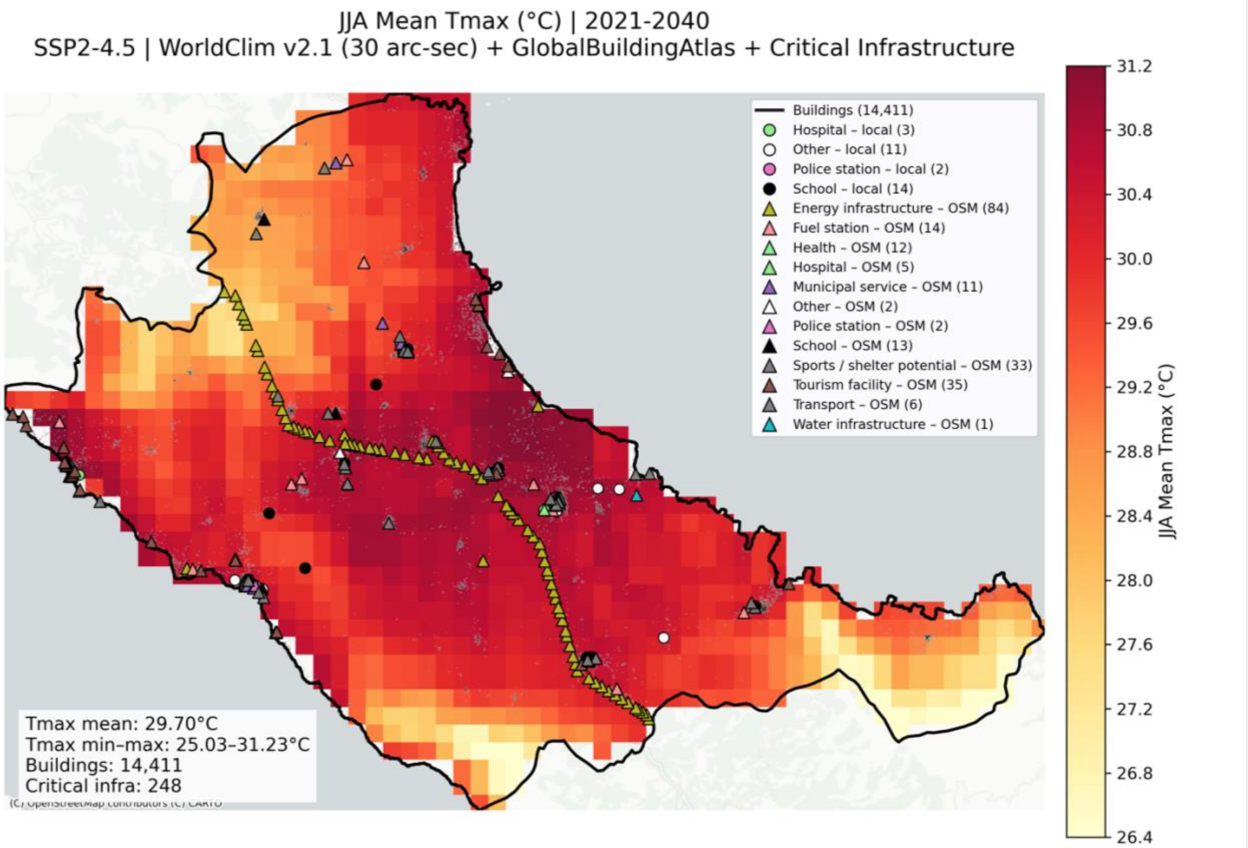


Fig. 2.3.1d Spatial distribution of projected mean JJA Tmax (°C) for 2021–2040 under SSP2-4.5, derived from WorldClim v2.1 and overlaid with GlobalBuildingAtlas building footprints and local critical infrastructure for Mantoudi–Limni–Agia Anna. Black contours indicate building and represent 14,411 structuress; points indicate classified critical infrastructure.

On the basis of the revised hazard evidence and exposure overlay, heatwave risk in Mantoudi–Limni–Agia Anna is assessed as substantial, with potential escalation during prolonged events and compound fire–heat episodes. The main operational needs are locally adapted heatwave preparedness, protection of elderly residents and children, public communication, identification of cooling spaces, and integration of heat warnings into the municipal civil-protection workflow.

2.3.2 Hazard #2 - River Floods finetuning to local context

Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
CLIMAAX Coastal Flooding workflow (GEV on modelled sea-level series);	LUISA land cover;	Settlements, buildings (OSM), critical infrastructure; Global Building Atlas (3x3 m)	Flood exposure hotspots; building damage & EAD;
Global Flood Maps; GTSMv3.0 surge;	demographic structure; critical facilities	GHS-POP / WorldPop population	population exposed/displaced; critical infrastructure within flood extent

2.3.2.1 Hazard assessment , river floods.

The river-flood hazard assessment centres on the Kireas system, the municipality's most critical flood corridor, which drains steep inland terrain toward Mantoudi and Kymasi port. Phase 1 established , and Phase 2 confirms , that the standard CLIMAAX river-flood products (JRC Global Flood Maps and Aqueduct Floods) materially underestimate the observed flash-flood behaviour of the basin. This limitation arises from three structural causes, restated here because they determine the Phase 2 methodological choice: (a) insufficient topographic resolution, since global DEMs (MERIT, HydroSHEDS) smooth out the narrow Kireas channel and steep slopes; (b) flood-typology mismatch, since the models simulate large-scale steady-state riverine overflow whereas local floods are flash-flood-driven (short-duration, high-intensity rainfall producing pluvial and debris-laden flows); and (c) the absence of calibrated local hydrometry, since there are no long-term discharge measurements to calibrate or validate modelled hydrographs.

Because the flash-flood mechanism is rainfall-driven, the hazard characterisation relies on projected sub-daily and daily rainfall extremes derived from the CLIMAAX Heavy Rainfall workflow. The projected intensification of short-duration rainfall is shown for 3-hour events in Fig. 2.3.2a, for the spatial 24-hour, 10-year field and its relative change in Fig. 2.3.2b, and for 24-hour intensity–duration–frequency curves across return periods in Fig. 2.3.2c. Across all durations and return periods, RCP4.5 projections for 2041–2070 indicate a marked increase in extreme rainfall totals relative to the 1976–2005 baseline, consistent with a higher flash-flood potential for the Kireas system.

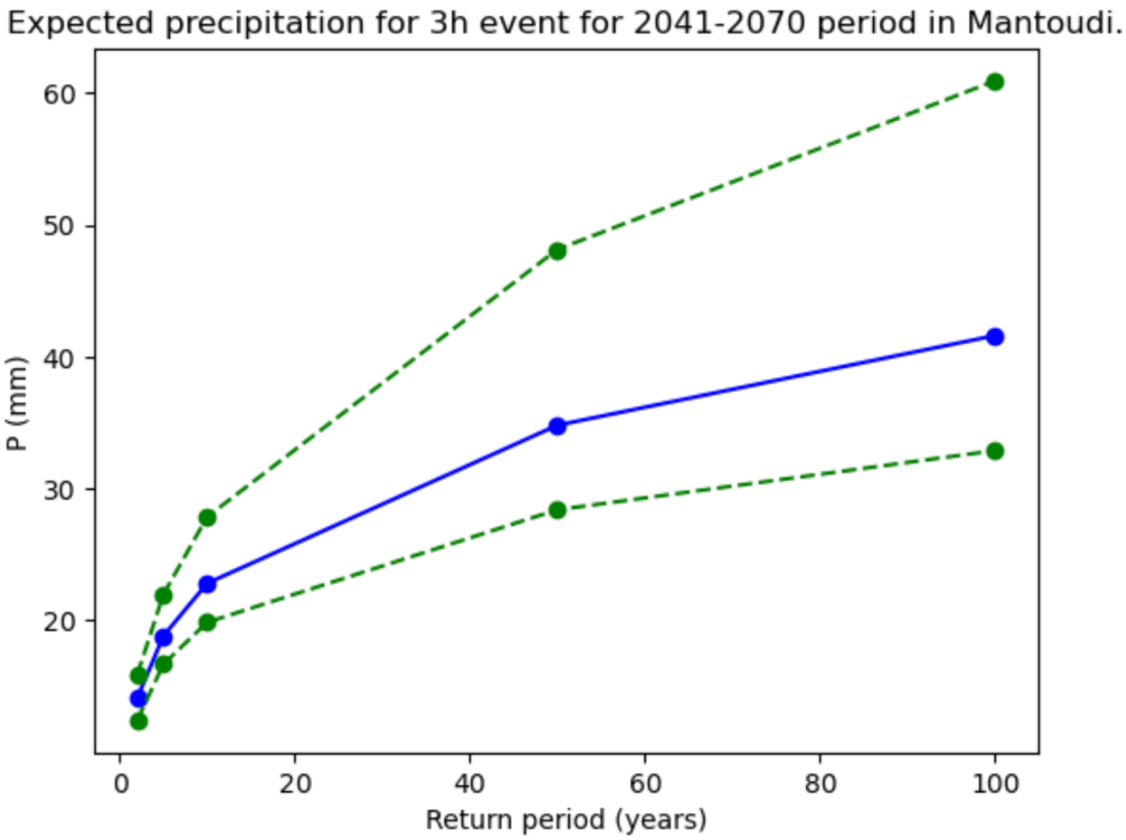


Fig. 2.3.2a Expected precipitation for 3-hour events for the 2041–2070 period under RCP4.5 over Mantoudi–Limni–Agia Anna, derived from the CLIMAAX Heavy Rainfall workflow. Curves show precipitation totals by return period and uncertainty range.

Validation against municipal records confirms systematic underestimation: areas around Mantoudi and Kymasi known to flood appear largely unaffected in the model outputs, and the future projections (RCP4.5 and RCP8.5 to 2080) show only negligible change , a result that contradicts the documented and intensifying flood history. For this reason, Phase 2 does not treat the coarse model inundation depths as quantitatively definitive. Instead, following the precautionary, evidence-based approach adopted for the equivalent problem in comparable Greek catchments, the hazard characterisation relies on observed rainfall extremes, basin morphology and post-fire runoff potential, documented historical events, and expert interpretation of structural bottlenecks.

The post-2021 fire is a material aggravating factor for flood hazard. Loss of forest cover and the spread of *Ceratocystis platani* among riparian plane trees have reduced infiltration and interception, increased runoff coefficients, accelerated flow velocities, and raised sediment and debris loads , all of which shorten the basin's time of concentration and amplify flash-flood peaks for a given rainfall. Future events of equal meteorological magnitude are therefore likely to produce larger and faster inundation than the historical record alone would suggest.

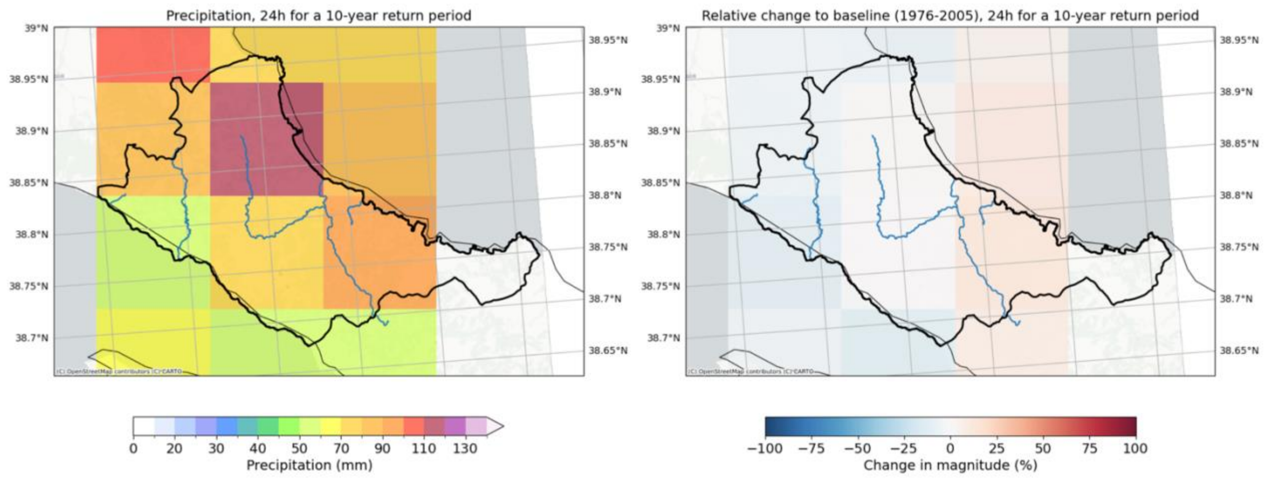


Fig. 2.3.2b Projected precipitation for a 24-hour, 10-year event and relative change under RCP4.5 (2041–2070) compared with the historical baseline. The maps illustrate spatial variability across and around the municipality.

Fig. 2.3.2c Mean precipitation for 24-hour duration events under historical and RCP4.5 scenarios. The IDF comparison indicates increased 24-hour precipitation totals for higher return periods.

2.3.2.2 Risk assessment

Combining hazard outputs with exposure layers (LUISA land cover, OSM buildings, critical infrastructure from local data) and damage models yields the following. For the Kireas urban core, the modelled direct building damages , which the Phase 1 assessment found broadly consistent with known past damages in the Mantoudi urban core , rise steeply with return period, from approximately €11.2 million for a 1-in-10-year event to €18.1 million (1-in-50), €21.1 million (1-in-100), and €28.6 million (1-in-500), with a mean Expected Annual Damage of approximately €1.57 million. Critical-infrastructure exposure is significant: main transport routes traverse low-lying corridors vulnerable to overflow and settlement isolation, and several commercial buildings and fuel stations sit within flood-prone zones. Population-exposure estimates (Expected Annual Population Exposed of approximately 57, Expected Annual Population Displaced of approximately 34) should be treated as lower bounds, since the coarse hazard inputs underestimate known flood-prone settlements and cannot capture the larger displacements characteristic of single flash-flood events.

For the flood exposure analysis, the GLOFAS/CEMS maximum flood-extent raster was clipped to the municipality and intersected with the GlobalBuildingAtlas building layer and local/OSM critical infrastructure. The output is a screening assessment of assets intersecting the observed/modelled flood footprint, not a fully depth-dependent hydraulic damage model. The full-municipality exposure map is shown in Fig. 2.3.2d, while Fig. 2.3.2e provides a local detail around Mantoudi village. A total of 14,411 buildings were identified within the municipality, of which 1,245 intersect the maximum flood extent.

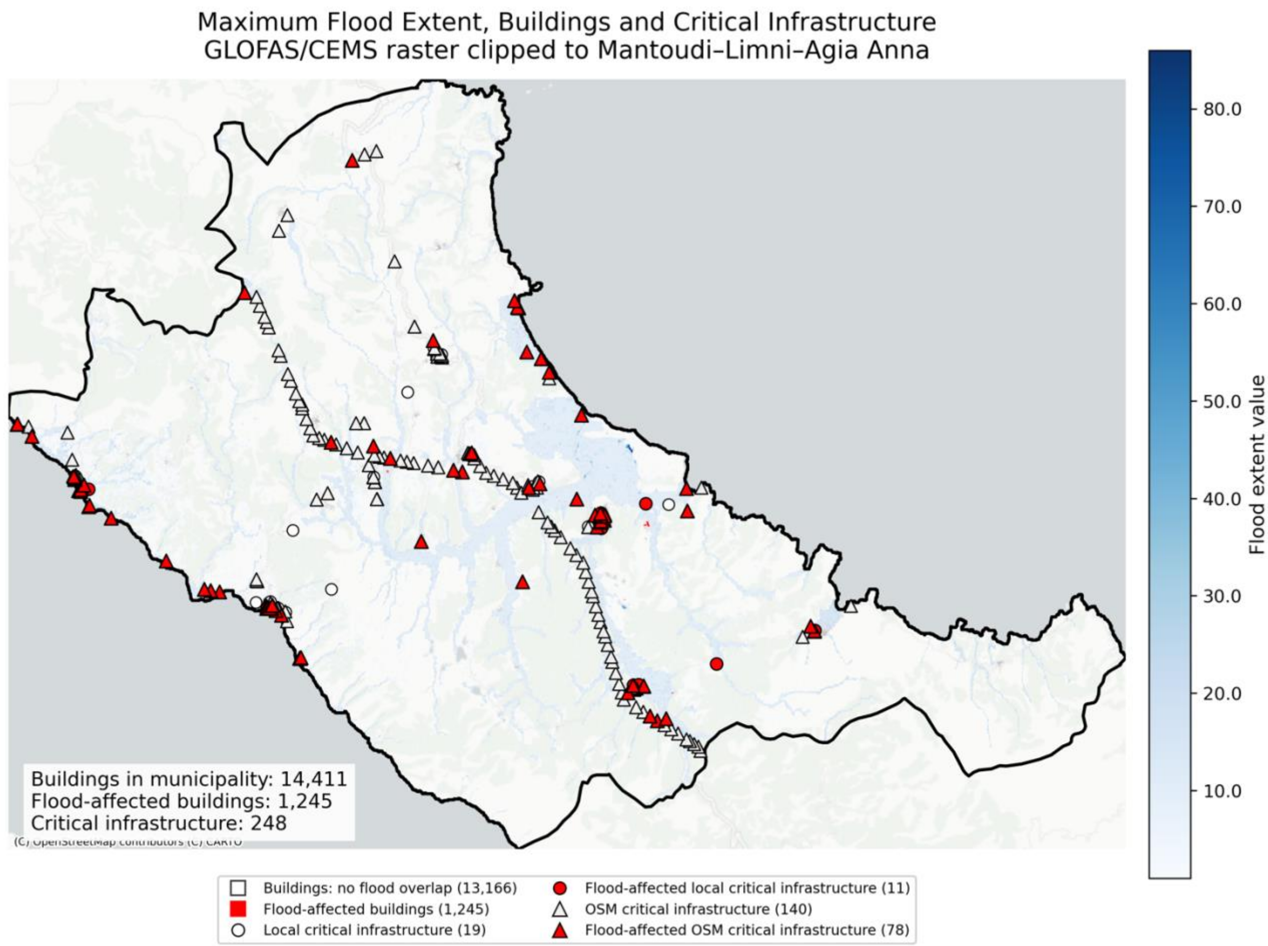


Fig. 2.3.2d Maximum flood extent (GLOFAS/CEMS raster clipped to Mantoudi–Limni–Agia Anna) overlaid with building footprints and critical infrastructure. Of 14,411 buildings in the municipality, 1,245 intersect the modelled flood extent; black squares denote buildings with no flood overlap and red squares flood-affected buildings, with triangles and circles marking critical infrastructure.

The exposed building footprint statistics for the 1245 affected buildings were as follows:

- Mean footprint area**:** 230 m²
- Median footprint area: 137 m²
- 10th percentile: 50 m²
- 90th percentile: 374 m²
- Minimum: 10.2 m²
- Maximum: 20,829 m²
- Total exposed footprint area: 286,593 m²

Unit replacement costs (€/m²) were derived from the official Greek objective property values (Αντικειμενικές Αξίες Ακινήτων) as published by the Independent Authority for Public Revenue (AADE) through the national valuation map platform (https://maps.gsis.gr/valuemaps/). The applicable zone values for Mantoudi-Limni-Agia Anna range between €500 and €1,000 per m² and were used to define the unit value band in the loss estimation.

The return-period damages reported in Phase 1 (approximately €11.2 million at the 10-year level rising to €28.6 million at the 500-year level, with an Expected Annual Damage of about €1.57 million) are derived from the CLIMAAX depth–damage workflow, which combines modelled flood depth with vulnerability curves and therefore varies by event severity. The two footprint-based methods below provide an independent, depth-agnostic cross-check on the order of magnitude of direct structural loss, applying a uniform 10% damage ratio to the exposed building footprint rather than depth-specific damage functions. The two approaches are complementary rather than alternative: they are presented together to bracket the plausible loss range, and their broad convergence on a central estimate of roughly €13–21 million increases confidence in the assessment.

Two complementary loss estimation methods were applied:

1. Method 1 – Aggregate Footprint Approach (Total Area-Based)

Using the total exposed footprint area: Loss=286,593 m²×750 €/m2×0.10

Estimated structural loss: **≈€21.5 million**

This method captures the full distribution of exposed building sizes.

2. Method 2 – Median Building Approach (Representative Building-Based)

Using the median building footprint: Loss=137 m²×1245 buildings×750 €/m2×0.10

Estimated structural loss: **≈€12.8 million**

3. Probabilistic Loss Band

To reflect unit value uncertainty (€500–€1,000/m²), the total-area method yields:

- Lower bound (500 €/m²) ≈ €14.3 million
- Upper bound (1,000 €/m²) ≈ €28.7 million

Therefore, the plausible structural loss range under the assumed 10% damage ratio is: €14–29 million

Central estimate: **€21.5 million**

In summary:

- Even under a conservative 10% damage ratio, direct structural losses are substantial.
- The results are sensitive to:
  - Unit value assumptions
  - Damage ratio
  - Flood depth (currently not applied)
- Loss estimates exclude:
  - Contents damage
  - Business interruption

- Infrastructure damage
- Indirect economic impacts

The estimates should therefore be interpreted as conservative first-order direct structural losses.

On this basis, flood risk in Mantoudi–Limni–Agia Anna is assessed as substantial to critical in severity, requiring immediate action. River (flash) flooding along the Kireas system is the dominant flood mechanism, economically significant and aggravated by post-fire catchment degradation; coastal flooding at Agia Anna is a localised but credible risk intensifying under sea-level rise. The estimates exclude contents damage, business interruption, infrastructure losses, and indirect economic and cascading impacts, and should therefore be read as conservative first-order direct losses. The assessment reinforces the Phase 1 conclusion that locally calibrated, higher-resolution flash-flood modelling, integrating pluvial processes and post-fire runoff, is the single most important methodological need for future phases.

Figure 2.3.2e shows the maximum mapped flood extent within a 2 km area of interest around Mantoudi village, overlaid with GlobalBuildingAtlas building footprints and local/OSM critical infrastructure. The figure indicates that flood exposure is not evenly distributed across the settlement. The denser residential core appears partly outside the mapped flood extent, but several peripheral built-up areas, access corridors and infrastructure points intersect the flood-classified raster cells.

Within the 12.55 km² AOI, 1,487 buildings were identified. Of these, 187 buildings intersect the mapped flood extent, corresponding to approximately 12.6% of the building stock within the local AOI. This is a much higher local exposure ratio than would be obtained from a municipality-wide average, confirming that Mantoudi village and its immediate surroundings represent a concentrated flood-risk hotspot.

The figure also highlights the exposure of critical infrastructure. A total of 23 critical infrastructure points are mapped within the AOI, combining local infrastructure data and OSM-derived features. Of these, 17 points fall within the flood extent: 5 local critical infrastructure points and 12 OSM critical infrastructure points. This suggests that flood impacts could affect not only individual buildings but also local service continuity, emergency access, and response capacity.

The concentration of flood-affected buildings and infrastructure around the western and southern parts of the settlement is consistent with the known vulnerability of the Mantoudi area to Kireas-related flooding and low-lying floodplain processes. The figure is therefore important because it shows that flood risk is spatially localised but operationally significant: even if the affected area is limited, it includes buildings and infrastructure that may be critical during an emergency.

The local exposure pattern shown in Fig. 2.3.2e should be interpreted together with the historical event inventory in Table 2.3.3. The figure identifies the buildings and critical infrastructure intersecting the mapped GLOFAS/CEMS flood extent around Mantoudi village, while the table confirms that destructive flood impacts have repeatedly occurred in the same broader Kireas–Mantoudi system. This combination of spatial exposure analysis and documented impact history provides a stronger evidence base than either source alone.

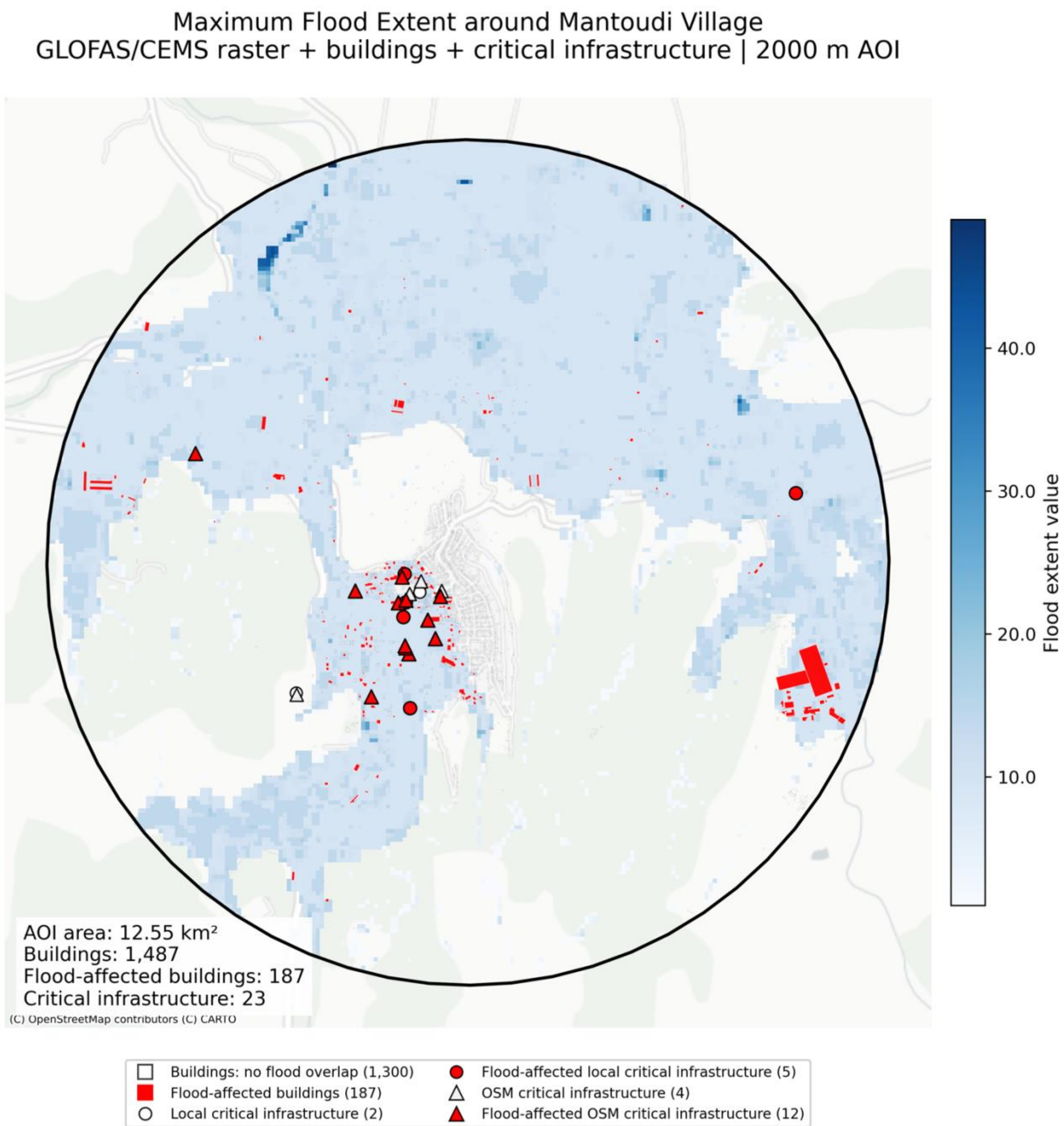


Fig. 2.3.2e Maximum mapped flood extent around Mantoudi village derived from the GLOFAS/CEMS raster product, overlaid with GlobalBuildingAtlas building footprints and critical infrastructure within a 2 km area of interest. Red building footprints indicate buildings intersecting the mapped flood extent, while red-filled symbols indicate critical infrastructure points located within flood-mapped pixels. The AOI contains 1,487 buildings, of which 187 are flood-affected, and 23 critical infrastructure points, of which 17 intersect the flood extent.

Table 2.3.3: Known Flood Events in Mantoudi-Limni-Agia Anna Municipality

DATE	ACCUMULATION (MM/HRS)	GENERAL DESCRIPTION	RISK TO PEOPLE	BUILDINGS DAMAGE	TRANSPORT DISRUPTION
29–30 Sep 2018	Around **140 mm / 24 h** reported in affected areas during Zorbas.	Medicane / cyclone **Zorbas** caused destructive flooding in Mantoudi, Prokopi and the Kireas river basin. Flooding was linked to overflow of Kireas, Xirias and tributaries.	**Very high.** Three people were reported missing in Mantoudi during the event.	**High.** Dozens of houses flooded; the river reportedly passed through streets and houses.	**High.** The Mantoudi–Prokopi road and wider road network were cut; Chalkida–Prokopi road remained closed during recovery.
5 Apr 2020	No local gauge found.	Severe rainstorm affected Evia; floods, landslides and emergency conditions were reported.	**Moderate.** Ten houses in Pyli were evacuated.	**Moderate.** Evacuations suggest direct exposure of homes; precise building-damage count not found.	**High.** Landslides interrupted access toward Galataki Monastery; an OTE pole also fell.
14–20 Dec 2020	No local gauge found.	Prolonged rainfall caused the **Kireas River** to overflow near the Mantoudi–Prokopi road.	**Low to moderate.** Preventive measures reportedly protected Prokopi and avoided risk to people and infrastructure.	**Low / limited.** Reports state that preventive river works largely protected the settlement.	**Moderate.** Traffic on the Mantoudi–Prokopi road was interrupted for several hours.
9–10 Oct 2021	No local gauge found; regional reports cite up to **700 mm / 72 h** at Zagora, Pelion during Storm Athina.	Storm **Athina** caused major post-wildfire flooding in North Evia, especially around Agia Anna, Achladi, Kotsikia and Psaropouli.	**Very high.** More than 100 people were reportedly rescued from Agia Anna to Kotsikia; water reached about 1 m in places.	**High.** Flooded houses, more than 100 basements, public spaces and playgrounds were reported.	**High.** Roads in the provincial network from Ellinika toward Agia Anna were affected; traffic disruption was reported due to flooded streams.
14–15 Oct 2021	No local gauge found.	Storm **Ballos** brought renewed flood only days after Athina.	**Moderate.** Main issue was preparedness due to saturated/burned catchments.	Limited damage.	**Moderate.** Several roads and bridges were impassable.
18 May 2022	No local gauge found.	Persistent rainfall with high rain rates.	**Moderate.** Official documents focus on damage recovery rather than casualties.	**High.** A ministerial decision delimited affected areas and granted housing assistance for building damage.	Several disruptions. Landslides reported.
5–7 Sep 2023	Literature reports **314 mm total rainfall** for Storm Daniel in the North Evia / Nileas-basin.	Storm **Daniel** caused flooding impacts in North Evia and triggered emergency declarations in municipal units of Mantoudi–Limni–Agia Anna.	**Moderate to high.** Emergency declarations refer to intense rainfall and floods beginning on **05-09-2023**.	**Moderate / not fully quantified.** Daniel created new flood problems in the already fire-affected landscape.	**High locally.** Daniel caused severe flooding and infrastructure disruption in central Greece; in the municipality it contributed to emergency-response needs.
27–28 Sep 2023	**150 mm / 3 h** reported in Mantoudi by the mayor; **260 mm** recorded at Vateri, Evia according to meteo.gr.	Storm **Elias** caused severe flooding in Mantoudi, Rovies, Limni, Metochi, Pefki and nearby areas.	**Very high.** 112 warning sent to Mantoudi; water reportedly reached about 1 m in Mantoudi streets.	**High.** Flooded homes were reported in North Evia; major problems were reported in Rovies, Limni and Mantoudi.	**High.** The Derveni area road connection between central and northern Evia was closed; also between Prokopi and Mantoudi.
25–27 Dec 2024	No local gauge found.	Christmas storm / severe rainfall caused renewed flooding concerns and river/stream swelling in Evia, including Mantoudi.	**Moderate.** No casualties found.	**Low to moderate.** Broader Evia reports mention flooded roads and problems with water infrastructure; municipality-specific building damage needs verification.	**Moderate.** Roads were closed preventively in Mantoudi as torrents swelled dangerously.

2.3.3. Hazard #3 , Wildfires

Table 2-3 Data overview workflow #3

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
CLIMAAX Fire workflow , Fire Weather Index (FWI) from daily T, RH, wind, precipitation;	LUISA land cover; Forest condition & post-fire recovery state; riparian vegetation loss (Ceratocystis platani);	Settlements, buildings (OSM), critical infrastructure; Global Building Atlas (3x3 m)	High-fire-danger-day frequency & change; WUI exposure classification by settlement;
NWP data by National Observatory of Athens for daily FWI in 2021; 2021 burn perimeter (Copernicus EMS/EFFIS)	demographic structure; presence of vulnerable groups	LUISA land cover; settlements at the wildland–urban interface; critical facilities and access/evacuation routes	priority areas for fuel management, firebreaks, and evacuation planning

2.3.3.1 Hazard assessment, fire-weather danger

The wildfire hazard assessment in Phase 2 responds directly to the Phase 1 finding that wildfire required further analysis. In Phase 1, the FIRE workflow was included only as complementary material, with the explicit intention that it would be refined in the subsequent phase, particularly for high-risk forested areas, post-fire recovery capacity, and prevention measures. Phase 2 therefore expands wildfire from an annex-level screening result into a full hazard and exposure assessment.

The assessment uses three complementary sources of evidence: (i) the CLIMAAX FIRE ML workflow and associated Fire Weather Index (FWI) information; (ii) a local reconstruction of the 2021 fire-weather season using the National Observatory of Athens operational MOLOCH model; and (iii) the independent FireScope 2026 wildfire-risk screening layer. These products describe different aspects of wildfire hazard and must not be conflated. FWI-based outputs describe fire-weather danger, meaning the degree to which meteorological conditions favour ignition and fire spread. The CLIMAAX ML hazard classes describe relative wildfire susceptibility/hazard within the workflow. FireScope provides an external AI-derived relative risk score. None of these outputs should be interpreted as deterministic fire spread, direct burn probability, or an operational forecast.

The historical CLIMAAX FIRE ML output identifies high and very-high wildfire hazard over substantial parts of Mantoudi–Limni–Agia Anna, especially in inland areas where fire-prone land cover, terrain and forested/post-fire vegetation conditions coincide (Fig. 2.3.3a). This result is consistent with the Phase 1 FIRE workflow, which showed that the municipality already experienced a substantial historical fire-danger load, typically 50–75 days per year with FWI > 30, with some central inland areas approaching 100 days. Under the Phase 1 future RCP8.5 configuration, most of the municipality was projected to face 75–100 high-fire-danger days per year, indicating a lengthening of the fire-conducive season.

The future CLIMAAX FIRE ML output for the selected RCP/model/period configuration is shown in Fig. 2.3.3b. However, the apparent reduction of wildfire hazard in this output is not interpreted as evidence that future wildfire threat decreases. This is an important methodological caveat. The CORDEX-derived climate information used in the workflow is relatively coarse compared with the municipality's complex terrain, coast–mountain gradients, and local fuel discontinuities. In addition, the ML hazard classification is sensitive to the limited training fire-perimeter record and to the way future meteorological predictors are transformed into categorical hazard classes. At municipal scale, such outputs can fail to represent local wind exposure, slope effects, fuel recovery after fire, and WUI conditions. Therefore, Fig. 2.3.3b is retained as a required workflow product, but it is interpreted cautiously and does not override the observed 2021 fire event, the historical FWI signal, the FireScope screening layer, or local exposure evidence.

This limitation is further illustrated in Fig. A.1, where the seasonal FWI field for the 2045–2054 RCP4.5 configuration is shown at the regional scale. Only a very small number of coarse grid points fall within the Mantoudi–Limni–Agia Anna boundary, meaning that the output cannot fully resolve local terrain, coast–mountain gradients, wind exposure, fuel discontinuities or settlement-scale WUI conditions. Fig. A.1 is therefore used as supporting evidence for the methodological limitation of the coarse FWI/CORDEX-based products, not as a precise municipality-scale fire-risk map.

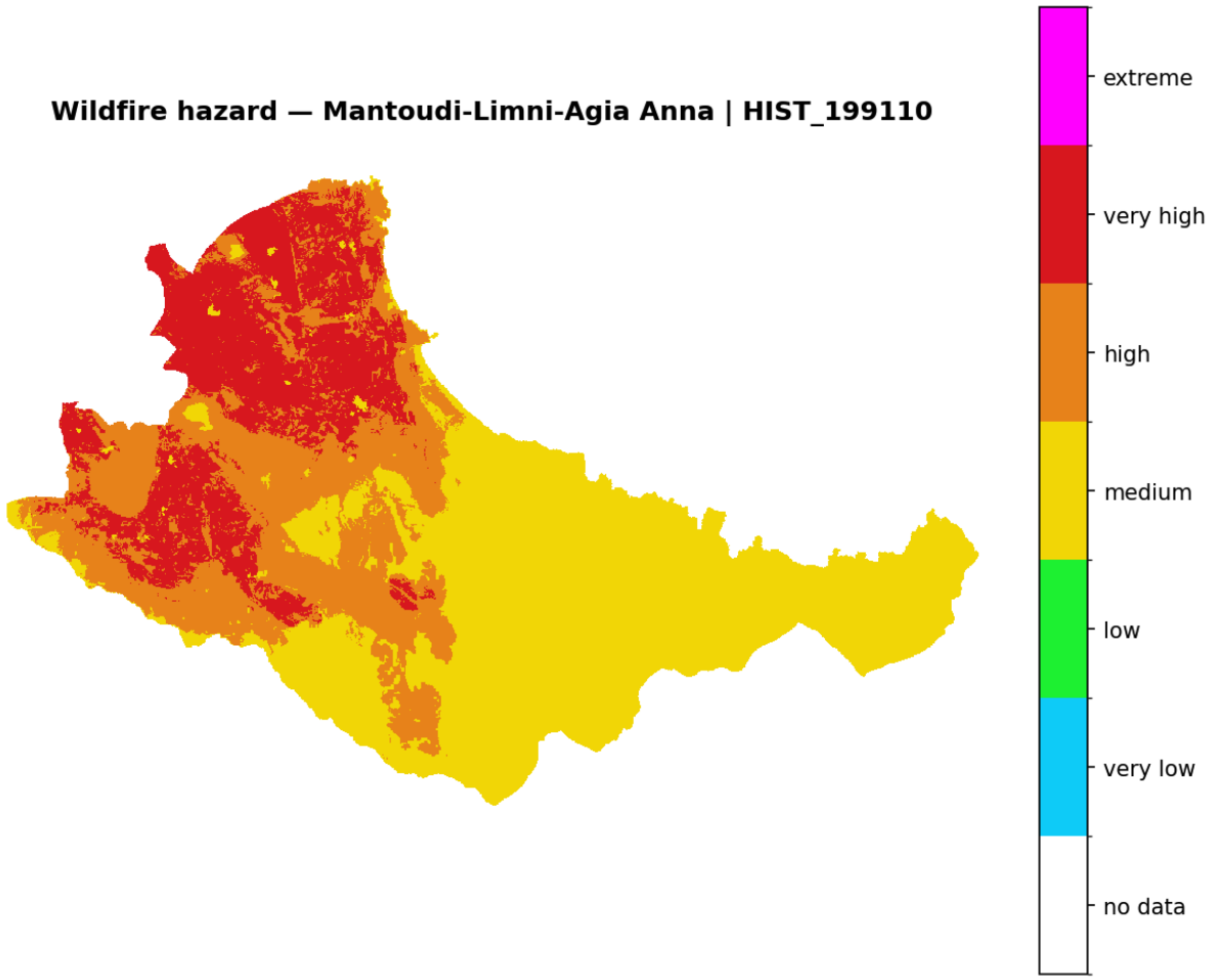


Fig. 2.3.3a Historical wildfire hazard from the CLIMAAX FIRE ML workflow for Mantoudi–Limni–Agia Anna. Classes represent relative hazard categories produced by the workflow and should not be interpreted as burn probability.

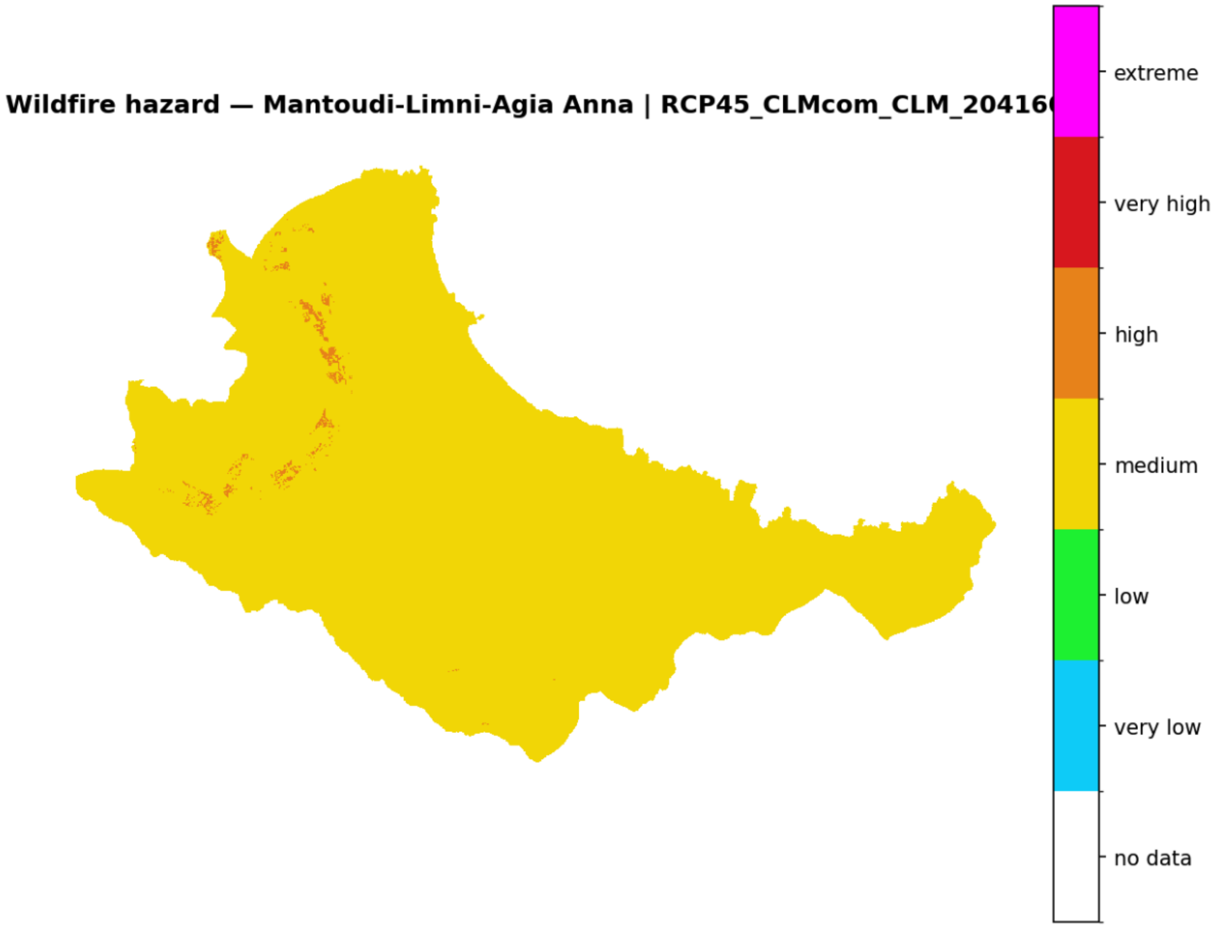


Fig. 2.3.3b Future wildfire hazard from the CLIMAAX FIRE ML workflow for the selected RCP/model/period configuration. The result is retained as a workflow output, but its lower future classes are interpreted cautiously because the local ML model is sensitive to the limited training fire record.

In addition to the CLIMAAX-based evidence, the FireScope 2026 Europe-wide wildfire-risk raster was used as an independent screening dataset (Fig. 2.3.3c). FireScope is an AI-derived research product that combines satellite and climate information to estimate relative wildfire risk. The raster was clipped to the Mantoudi–Limni–Agia Anna municipal boundary at 30 m resolution and used only as supplementary evidence, not as a substitute for the CLIMAAX methodology.

For Mantoudi–Limni–Agia Anna, FireScope indicates widespread elevated relative wildfire risk: 38.7% of the municipality falls in the High class and 54.4% in the Very high class using the equal-width 0–254 classification adopted in this report. This result is consistent with the municipality's extensive fire-prone vegetation, mountainous terrain, wildland–settlement interfaces, and the documented 2021 fire history. However, FireScope remains a screening layer and should not be interpreted as an official warning scale or operational fire-risk forecast.

Taken together, the wildfire hazard evidence supports a precautionary interpretation: the municipality already has a high baseline wildfire hazard, demonstrated by the 2021 disaster and the MOLOCH FWI reconstruction; Phase 1 and Phase 2 FWI analyses indicate a substantial number of high-fire-danger days; and independent FireScope screening identifies widespread elevated relative risk. The apparently lower future hazard classes in one CLIMAAX FIRE ML configuration are therefore treated as a workflow limitation rather than as evidence of reduced future wildfire risk.

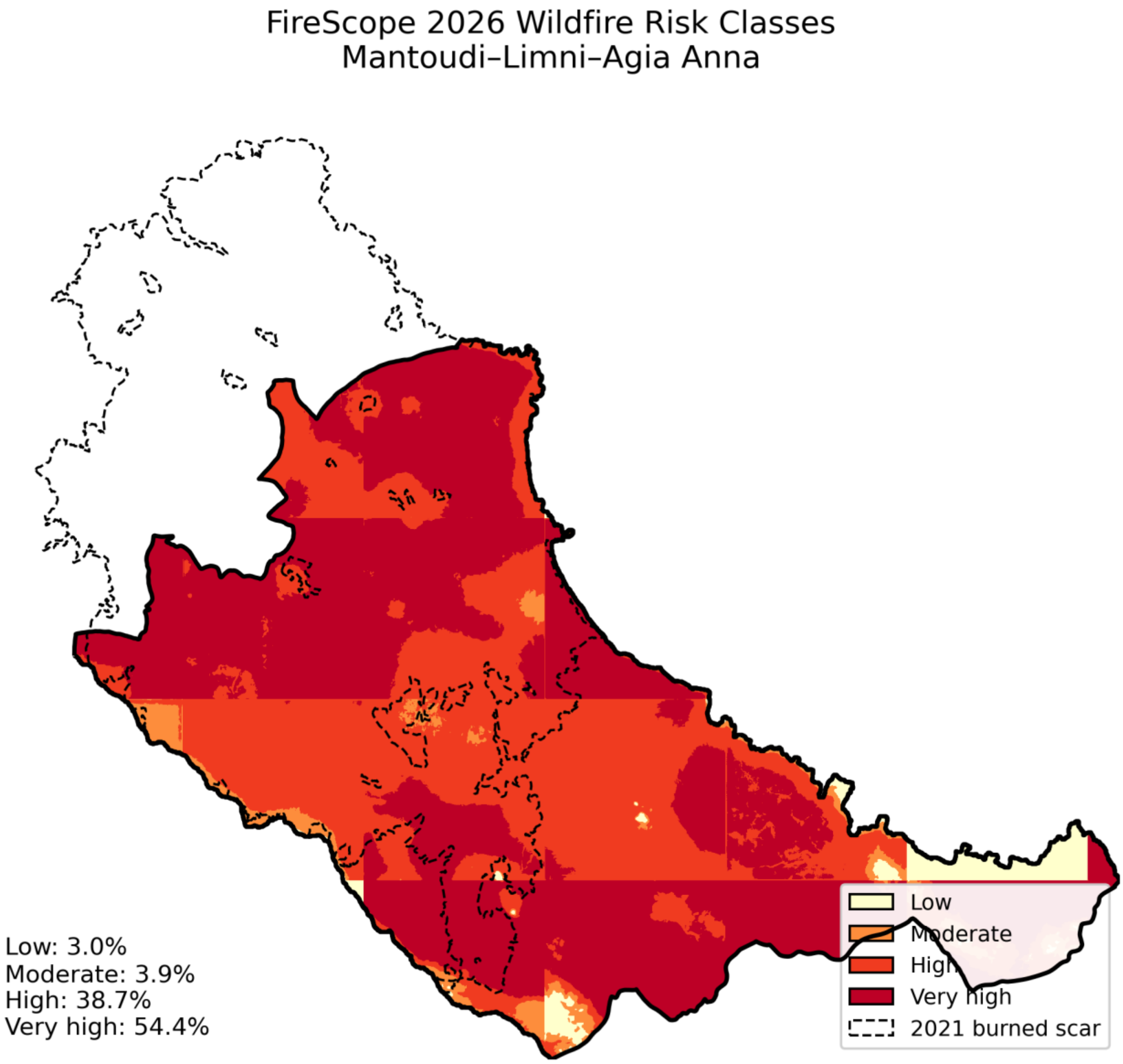


Fig. 2.3.3c FireScope 2026 wildfire-risk classes clipped to Mantoudi–Limni–Agia Anna. The FireScope score is an external AI-derived relative risk index and was grouped here into four equal-width classes for reporting.

The 2021 burn scar as hazard and vulnerability legacy

To provide local fire-weather context, Phase 2 also analyses the 2021 wildfire season using the National Observatory of Athens operational MOLOCH model at 2 km resolution (Fig. 2.3.3d). This figure shows that the 2021 fire season was characterised by repeated and prolonged periods of high to extreme fire-weather danger. Daily maximum FWI inside the municipality exceeded the high-danger threshold of 30 for much of the May–October period, frequently exceeded 50 during July–September, and reached extreme peaks above 90 in early August, coinciding with the period of the catastrophic northern Evia wildfire. This local, high-resolution operational reconstruction is therefore used to document the meteorological severity of the season in which the observed disaster occurred.

The 2021 MOLOCH-based FWI analysis is not a future projection and does not replace the CLIMAAX workflow. Its value is that it anchors the wildfire assessment in a real, locally relevant extreme season. It demonstrates that the municipality can already experience fire-weather conditions capable of supporting catastrophic wildfire behaviour under present climate variability. This is essential for interpreting future projections: even where coarse future ML/CORDEX outputs appear muted or contradictory, the observed 2021 event and the daily FWI reconstruction show that the present-day hazard envelope is already severe (see also Fig. A.2).

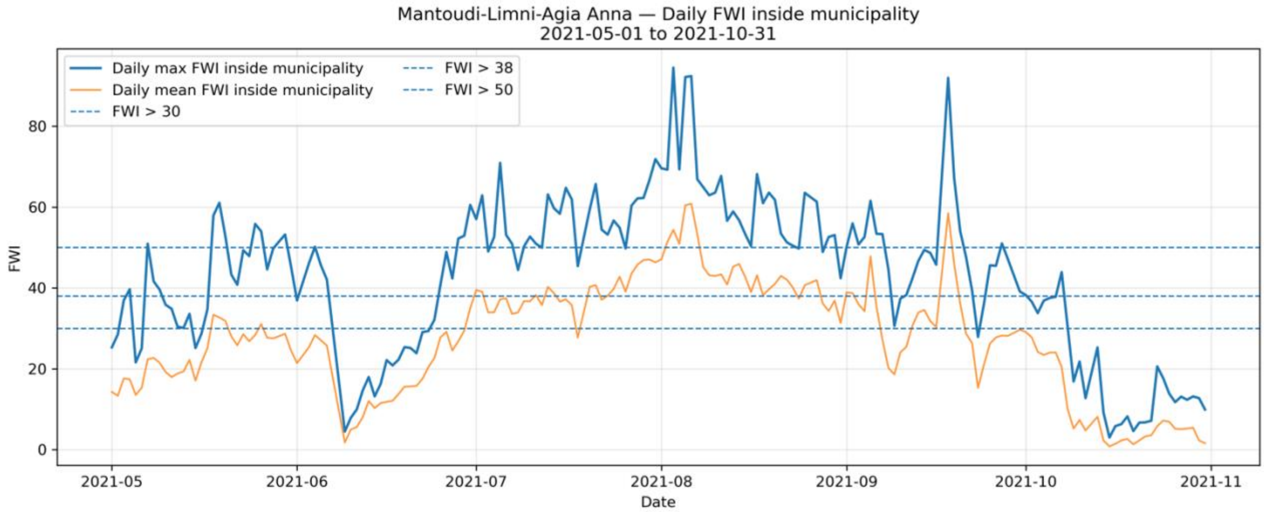


Fig. 2.3.3d Daily fire-risk / FWI time series for 2021 from the National Observatory of Athens operational modelling chain (MOLOCH model 2x2 km). The time series provides event-season context for the wildfire analysis.

The August 2021 northern Evia mega-fire is the defining wildfire event for the municipality and is treated in Phase 2 as a documented realisation of catastrophic fire risk rather than a hypothetical scenario. The burn perimeter, mapped authoritatively by the Copernicus Emergency Management Service and the European Forest Fire Information System (EFFIS), removed extensive pine and mixed-forest cover across the inland municipality. Its legacy is two-fold and feeds directly into the other two hazards. First, as a vulnerability legacy, the loss of mature forest has degraded the regulating services that previously buffered both heat (shading, evapotranspiration) and flooding (interception, infiltration, slope stabilisation), so that the same fire that burned the forest has measurably raised inland land-surface temperatures and increased flash-flood runoff potential. Second, as a fuel condition, post-fire herbaceous and shrub regrowth is fast-accumulating and highly flammable, meaning the burned area does not represent reduced future fire risk but, after a few seasons of regrowth, a renewed and in some respects more volatile fuel load at lower height and higher continuity.

Risk assessment

Because of the limitations identified in the hazard assessment, the wildfire component of this Phase 2 deliverable is not interpreted as a fully realistic quantitative wildfire-risk study. The available CLIMAAX FIRE ML outputs are useful for structured screening, but they do not simulate ignition, fire spread, suppression capacity, evacuation behaviour, smoke exposure, or building-level damage. In addition, the coarse resolution of the climate predictors and the limited training record of fire perimeters restrict the reliability of the future mapped hazard classes at municipal scale. For this reason, the future CLIMAAX/CORDEX-based decrease in mapped hazard is not interpreted as a real reduction of future wildfire threat.

Instead, the wildfire risk assessment is framed as a screening-level assessment combining several complementary lines of evidence: the historical CLIMAAX FIRE ML hazard output, the 2021 MOLOCH-based FWI reconstruction, the 2021 burned-area legacy, land-cover/fuel conditions, the FireScope 2026 independent screening layer, and the vulnerability of settlements and road corridors. This approach is consistent with Phase 1, where the FIRE workflow was already identified as requiring further refinement in the subsequent phase, especially for high-risk forested areas, post-fire recovery and prevention measures.

The main conclusion is therefore not that a specific model run provides a definitive future risk estimate, but that multiple independent sources identify wildfire as a priority risk for Mantoudi–Limni–Agia Anna. The 2021 event demonstrates the municipality's capacity for catastrophic single-event loss; the MOLOCH FWI time series shows that extremely severe fire-weather conditions occurred during the 2021 fire season; FireScope identifies widespread high to very high relative wildfire risk; and the road-vulnerability screening highlights that several important access and evacuation corridors cross fire-prone landscapes.

Within this context, wildfire risk is assessed as substantial, with credible potential for critical single-event impacts under severe fire-weather conditions. The most relevant operational priorities are not derived from the future ML hazard map alone, but from the combined evidence base: fuel management around settlements, maintenance of firebreaks, clearance and redundancy of evacuation/access roads, integration of FWI-based early warning into municipal civil protection planning, and targeted preparedness for smoke and heat impacts on vulnerable populations.

Additional outputs from the annexed FWI/risk-assessment workflow are provided in Fig. A.3. These outputs are used as methodological diagnostics and supplementary screening material only.

- **Exposure — wildland–urban interface and road network**

Wildfire exposure is concentrated at the wildland–urban interface (WUI), where settlements, dispersed housing, tourism facilities, agricultural assets and critical infrastructure are located close to forest, shrubland, post-fire regrowth and other fire-prone land-cover classes. The key exposed areas include inland and peri-forest settlements, as well as coastal communities with limited evacuation alternatives during peak tourism periods.

The road network is a critical exposure element because it serves a double function during wildfire emergencies: it provides evacuation routes for residents and visitors, and access routes for fire-service response. Figure 2.3.3e presents the relative vulnerability level of roads in the municipality. This should not be interpreted as a map of fire intensity or probability. Rather, it is a screening layer indicating where road segments may be more functionally important or vulnerable in the event of wildfire disruption.

The road-risk maps in Fig. 2.3.3f combine road vulnerability with the wildfire hazard classes for the historical and selected future configuration. These outputs are useful for identifying corridors where road importance and wildfire hazard overlap. However, they remain screening products. They do not include road width, surface condition, vegetation encroachment, traffic load, evacuation timing, smoke visibility, fire-spread direction, suppression access, or real-time emergency-management constraints. Therefore, they should be used to guide field validation and operational planning, not as final evacuation-risk maps.

The historical road-risk map indicates that several road corridors in the northern, western and central parts of the municipality fall into High or Very High screening classes. These areas deserve particular attention because road disruption during a wildfire could isolate settlements, delay emergency response or constrain evacuation. The selected future road-risk output appears less severe in some areas, but this pattern should be interpreted cautiously for the same methodological reasons discussed in the hazard section. It should not be used to conclude that future road-related wildfire risk will decrease.

This screening is also consistent with local concerns recorded in Phase 1, where stakeholders had already identified the need for perimeter firebreaks and accessible fire-service routes in settlements such as Rovies, Ahladi, Limni and Kerameia. Phase 2 therefore uses the road-vulnerability maps to strengthen, rather than replace, local operational knowledge.

- **Vulnerability**

Vulnerability to wildfire is shaped by demographic, social, infrastructural and ecological factors. Elderly residents, children, low-income households, people with reduced mobility and people with chronic health conditions are more vulnerable because they may have reduced capacity to evacuate quickly or cope with smoke, heat and disruption. Seasonal visitors and tourists add another vulnerability dimension because they may be unfamiliar with local evacuation routes and warning procedures.

Settlement vulnerability is increased where housing is dispersed within or adjacent to fire-prone vegetation, where settlements depend on one or few access roads, and where fire-service approach routes overlap with evacuation routes. This is especially important in a municipality with mountainous terrain, coastal-inland connectivity constraints and a recent history of large-scale wildfire evacuation.

The post-2021 landscape also creates ecological vulnerability. The burned area does not automatically imply lower future fire risk. Although mature forest fuels were removed, post-fire herbaceous and shrub regrowth can create continuous, low-height and highly flammable fuel beds after a few seasons. At the same time, the loss of mature forest cover has reduced slope stability, interception, shading and evapotranspiration, increasing compound risks related to flash flooding, erosion and heat exposure.

Agriculture, forestry and tourism are also highly fire-sensitive. Wildfire can damage productive land, disrupt access to coastal tourism areas, affect local livelihoods, and degrade ecosystem services that are essential for flood regulation, cooling and landscape recovery. For this reason, wildfire vulnerability in Mantoudi–Limni–Agia Anna is not only a matter of buildings exposed to fire, but also of mobility, emergency access, economic continuity and post-fire environmental resilience.

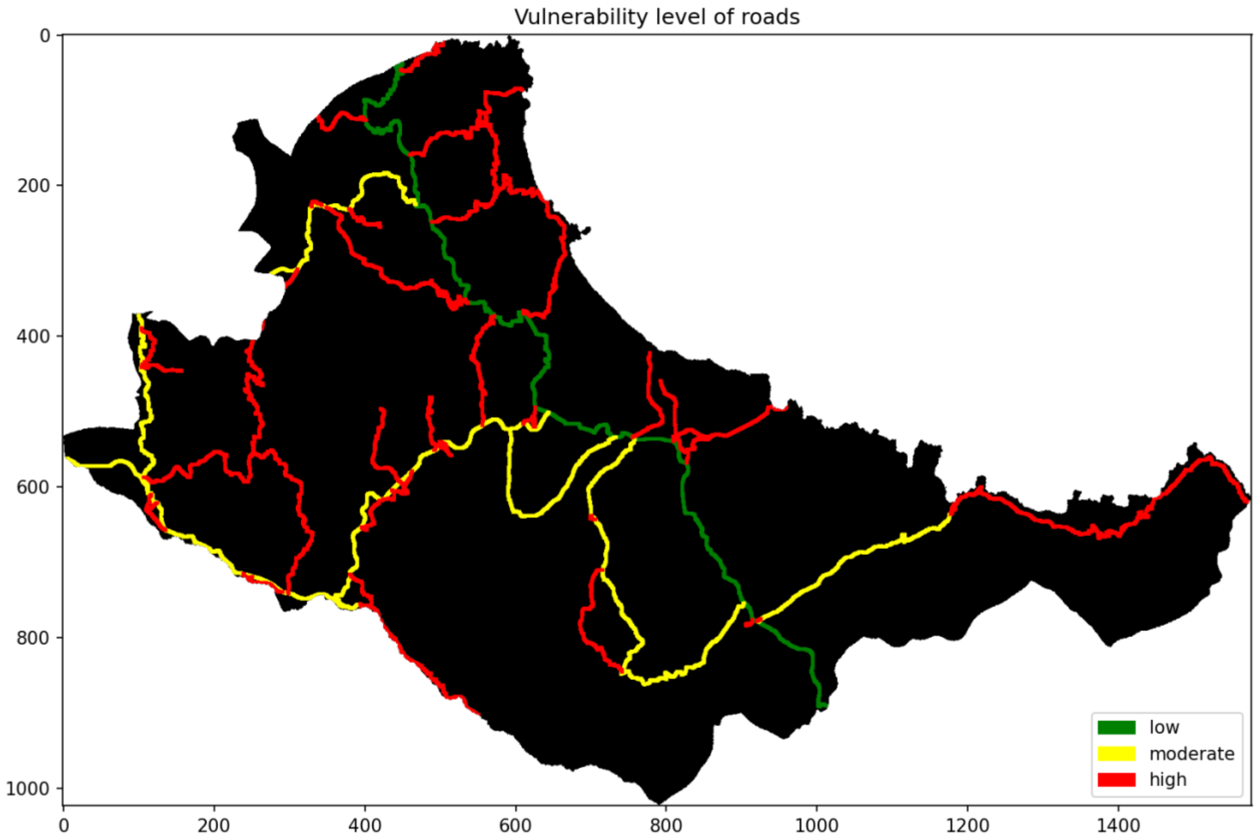


Fig. 2.3.3e Road-network vulnerability screening used in the FIRE ML risk assessment. The map supports the identification of road segments relevant for access, evacuation, and emergency response.

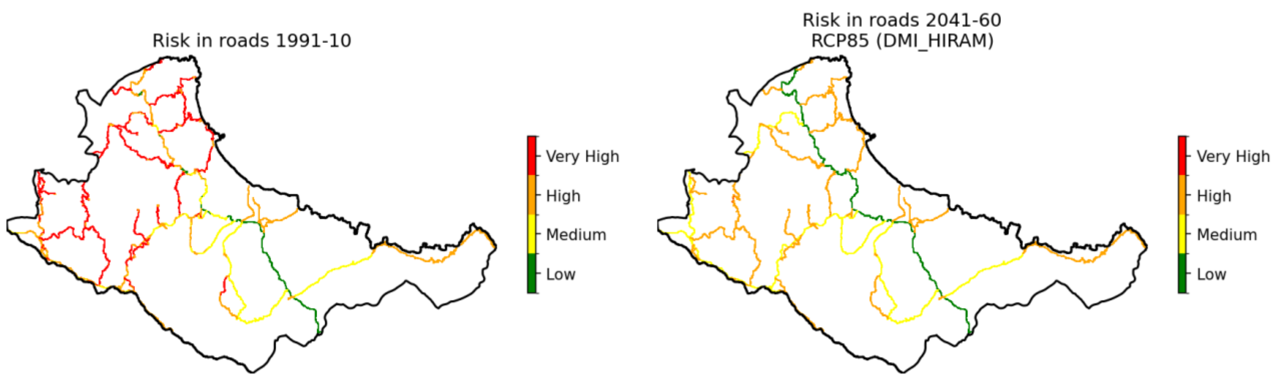


Fig. 2.3.3f Historical and future road-risk outputs from the FIRE ML risk assessment. The maps are used for screening road exposure and should be interpreted in conjunction with local civil-protection knowledge.

2.4 Key Risk Assessment Findings

The multi-hazard Key Risk Assessment integrates the outputs of the regionalised risk analyses for the three priority hazards , heatwaves, river/coastal flooding, and wildfire , and evaluates each against the CLIMAAX dimensions of severity, urgency, and resilience capacity, before deciding on risk priority. It draws on observed data, downscaled projections, exposure and damage analysis, the 2021 burn-scar evidence, and stakeholder input. The defining feature of the Mantoudi–Limni–Agia Anna risk profile is that the three hazards are coupled rather than independent: the assessment therefore considers not only each hazard in isolation but also the compound interactions between them , in particular the fire→heat and fire→flood cascades through which the 2021 burn scar amplifies both inland heat and flash-flood potential , so that severity, urgency, and resilience capacity are judged for the coupled system as well as for the individual hazards.

2.4.1 Mode of engagement for participation

The Key Risk Assessment was informed by the stakeholder engagement described in Section 2.1, including workshops and consultations with municipal services, the Fire and Forestry Services, civil protection actors, sectoral stakeholders, and representatives of vulnerable groups. Stakeholders were engaged through presentation of Phase 1 and Phase 2 findings, structured discussion of the three hazards using qualitative severity–urgency–capacity criteria, and exchange of views on perceived risks, response challenges, and priorities. Feedback showed strong convergence between analytical findings and local experience , particularly on the role of Kireas hydraulic bottlenecks in flooding, the post-2021 amplification of inland heat, and the wildland–urban interface and evacuation-route vulnerabilities underlying wildfire risk , and was used to validate the prioritisation and to identify capacity gaps, especially for heat and wildfire.

2.4.2 Gather output from Risk Analysis step

Consolidating the regionalised analyses: heat hazard shows a historical mean JJA Tmax of 28.55°C and a near-term SSP2-4.5 warming signal of about +1.15°C, with CORDEX indicators showing increasing tropical nights and extreme hot days; flood exposure analysis identifies 1,245 buildings intersecting the maximum flood extent and a conservative direct structural-loss range of approximately €14–29 million under the adopted 10% damage assumption; and wildfire is supported by CLIMAAX FIRE ML outputs, the 2021 burn-scar legacy, road/exposure screening, and the external FireScope layer, which places more than 90% of the municipality in High or Very high relative risk classes under the reporting classification.

2.4.3 Assess Severity

Severity was assessed for current and future conditions using the qualitative categories limited, moderate, substantial, and critical, considering the magnitude of potential impacts rather than their timing.

River and coastal flood severity is assessed as substantial to critical. Kireas flash floods have repeatedly caused material damage, mobility disruption, and risk to life; impacts are spatially concentrated but severe where dense development, critical infrastructure, and hydraulic constraints coincide, and are aggravated by aging bridge structures and by post-fire catchment degradation. The potential for cascading and partly irreversible impacts , damage to residential and commercial areas, disruption of emergency access and evacuation routes, and loss of natural flood-attenuation capacity , places flood risk at the upper end of the severity spectrum, approaching critical under unfavourable conditions.

Wildfire severity is assessed as substantial, with demonstrated potential to be critical. The 2021 mega-fire is direct evidence that the municipality can suffer a municipality-scale, fast-onset loss event with long-lasting ecological and economic consequences. While not every fire season will produce such an event, the combination of a high and lengthening fire-danger season, extensive wildland–urban interface, single-access settlements, and a degraded post-fire landscape means the credible worst case is severe. Severity is heightened by the slow recovery of forest ecosystems and by the compounding of fire with subsequent flood and heat impacts.

Heatwave severity is assessed as substantial, with potential to become critical under prolonged or compound heat–fire episodes. Although heat seldom causes immediate visible damage, its severity is expressed through public-health impacts and cumulative physiological stress, particularly for elderly residents and children, and is amplified inland by post-fire land-surface heating. Stakeholders acknowledged that heat impacts are often underestimated relative to the more visible flood and fire hazards, indicating a perception gap that may mask true severity.

2.4.4 Assess Urgency

Urgency was assessed using the categories indicating the need for timely action, considering current impacts and near-term trends.

River and coastal flooding , immediate action needed. Flash floods already occur under current conditions and recur along the Kireas system despite past works; sudden onset and limited warning time constrain response, aging bridges increase overflow risk, and post-fire degradation plus intensifying short-duration rainfall raise near-term risk. Coastal urgency at Agia Anna escalates with sea-level rise. Postponing action would likely result in avoidable damage.

Wildfire , immediate action needed. Fire danger is already high every summer, the landscape is primed by post-fire regrowth, and the 2021 event demonstrates that catastrophic loss is a present rather than a distant possibility. The absence of fully developed settlement-level fuel management, firebreaks, and redundant evacuation routes , together with the seasonal concurrence of peak fire danger and peak tourism , makes wildfire a time-critical risk for which preparedness must be strengthened before, not after, the next severe season.

Heatwaves , more action needed, escalating toward immediate. Heatwaves occur regularly and are increasing in frequency and persistence; impacts accumulate over time and escalate during prolonged episodes. The absence of dedicated local heat protocols and the reliance on generic national guidance increase urgency, as does the shared seasonality with wildfire. The trajectory points clearly toward immediate action as temperatures and post-fire amplification continue to rise.

2.4.5 Understand Resilience Capacity

Resilience capacity was assessed using the categories low, medium, substantial, and high, considering financial, human, physical, natural, and social dimensions.

Flooding , medium. Strengths include operational experience with flood response, cooperation with regional civil protection, ongoing and completed technical works along the Kireas system, and available technical studies. Weaknesses include aging bridges and hydraulic bottlenecks, limited redundancy in critical transport routes, insufficient integration of post-fire runoff and sea-level rise into planning, and constrained finance for structural upgrades. Natural flood-attenuation capacity is itself degraded by the 2021 fire and by riparian vegetation loss.

Wildfire , low to medium. Strengths include the Fire and Forestry Services' operational experience (sharpened by 2021), regional coordination structures, and stakeholder awareness following the mega-fire. Weaknesses are pronounced: incomplete settlement-perimeter fuel management and firebreaks, limited redundancy of evacuation/access routes, constrained local suppression resources during peak season, slow forest recovery reducing natural resilience, and the absence of an integrated fire-weather early-warning-to-evacuation chain at municipal level. Financial capacity for large-scale fuel management and reforestation is limited.

Heatwaves , low to medium. Capacity rests largely on national heatwave guidance and general public awareness, supported by social services and elderly-care facilities. Local limitations are significant: no municipality-specific heat protocols, limited cooling infrastructure or designated cooling spaces, and uneven awareness of heat severity relative to the more visible fire and flood hazards.

Across all three hazards, cross-cutting constraints include limited financial capacity, the need for stronger integration of climate projections into operational decision-making, and the challenge of protecting vulnerable and transient populations. A key enabler, repeatedly raised by stakeholders, is the development of an integrated, multi-hazard communication and early-warning approach rather than three separate single-hazard systems.

2.4.6 Decide on Risk Priority

Risk prioritisation followed the CLIMAAX Key Risk Assessment Protocol, combining the severity, urgency and resilience-capacity assessments with stakeholder input and expert judgement, giving particular weight to risks where high severity and urgency coincide with limited resilience capacity. On this basis, river flooding and heatwaves are assigned Very High priority, while wildfires are assigned Moderate priority.

River flooding receives a Very High priority because it combines high severity under both current and future conditions, immediate urgency due to recurrent sudden-onset events, and only medium resilience capacity, with significant structural, planning and post-fire catchment-management gaps. Heatwaves are also assigned Very High priority, reflecting rapidly increasing future severity, immediate urgency, widespread exposure of the population, and low resilience capacity, particularly in relation to locally adapted preparedness and protection of vulnerable groups. Wildfires are assigned Moderate priority in the dashboard. Although wildfire risk remains highly relevant for the municipality, especially given the 2021 mega-fire, fire-prone landscapes and the need for prevention and evacuation readiness, the overall dashboard scoring places it below river flooding and heatwaves in the final prioritisation.

While river flooding and heatwaves therefore require the most immediate and focused action, wildfire should remain an important complementary priority, particularly for fuel management, maintenance of firebreaks, protection of wildland–urban interface areas, and seasonal civil-protection preparedness. The prioritisation also recognises that these hazards are interconnected: post-fire degradation can amplify flood risk, while heatwaves and drought can increase fire danger. For this reason, the municipality should address them through an integrated, multi-hazard adaptation and civil-protection strategy.

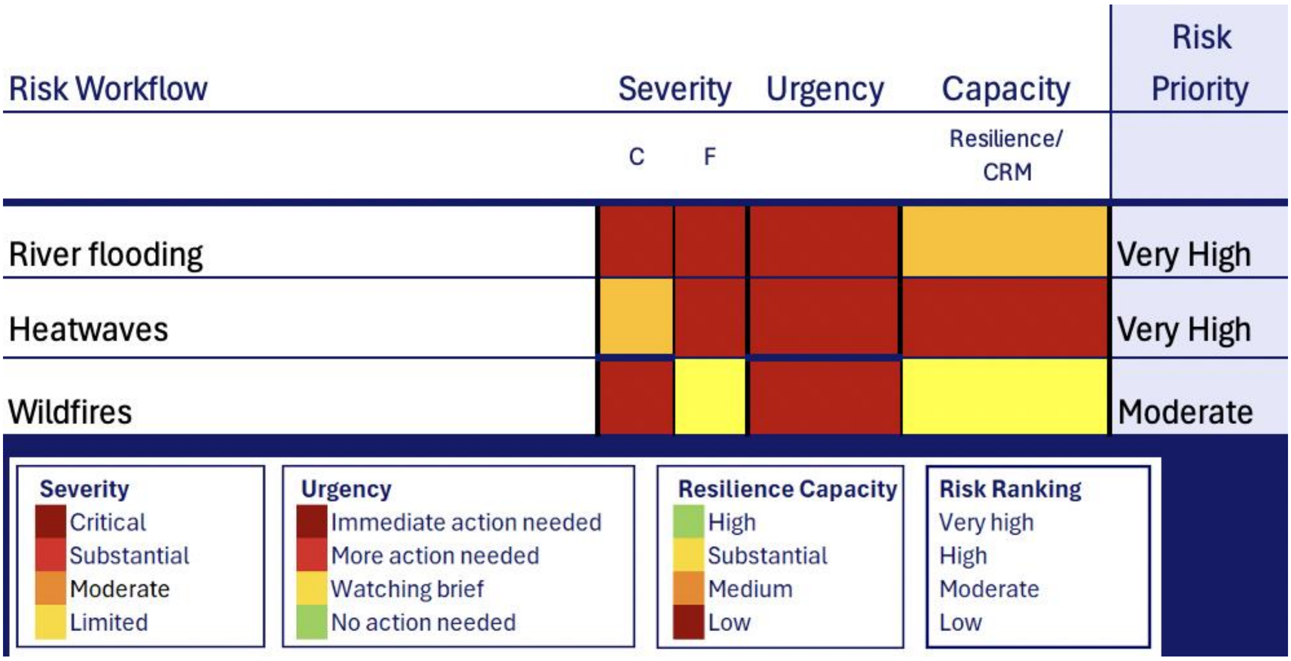


Fig. 2.4.6 The Key Risk Evaluation Dashboard.

2.5 Monitoring and Evaluation

Lessons learned from Phase 2 and difficulties encountered. Phase 2 added substantial value over Phase 1 by refining risks with local, higher-resolution data and stakeholder input, and by elevating wildfire to a full hazard. The most important lesson is that risk in this municipality is fundamentally compound: heat, flood, and fire share drivers and reinforce one another through the post-2021 landscape, and cannot be adequately managed hazard by hazard. Phase 2 also confirmed the importance of being explicit about methodological limits , particularly the inability of coarse river-flood products to resolve Kireas flash floods, and the distinction between fire-weather danger (FWI) and burn probability. Difficulties included the heterogeneity of data sources, formats, and spatial scales; limited structured local exposure and vulnerability data; the absence of calibrated local hydrometry; and the operational unavailability of some stakeholders (notably the Fire Service during fire season).

Role of stakeholders, learning, and institutional memory. Stakeholders validated findings against operational knowledge, interpreted them in light of institutional realities, and confirmed the prioritisation. Learning is secured through documentation of methods and assumptions in this deliverable, use of the CLIMAAX Key Risk Evaluation Dashboard as a repeatable framework, and integration of findings into the municipal Civil Protection Plan, ensuring uptake beyond the project. Stakeholders expressed interest in treating the CRA as a living reference supporting periodic updates.

Data availability and future needs. Phase 2 benefited from local meteorological observations, land-cover and burn-scar data, and existing technical studies. Priority future needs are: locally calibrated, higher-resolution flash-flood modelling integrating pluvial and post-fire runoff; a full wildfire burn-probability simulation (ignition × spread × susceptibility) to complement the FWI danger analysis; updated, finer burned-area and fuel-regrowth mapping; systematic monitoring of flood and fire events and impacts; and improved socio-economic vulnerability datasets.

Communication, monitoring systems, and overall impact. Outcomes will be communicated through this deliverable, targeted briefings to municipal services, the Fire and Forestry Services, and the Port Authority, and integration into civil protection procedures and public communication, with non-technical summaries prioritised. While no fully integrated multi-hazard monitoring system is yet in place, the CRA provides the baseline framework: existing flood and fire-weather early-warning systems can be progressively enhanced and linked to identified priority areas, vulnerable groups, and the wildland–urban interface. Overall, the CRA has had a high positive impact on local understanding of compound climate risk, institutional awareness and engagement, and readiness to integrate climate risk into planning and investment.

2.6 Work plan Phase 3

Phase 3 will translate the Phase 2 Key Risk Assessment into concrete contributions to local adaptation strategies and to improved risk management and civil protection planning, with explicit emphasis on the compound, multi-hazard character of risk in Mantoudi–Limni–Agia Anna. The main objectives are to support the integration of the three priority risks into the municipal Civil Protection Plan; to contribute to locally adapted measures addressing flood, wildfire, and heat risk; to strengthen institutional capacity and inter-service coordination (Municipality, Fire Service, Forestry Service, Port Authority, regional authorities); and to ensure that CRA outcomes become practical, actionable guidance.

Main Phase 3 activities will include:

- **Follow-up on Key Risk Assessment findings ,** reviewing how the three priority risks are addressed in existing plans, identifying gaps, and validating priorities with stakeholders.
- **Contribution to civil protection and risk management plans ,** translating priorities into operational considerations (priority areas, vulnerable groups, critical infrastructure), incorporating compound-risk logic (fire → flood → heat), and providing input for early warning, preparedness, response, evacuation, and communication tailored to local conditions, with particular attention to the Kireas corridor, the Agia Anna coastal front, and the wildland–urban interface settlements.
- **Identification and structuring of adaptation measures ,** non-structural measures (preparedness protocols, multi-hazard early warning, awareness campaigns, coordination mechanisms); nature-based and ecosystem-sensitive measures that deliver across hazards (e.g. reforestation and fuel management that also restore flood-regulating and cooling services, riparian restoration replacing diseased plane trees); and measures improving institutional readiness rather than detailed engineering design.
- **Stakeholder engagement and validation ,** targeted workshops to discuss proposed measures, ensure feasibility and acceptability, and strengthen local ownership.

Phase 3 will not include detailed engineering design of structural flood or fire-protection works, cost–benefit analysis of large-scale infrastructure, full wildfire burn-probability simulation, or quantitative health-impact assessment; these require dedicated studies and resources beyond the CLIMAAX scope and are flagged as future needs. By the end of Phase 3 the project will deliver clear input to local adaptation strategies addressing the three priority risks, improved alignment between the CRA and civil protection planning, enhanced multi-hazard awareness and capacity among municipal stakeholders, and a structured pathway for continued monitoring, evaluation, and future updates.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of the Climate Risk Assessment for Mantoudi–Limni–Agia Anna provides a refined, locally grounded and forward-looking evaluation of the three main climate hazards affecting the municipality: heatwaves, river and coastal flooding, and wildfire. Compared with Phase 1, wildfire has been developed from a preliminary annex-level screening into a full hazard and risk assessment, responding to the need for deeper analysis of fire-weather danger, post-fire landscape degradation, wildland–urban interface exposure, buildings and critical infrastructure.

The assessment combined observed meteorological and satellite data, downscaled climate projections, fire-weather indicators, land-cover information, the 2021 burned-area perimeter, building-footprint data, critical-infrastructure layers and flood-damage estimates. These datasets were processed within the CLIMAAX framework and interpreted together with local knowledge and stakeholder input.

The heat analysis confirms that the municipality is already exposed to increasing thermal stress. Phase 1 results showed heatwave days rising from a historical baseline of approximately 4–5 days per year to 13–14 days under RCP4.5 and 17–19 days under RCP8.5 by 2050. Phase 2 strengthens this finding by adding spatial analysis of summer maximum temperature, projected JJA warming, and exposure of settlements and infrastructure. Satellite-based land-surface temperature evidence also indicates that the 2021 wildfire has contributed to stronger inland heating by removing forest cover and reducing natural cooling capacity. Heatwaves are therefore not only a future hazard, but an already emerging risk with implications for vulnerable residents, outdoor workers, tourism, schools, public buildings and emergency services.

The flood analysis confirms the Kireas river system and the wider Mantoudi–Kymasi lowland as the municipality's most economically significant flood-risk area. Previous modelled damage estimates indicate direct damages of approximately €11.2–28.6 million across 10- to 500-year return-period events, with an estimated annual damage of about €1.57 million. However, the assessment also confirms that coarse river-flood products do not adequately represent local flash-flood dynamics, channel constraints, debris transport, post-fire runoff amplification and small-catchment response. Therefore, modelled flood outputs should be interpreted as a partial representation of risk rather than a complete estimate of the municipality's true flood exposure. Coastal flooding is more spatially limited, mainly affecting the low-lying Agia Anna coastal zone, but becomes more relevant under sea-level rise because even shallow inundation can disrupt tourism activity, coastal access, parking areas and local infrastructure.

The wildfire analysis shows that fire danger is a central component of the municipality's risk profile. The historical baseline already indicates approximately 50–75 days per year with Fire Weather Index values above 30, while future projections under RCP8.5 suggest a lengthening of the high-fire-danger season toward 75–100 or more days per year in parts of the municipality. This signal is particularly important because the area has already experienced catastrophic wildfire impacts during the 2021 northern Evia mega-fire. The burned landscape, remaining forested areas, dispersed settlements and extensive wildland–urban interface create continuing exposure, especially where settlements, roads, critical infrastructure and tourism areas are close to fire-prone vegetation. Supplementary FireScope 2026 results further support the interpretation that large parts of the municipality remain under elevated wildfire-risk conditions, although FireScope is treated as an external screening layer and not as a replacement for the CLIMAAX workflow.

The central conclusion of Phase 2 is that climate risk in Mantoudi–Limni–Agia Anna is compound and interconnected. The 2021 wildfire did not only create direct fire impacts; it also altered the local risk landscape by increasing land-surface heating, reducing vegetation cover, degrading slope stability and potentially amplifying runoff and flash-flood response. At the same time, future warming and drying conditions can increase fire danger and heat stress. These interactions mean that the three hazards should not be managed as isolated problems.

The Key Risk Assessment reflects this multi-hazard picture. River flooding and heatwaves are assigned Very High risk priority, due to their combination of high severity, urgent need for action and limited or only moderate resilience capacity. Wildfire is assigned Moderate priority in the final dashboard, but remains a major complementary concern because of the municipality's recent catastrophic fire history, high fire-weather baseline, remaining fuel exposure and the need for continuous prevention, preparedness and evacuation planning.

Overall, Phase 2 provides a stronger evidence base for updating the municipal Civil Protection Plan, informing local adaptation strategies and guiding future investments. Priority areas include flash-flood resilience in the Kireas basin, maintenance and restoration of riparian and post-fire landscapes, heatwave preparedness for vulnerable groups, fuel management, firebreak maintenance, protection of wildland–urban interface settlements, and improved use of early-warning information. The clearest methodological needs for the next phase are locally calibrated flash-flood modelling, improved exposure and damage data, and more advanced wildfire modelling, including burn-probability or spread simulations where feasible.

Phase 2 confirms that proactive adaptation in Mantoudi–Limni–Agia Anna is not precautionary but necessary. Heatwaves, flooding and wildfire are already present, measurable and linked through common drivers. The municipality therefore needs an integrated, multi-hazard adaptation and civil-protection strategy that reduces risk across hazards rather than separate, single-hazard responses.

4 Progress evaluation

Phase 2 met its defined objectives, refining the Phase 1 assessment with local data and delivering a complete three-hazard Climate Risk Assessment. The heat, flood, and wildfire workflows were executed and documented, exposure and vulnerability mapping was refined at settlement and interface level, and the Key Risk Assessment (severity, urgency, resilience capacity, prioritisation) was completed for all three hazards with scenario-based projections and stakeholder validation. Methodological limitations , the under-resolution of Kireas flash floods by coarse products, and the danger-versus-probability distinction for wildfire , were identified explicitly and translated into clear future-data needs.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Heatwaves , regionalised risk analysis	Completed
River and coastal floods , regionalised risk analysis	Completed
Wildfire , regionalised risk analysis (new full hazard)	Completed
Key Risk Assessment (severity / urgency / capacity / priority)	Completed
Stakeholder engagement and validation	Completed

Table 4-2 Overview milestones

Milestones	*Progress*
Refined hazard layers acquired and validated (3 hazards)	Completed
Exposure and vulnerability mapping refined	Completed
Composite three-hazard risk assessment	Completed
Presentation of results to municipal decision-makers	Under preparation

5 Supporting documentation

Fig.2.3.3b.png
Fig_2.3.1.png
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Fig_2.3.1c.png
Fig_2.3.1d.png
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tr-CORDEX-EUR-11_timeseries.csv
tx35-CORDEX-EUR-11_timeseries.csv

6 References

- CLIMAAX Consortium (2023): CLIMAAX Handbook , A Guide to Regional Climate Risk Assessment.
- Copernicus Climate Change Service (2023): ERA5 Dataset; European State of the Climate 2023. ECMWF.
- Copernicus Emergency Management Service (2021): Rapid Mapping activation, northern Evia wildfires, August 2021.
- European Forest Fire Information System (EFFIS), Copernicus / Joint Research Centre: burned-area and fire-danger products.
- EEA (2022): Europe's changing climate hazards , an index-based interactive report. European Environment Agency.
- EEA (2023): European Climate Risk Assessment. EEA Report No 01/2023. Copenhagen.
- European Commission (2021): Forging a Climate-Resilient Europe , the new EU Strategy on Adaptation to Climate Change.
- Galanaki, E., Lagouvardos, K., Kotroni, V., Giannaros, T., Giannaros, C. (2021): Implementation of WRF-Hydro at two drainage basins in the region of Evia, Greece, for operational flood forecasting. Nat. Hazards Earth Syst. Sci., 21, 1983–2000.
- Galanaki, E., Giannaros, C., Kotroni, V., Lagouvardos, K., Papavasileiou, G. (2023): Spatiotemporal analysis of heat-wave characteristics in Greece from 1950 to 2020. Climate, 11(1), 5.
- Giannakopoulos, C., Kostopoulou, E., Varotsos, K. V., et al. (2021): Projected heatwave characteristics over Greece in the 21st century. Global and Planetary Change, 199, 103450.
- IPCC (2021): Climate Change 2021: The Physical Science Basis. Contribution of WG I to the Sixth Assessment Report. Cambridge University Press.
- IPCC (2022): Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of WG II to the Sixth Assessment Report. Cambridge University Press.
- Lagouvardos, K., Kotroni, V., Bezes, A., et al. (2017): The Automatic Weather Stations NOANN Network of the National Observatory of Athens: operation and database. Geosci. Data J., 4, 4–16.
- MedECC (2020): Climate and Environmental Change in the Mediterranean Basin , Current Situation and Risks for the Future. First Mediterranean Assessment Report. Union for the Mediterranean.
- Papagiannaki, K., Lagouvardos, K., Kotroni, V., Bezes, A. (2015): Flash flood occurrence and relation to the rainfall hazard in a highly urbanized area. Nat. Hazards Earth Syst. Sci., 15, 1859–1871.
- Van Wagner, C. E. (1987): Development and structure of the Canadian Forest Fire Weather Index System. Canadian Forestry Service, Forestry Technical Report 35.
- Fick, S. E., & Hijmans, R. J. (2017): WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology, 37(12), 4302–4315.
- Jacob, D., Petersen, J., Eggert, B., et al. (2014): EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional Environmental Change, 14, 563–578.
- Lange, S. (2019): Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD. Geoscientific Model Development, 12, 3055–3070.
- Zhu, X. X., Chen, S., Zhang, F., Shi, Y., & Wang, Y. (2025): GlobalBuildingAtlas: an open global and complete dataset of building polygons, heights and LoD1 3D models. Earth System Science Data, 17, 6647–6668.

- INSAIT Institute (2026): FireScope AI wildfire-risk map for Europe and the FireScope-risk-2026 dataset. Used here as an external supplementary screening layer, not as a CLIMAAX replacement.

Annex

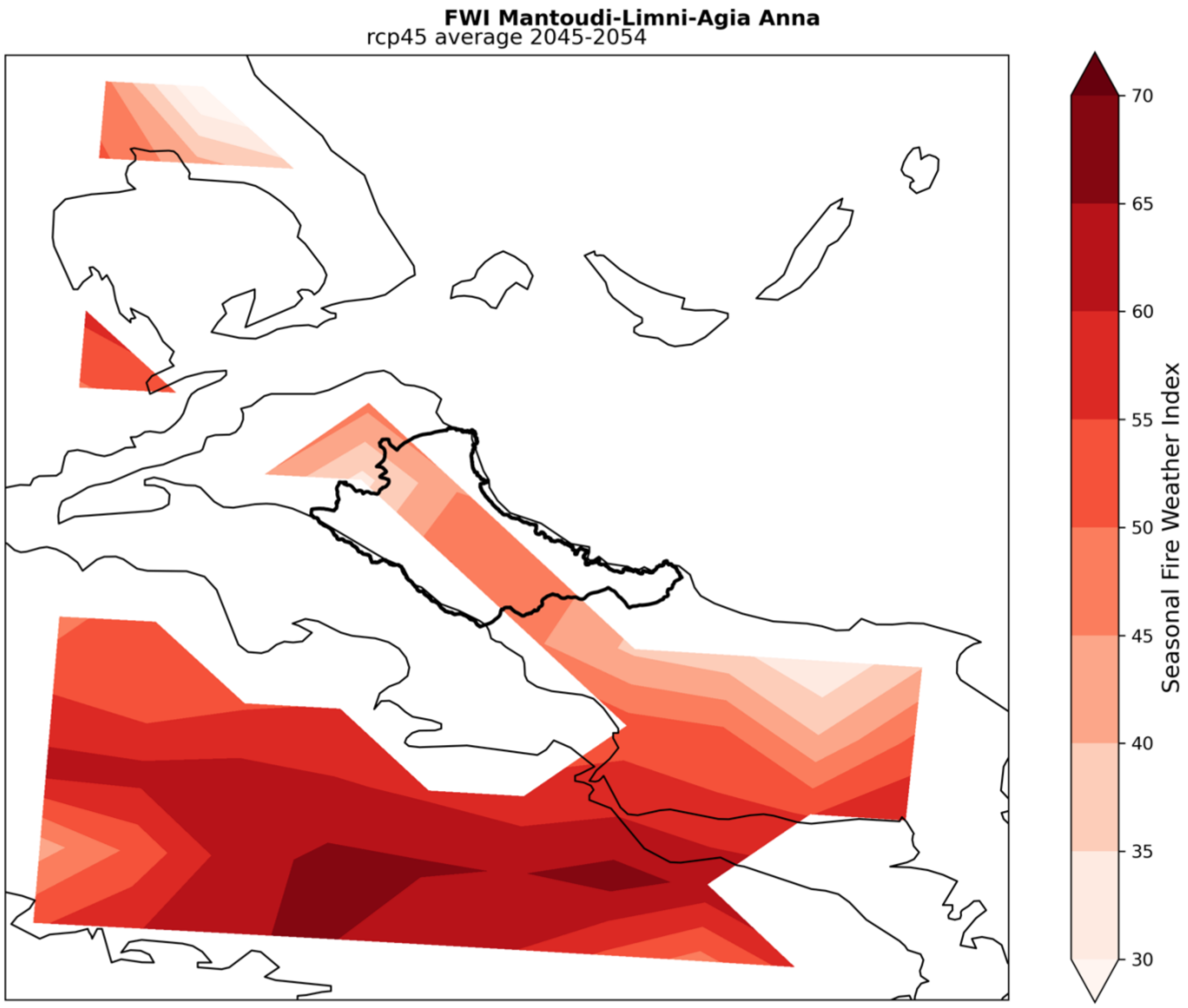

Fig. A.1 Seasonal Fire Weather Index for Mantoudi–Limni–Agia Anna, RCP4.5 average for 2045–2054 based on the CLIMAAX Wildfire FWI workflow. Only 3 grid points fall within the Mantoudi-Limni-Agia Anna municipality.

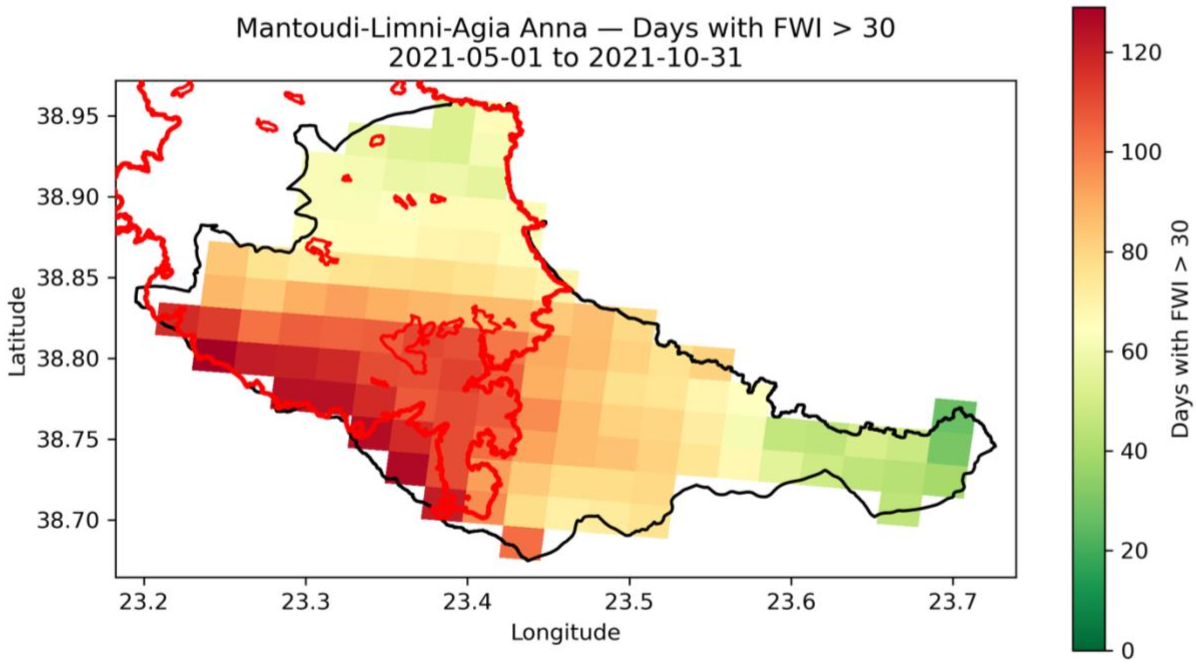

Fig. A.2 Number of days with FWI > 30 inside the municipality for the 2021 season (1 May–31 October), computed from the NOA MOLOCH model. Inland western and central areas record the highest seasonal day counts (up to ~120 days), consistent with the fire-danger load described in Section 2.3.3.

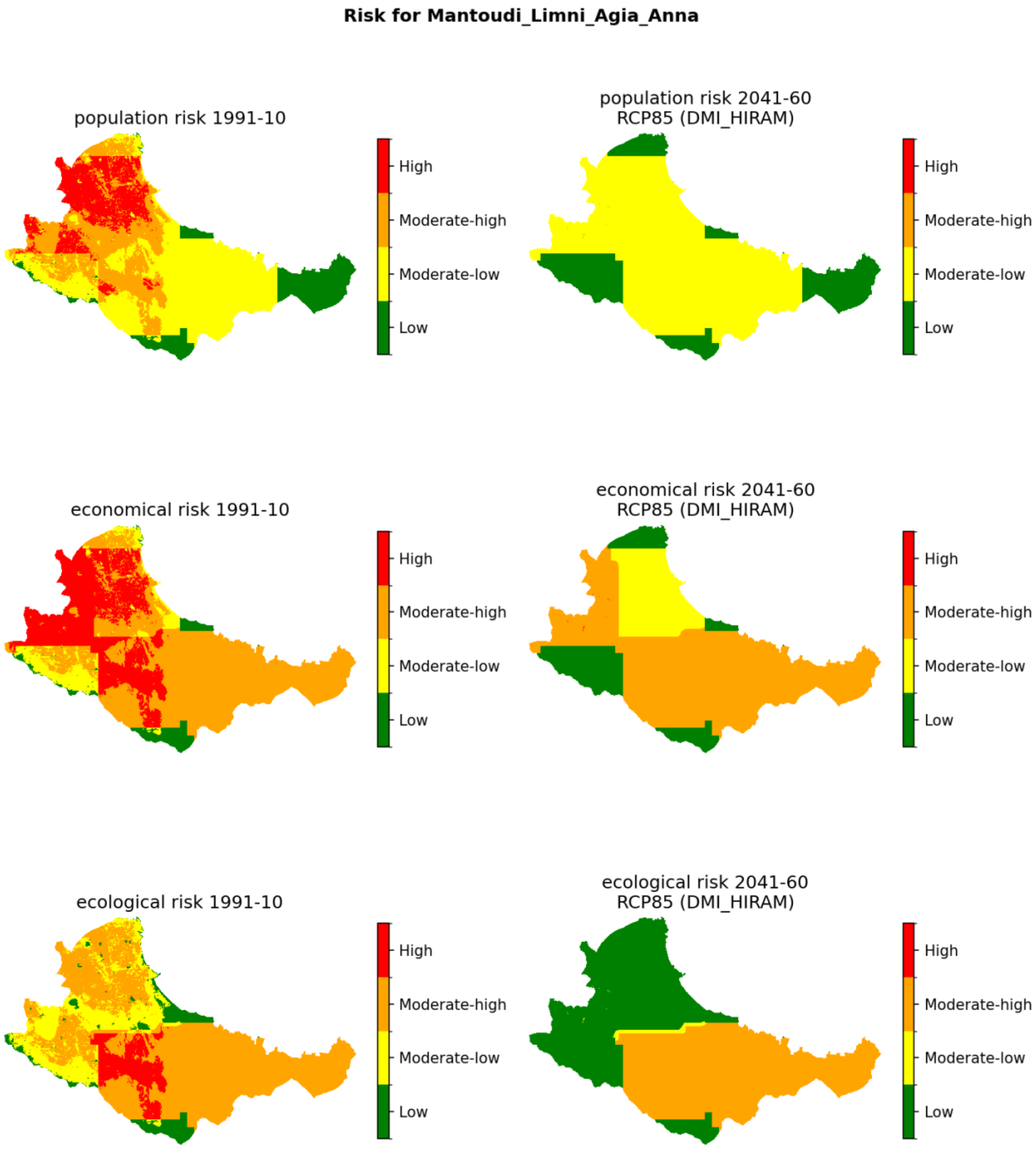

Fig. A.3 Multi-panel FIRE ML risk outputs and sensitivity diagnostics. Coarse data and artifacts come from numerical constraints in the CLIMAAX FIRE ML workflow.