Deliverable Phase 1 – 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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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	This is a Climate Risk Assessment (CRA) tailored to the local context of Mantoudi-Limni-Agia Anna, a coastal municipality in Evia, Greece, which faces escalating exposure to climate-induced hazards
Project name	RIVA – RIsk Vulnerability Assessment in Municipality of Mantoudi-Limni-Agia Anna
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Author(s)	• Antonis Bezes
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1.0	07/09/2025	METEOME	Deliverable submitted
2.0	…	CLIMAAX's FSTP team	Review completed
5.0	…		Final version to be submitted

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Abbreviations and acronyms

Insert here all acronyms appearing along the deliverable in alphabetical order. This text marked in green should be deleted before submitting the deliverable.

Abbreviation / acronym	Description
RIVA	Risk and Vulnerability Assessment in Municipality of Mantoudi-Limni-Agia Anna
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
RAST	Regional Adaptation Support Tool
SLR	Sea-level rise
CORDEX	Coordinated Regional Climate Downscaling Experiment
EAD	Estimated Annual Damage
CRA	Climate Risk Assessment
OSM	Open Street Map
LUISA	Land Use-based Integrated Sustainability Assessment
MSL	Mean Sea Level
SME	Small and Medium Enterprises
RCP	Representative Concentration Pathway
GEV	Generalized Extreme Value
FWI	Fire Weather Index

Executive summary

*The following text is a **generic guideline** for the authors to produce the Executive summary section.* ***The text marked in green should be deleted before submitting the deliverable.***

Please follow these guidelines:

- ***Length:** please limit it to 1 page (2 pages in exceptional cases).*
- *The executive summary must have conclusions.*
- ***Goal:** The Executive summary is not an "introduction" to the deliverable. The main goal of this section is to provide readers with a whole picture of the document, so that they can understand the content of the deliverable at once without further reading.*
- ***Self-contained:** If there is any input coming from other deliverables, it must be mentioned here.*
- *Motivation for the reader (Recommended: 1 –10 lines):*
    - *Why was this deliverable developed? Which does it address?*
    - *What will the reader learn from it?*
- *Main results and findings (Recommended: 5 to 50 lines):*
    - *What are the main actions undertaken during this phase?*
    - *What are the main results achieved?*
    - *How does it contribute to the overall project?*
- *Short conclusions (Recommended: 1 to 10 lines):*
    - *Key take-away messages*
- *Style:*
    - *Please use a formal and practical writing style without jargon.*
    - *Do not use "We" when writing the Executive summary.*

This deliverable presents the results of Phase 1 of the RIVA project—*Risk and Vulnerability Assessment in the Municipality of Mantoudi-Limni-Agia Anna*—conducted under the Horizon Europe CLIMAAX programme. The aim of this phase is to establish a scientifically rigorous, harmonised Climate Risk Assessment (CRA) tailored to the local context of Mantoudi-Limni-Agia Anna, a coastal municipality in Evia island, Central Greece, which faces escalating exposure to climate-induced hazards. The main focus of this assessment lies on two climate-related threats: (i) heatwaves and (ii) river and coastal flooding.

This deliverable was developed to address urgent needs for locally relevant, data-informed adaptation planning in a municipality known for its vulnerability to both meteorological and hydrological extremes. The reader will gain a complete picture of the municipality's current climate risk profile, the methodological steps taken for risk quantification, and the basis upon which targeted adaptation and resilience actions will be developed in subsequent phases. The contractor METEOME led the technical implementation of hazard and risk workflows, applying the CLIMAAX Handbook and toolbox, including downscaled Euro-CORDEX projections, EU-wide hazard layers, and local datasets wherever available. The CLIMAAX Regional Adaptation Support Tool (RAST) provided the overarching structure for the assessment, ensuring compliance with EU adaptation planning best practices. The key findings on the studied hazards are summarised as follows:

- Heatwaves are projected to increase markedly under both RCP4.5 and RCP8.5 scenarios. By 2050, the number of heatwave days may rise to 13–14 days under RCP4.5 and to 17–19 under RCP8.5. The inland urban core exhibits high vulnerability due to overlapping exposure (high land surface temperatures >40°C), sensitive populations (elderly, children), and limited cooling infrastructure. The port areas, which host hundreds of thousands of annual passengers, also face elevated exposure.

- River flooding, especially flash floods in the Kireas basin, represents a historically significant hazard. However, the model projections of CLIMAAX workflows—based on coarse resolution and riverine flood typologies—failed to replicate the observed flood behavior, leading to a critical underestimation of future risk. As a result, modeled inundation, damage estimates, and population exposure should be treated with caution.
- Coastal flooding presents a localized but credible risk, especially under sea level rise (SLR) scenarios. Low-lying zones around the Agia Anna beach face increased inundation depths (up to 0.7 m by 2050), with potential disruptions to commercial activities, municipal car parks, critical access routes, and port operations.

Main actions undertaken include stakeholder mapping, hazard screening, workflow selection and execution, scenario definition (RCP4.5 and RCP8.5 up to 2050), and the generation of preliminary risk maps and exposure overlays using the CLIMAAX toolbox. Contributions to the overall CLIMAAX project include the operationalisation of the methodological framework in a high-vulnerability, data-scarce setting, identification of workflow limitations, and the establishment of baseline risk metrics that will inform future adaptation planning, civil protection updates, and regional policy alignment.

Conclusions: This phase confirms that heatwaves represent an intensifying and well-characterized threat, warranting immediate local adaptation actions (early warnings, passive cooling strategies, vulnerable group protection). Coastal flooding is also a credible hazard requiring localized mitigation. Most importantly, river flood risk remains the most significant threat and calls for urgent methodological refinement, including integration of pluvial and flash flood modeling and the use of locally calibrated topographic and exposure data. Stakeholder feedback confirms the need for stronger local participation and higher data granularity in the next phase. The RIVA lays a strong foundation for evidence-based resilience planning in Mantoudi-Limni-Agia Anna.

1 Introduction

1.1 Background

- *Briefly describe your region or community.*

The Municipality of Mantoudi-Limni-Agia Anna is a largely rural and semi-mountainous coastal region situated in northern Evia, Greece (Fig.1-1). Established through the 2011 Kallikratis administrative reform, the municipality covers an extensive area of approximately 584.8 km² and is home to around 12,230 residents. Its territory stretches from the Aegean coastline with its long sandy beaches and rugged cliffs, to the inland mountainous landscapes dominated by Mount Xiro and dense pine forests. The municipality is composed of three main municipal units: Mantoudi, Limni, and Agia Anna. Mantoudi serves as the local administrative and commercial hub, while Limni is notable for its traditional architecture and maritime history. Agia Anna lies near one of the longest beaches in Evia, attracting significant seasonal tourism, and Rovies to the north also draws visitors for its coastal setting and hospitality sector. Kymasi, the port area of Mantoudi, provides a vital link between northern Evia and mainland Greece, supporting both passenger transport and trade. Further inland, Prokopi is a cultural and religious center, home to the Church of Saint John the Russian, which attracts year-round pilgrimage and tourism. Together, these settlements form the social, cultural, and economic backbone of the municipality, while also representing the main zones of exposure to climate-related hazards.

The municipality's natural wealth includes significant forest ecosystems, river valleys, and coastal habitats, which contribute both to its ecological value and to its vulnerability. The combination of steep slopes, densely vegetated terrain, and exposed coastlines makes the area prone to hydrometeorological hazards. In recent decades, Mantoudi-Limni-Agia Anna has experienced severe wildfires, most notably during the catastrophic August 2021 mega-fire in northern Evia, which destroyed vast forested areas, caused evacuations, and inflicted long-lasting ecological and economic damage. Floods and landslides are also recurrent threats, particularly after wildfire events that reduce natural water absorption capacity.

A growing ecological challenge is the spread of Ceratocystis platani, a fungal disease that has devastated plane tree populations across Greece. In Mantoudi-Limni-Agia Anna, the pathogen is threatening riparian ecosystems and accelerating the loss of protective vegetation along riverbanks. This disease, exacerbated by climate change through warmer temperatures and altered hydrological patterns, has direct implications for flood risk, soil erosion, and biodiversity conservation. The decline of plane trees reduces natural shading, accelerates streamflow, and increases the vulnerability of riverside communities.

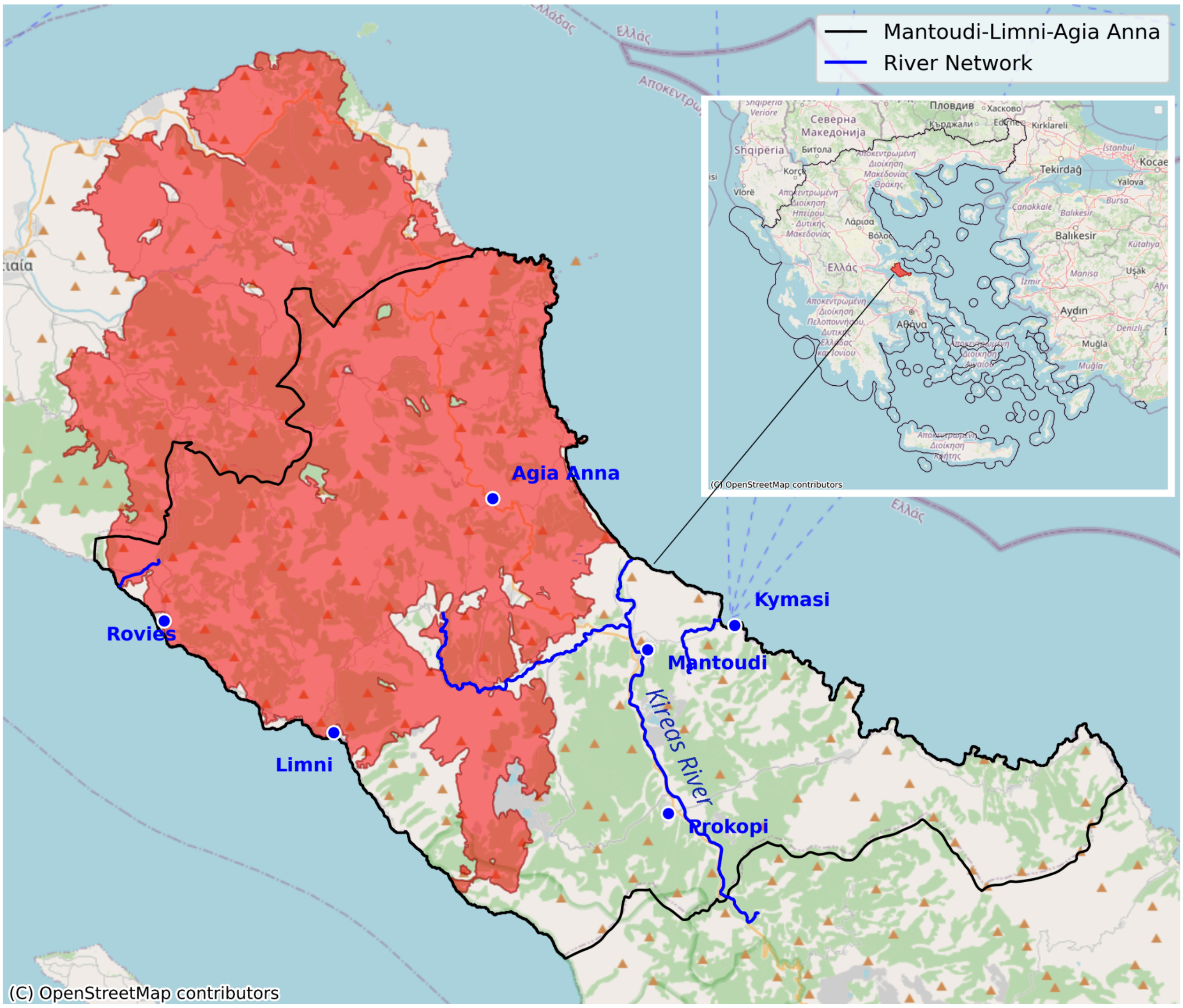

Fig. 1-1 Location of the Municipality of Mantoudi-Limni-Agia Anna in Evia island. The map shows the main settlements (blue labels), the river network with emphasis on the Kireas River (blue lines), and the area affected by the 2021 wildfire (in red). The inset highlights the municipality's position within Greece.

In addition, local stakeholders have identified a wide range of risks across the municipality, spanning river flooding, landslides, coastal hazards, seismic activity, and wildfire threats. These challenges are compounded by critical vulnerabilities in schools, sports facilities, and transportation infrastructure, as well as emerging pressures on water supply, agriculture, and marine ecosystems. To address these, stakeholders have proposed a comprehensive package of structural and non-structural measures, including riverbed widening and sediment management, slope stabilization, firebreak creation, flood protection works for schools and public buildings, improved monitoring systems, and the development of new water storage reservoirs. A detailed presentation of these identified risks and proposed measures is provided in the Annex I of this report.

Climate change is intensifying these risks, with observable shifts in precipitation patterns, longer drought periods, and more frequent extreme storms in the Aegean. These include events such as the Medicane “Ianos” (2020), which battered northern Evia with gale-force winds and coastal flooding, Storm “Daniel” (2023), and Storm “Elena” (2024) which caused destructive flash floods in low-lying communities. The municipality’s aging infrastructure, limited flood protection works, and insufficient forest management exacerbate its exposure to such climate extremes.

Socioeconomically, the municipality depends on a mix of agriculture, forestry, small-scale fishing, and growing tourism, sectors that are all highly climate-sensitive. The prolonged impacts of the Greek financial crisis, combined with recurring disaster-related damages, have strained local resources and capacity for climate adaptation. A comprehensive resilience strategy is urgently needed to protect residents, safeguard critical infrastructure, and preserve the rich natural and cultural heritage of Mantoudi-Limni-Agia Anna against escalating climate-related threats.

1.2 Main objectives of the project

- *Describe the objectives and significance of the project to the region or community*
- *Include the expected benefits of applying the CLIMAAX Handbook*

The primary objectives of the RIVA Project are centered around conducting a detailed, transparent, and harmonized climate risk assessment specifically tailored to the municipality’s unique geographical, ecological, and socio-economic context. Utilizing the CLIMAAX Handbook, the project aims to identify and quantify key hazards such as extreme heat events and floods, as well as associated exposures and vulnerabilities at the local level.

A critical goal of RIVA is to provide a robust scientific foundation and methodology that supports informed decision-making for local climate adaptation policies. Through the application of the CLIMAAX methodological framework and risk assessment tools, Mantoudi-Limni-Agia Anna will be empowered to establish clear priorities and actionable strategies to mitigate and adapt to climate risks. Moreover, the project seeks to align the municipality’s planning and governance processes with the best practices outlined in the CLIMAAX Handbook and broader EU climate resilience initiatives.

The expected benefits of adopting the CLIMAAX Handbook within this project are numerous. It will:

- facilitate risk-informed governance,
- enhance the effectiveness of targeted adaptation measures, and
- improve local emergency response planning.

Additionally, the increased transparency and involvement of stakeholders will lead to greater community awareness, strengthening public support for climate resilience measures. Overall, the outcomes of RIVA will significantly contribute to safeguarding the local economy, enhancing public safety, preserving ecological integrity, and ultimately fostering a resilient and sustainable future for the Mantoudi-Limni-Agia Anna community.

1.3 Project team

- *Describe the team working on the project.*

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 specifically responsible for conducting climate hazard analyses, implementing risk assessment workflows, and ensuring rigorous scientific application of the CLIMAAX framework.

The project team involves close cooperation with municipal departments integral to climate risk management and urban development, notably civil protection and urban planning departments. Their local insights and sector-specific expertise are instrumental in accurately defining and evaluating the regional climate risks and implementing appropriate adaptation strategies.

In addition, the project emphasizes active stakeholder engagement, capturing input and feedback from a diverse range of local actors. This comprehensive engagement ensures that the outcomes of the RIVA are locally relevant, broadly supported, and effectively integrated into the municipality's long-term adaptation and resilience strategies.

1.4 Outline of the document's structure

- *Brief summary of how this document is organized.*

- Section 2 presents the scoping process, selection of workflows, and preliminary risk analysis for heatwaves and river/coastal floods.

- Section 3 summarizes the conclusions of Phase 1 and key takeaways.

- Section 4 evaluates progress and outlines the contribution to the next phases.

- Section 5 provides an overview of supporting outputs.

- Section 6 lists references used in the assessment.

- Section 7 provides additional information in Annexes

2 Climate risk assessment – phase 1

For this analysis, follow the steps outlined in the CLIMAAX Framework[1](see link in the footnote). The sections below provide guiding questions from the Handbook that can help shape your report. Please also indicate when too little information is available to answer them. The text marked in green should be deleted before submitting the deliverable.

[1] Summary of the framework:
https://handbook.climaax.eu/CRA_steps/framework.html

Detailed description of the framework:
https://files.cmcc.it/climaax/Deliverables/CLIMAAX_D1.4_Climate%20Risk%20Assessment%20Framework_revised.pdf

2.1 Scoping

*The scoping phase of the climate risk assessment defines **objectives** (desired results of the analysis), **context** (conditions for implementation) and **identifies stakeholders** that need to be involved in the project preparation.*

2.1.1 Objectives

- *What is the objective, purpose and expected outcome of your CRA? How should your objective feed into policy and decision making? Include how the project outcomes can inform upcoming local/regional development plans, strategies and policies*
- *What are the limitations and boundaries for your climate risk assessment (CRA)? (such as availability of data, involvement of stakeholders, other relevant constraints)*

The primary objective of the Risk and Vulnerability Assessment (RVA) for the Municipality of Mantoudi-Limni-Agia Anna (RIVA) is to provide a detailed, structured, and transparent understanding of the climate risks facing the municipality, focusing particularly on heatwaves, and river and coastal flooding. The RVA seeks to inform and facilitate targeted climate adaptation strategies, enhance local emergency planning capabilities, and support effective policymaking. It aims to identify the sectors and population groups most vulnerable to these climate-related risks, guiding prioritization and resource allocation for adaptation measures.

The outcomes of this assessment will feed directly into municipal climate adaptation policies, the updating of local civil protection plans, and emergency preparedness initiatives. It will also contribute to wider regional and national strategic adaptation planning frameworks.

Limitations of this climate risk assessment include:

- data availability constraints related to gaps in historical local weather/climate observations for a long period (e.g., detailed weather data from ground weather stations exist only after 2012),
- data gaps for certain vulnerability indicators and limited availability of high-resolution socio-economic projections.

Stakeholder participation at this stage has been primarily institutional. In addition to supporting the assessment process, the municipality contributed critical infrastructure data and a structured set of identified risks and proposed measures, which are included in the Annex. Broader engagement with community groups and local actors is planned for future phases.

2.1.2 Context

- *How have climate hazards, impacts and risk been assessed and handled in your region until now?*
- *Describe the problem the project is trying to address and how this problem is placed in the context of the wider system (regional/national development)*
- *What is the governance context (policies, regulations, legal obligations, strategies, resources) of your region's or community's climate risk assessment*

- *Which sectors are relevant in your region and how might they be affected by climate change?*
- *Are there any outside influences on the problem? For example larger or nearby initiatives that may influence the problem*
- *What are possible adaptation interventions that can help meet objectives?*

Historically, the Municipality of Mantoudi-Limni-Agia Anna, situated in northern Evia, has increasingly faced significant climate hazards, including severe flooding along the Kireas River, recurring heatwaves, and destructive wildfires. Past incidents such as the catastrophic wildfires of August 2021 in northern Evia, which devastated vast forested areas within the municipality and forced large-scale evacuations, underscored critical vulnerabilities in emergency preparedness, spatial planning, and forest management. Similarly, repeated flood incidents in Mantoudi due to the overflow of the Kireas River, especially during storms like Ianos (2020), Diomidis (2022), and Elias and Daniel (2023), and Storm "Elena" (2024) have highlighted the region's exposure to hydrometeorological extremes. Despite growing recognition of these threats, assessments and management of climate risks in the municipality have remained largely reactive and fragmented, constrained by limited resources and the insufficient integration of climate change considerations into local planning and development processes.

The Mantoudi-Limni-Agia Anna RVA project aims to systematically address these growing climate vulnerabilities by implementing a structured, harmonized approach aligned with the broader European Union and national strategies for climate resilience. The key problem being addressed is the increasing vulnerability and exposure of Mantoudi-Limni-Agia Anna to climatic extremes—particularly floods and heatwaves—due to the combination of climate change impacts, inadequate spatial planning, aging infrastructure, and limited financial resources.

Within a wider regional and national development context, Mantoudi-Limni-Agia Anna's vulnerabilities are reflective of broader challenges faced by Greek municipalities, including economic constraints stemming from the prolonged Greek financial crisis. This crisis has hindered necessary infrastructural investments and reduced the capacity for proactive climate risk management. Furthermore, urban expansion and inadequate land-use management have increased environmental pressures, exacerbating the severity of impacts from extreme climate events.

The governance context of Mantoudi-Limni-Agia Anna is shaped by national policies and frameworks, including Greece's National Adaptation Strategy and the EU Mission on Adaptation to Climate Change. Local regulations, such as spatial and urban planning laws, civil protection guidelines, and environmental management policies, provide an operational context for integrating climate risk assessments into broader municipal governance structures.

Relevant sectors in Mantoudi-Limni-Agia Anna include urban infrastructure, public health, transportation (especially port infrastructure critical for tourism and commerce), environmental management, agriculture, and local economies dependent on tourism and fishing. These sectors face varying but substantial risks from climate change impacts, such as increased heat stress affecting human health, flooding disrupting transportation and infrastructure, as well as threats to ecological and residential zones, and adverse economic impacts from tourism disruption.

External influences affecting Mantoudi-Limni-Agia Anna's vulnerability include regional initiatives such as broader Evia climate resilience planning, national disaster risk reduction strategies, and EU-funded projects designed to enhance climate adaptation and sustainability. Collaboration with these external initiatives can provide beneficial synergy, data sharing, and resource optimization.

Possible adaptation interventions identified include the development and implementation of comprehensive early warning and emergency response systems, investment in cooling infrastructure and passive cooling solutions for buildings, improvement and expansion of drainage networks, sustainable floodplain management, integrated spatial and risk management planning, and extensive community education and awareness programs. These adaptation measures aim to significantly enhance Mantoudi-Limni-Agia Anna's resilience to future climate impacts, aligning local actions with broader regional and national adaptation goals.

2.1.3 Participation and risk ownership

Describe the first steps taken to set-up the stakeholder involvement process. Briefly describe relevant stakeholders for your project: this may refer to different levels of government, non-governmental organizations, citizens, the private sector, academia, and other relevant stakeholder groups. It is useful to present this in an organogram that maps the institutions and responsibilities and how they are interconnected.

- *Who are relevant representatives of known vulnerable groups or exposed areas (priority groups)?*
- *How is risk ownership regulated?*
- *What level of risk is acceptable to your community?*
- *How and who do you want to communicate your results to?*

The initial steps towards stakeholder involvement began with consultations targeting municipal departments essential to climate adaptation planning, including urban planning, civil protection units, and technical infrastructure services. These initial engagements have established the groundwork for a structured stakeholder management strategy, ensuring clarity of roles, responsibilities, and communication channels.

Relevant stakeholders identified various levels of governance and societal representation, including regional government authorities, civil protection agencies, and sector-specific municipal departments such as infrastructure and environmental management. Non-governmental organizations active in environmental protection, climate advocacy, and local development have been identified as crucial partners in facilitating community engagement and awareness.

Representatives of vulnerable and priority groups, including elderly residents, economically disadvantaged residents, and communities residing in coastal areas particularly exposed to flooding risks, have been prioritized for targeted consultations. Additionally, stakeholders such as local business owners (especially Small and Medium Enterprises -SMEs), urban planners, engineers, the Port Authority, emergency services (including firefighters and emergency action agencies like the national 112 service), and representatives from academia and schools have been recognized as key contributors due to their roles in urban functionality, education, and community mobilization.

Risk ownership is regulated through clearly defined responsibilities within the municipal governance structure, with the local Civil Protection Authority playing the central coordinating role. This coordination is supported by cross-departmental collaboration frameworks, facilitating integrated responses and proactive risk management strategies. Risk ownership mechanisms are formalized within the Municipality's Civil Protection Plan, which is undergoing updates to incorporate new climate risks identified through this assessment process.

The community's acceptable level of risk will be evaluated and reassessed through stakeholder dialogues, structured consultations, and periodic reviews of municipal policies and community surveys. This approach ensures that local perceptions, societal values, and risk tolerance levels inform the adaptive measures and strategies deployed.

Communication of the RIVA findings and outcomes will be strategically conducted through diverse channels tailored to the stakeholder profiles. These include structured technical reports for governmental and expert stakeholders, digital media and municipal websites for broader community engagement, and targeted participatory workshops aimed at vulnerable groups and sectors directly impacted by identified risks. Educational initiatives in collaboration with local schools and academia could be considered to enhance awareness, preparedness, and resilience-building across community levels, fostering a participatory and inclusive approach to climate adaptation.

2.2 Risk Exploration

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

2.2.1 Screen risks (selection of main hazards)

- *Which climate-related hazards and potential risks are relevant for your context?*
- *What is the current situation? Where is the hazard occurring? Who is being affected?*
- *Which hazards are observed/expected for the community/region? Explore the Copernicus Atlas (https://atlas.climate.copernicus.eu/atlas) and add a summary of the findings for your region*
- *Which hazards will you cover in this risk assessment? Why did your project decide to focus on these hazards?*
- *Which data or knowledge do you have on these hazards/impacts/risks? Which data, information or knowledge is further needed?*

The Municipality of Mantoudi-Limni-Agia Anna is particularly vulnerable to several climate-related hazards. Based on an extensive review of local climate data, historical incidents, and expert consultations, the following hazards have been identified as especially significant:

Heatwaves: Heatwaves are becoming increasingly frequent and severe in Greece, with studies such as Galanaki et al. (2023) showing a marked rise in frequency, intensity, and duration from 1950 to 2020, especially after 1990. Evia, including the Municipality of Mantoudi-Limni-Agia Anna, is identified as one of the country's heatwave hotspots, experiencing frequent and prolonged events. Although the municipality is predominantly rural and not densely populated—factors that somewhat limit direct health impacts compared to major urban centres—heatwaves still pose risks, particularly for vulnerable groups such as the elderly and those with pre-existing conditions. Agricultural production and biodiversity are also highly sensitive to prolonged periods of extreme heat. The urban heat island effect is less pronounced locally due to limited urbanisation, but the consequences of recent large wildfires have weakened the natural protective function of forest ecosystems. Vast areas of pine forest destroyed in 2021 no longer provide shade, evapotranspiration, or microclimatic regulation, thereby amplifying local exposure to extreme heat. This loss of natural buffers, combined with increasing numbers of days under extreme heat stress conditions, underlines the municipality's growing vulnerability. Prolonged heat events are also linked to reduced labour productivity, greater strain on water and energy resources, and deterioration of living conditions, even in semi-rural settings.

River and Coastal Flooding: Mantoudi-Limni-Agia Anna faces notable vulnerabilities associated with river and coastal flooding due to intense rainfall events and rising sea levels. Historically, the Kireas river, a crucial natural watercourse in Mantoudi, has experienced several severe flooding incidents (e.g., 26 March 1988; 22 February 2013; November 2016; 29 September 2018; December 2020; 27 September 2023; 25 December 2024). Anthropogenic interventions, urban expansion, and inadequate flood management practices have compounded these vulnerabilities, resulting in substantial damage to residential properties and critical infrastructure. Recent incidents during flood control construction works have further highlighted deficiencies in current flood management strategies. Local communities and environmental organizations have increasingly advocated for integrated and sustainable flood management practices that combine infrastructure improvements with ecological preservation.

Data and Knowledge Sources: For hazard identification and risk screening, multiple data sources were utilized, including the High Impact Weather Events database developed by the METEO Unit at the National Observatory of Athens, METEOME hazard simulations, and Copernicus datasets. Historical climate data and local weather observations provided detailed records of hazard occurrences, while available socio-economic vulnerability profiles helped highlight populations at greatest risk. Nonetheless, further detailed information and high-resolution data are required, including comprehensive socio-economic vulnerability assessments, improved projections of climate change impacts at the municipal level, and detailed evaluations of existing infrastructure resilience. These data enhancements will support more refined and effective risk analysis and adaptation planning in subsequent project phases.

Selected Hazards for Assessment: Based on the above, the climate risk assessment will specifically focus on two primary hazards:

- Heatwaves
- River and coastal floods

The assessment aims to evaluate these hazards comprehensively, considering their current and projected future impacts, and informing targeted strategies for improved resilience and adaptive capacity within the Municipality of Mantoudi-Limni-Agia Anna.

2.2.2 Workflow selection

Considering your hazard selection, identify the risk workflows relevant to your climate risk assessment. Additionally, identify the relevant vulnerable groups or exposed areas for each of the risks. Describe this information for each of the selected workflows.

The selected workflows for this CRA are:

2.2.2.1 **Workflow #1**: Heatwaves

The risk workflow for heatwaves includes:

(a) Scoping: define clear objectives based on the local context of Mantoudi-Limni-Agia Anna and establish boundaries for the analysis, specifically temporal (up to 2050), spatial (Municipality of Mantoudi-Limni-Agia Anna), and hazard definition (EuroHEAT methodology).

(b) Hazard analysis: Utilize climate hazard data and scenarios available from the CLIMAAX Handbook, particularly high-resolution temperature projections (EURO-CORDEX datasets) for RCP 4.5 and RCP 8.5, and apply EuroHEAT definitions to identify heatwave episodes, focusing on both daytime and nighttime temperature extremes during June–August. Calculate frequency, intensity, and duration indices of heatwave days based on future projections.

(c) Exposure and Vulnerability assessment: Identify critical exposure areas using population density, land use data, and key vulnerable groups (i.e, elderly, disadvantaged populations).

(d) Risk evaluation: Synthesize hazard, exposure, and vulnerability information to prioritize high-risk areas and populations for targeted adaptation and emergency response.

For the heatwave risk, the following vulnerable groups are identified:

(a) elderly and people with chronic illnesses who present a heightened risk of heat-related health issues due to compromised physiological resilience;
(b) low-income residents with limited access to air conditioning or adequate cooling infrastructure, increasing vulnerability;
(c) travelers and tourists with increased vulnerability during transit and exposure in areas around the port of Mantoudi-Limni-Agia Anna;
(d) school children who are exposed in school environments lacking adequate cooling facilities or green infrastructure.

For the analysis performed in this phase of the CRA we will focus the discussion on the available datasets of vulnerability and exposure available in CLIMAAX CRA Handbook.

2.2.2.2 **Workflow** : River and Coastal Floods

The risk workflow for river and coastal floods include: (a) risk identification: mapping of historical flooding events, climate data analysis on precipitation patterns, and sea-level rise projections; (b) risk analysis based on precipitation intensity, and sea-level scenarios; (c) risk assessment based on assessing population exposure, and potential impacts, with a particular focus on areas adjacent to riverbeds and coastal zones.

For the River and Coastal Floods risk, the following vulnerable groups and exposed areas are identified:
(a) residents near Kireas River and coastal neighborhoods who are directly exposed to flooding risks exacerbated by urban development and historically inadequate flood management practices;
(b) local businesses and SMEs (i.e., fuel stations) who are exposed to economic disruption due to infrastructure damage and interruption of commercial activities;
(c) public infrastructure, which is considered as critical infrastructure such as roads and public buildings facing increased flood exposure.

Through these risk workflows, the RIVA aims to generate a thorough understanding of the vulnerabilities and exposures specific to heatwaves and flooding within Mantoudi-Limni-Agia Anna Municipality. The findings will significantly contribute to shaping targeted local adaptation and resilience strategies, strengthening community safety, preserving ecological assets, and ensuring sustainable urban and economic development.

2.2.3 Choose Scenario

- *Which scenario assumptions are relevant for your region? Consider climate change, socio-economic developments such as population growth and economic activities, food and energy consumption and prices. This may include short-term (e.g., 5 years), medium-term (e.g., 20-30 years) and long-term (e.g., 50-100 years).*
- *Which scenarios available in the workflows are useful for your region?*

The scenarios applied include near-term (2030) and mid-term (2050) projections under RCP4.5 (moderate emissions scenario) and RCP8.5 (high emissions scenario). These consider temperature and rainfall trends, sea-level rise projections, and socio-economic factors such as population growth in the Municipality.

2.3 Risk Analysis

Describe how the selected risk workflows from the CLIMAAX Handbook were applied to your region. Which hazard, exposure and vulnerability data were used? Include the overview of the datasets in the tables below. For a broader overview of hazard, exposure and vulnerability datasets, consult the dedicated page in the Handbook: Datasets — CLIMAAX CRA Handbook[2]

Note: We recommend that you include only the necessary visual material (maps, graphs) to support your climate risk assessment. Additional material can be shared through the Zenodo repository.

[2] https://handbook.climaax.eu/CRA_steps/analysis/datasets.html
https://handbook.climaax.eu/CRA_steps/analysis/exposure_data.html
https://handbook.climaax.eu/CRA_steps/analysis/vulnerability_data.html#

2.3.1 Workflow #1- Heatwaves

Table 2-1 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
EuroHEAT	WorldPop	Landsat8 satellite	10x10 risk matrix
	High Resolution Population Density Maps + Demographic Estimates		

2.3.1.1 Hazard assessment

The primary objective of this climate hazard assessment is to comprehensively evaluate the evolving threat posed by heatwaves in the Municipality of Mantoudi-Limni-Agia Anna, leveraging high-resolution climate projections extending up to the year 2050. This detailed assessment employs the EuroHEAT methodology, an EU-wide standard that defines heatwaves based on significant health-related thresholds. Specifically, the method considers both daytime and nighttime temperature extremes, ensuring a holistic analysis of thermal stress experienced by the population during the warmest months of the year (June through August).

The assessment aims to deliver a structured and data-driven understanding of anticipated changes in the frequency, duration, and intensity of heatwave days under two distinct climate scenarios:

- RCP 4.5, representing a moderate emissions pathway where mitigation efforts significantly curb greenhouse gas emissions.
- RCP 8.5, which reflects a high emissions scenario corresponding to a business-as-usual trajectory with limited intervention measures.

By clearly identifying and comparing the projected trends and differences across these scenarios, this assessment aims to support the development of targeted, evidence-based adaptation strategies. Additionally, the insights derived will enhance local emergency preparedness measures and provide crucial guidance for municipal policy decisions. Ultimately, the goal is to effectively respond to and mitigate the growing public health challenges and infrastructure risks associated with extreme heat events, thereby improving community resilience and safeguarding the well-being of residents.

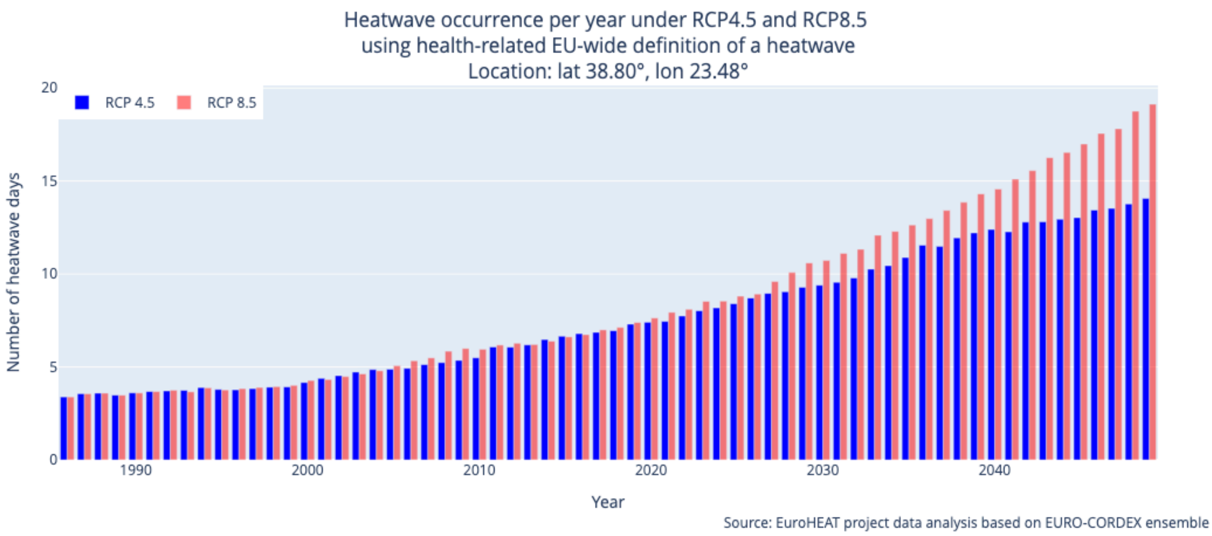

Fig. 2-1 Projected Evolution of Heatwave Days in Mantoudi-Limni-Agia Anna up to 2050 based on the EuroHEAT project data.

Figure 2-1 presents the projected number of annual heatwave days in Mantoudi-Limni-Agia Anna, Greece, using the health-related EU-wide heatwave definition. This definition classifies a heatwave day as one on which both daytime (Tmax) and nighttime (Tmin) temperatures exceed their respective 90th percentile thresholds for at least two consecutive days between June and August. The main findings based on Figure 2-1 are summarised below:

- Increase of annual heatwave days under both scenarios: Historically, the municipality experienced approximately 4–5 heatwave days per year during the last decades of the 20th century. Projections indicate a consistent upward trend in heatwave frequency across both climate scenarios considered:
    - By 2050, heatwave occurrences are projected to increase substantially to around 13–14 days per year under the moderate emissions scenario (RCP 4.5).
    - Under the high-emissions scenario (RCP 8.5), projections suggest a further increase to approximately 17–19 days per year.

- Mid-Century Divergence Between Scenarios: Initially, both RCP scenarios show comparable trends up until the early 2020s. However, a marked divergence becomes increasingly apparent after 2030. The higher-emission scenario (RCP 8.5) distinctly accelerates the heatwave frequency compared to RCP 4.5, illustrating significant implications and elevated risk levels associated with continuing current emissions trajectories without mitigation.

- Nonlinear Increase Under RCP 8.5: The increase of heatwave days under RCP 8.5 scenario intensifies notably from 2030 onward, indicating accelerated increases and rising risks of compounded heat stress events. This underscores the urgent need for effective climate mitigation and adaptive strategies to prevent severe health, ecosystems and infrastructure consequences.

Overall, the analysis underscores that immediate and effective climate action can substantially mitigate future heatwave risks. The lower heatwave frequency projected under RCP 4.5, especially post-2030, clearly demonstrates the significant benefit and reduced health risk achievable through proactive climate intervention measures.

2.3.1.2 Risk assessment

This analysis incorporates Landsat 8 satellite-derived land surface temperature (LST), population data, and vulnerability indicators to map hazard, exposure, and vulnerability, which are then combined into a spatial risk assessment map. The results highlight that the western and central inland parts of the municipality show High to Very High LST values, indicating intense heat accumulation (Fig. 2-2). In contrast, the eastern coastal zones appear less exposed, likely due to their proximity to the sea and the moderating influence of sea breezes.

The spatial pattern of overheating aligns strongly with the areas that were most severely affected by the 2021 wildfires. The destruction of dense pine forests has reduced natural shading and evapotranspiration, leaving soils and surfaces more exposed to direct solar radiation. As a result, these post-fire landscapes now record markedly higher LST values than coastal and still-forested areas.

Temperatures in these inland hotspots regularly exceed 40 °C during peak summer, particularly in early August. This underscores the dual vulnerability of Mantoudi-Limni-Agia Anna: the municipality is already subject to extreme heat conditions, and the loss of forest cover due to wildfires has significantly diminished its natural protection against overheating, increasing both environmental and human exposure.

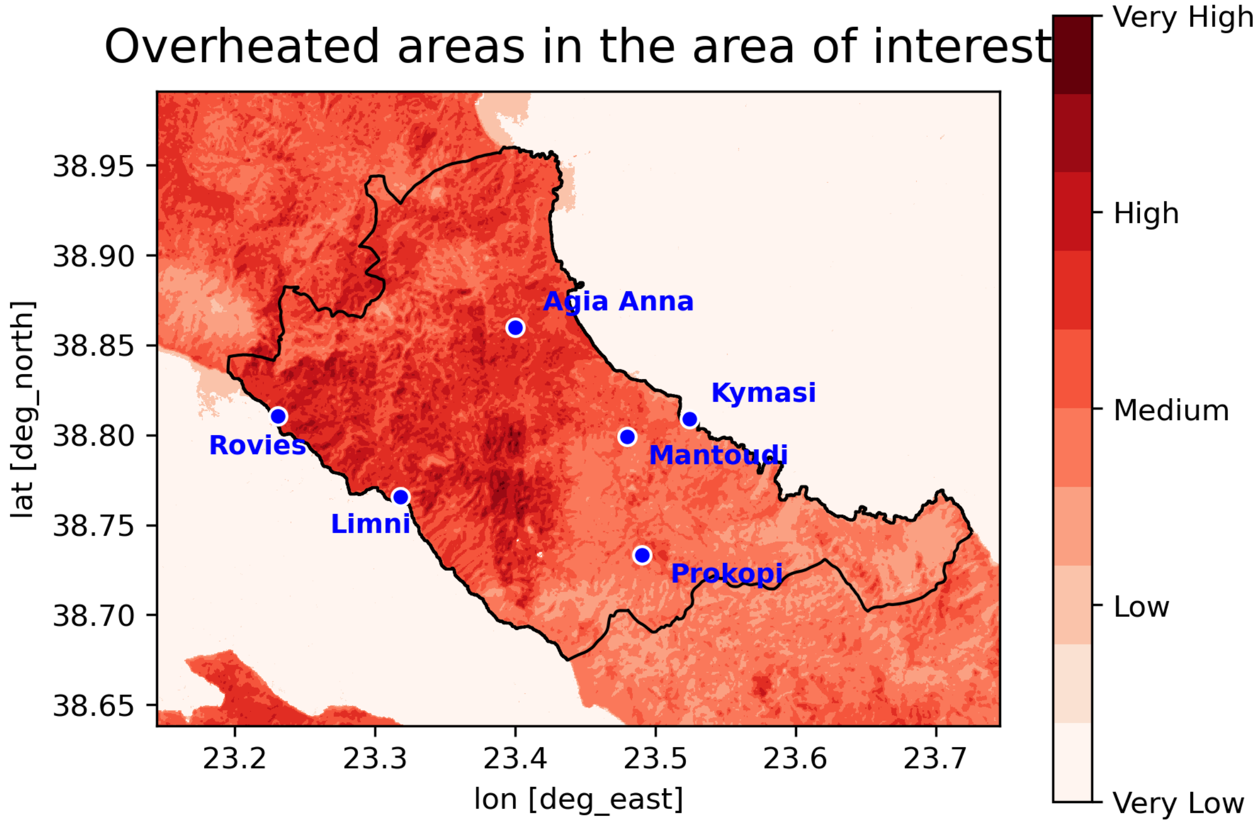

Fig. 2-2 Classification of Land Surface Temperature (LST) values into 10 groups: Very low [< 20-25°C], Low [25-35 °C], Medium [35-45 °C], High [45-55 °C], Very High [>55-60°C].

The time-series of LST mean values (Fig. 2-3) covering the period 2020–2025 (days with cloud coverage <50% and using ASTER-based emissivity) illustrates clear interannual variability in land surface temperatures. During the summers, values consistently rise above 35 °C, with peaks reaching or exceeding 40 °C, particularly in July and August. These results confirm that the Municipality of Mantoudi-Limni-Agia Anna is repeatedly exposed to intense heat episodes, which are expected to intensify under climate change.

A key feature of the dataset is the noticeable shift in thermal conditions after the catastrophic wildfires of August 2021. Before 2021, average summer LST values were comparatively lower, barely reaching 34 °C. Following the destruction of extensive pine forest cover, maximum LST peaks increased markedly, with several observations reaching 40 °C. The loss of dense forest canopy has reduced shading, evapotranspiration, and the natural regulation of local microclimates, exposing bare soils and burned surfaces to direct solar radiation.

This post-fire increase in land surface heating highlights the dual vulnerability of the municipality: first, to direct climatic pressures from more frequent and intense heatwaves, and second, to the degradation of ecosystem services that previously buffered extreme heat. The combined effect not only amplifies local exposure but also exacerbates risks for agriculture, biodiversity, and human well-being, even in a predominantly rural setting.

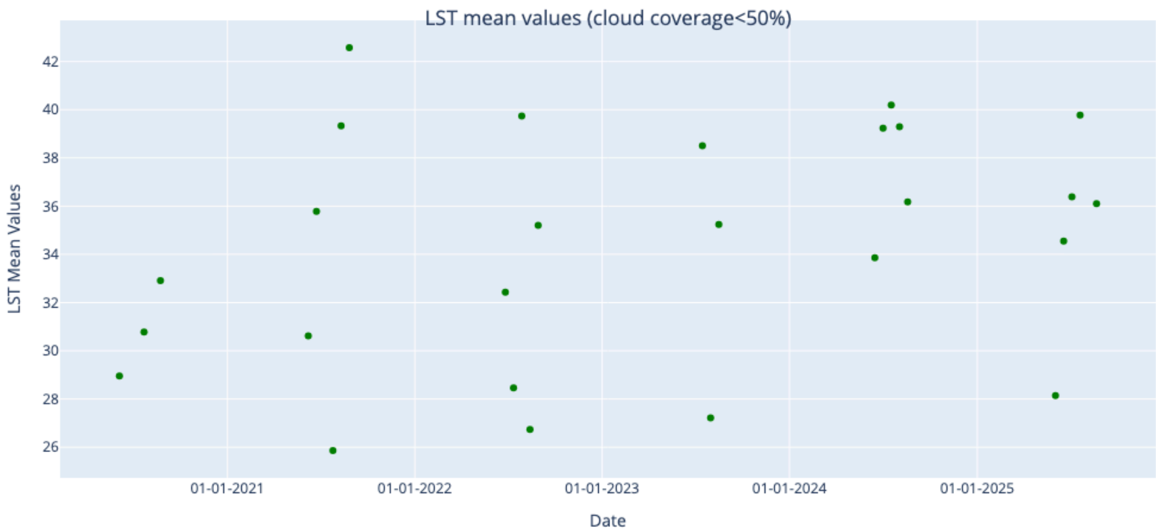

Fig. 2-3 Land surface temperature mean values for the Municipality Mantoudi-Limni-Agia Anna, per Landsat8 image. Only the days corresponding to the LST pictures with cloud coverage lower than 50% are plotted.

Figure 2-4 presents the spatial distribution of overheated areas (exposure) and population density (vulnerability) within the Municipality of Mantoudi-Limni-Agia Anna. The exposure map indicates that the western and central inland zones experience High to Very High levels of overheating, consistent with areas affected by recent wildfires and reduced vegetation cover. In contrast, the eastern coastal areas are characterized by Low to Medium exposure, benefiting from sea breeze effects and less heat accumulation.

The vulnerability map, based on population density, shows that the municipality is overall sparsely populated, with pockets of higher density in the eastern-central part, which are flagged as High to Very High vulnerability. Smaller clusters of settlements in the central inland area display Medium to High vulnerability, while most coastal and mountainous regions remain Low to Very Low due to low population presence.

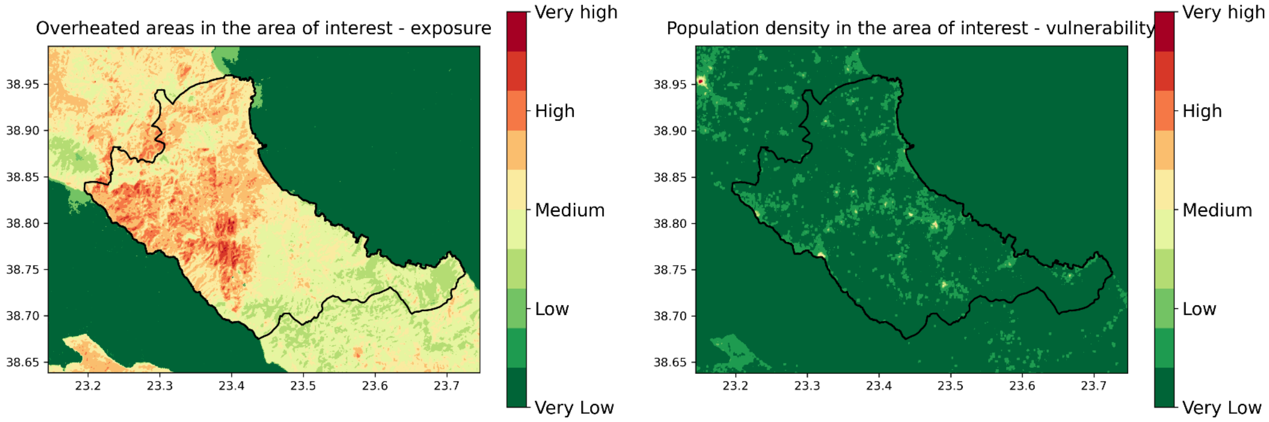

Fig. 2-4 The most overheated areas together with the population density of the vulnerable groups of the population (ages 0-5 and 65-90).

Using the risk matrix methodology shown in Fig. 2-5 that combines exposure and vulnerability, we have calculated the heat risk level provided in Fig. 2-6.

Risk matrix 10+10

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

Vulnerable population density

Fig. 2-5 Vulnerability vs Heat Exposure based on LST.

Figure 2-6 illustrates the possible heat risk level to vulnerable populations across the Municipality of Mantoudi-Limni-Agia Anna, combining exposure and vulnerability layers through the risk matrix (Fig. 2-5). The map also overlays the locations of critical infrastructure as provided by the municipality, including schools, health facilities, municipal buildings, fire and police stations, and other essential services.

The results show that most critical facilities are located in zones of Low to Medium heat risk, particularly in coastal settlements such as Limni and Rovies, where sea breezes moderate land surface temperatures. However, inland areas with higher population density and limited vegetation cover correspond to Medium to High risk, notably around Mantoudi, Prokopi, and Agia Anna. In these settlements, clusters of schools and municipal buildings coincide with elevated risk zones, highlighting the vulnerability of both sensitive population groups (e.g., children, elderly) and essential service providers.

The analysis further indicates that some health and fire service facilities in Mantoudi are situated in areas of Medium to High heat risk, which may compromise their operational resilience during prolonged heatwaves. Schools scattered across the inland core, particularly near Mantoudi and Prokopi, also fall within areas of increased heat exposure, suggesting a need for targeted adaptation measures.

In summary, while the municipality's coastal infrastructure enjoys relatively lower exposure, critical inland services—especially schools, health, and emergency response facilities—are disproportionately at risk, requiring priority consideration in future adaptation and resilience planning.

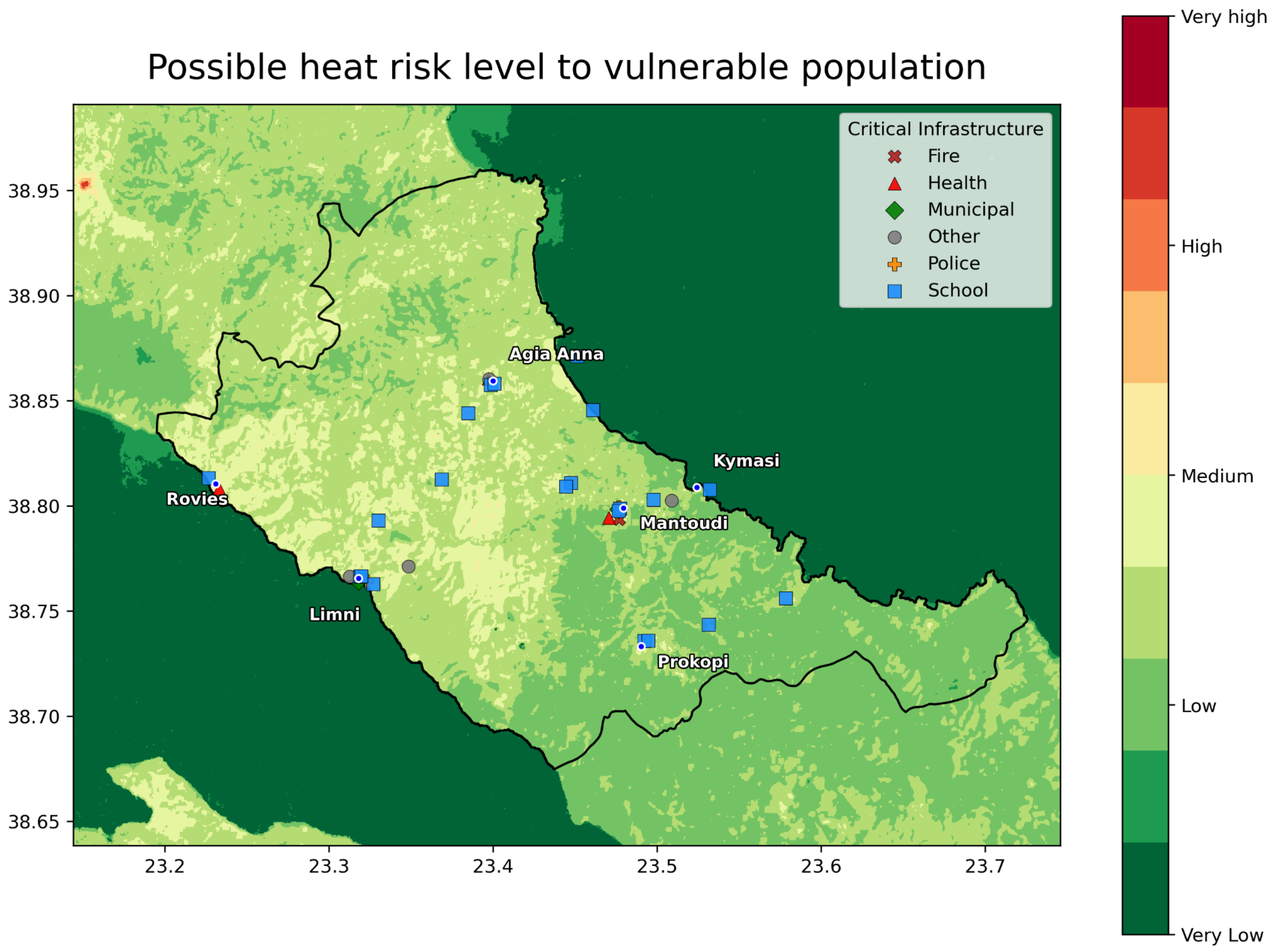

Fig. 2-6 Possible heat risk level to vulnerable population, derived by multiplying the exposure by vulnerability and using the Risk Matrix in Figure 2-5.

The intensification of heatwaves projected for the municipality is expected to further aggravate extreme fire weather conditions. Higher summer temperatures, in combination with already degraded post-fire landscapes, create an environment where vegetation dries out more quickly and fuels become more flammable. This trend is evident in the projected increase in the number of days with Fire Weather Index (FWI) > 30, a threshold indicating high fire danger. Within the municipal boundary, historical conditions (1980-2010) already showed a substantial number of high-risk days, and under RCP8.5 (2030–2050), these are projected to rise further, lengthening the fire season and increasing the likelihood of extreme fire behavior. In the Annex, we present the relative change in the number of elevated FWI days, confirming that the inland core of Mantoudi-Limni-Agia Anna will face a longer and more hazardous fire season in the coming decades.

2.3.2 Workflow #2 River and Coastal Floods

Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Global Tide and Surge Model results (GTSMv3.0)		Digital Elevation model SRTM	Coastal flood risk
JRC's high-resolution flood maps (present)	LUISA Land cover	Population GHS-POP R2023A dataset	Flood and population risk maps
Aqueduct Floods coarse-resolution flood maps (future)		OpenStreetMap Building data Critical infrastructure data	Building damage risk maps Population displacement risk Critical infrastructure exposed

2.3.2.1 Hazard assessment

2.3.2.2 River floods

The analysis followed the standardized methodology of the CLIMAAX Handbook for River and Coastal Flooding, employing workflows for hazard identification, risk calculation, and land cover exposure. The objective was to characterize flood hazards across a range of present and future climate scenarios and to estimate potential damages under different return periods.

Despite the application of established modeling tools, the outputs did not fully reproduce the documented historical flood behavior in the municipality. In particular, the Kireas River, known for destructive flash floods such as the severe 2024 event, was not adequately represented in terms of rapid-onset flood dynamics. This limitation is linked to the coarse resolution and generalized typologies of the JRC Global Flood Maps and Aqueduct Floods datasets used in the CLIMAAX workflows.

Nevertheless, the JRC present-day flood hazard maps (ca. 2018) highlight the Kireas River basin near Mantoudi and Kymasi Port as the only area within the municipality with significant modeled flood potential (Fig. 3-1). Other parts of Mantoudi-Limni-Agia Anna do not appear to face notable river flood hazards under the available datasets, which justifies the focus of this assessment on this localized hotspot.

The maps show increasing inundation extent and depth with longer return periods:

- For a 1-in-10 year event, flooding is limited but already visible along the Kireas riverbed.
- For a 1-in-50 year event, inundation expands into adjacent low-lying zones, including areas around Mantoudi.
- For a 1-in-100 year event, extensive flooding is modeled, with inundation depths locally exceeding 5 meters, particularly near the river outlet and surrounding floodplain.

These results confirm the Kireas stream corridor as the municipality's most critical river flood risk zone, threatening residential areas, infrastructure, and economic activities around Mantoudi and Kymasi Port. Validation against municipal records and historical flood extents suggests that the models capture well the broad location of flood-prone areas, but they also highlight the need for future refinement with higher-resolution, locally calibrated hydrological and topographic data.

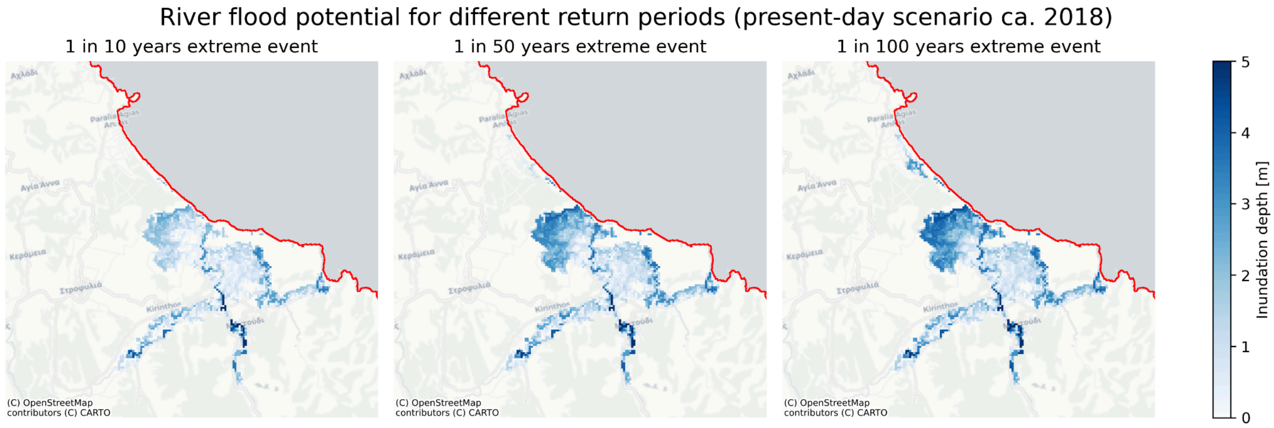

Fig. 3-1 River flood potential depth (m) for return period= 10, 50, and 100 years in the present climate (ca.2018).

For future river flood projections under both RCP4.5 (Fig. 3-2) and RCP8.5 (Fig. 3-3) scenarios up to 2080, the hazard maps show minimal expansion of flood-prone zones. Inundation is consistently concentrated in a narrow corridor near the Kireas River mouth and adjacent lowlands, with modeled depths remaining well below 0.2 m and rarely exceeding 0.3–0.4 m under extreme return periods. The comparative maps (lower panels) demonstrate only negligible differences in inundation depth compared to the 1980 baseline, with localized increases on the order of just a few centimeters.

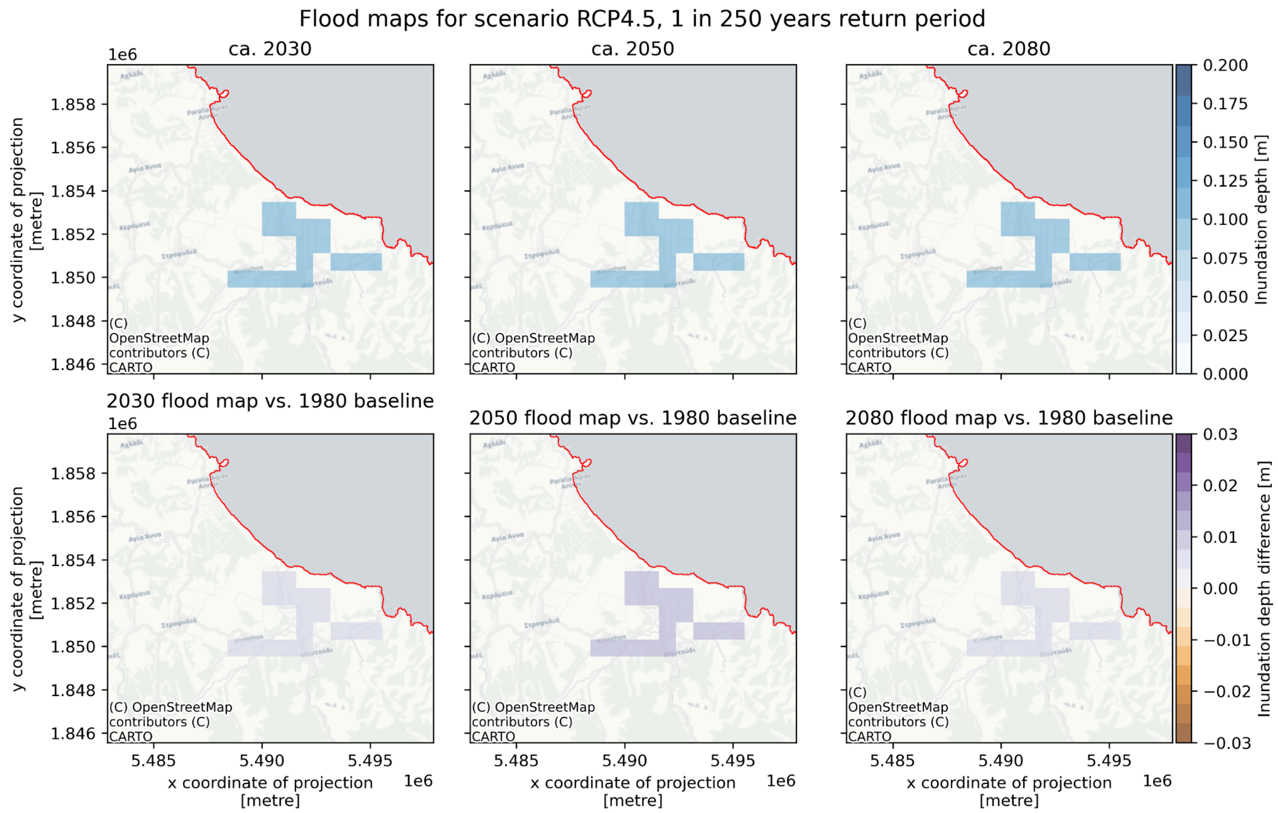

Fig. 3-2 Inundation depth (m) for climate scenario RCP4.5 for an event with a return period 250 years in 2030, 2050 and 2080 (upper row) and inundation depth difference (m) with respect to 1980 baseline.

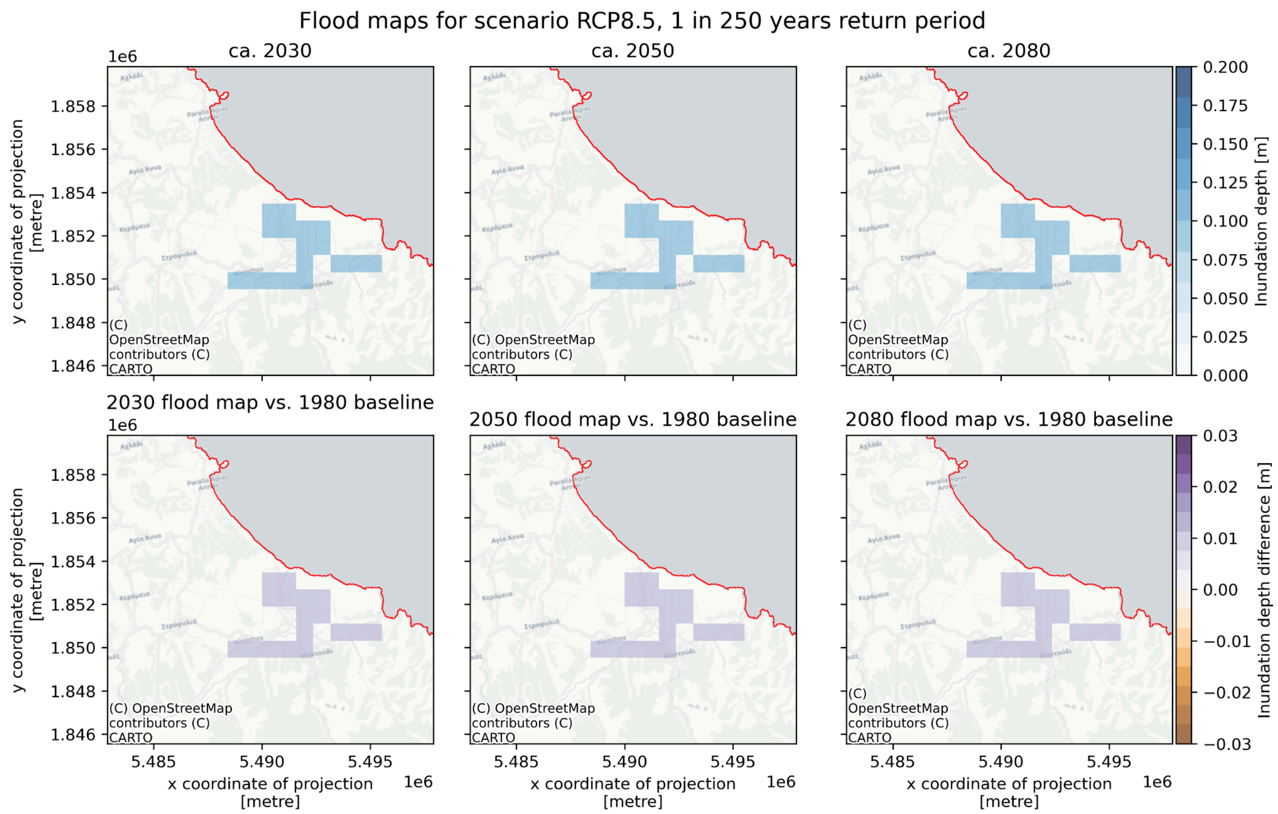

Fig. 3-3 Inundation depth (m) for climate scenario RCP8.5 for an event with a return period 250 years in 2030, 2050 and 2080 (upper row) and inundation depth difference (m) with respect to 1980 baseline.

These results indicate that, according to the CLIMAAX methodology, river flood risk is not projected to intensify significantly under future climate conditions, even for a 1-in-250 year event. The outputs suggest only marginal changes by 2030, 2050, and 2080, with no meaningful spatial expansion of inundation areas. In contrast, independent historical evidence—including the 2024 Kireas flash flood and subsequent municipal reports—confirms that the basin is highly flood-prone, highlighting a major disconnect between modeled and observed risk.

The failure of the CLIMAAX river flood methodology to replicate the known flood dynamics of Mantoudi-Limni-Agia Anna can be attributed to several structural limitations:

- Insufficient topographic resolution – The reliance on global DEM datasets (MERIT DEM, HydroSHEDS) smooths out small river channels and steep slopes, omitting key flow pathways such as the Kireas stream corridor.
- Flood typology mismatch – The applied models simulate large-scale, steady-state riverine overflow, while local floods are flash-flood driven (short-duration, high-intensity rainfall leading to pluvial and debris-laden flows).
- Simplified exposure representation – The LUISA land cover dataset (Fig.7-2), while suitable for regional-scale studies, lacks the granularity to represent local urban fabric, roads, schools, and critical assets known to be exposed.
- Validation discrepancies – Comparisons with observed flood extents reveal systematic underestimation: areas known to flood around Mantoudi and Kymasi are shown in the model as largely unaffected.

As a result, the projected hazard maps do not provide a reliable basis for local adaptation planning, since they understate both present and future flood risk in the municipality. For meaningful decision-making, future work must incorporate high-resolution topographic data, locally calibrated hydrological models, and explicit pluvial/flash flood processes to reflect the true nature of flood hazards in Mantoudi-Limni-Agia Anna.

2.3.2.3 Coastal floods

This assessment evaluates the coastal flooding hazard for the Municipality of Mantoudi-Limni-Agia Anna, following the standardized methodology of the CLIMAAX Handbook. The approach uses historical extreme sea level statistics to estimate current hazard levels for specific return periods, providing a baseline for coastal planning, flood protection, and adaptation to future SLR.

The analysis applies the CLIMAAX Coastal Flooding Workflow, which derives extreme water levels from modeled sea level time series (1979–2018) using a Generalized Extreme Value (GEV) distribution. Results are expressed relative to Mean Sea Level (MSL) around the year 2000, with future SLR added separately to generate 2050 projections. Given the absence of modeled inundation along other coastal stretches of the municipality, the Agia Anna beach zone has been identified as the primary focus for coastal flood risk management and adaptation planning.

Key features of the methodology:

- Water level extremes are calculated relative to MSL around the midpoint of the dataset (approximately the year 2000).
- The values do not include future sea level rise, which must be added separately for future projections.
- The results are expressed as height above MSL for different return periods (i.e., how often a given extreme water level is statistically expected to occur).

Based on the closest station in the Copernicus Climate Data Store database, the estimated extreme water levels above MSL in the coasts of Mantoudi-Limni-Agia Anna Municipality are:

- **0.5 m for a 5-year return period event –** representing a moderate but recurring flood risk, which may affect low-lying coastal infrastructure, particularly when combined with storm surge or high tides.
- **0.7 m for a 100-year return period event –** representing a rarer but more severe event, with potential high impacts for ports, roads, and waterfront development.

To further investigate the coastal flood potential, we processed the Global Flood Maps data via the Microsoft Planetary Computer, available for the present-day climate (ca. 2018) and future climate.

Using a Digital Elevation Model (MERIT DEM, 90 m resolution), flood extents and depths were modelled for:

- Return periods from 2 to 250 years
- Present-day (ca. 2018) and projected 2050 scenarios
- Water level scenarios adjusted for projected SLR in 2050

The results reveal that coastal inundation is spatially limited to the low-lying beachfront of Agia Anna, which emerges as the municipality's only significant coastal flood hotspot. Here, inundation depths may reach up to 1 meter under higher return periods and 2050 SLR-adjusted conditions, affecting commercial buildings, municipal car parks, access roads, and port facilities immediately adjacent to the shoreline. Importantly, floodwaters remain confined to the immediate coastal fringe and do not extend inland toward major infrastructure or densely populated settlements.

Figure 3-4 compares modeled flood extents for extreme water levels in 2018 and 2050 for the Agia Anna region, the only coastal sector of Mantoudi-Limni-Agia Anna Municipality where inundation was detected. The results show that even modest water depths—up to 1 meter along the beachfront—can have disproportionate consequences for critical assets. While most buildings are likely to avoid major structural damage at these depths, disruption to port facilities, municipal car parks, and coastal access roads is highly probable.

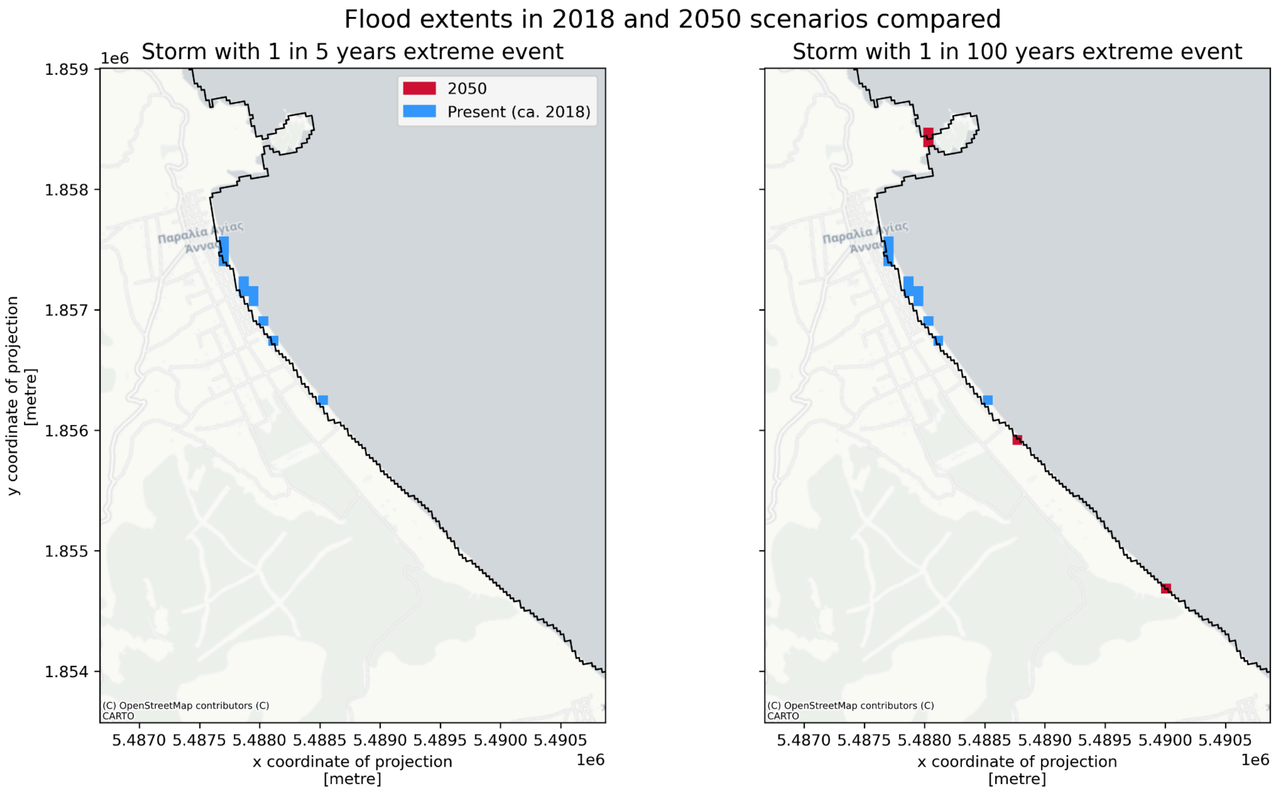

Fig.3-4 Flood extent in extreme water level in 2018 and 2050 scenarios with different return periods, for Agia Anna region, in the Northeastern part of the municipality.

Figure 3-5 illustrates the progression of coastal flood potential across different return periods (1-in-2, 1-in-10, and 1-in-100 years) for both 2018 and 2050. The following patterns are evident:

- 1-in-2 year return period: Minimal but recurrent inundation, consistent with nuisance-level flooding along the seafront.
- 1-in-10 year return period: Noticeably higher depths, placing transportation routes and coastal businesses at regular risk.
- 1-in-100 year return period: The broadest extent and deepest water levels, particularly under the 2050 scenario, producing the most severe impacts.

The comparison between 2018 and 2050 scenarios confirms that flood depths increase systematically over time for the same return period, reflecting the combined effects of rising MSL and potentially more intense storm surges.

Overall, the results demonstrate that coastal flood risk in the municipality is spatially confined to Agia Anna, but that within this zone, even moderate SLR and storm surge conditions could significantly affect local infrastructure and economic activity. This underlines the importance of prioritising flood-resilient planning, shoreline protection, and emergency response strategies for this specific hotspot.

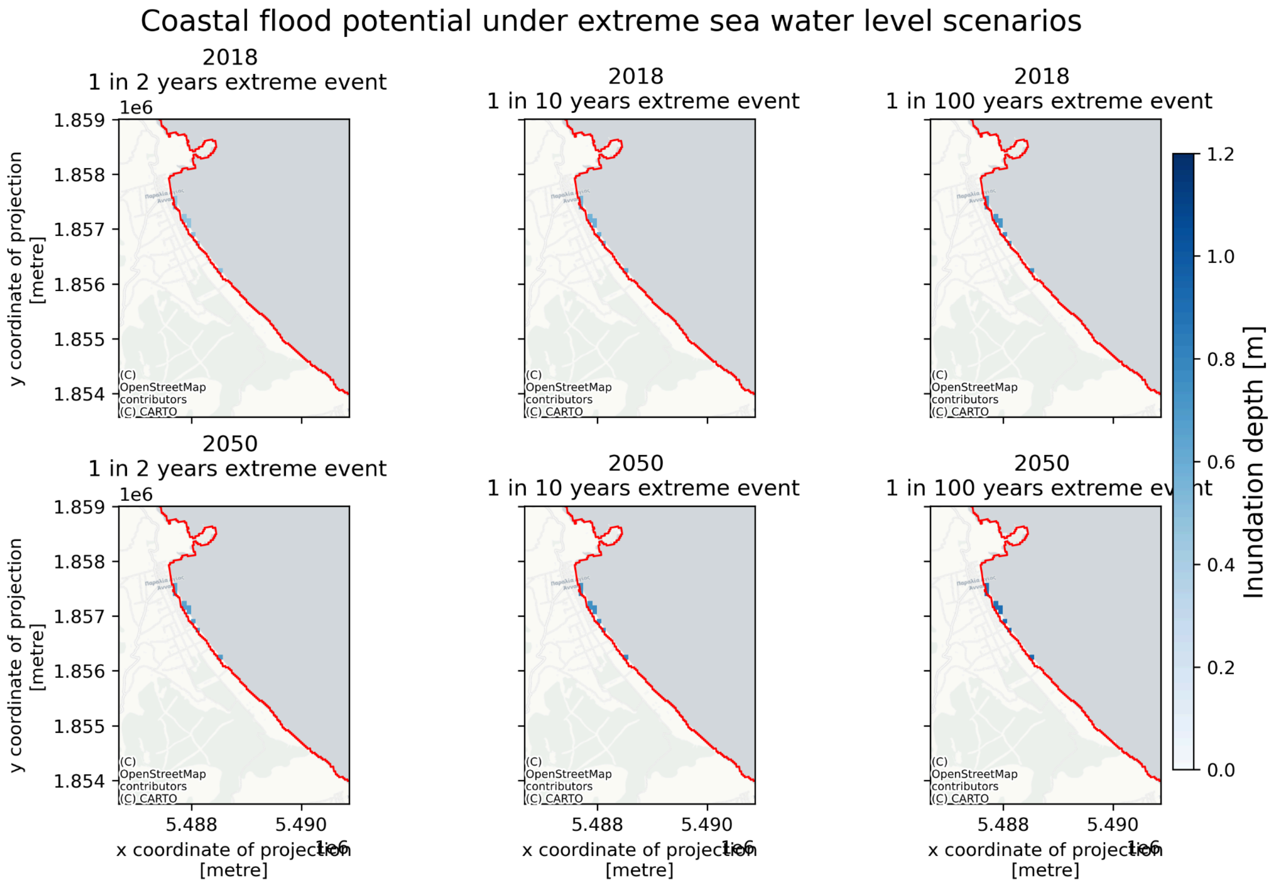

Fig. 3-5 Coastal flood potential under extreme sea-water level scenarios in present (2018) and future climate (2050) for Agia Anna region, in the Northeastern part of the municipality.

2.3.2.4 Risk assessment

The risk assessment, which combines hazard outputs with exposure layers and economic damage models, shows minimal to moderate damage potential, with a few critical observations:

Building Exposure and Damage

The integration of LUISA land cover (Fig.7-2), OSM building datasets, as well as the critical infrastructure data provided by the stakeholders, allowed estimation of direct economic damages. Due to the very high flood hazard in riverine zones and coastal flood hazard in touristic areas (i.e. Fig. 3-6), the estimated flood damages are very high, with values over €10 million even for the least extreme events in 2050.

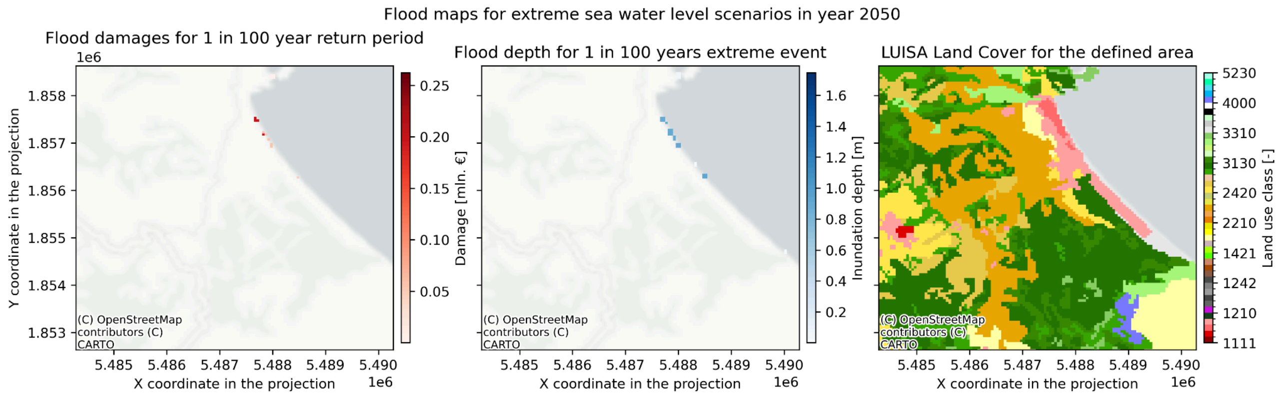

Fig. 3-6 Coastal flood damage potential (mil Euros), Flood depth potential (m) for an event with a return period equal to 100 years, and the LUISA Land Cover in Agia Anna region, in the Northeastern part of the municipality.

The damage-to-return period confirms that total direct damages could exceed €25 million for a 1-in-500 year flood, with the mean Expected Annual Damage (EAD) being approximately €1.57 million. This is consistent with known past damages in the Mantoudi-Limni-Agia Anna urban core, reflecting a good estimation of both hazard and exposed asset values.

Damage for Mean depth and corresponding return period events in years (RP):

- RP=10: Total damage (€) = 11,225,179
- RP=50: Total damage (€) = 18,122,297
- RP=100: Total damage (€) = 21,112,159
- RP=500: Total damage (€) = 28,640,041

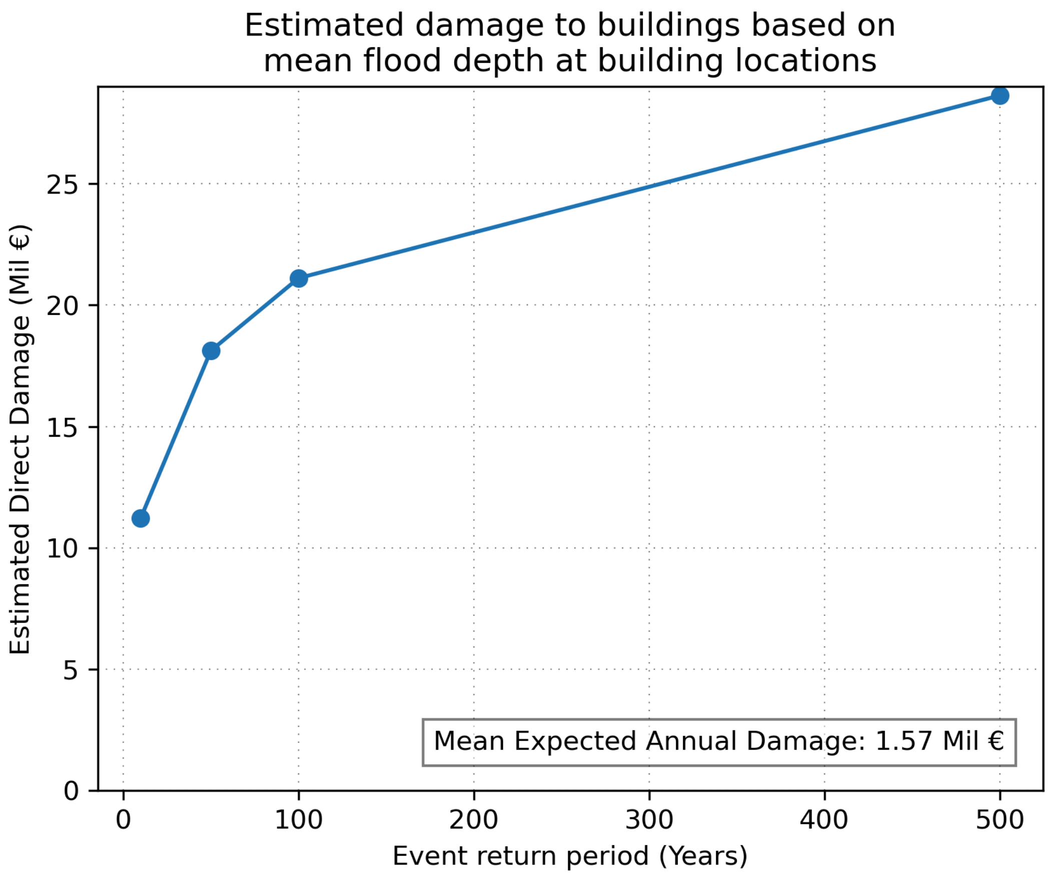

Fig. 3-7 Building damages vs return periods of the flood, for mean flood depth.

<u>Critical Infrastructure Risk</u>

The assessment of critical infrastructure exposure to flooding under 10-year and 500-year return periods highlights substantial risks for Mantoudi-Limni-Agia Anna (Figs. 3-8 and 3-9).

The flood hazard maps indicate that:

- For the 10-year event, inundation depths already reach several meters in localized areas near Mantoudi, with floodwaters extending into the urban core and surrounding infrastructure corridors.
- For the 500-year event, inundation becomes widespread, with depths exceeding 4 meters in some locations, covering larger swaths of the Mantoudi basin and coastal plain.

When overlaid with the population raster for 2025, the results confirm that several critical assets and population clusters fall within the flood-prone zones. These include:

- Main transportation routes, which traverse low-lying corridors vulnerable to river overflow, creating potential isolation of settlements.
- Commercial buildings and fuel stations, several of which are located within inundated areas, exposing both economic activities and safety-sensitive facilities.

- Healthcare and emergency service sites, which are indirectly affected due to their proximity to road networks and flood-affected districts.

This outcome appears reliable in terms of road and commercial building exposure, since these structures are situated in historically flood-prone zones and at a considerable distance from the main Kireas stream channel—consistent with reported flash-flood behavior in the area.

Overall, the analysis underscores that critical infrastructure in Mantoudi is highly exposed to flooding, particularly under high return period scenarios, where deep and widespread inundation would compromise mobility, service delivery, and economic continuity.

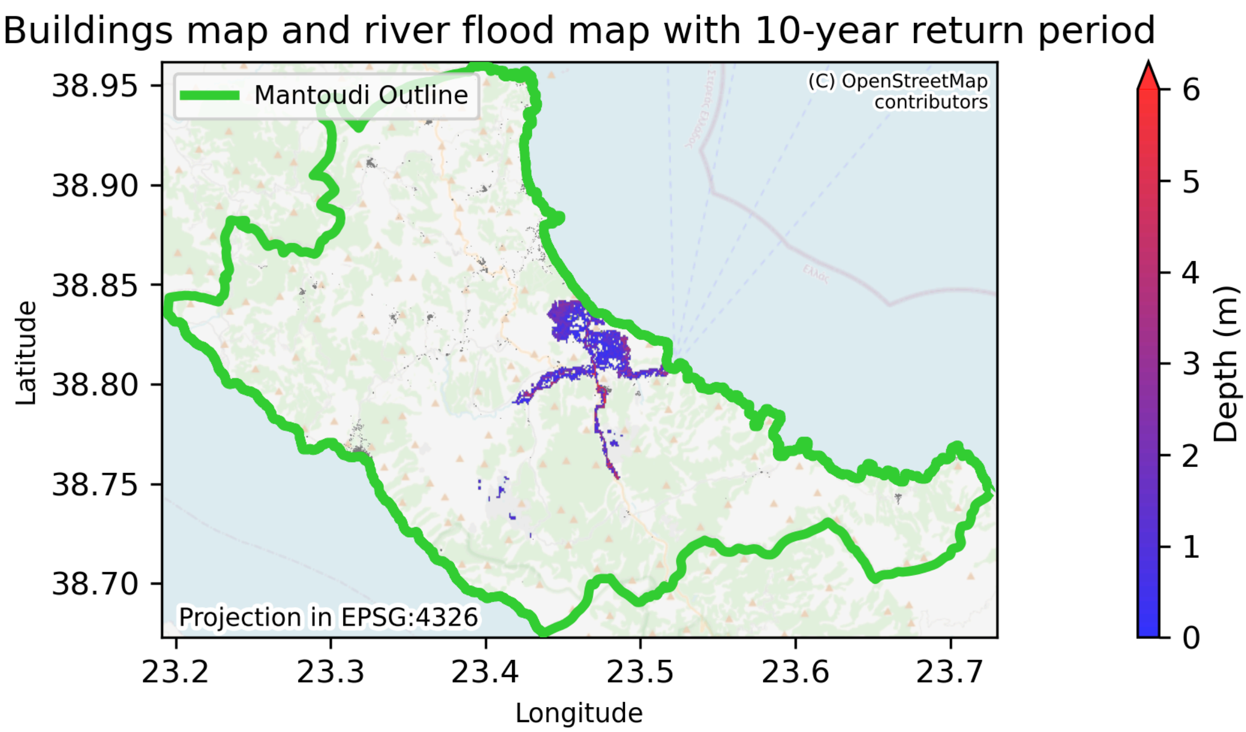

Fig. 3-8 Buildings and river flood depth (m) for an event with a return period of 10 years.

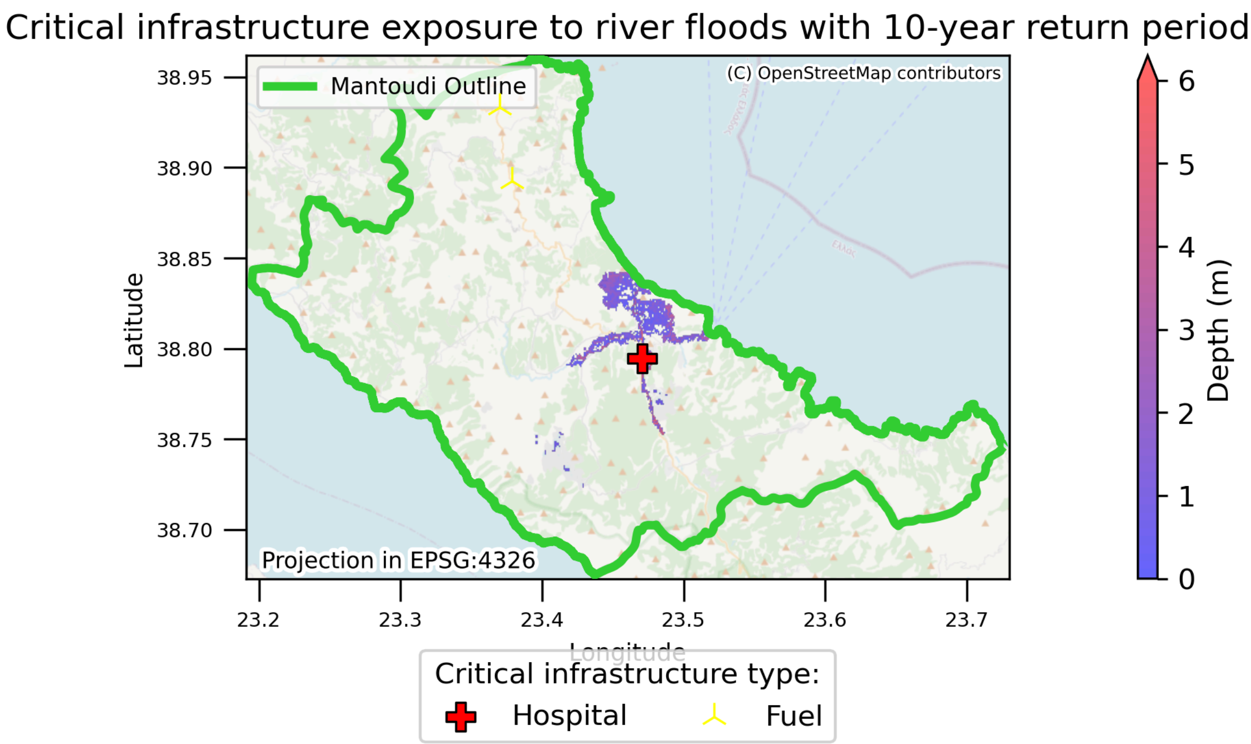

Fig 3-9 Hospital and fuel stations position, and river flood depth (m) for an event with a return period of 10 years.

Population Exposure

The 2025 population raster, when overlaid with the simulated flood extents, shows limited population exposure, as most populated areas fall outside the modeled hazard zones. This is largely a result of the flawed hazard input layers, which underestimate known flood-prone settlements in Mantoudi-Limni-Agia Anna, and highlights the importance of calibrating models with observed events.

Nevertheless, the mean annual estimates are informative: the analysis suggests an **Expected Annual Population Exposed of 57 people** and an **Expected Annual Population Displaced of 34 people.** These values, while relatively low, capture the average yearly burden of flood risk and indicate that a non-negligible share of residents are consistently at risk of disruption. However, they do not fully reflect the severity of extreme flash-flood events, which can displace far larger populations during single occurrences.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

- *How severe is the risk, considering historic and current trends or potential impacts?*
- *Is your respective climate risk high in impact and/or frequency in your region/community? E.g., high human loss, large areas affected, massive financial damage, important sectors affected, roads blocked.*

- *Does your respective climate risk possibly unleash irreversible consequences (e.g., human loss, destruction of ecosystems) or cascading effects (e.g., disease outbreak, social unrest)? E.g., human loss, loss of industrial or economic areas, destruction of ecosystems and biodiversity, loss of agricultural land.*

The heatwave risk assessment for the Municipality of Mantoudi-Limni-Agia Anna highlights a clear and escalating threat, intensified by rising temperatures, wildfire-driven landscape changes, and uneven patterns of vulnerability across the municipality. By integrating high-resolution climate projections, satellite-derived LST data, and demographic indicators, the analysis shows that the region is already experiencing, and will increasingly face, extreme heat episodes—particularly under high-emission scenarios.

The primary hazard identified is the increasing frequency, duration, and intensity of heatwaves, as defined by the EuroHEAT methodology. Projections indicate that by 2050, the average annual number of heatwave days will rise from a historical baseline of 4–5 days to 13–14 days under RCP4.5 and to 17–19 days under RCP8.5, reflecting a more prolonged and hazardous thermal environment. The divergence between scenarios becomes pronounced after 2030, with RCP8.5 showing a steeper acceleration in extreme heat events, underscoring the risks of a high-emission trajectory.

Spatial analysis reveals that the most overheated zones coincide with areas severely affected by the 2021 wildfires (see Annex), where the loss of forest cover has reduced natural cooling capacity. Vulnerability is highest in inland settlements with higher population density, in areas with limited vegetation or shading, and within the urban fabric of Mantoudi, Limni, and Agia Anna, which—despite their relatively small size—exhibit localized heat island effects. Kymasi Port, which handles large seasonal tourist flows, is also flagged as an area of concern. Without proactive adaptation, the municipality risks facing heightened public health impacts, reduced labor productivity, and stress on infrastructure and emergency services. These findings emphasize the need for local heatwave adaptation strategies, improved urban planning, and targeted protection for vulnerable groups.

The municipality is also exposed to two distinct flooding hazards: riverine flash floods and coastal inundation. River flooding, especially in the Kireas River basin, poses a well-documented risk, with past flash-flood events causing severe damages. However, the CLIMAAX river flood models underestimate flood extents across all return periods (10, 50, and 100 years for present-day; 250 years for 2030, 2050, and 2080). As a result, modeled damages, projected population exposure or displacement exposure should be treated with caution. This misrepresentation reinforces the urgent need for locally calibrated flash flood models that capture the real dynamics of intense rainfall, rapid runoff, and debris transport.

The coastal flood assessment produces credible outputs. Inundation is concentrated around Agia Anna's low-lying coastal zone, with measurable flooding projected under multiple return periods. Depths are modest under present-day conditions but increase steadily with both return period and sea level rise, reaching up to ~1 meter by 2050 in localized hotspots. While the spatial footprint of flooding is confined to the coastal fringe, the impacts on critical infrastructure—including port facilities, municipal car parks, and transportation links—are significant. Even shallow inundation (<0.5 m) can severely disrupt mobility, logistics, and emergency response.

Although modeled direct damages are significant—exceeding €11 million for a 1-in-10 year event and rising to nearly €29 million for a 1-in-500 year event—these figures likely still underestimate the full scope of losses. Indirect impacts linked to operational downtime, tourism disruption, and cascading failures in transport or drainage systems are not captured in the models but could substantially amplify total damages. The inclusion of projected sea level rise further highlights the growing importance of coastal flood risk by mid-century, reinforcing the urgency of integrating flood-resilient design and adaptation measures into local planning.

In summary, the findings confirm that riverine flooding represents the most pressing and well-characterized climate hazard in Mantoudi-Limni-Agia Anna, requiring immediate adaptation actions. Together, these results provide a robust baseline for targeted resilience planning, but also underline the necessity of enhancing data resolution, calibrating hazard models, and integrating local knowledge in the next phases of the project.

Key Takeaways

- **Heatwaves:** Projected to increase to 13–14 days/year (RCP4.5) and 17–19 days/year (RCP8.5) by 2050. Highest risk in wildfire-affected inland areas and high-exposure sites such as Kymasi port. Immediate adaptation needed (cooling, early warning, urban greening).
- **River floods:** Historically the most destructive hazard, especially in the Kireas River basin. Current CLIMAAX models capture flood dynamics, producing realistic damage and exposure estimates. On the other hand, model projections for the next 30 years require higher resolution numerical models, locally calibrated, and integration of municipal flood records in order to realistically capture the future changes in flood dynamics.
- **Coastal floods:** A localized but credible hazard, primarily affecting Agia Anna beach and local port. Inundation depths may reach ~0.7 m by 2050, threatening transport routes, municipal car parks, and tourism assets. Damages are moderate in models but likely underestimate indirect disruptions.
- **Overall:** Mantoudi-Limni-Agia Anna faces intensifying heat stress, significant river flood risk, and localized coastal flood threats. The results form a solid baseline for adaptation planning but highlight the urgent need for higher-resolution data, model calibration, and locally grounded risk assessments.

2.4.2 Urgency

- *When will these risks have a major impact? When would you need to take action to minimize damages?*
- *Is your respective climate hazard expected to worsen significantly in the near future?*
- *Is your respective climate hazard associated with sudden events (e.g., heavy rain) or with slow onset processes (e.g., sea level rise)? How may this influence your urgency scoring?*
- *Does your respective climate hazard have the potential to persist?*

The Municipality of Mantoudi-Limni-Agia Anna faces significant and immediate impacts from the two primary climate risks assessed: heatwaves, and river and coastal flooding.

Heatwaves represent a clear and immediate threat, driven by steadily rising temperatures and increasing frequency and intensity of extreme heat events, especially under the RCP8.5 scenario. This risk requires urgent short-term actions, such as the immediate implementation of effective early-warning systems and the enhancement of existing cooling infrastructure in critical locations (e.g., healthcare facilities, elderly care homes, schools, and densely populated urban neighborhoods). Medium-term planning should prioritize widespread adoption of passive cooling techniques in building designs and urban planning strategies (e.g., expansion of green areas), aiming to significantly reduce urban heat stress and improve overall community resilience to extreme heat.

River and coastal flooding pose both immediate and evolving risks. Sudden-onset flooding events from intense rainfall episodes demand rapid response and preparedness in the short term. It is essential to urgently enhance existing civil protection measures, establish robust early-warning and evacuation systems, and secure critical infrastructure. In the medium to long term, comprehensive planning for structural interventions (such as improved drainage networks and flood barriers) combined with nature-based solutions (including restoration of natural floodplains and coastal ecosystems) is crucial. These measures not only address immediate vulnerabilities but also build enduring resilience against progressively worsening flood risks associated with climate change impacts like increased precipitation intensity and sea-level rise.

In conclusion, the urgency evaluation highlights that immediate, proactive action combined with strategic, forward-looking planning is essential. Addressing heatwaves requires rapid implementation of short-term interventions and subsequent medium-term infrastructural adaptations, while river and coastal flooding necessitate immediate preparedness enhancements coupled with sustained long-term investments in both structural and ecological solutions.

2.4.3 Capacity

- *What are your climate risk management measures that are already in place to tackle the risk? Consider financial, social, human, physical and natural aspects.*
- *Does your region/community have sufficient capacity to address the respective climate risk including related events and processes? E.g., comprehensive financial capacity (available means to prepare and respond to the risk), human capacity (awareness, knowledge and learning), natural capacity (resource management and ecosystem health), physical capacity (ability to forecast and warn, provide critical infrastructure and services), and social capacity (social inclusion in DRM, equity, representation, favourable policy environment).*
- *Does your region have specific interventions implemented or planned that may reduce the respective climate risk? E.g., built hazard protection, hazard protection plans, specific policies, hazard warning systems, hazard insurance, hazard awareness campaigns.*

The Municipality of Mantoudi-Limni-Agia Anna demonstrates a moderate level of capacity to address climate-related risks, largely supported by its active civil protection services and existing emergency response mechanisms. These structures provide a functional degree of preparedness for dealing with extreme weather and climate hazards. Yet, broader financial pressures limit the municipality’s ability to undertake large-scale, long-term investments—such as infrastructure upgrades, advanced early-warning systems, and integrated resilience strategies—that are critical for reducing future risks.

Human resource shortages add another layer of challenge, constraining both the pace and breadth of adaptation measures. Even so, the municipality benefits from strong political will and a growing societal awareness of the urgency of climate adaptation. This combination of political backing and public recognition of risks creates a solid basis for mobilizing further actions, provided efforts are strategically guided and resources are effectively allocated.

Looking ahead, there is significant potential in deepening community participation and strengthening regional partnerships. Greater involvement of residents, businesses, schools, and civil society organizations in climate resilience initiatives could meaningfully expand local adaptive capacity. A key enabler will be the development of a robust communication strategy, designed to share risk information clearly, raise awareness of community responsibilities, and build widespread engagement and trust.

In parallel, closer collaboration with neighboring municipalities and stronger alignment with national and European adaptation frameworks offer avenues to access funding, exchange expertise, and coordinate broader resilience measures. This Risk and Vulnerability Assessment provides a strategic foundation to support such efforts, guiding decision-making, prioritization, and resource allocation aimed at bolstering the municipality's ability to cope with future climate-related challenges.

2.5 Preliminary Monitoring and Evaluation

- *What did you learn from the first-phase of the climate risk assessment? Where did you encounter the most difficulties?*
- *What feedback did you receive from stakeholders? Do other stakeholders need to be involved in the next iteration of the analysis?*
- *Is new data available regarding the risks and/or the system? What else is needed (e.g., data, resources, competencies, research) to understand the risks better?*

The first-phase of the climate risk assessment has provided significant insights into both the strengths and limitations of current methodologies and data availability for the Municipality of Mantoudi-Limni-Agia Anna. Key lessons include recognizing the pressing need for enhanced local vulnerability datasets, particularly concerning demographic groups, housing conditions, infrastructure resilience, and precise socio-economic indicators. These data gaps have highlighted the importance of improving granularity to better identify and address the specific needs of the municipality's diverse communities.

During the initial assessment phase, METEOME encountered specific challenges related to integrating local spatial and observational data with broader EU-level hazard projections, emphasizing the necessity for standardized and interoperable datasets. Aligning these different scales of data posed practical difficulties, underscoring a critical need for streamlined processes and capacity-building within local administrative units.

Feedback from stakeholders has been encouraging and constructive, emphasizing a strong desire for active involvement in the next phases of the project, particularly regarding the co-design of tailored climate adaptation solutions. Stakeholders have expressed interest in developing localized adaptation strategies that consider specific vulnerabilities, community priorities, and existing capacities. Moving forward, engaging additional stakeholders such as healthcare providers, educational institutions, business representatives, and community groups will be vital to enrich the next iteration of the analysis, ensuring comprehensive and representative inputs.

To better understand and effectively mitigate identified risks, further resources and competencies will be required, including specialized training for municipal staff in the issue of early warning systems, climate data interpretation, vulnerability assessment methods, and the application of EU-level projections at the local scale. Additionally, fostering closer collaboration with research institutions and regional climate experts could greatly enhance the municipality's analytical capabilities, supporting a more detailed and actionable risk assessment process in the subsequent phases.

2.6 Work plan

Briefly describe the work plan for the remaining phases of the project. Specify the main activities (what will be studied, why and how). Also indicate what aspects of the system will not be studied and why).

The next phases of the project will expand the scope of the Risk and Vulnerability Assessment to include additional climate-related hazards and to strengthen the integration of findings into municipal civil protection planning.

As part of this process, the FIRE workflow has already been executed, providing preliminary insights into the future threat of wildfires (i.e. see Annex). These results will be further refined and incorporated into the subsequent phase of the project, with emphasis on identifying high-risk forested areas, evaluating post-fire recovery capacity, and developing tailored adaptation and prevention measures.

Complementary analyses using the HEAVY RAINFALL, SNOWFALL, and DROUGHT workflows will be undertaken. These will contribute valuable information on hydrometeorological extremes that have historically affected the municipality and are projected to intensify under climate change. Together, these workflows will provide a more comprehensive picture of future risks and their implications for critical infrastructure, local livelihoods, and ecosystems.

In parallel, the project team will work closely with municipal stakeholders to ensure that the updated risk evidence directly informs the revision of civil protection plans. This collaboration will support the integration of hazard-specific measures, prioritization of vulnerable areas, and improved emergency preparedness strategies.

It is important to note that the WIND workflow will not be included in the scope of this project. Based on local hazard records and stakeholder input, wind-related impacts are not considered a significant threat to the municipality compared to other climate hazards.

The results of these additional analyses, combined with the existing findings on heatwaves, river flooding, and coastal inundation, will provide a robust basis for the municipality to strengthen its long-term climate resilience strategy.

3 Conclusions Phase 1- Climate risk assessment

Please follow these guidelines:

- *Include the main conclusions reached in this project phase (challenges addressed and not addressed).*
- *If applicable, include the main key findings.*

Phase 1 of the CLIMAAX project in Mantoudi-Limni-Agia Anna carried out a comprehensive climate risk assessment focusing on three major hazards expected to intensify under climate change: extreme heatwaves, river flooding, and coastal flooding. The analysis applied harmonized, open-source methodologies from the CLIMAAX Handbook to model hazards, assess exposure, and quantify risk. This phase represents a foundational step in understanding localized climate threats and building an evidence base for future adaptation planning.

The results generated important insights but also revealed methodological limitations, particularly for flood hazards in this complex local context.

1. Extreme Heatwaves – Accurately Identified and Intensifying Threat

The assessment of heatwave risk was the most robust component of this phase. Using EuroHEAT thresholds, downscaled climate projections, and satellite-derived LST data, the study confirmed that Mantoudi-Limni-Agia Anna is already a heatwave hotspot and will face worsening thermal extremes.

- By 2050, heatwave days are projected to rise from a historical baseline of 4–5 per year to 13–14 under RCP4.5 and 17–19 under RCP8.5.
- The divergence between the scenarios after 2030 underscores the importance of global mitigation pathways.
- LST analysis showed inland hotspots with summer peaks exceeding 40 °C, particularly in areas affected by the 2021 wildfires, where the loss of forest cover has reduced natural cooling.
- Vulnerability is highest in eastern-central settlements and the urban fabric of Mantoudi, Limni, and Agia Anna, which—even as small towns—display localized heat island effects.
- Overall, heatwave risk is well-characterized and severe, requiring immediate focus on adaptation measures such as early warning systems, urban greening, passive cooling, and protection of vulnerable groups.

2. River Flooding – Critical Hazard

In contrast, the river flood risk assessment failed to reflect the historically documented flood behavior in the municipality. Despite using CLIMAAX's standardized workflows and data from JRC and Aqueduct Floods:

- The models did not simulate any flood hazard in the Kireas River stream, which has experienced major flash floods (e.g., 2013).
- All return periods and future climate scenarios showed negligible inundation, with maximum depths below 0.4–0.6 meters and no modeled impacts inland.
- Consequently, the estimated economic damages and population exposure were extremely low and inconsistent with known past impacts.

This failure stems from fundamental methodological limitations, including the use of coarse-resolution DEMs and the lack of representation of pluvial and flash flood dynamics typical of the local hydrology. As a result, the hazard and associated risk are severely underestimated, making the current outputs unreliable for local flood preparedness planning.

3. Coastal Flooding – Localized but Increasing Risk

The coastal flood hazard assessment was more effective in identifying areas at risk:

- Present-day and 2050 flood extents, derived from extreme sea level projections, show consistent inundation along the port and low-lying waterfront.
- Depths of up to 1 meter by 2050 are expected in high return period events (e.g., 1-in-100 or 1-in-250 years), posing risk to critical infrastructure such as municipal car parks, roads, and the port area.
- While the overall affected area is small, the potential disruption to mobility and infrastructure is significant, especially as sea level rise continues.

The damage estimates remain moderate due to the limited extent of inundation, but the results provide a credible warning of worsening flood risk due to rising sea levels.

The assessment successfully addressed:

- The integration of climate scenarios and health-related thresholds for heatwave hazard.
- Spatially resolved risk identification using exposure and vulnerability overlays.
- Initial screening of coastal flood risk under sea level rise scenarios.

However, key challenges remain unresolved:

- River flood modeling requires urgent refinement; current global datasets and assumptions do not reflect local flash flood behavior, particularly in the Kireas River basin.

- Exposure and damage models need calibration with local cadastral and infrastructure data for improved accuracy.

- Compound flood risks (e.g., pluvial + coastal) were not considered in this phase but may be relevant in urbanized coastal valleys.

Key Findings Summary

- Extreme heat is a growing and well-characterized hazard for Mantoudi-Limni-Agia Anna, requiring immediate adaptation focus.

- River flood risk is critically underrepresented using standardized models and needs local hydrological calibration.

- Coastal flood risk is present and increasing, particularly near the port, although spatially confined.

This first phase establishes a valuable baseline but also highlights the need for local model refinement, improved data resolution, and integrated hazard approaches in future phases of climate resilience planning.

4 Progress evaluation and contribution to future phases

- *Describe the connection between this deliverable, its outputs and the planned activities for the following phases of the project.*
- *Include the **Key Performance Indicators** and **Milestones** achieved in this phase and the actions executed to achieve these as per the Individual Following Plan. Please use the summary tables below to give an overview of the progress.*

Phase 1 of the CLIMAAX project has laid the analytical foundation for evidence-based climate adaptation planning in the Municipality of Mantoudi-Limni-Agia Anna. The principal output of this phase—the Climate Risk Assessment (CRA)—provides a spatially explicit and hazard-specific evaluation of the municipality's exposure and vulnerability to extreme heatwaves, riverine flooding, and coastal flooding. This deliverable integrates hazard modeling, exposure assessment, and vulnerability analysis to inform both short-term risk management and long-term adaptation strategies. This assessment constitutes a critical input to the CLIMAAX methodological pathway and ensures alignment with the project's overarching objective of supporting harmonised climate risk management across Europe.

This deliverable directly contributes to the design and execution of the following project phases. In Phase 2, the CRA findings will support relevant adaptation strategies in collaboration with key stakeholders such as the Civil Protection Office, urban planning departments, and community representatives. In Phase 3, results will be synthesised into communication materials to support stakeholder engagement, raise public awareness, and promote institutional uptake of the proposed adaptation measures.

Importantly, the execution of Phase 1 has revealed both methodological strengths and operational gaps that will shape the implementation of future phases. The successful application of the CLIMAAX workflows for heatwave and coastal flood analysis provides a robust technical base for planning adaptation interventions (e.g. urban cooling zones, port infrastructure protection). Conversely, the limitations encountered in simulating riverine flash flood risk underscore the need for methodological refinement and local model calibration.

Phase 1 successfully met all of the defined Key Performance Indicators (KPIs) as outlined in the Individual Following Plan. The hazard assessments for heatwaves and coastal floods were implemented using the CLIMAAX Toolbox and integrated with demographic and land use datasets. Despite limitations in river flood modeling, the workflow was completed and documented, with explicit identification of performance gaps.

The mapping of vulnerable groups, land surface temperature anomalies, and infrastructure exposure contributed to the completion of composite risk assessments across all three hazard types. Each workflow was executed with scenario-based projections (RCP4.5 and RCP8.5), strengthening the forward-looking nature of the analysis.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Heatwaves	Completed
River and Coastal Floods	Completed

Table 4-2 Overview milestones

Milestones	*Progress*
Hazard Layer Acquisition and Validation	Completed
Exposure and Vulnerability Mapping	Completed
Composite Risk Assessment	Completed
Gap Identification for Local Calibration	Completed

5 Supporting documentation

Classify and list all outputs produced during this stage. This can include:

- *Main Report (PDF or Word)*
- *Visual Outputs (infographics, maps, charts)*
- *Communication Outputs (Press release, media)*
- *Datasets collected (Excel or CSV)*

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

6 References

Please use the typical paper referencing, that is for example: (Buskop et al., 2024)

Buskop, F., Sperna Weiland, F., and van den Hurk, B.: Amplifying Exploration of Regional Climate Risks: Clustering Future Projections on Regionally Relevant Impact Drivers Not Emission Scenarios, https://doi.org/10.1088/2752-5295/ad9f8f, 2024

1. *Go to the Reference section and add your reference following the provided model and style.*
2. *Place your cursor in the main text where the cross-reference should be inserted.*
3. *Click **Insert | Cross-reference**. A Cross-reference dialog box will appear.*
4. *Click the **Reference type**: drop down and select the type of object you want to provide a cross-reference to.*
5. *Click the **Insert reference to**: drop down and select the information to be displayed in the cross-reference field.*
6. *Available headings, captions or footnotes will appear. Select the item you wish to reference.*
7. *Click **Insert.***

CLIMAAX Consortium (2023): CLIMAAX Handbook – A Guide to Regional Climate Risk Assessment.

Copernicus Climate Change Service (2023): ERA5 Dataset, European Centre for Medium-Range Weather Forecasts.

EEA (2022): Europe's changing climate hazards — an index-based interactive EEA report, European Environment Agency.

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Galanaki, E., Lagouvardos, K., Kotroni, V., Giannaros, T., and Giannaros, C.: 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; https://doi.org/10.5194/nhess-21-1983-2021, 2021.

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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.

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Lagouvardos K., V. Kotroni, A. Bezes, I. Koletsis, T. Kopania, S. Lykoudis, N. Mazarakis, K. Papagiannaki, and S. Vougioukas, 2017: The Automatic Weather Stations Network of the National Observatory of Athens: Operation and Database. Geoscience Data Journal, 4, 4-16; https://doi.org/10.1002/gdj3.44.

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Papagiannaki K., K. Lagouvardos, and V. Kotroni, 2013: A database of high-impact weather events in Greece: a descriptive impact analysis for the period 2001–2011, Natural Hazards and Earth System Sciences, 13, 727–736.

Papagiannaki K., K. Lagouvardos, V. Kotroni, and A. Bezes, 2015: Flash flood occurrence and relation to the rainfall hazard in a highly urbanized area. NHESS ; doi:10.5194/nhess-15-1859-2015.

WHO (2021): Heat and Health in the WHO European Region: Updated evidence for effective prevention.

7 Annex

7.1 Identified Risks and Proposed Measures

1) River Outlets of Nileas & Kireas (Krya Vrysi & Kirinthos)

- Problem: Accumulation of sediments and bank erosion, creating a risk of overflow during heavy rainfall.
- Measures:
  - o Regular inspection and removal of sediments.
  - o Construction of retention basins for flood mitigation.
  - o Bioengineering interventions with deep-rooted vegetation for bank stabilization.

2) Plane Tree Disease & Accelerated Flow in Kireas

- Problem: Loss of riparian vegetation → increased flow velocity, erosion, and flood risk.
- Measures:
  - o Replacement of diseased plane trees with resistant tree species.
  - o Installation of rock traps and natural barriers in the stream.
  - o Continuous monitoring of water discharge for flow regulation.

3) River within the Settlement of Prokopi

- Problem: Stream overflow during storms, leading to road closures and risk to residential areas.
- Measures:
  - o Widening of the riverbed, reinforcement of embankments, and construction of drainage inlets.
  - o Development of a peripheral road serving also as a firebreak.
  - o Installation of water level sensors for early warning.

4) Three Torrents within the Settlement of Pili

- Problem: Limited cross-sections and lack of maintenance cause flooding after storms.
- Measures:
  - o Hydraulic section control and embankment reinforcement with appropriate slopes.
  - o Scheduled sediment removal after heavy rainfall events.
  - o Integration of vegetated “wet zones” for natural water retention.

5) Pili School Adjacent to River

- Problem: Flood risk endangering students and school facilities during heavy rains.
- Measures:
  - o Construction of tiered retaining walls.

o Design of safe evacuation routes and designated gathering areas on higher ground.

6) Torrent within Properties in Loutro Kotsikia

- Problem: Inflow of water into private plots, infrastructure damage, and risk to inhabited areas.
- Measures:
  - o Mapping of the torrent path and adjacent properties.
  - o Construction of embankments or relief channels.

7) Landslide Risk in Ahladi Settlement

- Problem: Slope instability with potential subsidence and damage to houses.
- Measures:
  - o Geotechnical investigation and saturation tests on slopes.
  - o Drainage works with pipes/wells and rock stabilization.
  - o Local waterproofing interventions.

8) Perimeter Firebreak Zones in Rovies, Ahladi, Limni, Kerameia

- Problem: Risk of rapid forest fire spread toward settlements.
- Measures:
  - o Creation of 50–100 m wide deforested buffer zones.
  - o Establishment of wide, accessible, and signposted fire service routes.

9) Seismic Faults in Prokopi & Kotsikia

- Problem: Active faults generating micro-earthquakes with potential for stronger seismic activity.
- Measures:
  - o Monitoring of microseismic events through a local sensor network.
  - o Structural integrity assessments of schools and public buildings.
  - o Preparedness drills and emergency response planning.

10) Landslides in the "Kioski" Area of Limni

- Problem: Cracks and subsidence affecting roads and buildings in the settlement.
- Measures:
  - o Slope stabilization with geotextiles and soil anchors.

11) Rovies Sports Field: Ground Retention

- Problem: Slope instability that may compromise the field surface and athlete safety.
- Measures:
  - o Geotechnical study of loads.

- o Construction of retaining walls (gabions, piles).
- o Drainage system to prevent erosion.

12) Flood Events at Mantoudi General & Vocational High School

- • Problem: Flooding up to ~2 m, causing severe damage to equipment and infrastructure.
- • Measures:
- o Installation of underground drainage pipes and inlets.
- o Waterproofing of ground floors and protection of electromechanical equipment.

13) Water Supply for Settlements & Irrigation of Agricultural Land

The project concerns the identification of suitable sites for the construction of water storage reservoirs utilizing streams and springs. These sites will be recorded and assessed through a preliminary study estimating potential storage volumes. Documented needs focus mainly on the supply of settlements and irrigation of agricultural land across the Municipality of Mantoudi–Limni–Agia Anna. The study aims to align water demand with existing water resources and the capacity to store significant volumes in both existing and newly created artificial lakes.

14) Mauve Stingers and Jellyfish

- • Problem: Threat to the economy, tourism, and marine ecosystem balance.
- • Context: The protected areas of the management unit form a large and complex mosaic of habitats. The marine zone is of high ecological importance due to the presence of extensive Posidonia oceanica meadows covering most of the seabed between 5–35 m depth, recognized as habitats of significant conservation value.

7.2 FIRE workflow complementary material

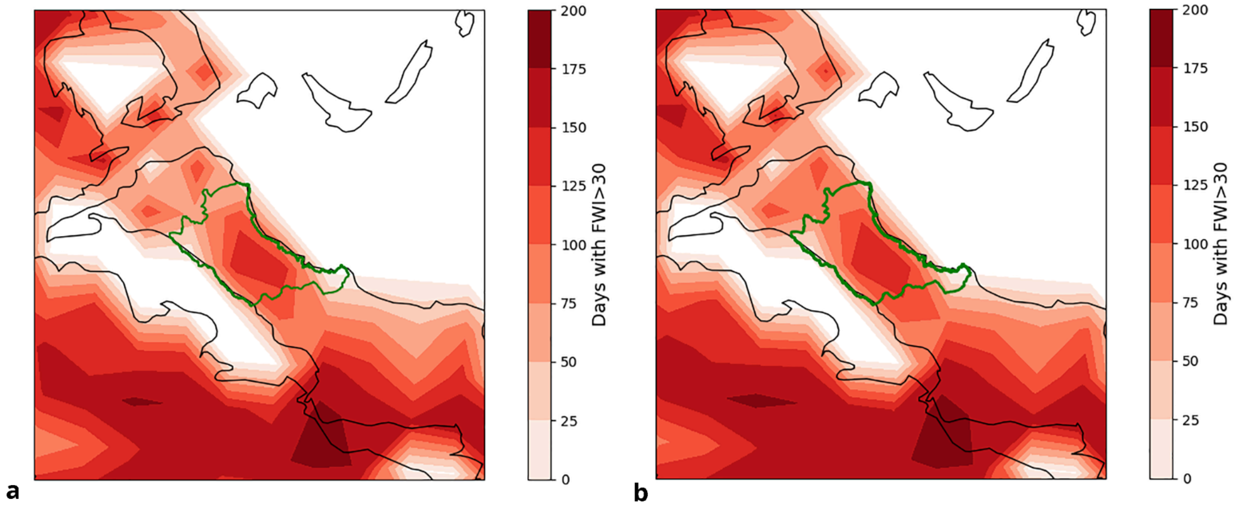

Figure 7-1. Annual number of days with Fire Weather Index (FWI) > 30, indicating high fire danger, within the Municipality of Mantoudi-Limni-Agia Anna (outlined in green). (a) Historical baseline (1980–2010). (b) Future projection under RCP8.5 for 2051–2055. Results show a moderate increase in the frequency of high fire danger days, particularly in the inland areas of the municipality.

Figure 7-2 shows the modeled annual number of days with FWI > 30, a commonly used threshold indicating high fire danger, for the historical baseline (panel a) and the future projection under RCP8.5, 2051–2055 (panel b), restricted to the Municipality of Mantoudi-Limni-Agia Anna. The analysis was conducted using the CLIMAAX Fire Workflow, which applies standardized indices of fire danger based on daily meteorological inputs of temperature, relative humidity, wind speed, and precipitation. For this study, we used a dataset of over 30 years of daily climate reanalysis data for the historical baseline (ca. 1980–2010), together with multi-model ensemble climate projections under the RCP8.5 scenario, providing robust information on potential future fire-weather conditions.

In the historical baseline, the municipality typically experienced 50–75 days per year of high fire danger, with some central inland areas occasionally reaching close to 100 days. These hotspots overlap with forested inland zones, where the presence of dense pine stands has historically contributed to elevated fire susceptibility.

Under the future RCP8.5 scenario, the number of days with FWI > 30 increases moderately. Most of the municipality is projected to face 75–100 high-fire-danger days per year, while limited pockets in the central interior may exceed this range, indicating a lengthening of the fire season.

Overall, the results suggest a gradual but noticeable extension of fire-conducive conditions within Mantoudi-Limni-Agia Anna. Although the increase is not extreme compared to surrounding regions, it still implies that inland areas will be more frequently exposed to elevated fire weather, compounding existing vulnerabilities from the 2021 wildfire scars and reduced forest resilience. These findings emphasize the need for proactive management, such as improved fuel reduction, early warning systems, and integration of fire-weather forecasts into civil protection planning.

7.3 LUISA Land Cover classification

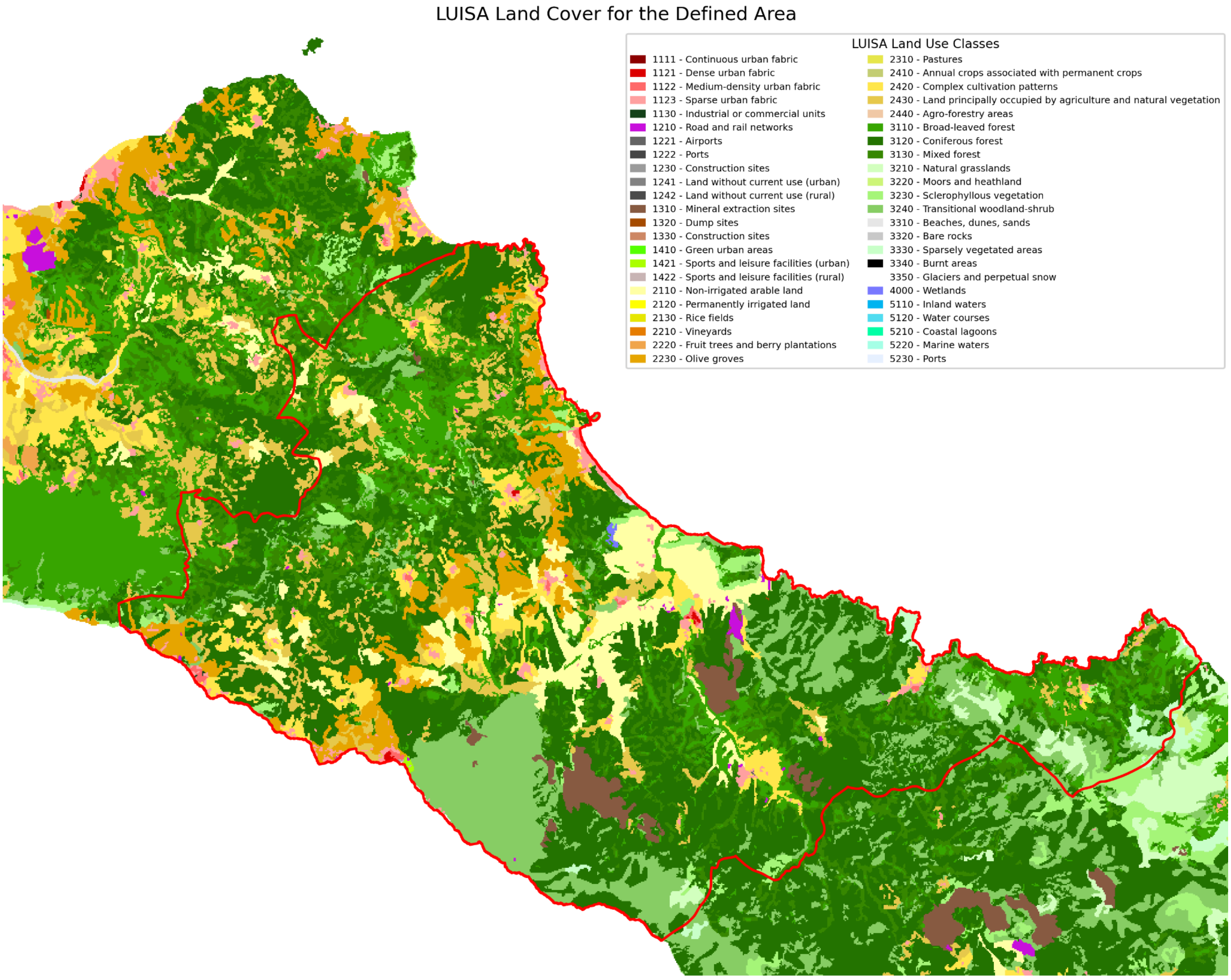

Figure 7-2. LUISA Land Cover classification for the Municipality of Mantoudi-Limni-Agia Anna. The map shows the spatial distribution of land use and land cover types, including forest areas (broad-leaved, coniferous, and mixed), agricultural zones (arable land, vineyards, olive groves), urban fabrics, and coastal features. These layers form the basis for exposure and damage assessments in the climate risk analysis.