CLIMAAX
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Deliverable Phase 2 – Climate risk assessment

Climate Risk Assessment in Nicosia, Cyprus Framework (CLIMAAX-NIC).

Cyprus, Nicosia Municipality

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Author(s)	• Olivia Skordi (Municipality of Nicosia) • Charis Theocharous (Municipality of Nicosia) • Savas Karatsiolis (CYENS Center of Excellence) • Andreas Kamilaris (CYENS Center of Excellence) • Chirag Padubidri (CYENS Center of Excellence) • Noor Sajjad (CYENS Center of Excellence)
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Abbreviations and acronyms

Abbreviation / acronym	Description
A/C	Air conditioning
CRA	Climate Risk Assessment
CRM	Climate Risk Management
CYENS	CYENS Center of Excellence
ECP	European Cohesion Policy
GDP	Gross Domestic Product
ICC	Intelligent Cities Challenge
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
LIFE	L'Instrument Financier pour l' Environment
M&E	Monitoring and Evaluation
RMP	Risk Management Plan
SSP	Shared Socioeconomic Pathways
UHIE	Urban Heat Island Effect
UNFCCC	United Nations Framework Convention on Climate Change
NDVI	Normalized Difference Vegetation Index
DEM	Digital Elevation Model
LCZ	Local Climate Zone
UNHCR	United Nations High Commissioner for Refugees
CMIP6	Coupled Model Intercomparison Project Phase 6
C3S	Copernicus Climate Change Service
LULC	Land Use/Land Cover
NDMI	Normalized Difference Moisture Index

Executive summary

This Phase 2 deliverable converts the Phase 1 CLIMAAX-NIC scoping, risk screening and stakeholder mapping into a localized climate risk assessment for the Municipality of Nicosia. It uses the CLIMAAX Framework and Handbook, Copernicus climate information, local municipal data, CYENS modelling capacity, WorldPop demographic layers, Sentinel-2 imagery and stakeholder input to assess three priority risks: Urban Heat Island Effect (UHIE), flooding, and drought-related vegetation stress. The document provides the evidence base needed to move from general climate-risk awareness to spatially targeted adaptation planning, with outputs that can inform municipal policy, the Sustainable Energy and Climate Action Plan 2021-2030 and future resilience investments.

During Phase 2, the three selected workflows were refined with local data and higher-resolution methods. For UHIE, custom sensors were installed on municipal vehicles and produced approximately 700,000 temperature and wind measurements during August and September 2025. A physics-inspired artificial intelligence model used these observations, Athalassa meteorological-station data and 200 m by 200 m grid cells to produce neighbourhood-scale UHI potential, exposure, vulnerability and risk maps. For flooding, a scenario-based hydraulic assessment was developed with terrain, roads, buildings, vegetation, simplified drainage-grating assumptions and 3-hour rainfall scenarios for 2-, 5-, 10-, 25- and 50-year return periods. For drought and vegetation stress, Sentinel-2 imagery for August 2025 was processed through the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) to map greenness, canopy moisture, water stress and vegetation-risk patterns across the municipality.

The results show that climate risks in Nicosia are highly spatially uneven. The UHIE analysis identified at least five areas of concern and showed a daily pattern in which morning cool-island conditions shift to strong afternoon and evening heat-island behaviour. Realised urban-rural temperature differences reached about 2.4-3.1 degrees Celsius in the afternoon and 1.4-1.6 degrees Celsius in the evening, with compact low-rise areas showing the highest heat potential. The flood assessment produced flood hazard, flood potential and flood risk datasets, showing localized risks influenced by terrain, land cover, drainage conditions and rainfall severity, especially near the Pediaios river corridor and the smaller river of Aglantzia. The drought and vegetation-stress assessment found that only 24.9 percent of the study area was classified as vegetated in August 2025, that 56.5 percent of vegetated pixels were in the high water-stress class, and that 94.3 percent of vegetated pixels were below the moisture-stress line. The highest drought and vegetation-stress concerns occur where sparse or stressed vegetation coincides with dense urban conditions, while irrigated agricultural areas and tree cover in the north-east show lower stress.

The risk evaluation combined the geospatial outputs with stakeholder discussions, severity, urgency and resilience capacity. Drought and vegetation damage emerged as the highest priority risk, with substantial current severity, critical future severity, immediate need for action, low resilience capacity and a very high overall priority. Flooding was assessed as a moderate priority because current mitigation and planning activities provide a stronger response capacity, although future extreme rainfall could increase impacts. UHIE was also assessed as a moderate priority, but with low resilience capacity because technical knowledge, monitoring systems and heat-adaptation

planning need further development. Phase 2 engagement strengthened the stakeholder network established in Phase 1, including municipal departments, technical experts, social-support organisations, other Cypriot municipalities and public dissemination events. The report also records progress against project indicators, including updated stakeholder mapping, refined workflows, published UHIE maps and several communication actions.

The main conclusion is that Nicosia now has a practical, spatial evidence base for prioritising adaptation, but the results should be treated as decision-support layers that require continued validation. The main limitations are incomplete drainage-network data and limited historical flood observations, temporal and road-surface bias in the mobile UHIE measurements, sparse late-night heat data, and uncertain crop-type labels for drought assessment. These limitations do not invalidate the results; they define the next improvements needed to increase confidence, improve monitoring and connect the maps with implementable actions.

During the final phase, the project will validate hotspots and cold spots through at least 10 site visits, conduct stakeholder interviews and questionnaires, use the municipality's 18 information points for awareness and feedback, and identify at least 10 specific adaptation and mitigation actions with attention to cost and expected impact. Final outputs will support local and national planning, including integration with Nicosia's SECAP 2021-2030 and the ZENON strategic master plan, while an online platform, policy-oriented materials, press releases and a final conference will communicate the maps, findings and recommended measures to decision-makers and the public.

1 Introduction

1.1 Background

The IPCC has named the Eastern Mediterranean a climate change hotspot (IPCC, 2022). Nicosia, the capital of Cyprus, is in this area. Long, hot summers with temperatures that often go above 43 degrees Celsius are already part of the city's climate. This problem is made much worse by a strong UHIE, which means that the dense concentration of buildings, asphalt, and other urban surfaces holds and absorbs more heat than rural areas nearby.

Because of this intense and long-lasting heat, A/C systems and other cooling measures need to be used widely. These are very important for keeping people healthy and comfortable. But this heavy use of air conditioning causes a spike in energy use, which puts a lot of stress on the power grid during the hottest months and adds to greenhouse gas emissions. Also, extreme temperatures are a direct and serious threat to public health, especially for vulnerable groups like the elderly. These factors contribute to an urgent need to systematically look at these and other climate-related risks that are connected to each other in the municipality to make the city more resilient and sustainable in the future.

Adding to these challenges, Nicosia also suffers from moderate water scarcity. Besides Nicosia, the country of Cyprus in general already experiences the highest levels of water stress in Europe (European Commission, 2025). This situation is projected to worsen with declining rainfall due to climate change. Desalination plants located in the coastal areas of the country currently provide a crucial supply of potable water, but their energy-intensive operation further exacerbates the country's electricity demands and carbon footprint. This unfortunate interplay of heat, drought, and water scarcity necessitates integrated, forward-thinking strategies to safeguard Nicosia's future habitability and economic stability.

1.2 Main objectives of the project

The project aims to move beyond a general identification of risks to the development of specific, actionable solutions for efficient risk mitigation and adaptation. By applying the CLIMAAX Handbook and its harmonized CRA framework, the project expects to derive significant benefits, including:

- Providing a standardized, scientifically robust foundation for climate action planning.
- Identifying specific geographic hotspots and population groups most at risk.
- Facilitating the prioritization of adaptation measures based on a clear understanding of risk severity and urgency.
- Strengthening local capacity for ongoing climate risk management and resilience building within the municipal administration and among key stakeholders.
- Engaging key community stakeholders and citizens in the risk assessment process to ensure local knowledge and perspectives are integrated, fostering ownership and support for adaptation initiatives.
- Quantifying the socio-economic impacts of identified climate risks, providing data-driven insights into potential damage, costs, and disruptions to local livelihoods and services.

- Establishing a framework for continuous monitoring and evaluation of climate risks and the effectiveness of implemented adaptation measures, allowing for dynamic adjustments and long-term climate resilience.

In effect, a set of interventions may be chosen for Nicosia to deal with existing vulnerabilities and prepare for future climate hazards. This is based on an approach that emphasizes the development of tailored measures, improvements to infrastructure, preservation of natural assets, and protection of the welfare of citizens, while facilitating a resilient and sustainably built urban environment.

1.3 Project team

This project is a collaborative effort led by the CYENS (CYENS Centre of Excellence, 2025) in close partnership with the Municipality of Nicosia (Nicosia Municipality, 2025). The project team combines the cutting-edge research and technical expertise of CYENS in areas such as data science, artificial intelligence, environmental monitoring, and smart city technologies with the local governance mandate, practical knowledge, and extensive stakeholder networks of the Nicosia Municipality. This synergistic partnership ensures that the scientific assessment is not only rigorous but also grounded in the local context, and that its outcomes are relevant, practical, and actionable for local policymakers, city planners, and the community at large.

CYENS has extensive R&D in environmental risk analysis, modelling the main natural risks of the real estate properties of the island (https://superworld.cyens.org.cy/project15.html), selling these analytics to local banks and insurance companies. CYENS created GAEA, a country-scale geospatial tool (https://superworld.cyens.org.cy/product3.html), which contains 27 environmental services (https://superworld.cyens.org.cy/product1.html) and aspires to become a digital twin of Cyprus. CYENS modeled risks at the hazard level, based on historical evidence, not touching upon vulnerability and exposure, and not employing concrete frameworks such as CLIMAAX. Nicosia Municipality and CYENS aspire to harmonize climate risk assessment, employing a wealth of data already available for Nicosia.

The authors of this report are Mrs Olivia Skordi and Charis Theocharous (Project Coordinators, Municipality of Nicosia) as well as Dr. Savvas Karatsiolis, Dr. Chirag Padubidri and Dr. Andreas Kamilaris (Partners, CYENS Center of Excellence). The team from CYENS are members of the SuPerWorld research group (http://superworld.cyens.org.cy), which performs research in environmental monitoring and modelling employing emerging technologies and AI. Dr. Savvas Karatsiolis, Dr. Chirag Padubidri, and Mrs Noor Sajjad have worked on the execution and adaptation of the CLIMAAX workflows for the region of interest (code modification, data collection).

1.4 Outline of the document s structure

This document is structured to follow the CLIMAAX deliverable template for the Phase 2 climate risk assessment, detailing the progress of the project. Section 2 details the execution of the CLIMAAX CRA Framework. Section 3 provides the main conclusions drawn from this first project phase. Section 4 evaluates the progress made and discusses the contribution of this phase to future project activities. Section 5 lists the supporting documentation.

2 Climate risk assessment - phase 2

This analysis follows the steps outlined in the CLIMAAX Framework. The sections below are structured around the guiding questions from the CLIMAAX Handbook to detail the work undertaken in Phase 1.

2.1 Scoping

The scoping phase will define the assessment's objectives, context, and stakeholder involvement, establishing a clear foundation for all subsequent activities.

Considering the three most important climate risks of the municipality of Nicosia, the context of each risk is described below.

Regarding flooding, there has traditionally been a low risk. However, climate change has increasingly amplified the risks of flooding, due to intense rainfall events, urbanization that led to reduced green spaces and natural water-absorbing areas, as well as the city's infrastructure, particularly its drainage systems, which are outdated and underprepared for intense weather patterns. Flooding in Nicosia can cause infrastructure damage, especially to roads and transportation, as well as buildings. Heavy rain can flood roads, bridges, and underpasses, causing severe traffic disruptions. Nicosia s road network, particularly in low-lying areas or near old drainage systems, can be submerged, disrupting daily commuting and economic activities. Additionally, floodwater can infiltrate homes, businesses, and public buildings, resulting in structural damage. This can lead to expensive repairs and the displacement of residents. Furthermore, there is a risk of contaminating water sources, including both surface and groundwater, through sewage or pollutants. This can lead to the spread of waterborne diseases such as dysentery and other gastrointestinal infections, particularly if the city s sewage systems overflow.

Regarding the UHI effect, it is becoming a significant concern as climate change increases the already hot conditions in the city. The UHI effect refers to the tendency of urban areas to become significantly warmer than their rural surroundings due to human activities, infrastructure, and development patterns. Nicosia experiences hot Mediterranean summers with average daily temperatures exceeding 36°C (Department of Meteorology, Republic of Cyprus, 2025). Climate change is increasing the frequency and intensity of heatwaves, raising the overall temperature and magnifying the UHI effect. The extensive use of materials like concrete and asphalt intensifies the UHI effect by absorbing heat during the day and releasing it at night. The UHI effect increases the need for air conditioning and cooling systems in buildings, leading to a surge in energy consumption (KNEWS Newsroom, 2025) and higher greenhouse gas emissions. Rising temperatures, combined with the UHI effect, pose significant public health risks, particularly for vulnerable populations such as the elderly (Pyrgou & Santamouris, 2018).

Regarding the damage to vegetation risk, as the frequency and intensity of heatwaves and drought periods increase, natural vegetation faces multiple challenges that can significantly disrupt ecosystems and food production. Most crops have specific temperature ranges for optimal growth. Prolonged heat exposes plants to temperatures above their threshold, causing heat stress, which can reduce their ability to photosynthesize, grow, and produce yields. Crops like wheat, olives, citrus, and vegetables, commonly grown in Cyprus, are highly susceptible to prolonged periods of high heat. Heat stress can cause wilting, reduced flowering, and lower fruit set, directly impacting yields (Lelieveld et al., 2020). Prolonged heat can cause crops to ripen prematurely, leading to poor-quality

produce that may not meet market standards in terms of size, taste, or appearance (Agricultural Research Institute, Republic of Cyprus, 2025). Prolonged heat can create favorable conditions for pests such as aphids, mites, and whiteflies (Lelieveld et al., 2020).

The main **stakeholders** of the above risks, who need to become mobilized during the risk assessment and adaptation processes, are the following:

- Local citizens: The ones mainly affected by disasters have a significant role to play in supporting and implementing actions and initiatives.
- Department of Environment, Ministry of Agriculture: The body responsible for policies that relate to climate risks. The project outcomes will inform the strategic master plan, managed by the Department.
- Environmental NGOs: High sensitivity to climate change and its risks, willing to contribute to initiatives that mitigate those risks.
- Research institutes and academia: Supportive in high-quality research that provides new insights, following proper methodologies. Expected to embrace the CLIMAAX framework and collaborate to perform risk assessments and derive effective solutions.
- Commercial entities: They can contribute to activities with social exposure, e.g., afforestation actions or urban green area restoration efforts.
- Municipalities and local communities: Fully supportive, to deal with their climate risks as well. Multipliers of action.
- Farmers: Especially the ones cultivating crops, as the prolonged drought might have a high impact on their production and productivity. At the same time, livestock farmers might experience risks of animals dying from overheating or becoming sick due to prolonged heat.

2.1.1 Objectives

The primary objective of this CRA is to systematically identify, analyze, and evaluate the major climate risks the Municipality of Nicosia is facing now and in the future. The purpose is to build a robust evidence base that empowers the Municipality to make informed decisions, develop targeted, effective adaptation and mitigation strategies, and integrate climate resilience into all facets of urban planning and policy.

The specific objectives of the project are the following:

- Understand and characterize the risk of flooding in the municipality of Nicosia.
- Understand and characterize the risk of urban heat island (UHI) effect in the municipality of Nicosia.
- Understand and characterize the risk of damage to vegetation in the municipality of Nicosia.
- Employing the CLIMAAX framework to analyze the targeted risks, assessing their urgency, significance and potential impact.
- Employing the CLIMAAX framework to quantify the exposure and vulnerability of the risks in a spatiotemporal context.

- Investigate and assess specific actions and solutions to mitigate those risks or perform adaptation measures, shaping better policies for Nicosia specifically and for Cyprus in general.

By understanding the dominant risks in Nicosia, the municipality will make more informed decisions and shape better policies that incorporate climate risks into local policy frameworks and include specific actions and solutions to mitigate those risks or implement adaptation measures. By employing the CLIMAAX framework, the analysis of the targeted risks will better characterize them, assess their urgency, significance and potential impact, quantifying exposure and vulnerability in a spatiotemporal context. Based on the overall project vision, the main outcome of this study is a risk assessment report together with spatiotemporal risk maps, risk-estimation models, and a set of concrete actionable recommendations for policymakers. These results should serve an immediate purpose, being consulted on their own in the upcoming local and regional development plans. Specifically, the outcomes of this project will become an integral part of the Nicosia Municipality Sustainable Energy and Climate Action Plan 2021-2030 (Cyprus Energy Agency, 2016; Kolyvas et al., 2019), created to fight climate change, understand the sources of pollution and CO2 emissions, and more broadly, derive strategies related to public health, urban planning, energy-oriented policy, and disaster risk management. Unfortunately, right now this plan does not include information about climate risks; thus, it is urgent to run actions such as this one to assess the risks of the city and derive mitigation strategies. In parallel, the outcomes of the project will improve the existing strategic master plan of the Republic of Cyprus, named ZENON (Cyprus Civil Defence, 2025). While this plan currently contains a report on disaster risk management in Cyprus (https://tinyurl.com/vyw5nzps), this report only lists various physical risks and climate change-related impacts. The risk assessment performed for these risks is limited, outdated and the information provided about the methodologies followed is non-existent. CLIMAAX-NIC will enrich the risk assessment on the proposed risks, setting the bar for assessing the rest of the national risks in a similar method, promoting the use of the CLIMAAX framework.

Nicosia can be considered a region with limited resources to significantly increase its climate or disaster resilience. Nicosia, while not resource-poor, does face significant challenges and limitations in increasing its climate and disaster resilience. Several factors contribute to these limitations, including economic constraints, governance challenges, infrastructure gaps, and socio-economic vulnerabilities. Although Cyprus is a developed country with access to EU funding and support, there are still significant barriers to building resilience, particularly in Nicosia. A core problem with the Municipality of Nicosia (and the region in general) is the distribution of the existing funds, where climate and disaster resilience are not top priorities, even though Nicosia is considered highly vulnerable to climate change, and this is something everyone accepts and understands. Similar to other regions around the world, the local authorities act reactively and not proactively. In other words, we expect a big disaster to occur before taking measures. This attitude and mentality are common to South Europeans and it is unfortunately our main enemy in mitigating or adapting to climate change early enough.

Another limitation for this CRA is the current availability of high-resolution, localized data for vulnerability and exposure assessment. Phase 1 utilizes the pan-European datasets provided within the CLIMAAX workflows, which raises a severe issue of data unavailability, especially for small regions like Nicosia. The datasets provided do not contain data for small municipalities/regions for almost every workflow available. This made our efforts very difficult because, to be able to run the

methodologies provided, not only did we have to collect our own data, but we also had to substantially modify the available code. A key objective for Phase 2 is to overcome this boundary by integrating detailed local data to refine the analysis and increase its local relevance and accuracy.

Flooding Study

The climate risk assessment conducted for flooding in Nicosia is subject to several limitations related to data availability and model representation. A primary limitation concerns the spatial resolution of the Digital Elevation Model (DEM) used in the analysis. While the 10 m DEM provides an adequate representation of the overall terrain and drainage patterns across the municipality, it cannot fully capture fine-scale urban features such as curbs, small drainage channels, retaining walls, underpasses, and localized depressions that can significantly influence flood behaviour. Similarly, surface roughness parameters were derived from roads, buildings, and vegetation datasets to estimate Manning coefficients. Although this approach provides a reasonable representation of hydraulic resistance, it does not account for local variations in surface materials, pavement conditions, or vegetation density, and therefore represents a generalized approximation of hydraulic conditions.

Another important limitation relates to the representation of the built environment and stormwater drainage infrastructure. Building information was obtained from available land registry datasets, which may not fully reflect recent urban development, building modifications, or newly constructed infrastructure. In addition, detailed information regarding the location, hydraulic capacity, operational status, and maintenance condition of the drainage network was not available. To address this limitation, drainage gratings were represented using a simplified assumption of regularly spaced inlets along the road network. While this allowed the drainage system to be incorporated into the modelling framework, the approach does not account for blocked inlets, damaged infrastructure, network capacity limitations, or operational failures that may occur during intense rainfall events.

A further limitation concerns the rainfall forcing and future development assumptions. The rainfall scenarios were derived from Intensity–Duration–Frequency (IDF) relationships and represent idealized design storm events rather than observed rainfall events with complex spatial and temporal variability. Consequently, actual flood behaviour during specific storms may differ from the simulated conditions. In addition, the assessment does not explicitly consider future changes in land use, urban expansion, drainage infrastructure upgrades, or socio-economic development, all of which may influence future flood risk. Despite these limitations, the methodology provides a robust first-order assessment of flood hazard and risk in Nicosia and establishes a strong foundation for future refinement as additional local data become available.

UHI study

The climate risk assessment (CRA) conducted for the Urban Heat Island (UHI) phenomenon in Nicosia was subject to several methodological and practical limitations, primarily related to data availability and representativeness. A key constraint arose from the data collection approach, which relied on a vehicle-mounted sensing system. While this method enabled flexible spatial coverage, it resulted in measurements that were both temporally and spatially sparse. Consequently, the dataset exhibited significant variability, which complicated the analysis of UHI patterns. This issue was

particularly pronounced given the inherently complex, nonlinear, and dynamic nature of UHI, which is influenced by a wide range of environmental and anthropogenic factors.

To address the sparsity and variability of the collected data, an artificial intelligence model was developed to predict UHI intensity with strong generalization capability. This approach mitigated the limitations of the raw dataset by enabling the extraction of consistent spatial patterns despite noise and gaps in the measurements. However, an additional source of bias was introduced by the fact that all measurements were collected along the road network, primarily over asphalted surfaces where UHI effects are typically more intense. As a result, the model exhibited a tendency to overestimate UHI values. Importantly, this overestimation was found to be uniform and systematic, which reduced its impact on the study s objectives, as the model remained effective in capturing relative spatial variations and subtle deviations in UHI intensity.

Another limitation concerned the temporal scope of the study, which was restricted to the months of August and September. While this constraint limits the model s direct applicability to other periods of the year, it is important to note that these months correspond to the peak summer season in Cyprus, during which UHI effects are most pronounced. Therefore, the findings remain highly relevant for informing policy decisions aimed at mitigating heat-related risks during periods of greatest concern for public health. Nevertheless, extending data collection across additional months is necessary for improving the model s robustness and enabling year-round applicability, and this has been identified as a priority for future work.

Operational constraints also affected the temporal completeness of the dataset. Data collection was conducted by municipal staff and was limited to working hours, with measurements extending until midnight (00:00). While this provided sufficient coverage for meaningful analysis, the absence of data during late-night and early-morning hours (00:00–07:00) represents a gap, particularly given that nocturnal UHI dynamics can differ significantly from daytime patterns. Addressing this limitation would require adjustments to the data collection process, potentially through automation or extended operational schedules.

The geographic scope of the study constitutes another boundary of the CRA, as it was confined exclusively to Nicosia. This limits the generalizability of the developed AI model to other urban environments with differing characteristics, such as variations in building materials, urban morphology, vegetation, proximity to the sea, and anthropogenic activity. Recognizing this limitation, future efforts have been planned to extend data collection to other Cypriot cities, including Limassol, to enhance the model s adaptability and applicability across diverse urban contexts.

A significant challenge encountered during the study was the validation of the model s predictions using independent data sources. This was addressed by leveraging third-party temperature measurements obtained from a network of private weather stations distributed across Nicosia. These data, accessed via the Wundermap platform, provided a reliable benchmark for comparison. The AI model demonstrated a high level of accuracy in predicting temperatures recorded at these stations across thousands of time intervals, thereby providing strong empirical support for the validity and robustness of the modeling approach.

The climate risk assessment (CRA) conducted for drought and its impact on agricultural land in Nicosia was subject to a notable methodological limitation, primarily related to data accuracy and

representativeness. Crop type labels were sourced from the Cyprus Agricultural Payments Organization (CAPO) under the Ministry of Agriculture, which classifies agriculture fields based on information self-reported by farmers. As this labelling process relies on farmer declarations rather than independent field verification or remote sensing validation, the crop type data may carry inconsistencies or inaccuracies that introduce uncertainty into the drought-crop impact assessments. To overcome this limitation, the analysis incorporated all vegetation within the Nicosia, ensuring broader spatial coverage and reducing the potential impact of misclassified or inaccurately labelled individual crop fields on the overall assessment.

Drought and vegetation-stress study

The drought assessment for Nicosia is based on satellite-derived vegetation and moisture indicators, primarily NDVI and NDMI, calculated from Sentinel-2 surface reflectance imagery for August 2025. While this approach provides consistent spatial coverage across the municipality and allows drought-related vegetation stress to be mapped at city scale, it remains dependent on the quality, resolution and timing of the available satellite observations. The results therefore represent the conditions captured during the selected late-summer period rather than a continuous or long-term drought record. A further limitation relates to the interpretation of NDVI and NDMI values. These indices are useful proxies for vegetation density, greenness and moisture content, but they do not directly measure plant health, soil moisture, irrigation practices or crop-specific drought impacts. Low index values may reflect drought stress, but they may also be influenced by land cover type, crop cycle, harvesting, fallow fields, vegetation species, soil background or local management practices. The use of a vegetation threshold also simplifies the distinction between vegetated and non-vegetated areas, which may introduce uncertainty in marginal or mixed pixels.

The available crop and vegetation information also constrains the level of detail that can be achieved. Crop type labels from CAPO are based on farmer declarations and may contain inconsistencies or inaccuracies, while detailed field-verified information on irrigation systems, crop condition, soil characteristics, tree species, maintenance regimes and adaptive capacity was not available. For this reason, the analysis was broadened to include all vegetation within Nicosia, reducing dependence on individual crop classifications and allowing a more spatially comprehensive assessment of drought-related vegetation stress.

Despite these limitations, the drought assessment provides a robust first-order indication of where vegetation in Nicosia is most exposed to summer water stress. The results highlight areas where sparse or stressed vegetation is concentrated, particularly in dense urban areas and drier agricultural or fallow land, while also identifying relatively healthier and better-watered vegetation patches. Future refinements could strengthen the assessment through multi-season monitoring, field validation, improved crop and irrigation datasets, and integration of future climate and land-use scenarios.

2.1.2 Context

Until now, the assessment and handling of climate hazards in Nicosia have been largely fragmented and not based on a harmonized, multi-hazard risk assessment framework. The most **important policies and strategies** currently adopted by the Nicosia Municipality are the following:

- Cyprus has a National Adaptation Strategy (NAS) and a National Adaptation Plan (NAP) for climate change (Department of the Environment, 2024), both were developed with the support of the CYPADAPT project. NAS identifies key areas and specific adaptation actions across 15 priority sectors, e.g., water resources, maritime and coastal areas, biodiversity, forests, energy, and tourism. The Ministry of Agriculture, Rural Development and Environment monitors the implementation of adaptation measures.
- National Energy and Climate Plan (NECP): Cyprus also has an Integrated National Energy and Climate Plan (INECP) (Republic of Cyprus, 2024, pp. 2021–2030) which aligns with EU regulations on the Governance of the Energy Union and Climate Action.
- Nicosia Municipality Sustainable Energy and Climate Action Plan (SECAP) 2021-2030: This is a crucial local plan that integrates climate risks and aims for emissions reduction. It identifies strategic areas such as buildings and equipment, transport, local energy production, land use planning, public procurement, citizen cooperation, and climate change adaptation (*Nicosia Municipality Sustainable Energy and Climate Action Plan 2021-2030*, 2021, pp. 2021–2203).
- EU Mission Adaptation to Climate Change Charter: Nicosia's commitment to this charter signifies its pursuit of a green, digital, resilient, and sustainable future (*EU Mission: Adaptation to Climate Change*, 2025).
- Integrated Sustainable Urban Development Strategy and Integrated Spatial Development Strategy: These municipal strategies are complemented by initiatives like the Intelligent Cities Challenge (ICC) (*Nicosia: Intelligent Cities Challenge*, 2025), which provides support for Nicosia's green, digital, resilient, and sustainable future.

The Municipality of Nicosia operates within a **framework of regulations and directives**, largely influenced by national Cypriot law and broader European Union policies such as:

- EU Directives and Regulations: As an EU member state, Cyprus is subject to various EU climate policies, such as Directive 2023/959 (*Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme*, 2023), which established a new Emissions Trading System for fuels in buildings, road transport, and the light industry. National laws are enacted to transpose these EU directives.
- UNFCCC Reporting Guidelines: Cyprus also adheres to the reporting guidelines of the United Nations Framework Convention on Climate Change (UNFCCC) (Republic of Cyprus, 2023).
- Planning Permits and Building Permits: Local planning authorities (like the Planning Authority and the Ministry of Interior/EOA) issue permits that include spatial planning and environmental terms, which can integrate climate considerations (*Town Planning Services*, 2025).
- National Governance System for Climate and Energy: Established in 2017 (and evolved into the national governance system for the Green Deal in 2020), this system includes working groups for biodiversity conservation, circular economy, and zero pollution (Republic of Cyprus, 2024, pp. 2021–2030).

- Ministry of Agriculture, Rural Development and Environment: This ministry is responsible for monitoring the implementation of adaptation measures and submitting evaluation reports (*Ministry of Agriculture, Rural Development and Environment*, 2025).

In essence, Nicosia's climate risk assessment operates within a multi-layered governance structure, integrating national directives, local plans, and international collaborations, often leveraging European funding and technical expertise to enhance its resilience to climate change. This project addresses the problem of transitioning from a general awareness of risks to a systematic, data-driven understanding of climate vulnerability and risk across the municipality. The governance context for this CRA is the strong commitment of the Nicosia Municipality to enhance urban resilience, supported by the technical expertise of the CYENS Center of Excellence. The project aligns national strategies for climate adaptation and the EU Mission on Adaptation to Climate Change.

The Municipality of Nicosia, as a major urban center in Cyprus, has several key sectors that are particularly relevant when considering the impacts of climate change. Cyprus, being in the Eastern Mediterranean, is identified as a climate change "hotspot," experiencing warming at a faster rate than the global average and a trend towards drier conditions (Ali et al., 2022).

Key sectors relevant to this assessment and potentially affected by climate change include:

- Public Health: Highly affected by heatwaves (heat stress, mortality).
- Energy: Affected by peak demand for cooling during heatwaves.
- Water Management: Affected by both droughts and flash floods.
- Urban Planning and Infrastructure: Affected by flooding, heat stress on materials, and the need for green infrastructure.
- Agriculture/Vegetation: Peri-urban agriculture and vital urban greenery are affected by heat and drought stress.
- Tourism and cultural heritage: Urban heat makes Cyprus city centers less popular for tourists.
- Economy and Livelihoods: High utility costs, energy prices, reduced productivity of employees.

In more detail, the impact of climate change to key sectors is as follows:

1. **Urban Infrastructure and Built Environment**: Nicosia has dense urban fabric, including historic walled city areas, residential buildings, commercial centers, and critical infrastructure like roads, drainage systems, and public utilities. The constantly prolonging extreme heat waves experienced, which are exacerbated by the UHIE, lead to increased energy demand for cooling, higher operating costs, and stress on the power grid. While flooding is not a big issue for Nicosia since very rarely intense rainfall events occur, the city proactively monitors potential flooding threats and adapts its plans and measures, especially against flash flood incidents. Such moderate-intensity incidents can cause significant damage to roads, bridges, underpasses, buildings (including structural damage to homes and businesses), and disrupt daily commuting and economic activities. The historic center,

with its impermeable surfaces, is particularly vulnerable (Toumazis et al., 2007). High temperatures and extreme weather can accelerate the degradation of building materials and infrastructure components, leading to increased maintenance costsand higher costs for repair and maintenance of public and private infrastructure.

2. **Public Health and Well-being:** The health and safety of Nicosia's residents, especially vulnerable populations (elderly, chronically ill, young children), are paramount. Heat-related Illnesses and mortality are increasing in Nicosia (Pyrgou & Santamouris, 2018), which highlights the importance of preparing for potential heat-related health impacts escalation in Nicosia (and Cyprus in general) in the coming years. Increased frequency, intensity, and duration of heatwaves significantly raise the risk of heatstroke, heat exhaustion, and exacerbate pre-existing cardiovascular and respiratory conditions, leading to increased morbidity and mortality (Phan et al., 2022). Heat waves and drought raise the likelihood of wildfires, causing increased air pollution that worsens respiratory problems. Although Nicosia Municipality is primarily urban, it includes a notable national forest park (*Athalassa National Forest Park*, 2025) and is adjacent to a wildlife forest on the Troodos Mountain, which experiences wildfires almost every summer. Furthermore, flooding can contaminate water sources (surface and groundwater) via sewage overflow, leading to the spread of waterborne diseases.
3. **Water Resources:** Nicosia, like the rest of Cyprus, faces inherent water scarcity due to its semi-arid climate, relying heavily on rainfall and desalination. Decreased precipitation and increased evapotranspiration due to higher temperatures lead to reduced natural water availability, stressing existing water supplies. This can impact domestic consumption, agriculture, and other sectors. Higher temperatures drive increased water demand for cooling, irrigation (e.g., for urban green spaces), and domestic use. Cyprus addresses periodic water scarcity, which occurs every few years, by implementing water supply cutoffs in an effort to reduce water demand to essential daily needs (Cyprus Property News, 2025). This places significant stress on the population and leads to frustration, as well as revenue losses for businesses that depend on a consistent water supply, such as water parks and car wash stations. Water supply cutoffs combined with higher water temperatures can exacerbate water pollution in water bodies. This raises public health concerns and requires more frequent water quality checks and frequent water treatment and purification. Making the situation even worse, the water supply system in Nicosia is old and experiences breaks that lead to massive water loss (in-cyprus, 2022) and is more prone to contamination when the water flow is cut off for several hours. Furthermore, the sudden water pressure deviations caused by the cutoffs further stress the old water supply system. Tourism is a cornerstone of Cyprus' economy, contributing approximately 13.5% to 15% of the country's GDP, with more than 4 million tourists visiting Cyprus every year (Statistical Service of the Republic of Cyprus, 2024). This means that the island hosts 4 times more tourists than its local population, who come to Cyprus to enjoy the hot summers, its beaches and tourist facilities like water parks and nice hotels with private pools. The tourism sector is a significant source of employment, with estimates indicating that it accounts for more than 18% of total employment in Cyprus (*Tourism Industries - Employment*, 2025). While being critical for the local economy, the tourism sector puts huge stress on the island’s water supply, intensifying the already serious water stress problem. An effective, though very costly, way to increase the available water supply is through the use of desalination plants installed along the

island's coast. The current capacity of the fixed desalination plants covers approximately 70% of national drinking water needs (~235,000 m³/day) (Cyprus Mail, 2025c). Cyprus is deploying four mobile desalination plants, each with a daily output of 30,000 m³, to cover the upcoming needs occurring due to a disabled plant. Expansion plans aim to raise total capacity to 510,000 m³ per day within a decade through additional fixed plants and scaled mobile facilities, enough to meet 100% of the island's drinking water demand, reserving dam water primarily for irrigation. Since severe water stress became a serious and recurring problem Cyprus has to face almost every Summer during the recent years, there is no solid national strategy that can proactively act and properly manage the on-time deployment of desalination plants and deploy contingency plans when one or more of these plants are disabled. Also, the cost of running these plants is huge (Cyprus Mail, 2025c) and each plant added to the water supply system burdens the electricity production plants that face similar technical problems that raise the production cost and the environmental pollution. Each desalination plant installed in Cyprus comes with an economic, environmental and technological cost for the country. Solving the water scarcity in Cyprus is a difficult problem that requires compromising uninterrupted water supply, economic/technological feasibility and environmental impact due to the huge electricity demand of the desalination plants. To make things worse, this balance needs to account for the availability of strategic reserves in emergencies, such as warfare or physical catastrophes. For example, the ongoing Middle East crisis led to an explosion of refugee flows into the island and humanitarian transportations carried out by Cyprus UN High Commissioner for Refugees (UNHCR, 2025). Also, the Ukrainian war, the increased cost of other tourist destinations, the rising quality in tourist services offered by Cyprus and other unpredictable factors led to an increased number of tourists visiting Cyprus during the last couple of years. Specifically in 2024, Cyprus welcomed an unprecedented number of tourists and this year local authorities expect to reach or overcome this number. While this contributes to the explosion of the tourism sector revenue, it also puts some extra stress on the water supply system capacity. To manage the problem, local authorities need reliable predictions for future demand, which could be split into two categories: the projection of the future needs based on the water offer and demand and the intensification of the problem due to climate change. The latter can render any projections to be off and have a catastrophic impact on the effectiveness of derived solutions if not accounted for. We aspire to deal with this uncertainty by applying and extending the CLIMAAX methodologies. The studies of drought and heat waves can provide valuable insights into how much water demand can be intensified by climate change.

4. **Tourism and Cultural Heritage:** Nicosia's historic center is a significant draw for cultural tourism, with museums, galleries, and unique architecture. Extreme heat during peak tourist seasons and especially during summer can make the city less appealing due to thermal discomfort, potentially reducing visitor numbers and impacting local businesses. As already discussed, water shortages could disrupt business operations and damage the tourists' experience during their visit to Nicosia. Also, higher temperatures cause higher energy costs for cooling, which leads hotels to increase accommodation prices. Extreme weather events (intense rainfall, heat, increased humidity) can accelerate the decay or damage of historic buildings and artifacts. This is especially true for Nicosia, which is renowned for its long, exposed city wall that surrounds the old city, showcasing its layered history. This exposed

city wall dates back to the Venetian period and stands as a testament to Nicosia's historical significance as a city that fought against many conquerors through time.

5. **Urban Green Spaces and Biodiversity:** Parks, urban trees and natural vegetation enhance the beauty of Nicosia, provide ecosystem services (e.g., cooling, air filtering), and contribute to the local biodiversity. Extended heatwaves and periods of drought can result in heat stress, stunted growth, and even mortality of urban trees and plants, which are then unable to shade and cool the city. This also increases the chances of urban wildfires. Changes in temperature and precipitation regimes can modify the presence of plant and animal species and may thus influence urban biodiversity. Higher temperatures can also mean more optimal conditions for pests that feed on plants.
6. **Economy and Livelihoods:** Nicosia is the economic and political center of Cyprus, with a diverse economy including services, retail, and a growing innovation and creative industries sector. Flooding, power outages, and infrastructure damage can halt business activities and supply chains. Already, businesses face higher utility costs (especially for cooling) that often threaten their viability. Energy prices in Cyprus are notably higher, making them a more prominent issue compared to other European nations. Due to the high energy demand, citizens in Nicosia also occasionally experience power outages that are caused by infrastructure damage or upgrades/modifications to withstand the ongoing demand increase. Heat stress can reduce worker productivity, particularly for outdoor labor. In Cyprus, the Ministry of Labor, Welfare and Social Insurance is responsible for enforcing the outdoor work ban during extreme heat, i.e., when the temperature is above 42° Celsius, especially during heatwaves in July and August. During recent years, these alerts have been issued more frequently, reaching an average of 18 per year (Cyprus Mail, 2024). The heatwaves not only disrupt economic activities, causing revenue loss, but also cause major discomfort to the population and become a serious health threat, especially for vulnerable population groups like the elderly and individuals with chronic illnesses. While heatwave-related deaths in Cyprus between 2004 and 2009 were estimated to be 32 per year, a European-wide study suggests that this number climbed to 1277 in 2022 (Ballester et al., 2023).

There are several **outside influences on the climate-related challenges** faced by Nicosia, stemming from regional, national, EU-level, and global initiatives. These external factors both shape and constrain how Nicosia approaches climate adaptation and water stress issues.

The CRA strategy of the Nicosia Municipality is influenced by the EU-level directives, especially through its constant participation in the EU Mission on Adaptation to Climate Change. By signing the European Union Mission Charter, the city has committed to climate resilience targets by 2030- an alignment of local priorities with European aspirations. By adopting the EU directives, Nicosia earns many concrete benefits. Direct funding, advanced analytical tools, and methodologies like CLIMAAX, all of which have very close access and rapport with Nicosia's CRA processes, are brought in through this partnership. The multi-level governance and system resilience focus of the European Union ensures that the local efforts in Nicosia are not merely ad-hoc projects but are harmonized with wider continental strategies. Concretely, the climate agenda in Nicosia is relevant for local needs but is also thoroughly clothed in the EU's long-term resilience architecture.

ECP and its funding instruments affect the way the Nicosia Municipality does its strategic planning on climate change. Thus, the way its CRA will be instrumented is affected by the city's scope of involvement in EU-funded programs, such as the ICC, LIFE, and Horizon Europe. These initiatives espouse data-driven decision-making processes, climate-proof investments in urban development, and principles of smart governance. Consequently, the involvement in these programs fundamentally shapes both the methodological process and the overall scope of Nicosia's CRA efforts. Cyprus, and thus its capital, Nicosia, is firmly committed to its international obligations under the UNFCCC and the European Union's climate targets within the framework of the Paris Agreement (Republic of Cyprus, 2023). These national and EU-level commitments profoundly influence climate monitoring efforts, the specific requirements for climate risk reporting, and the accessibility of funding that Nicosia can leverage for its CRA initiatives and broader resilience-building projects. As a result, Nicosia's local actions are integral to Cyprus's ability to meet its global climate responsibilities. Nicosia, situated in the Eastern Mediterranean, faces the stark realities of a climate change "hotspot." This region is experiencing significant vulnerability to climate change consequences, marked by expanding desertification, pronounced temperature anomalies, and persistent water scarcity. This shared environmental reality creates transboundary risks that extend beyond individual national borders, encompassing large-scale regional droughts and a growing energy interdependence. These challenges raise crucial opportunities for collaboration, a fact that is seemingly well understood by the countries involved, which recently began negotiating several energy agreements. The region is actively fostering initiatives in climate diplomacy and working to develop shared early warning systems. A prime example of this regional cooperation is the ongoing effort to establish an electrical connection, notably the EuroAsia Interconnector, connecting nations such as Greece, Cyprus and Israel (*Great Sea Interconnector*, 2025). This vital undertaking is designed to bolster regional energy security and cultivate collective resilience against the common climate challenges that affect the countries. While several treaties regarding economic, investment, climate, energy and migration aspects have been signed between these neighboring countries, impactful agreements on energy matters have been slowly progressing and often postponed due to disagreements regarding the exploitation plans discussed.

The protracted division of Cyprus, as a result of the Turkish occupation of its northern part since 1974, poses a unique and complex challenge to the implementation of a unified and comprehensive climate change strategy across the city of Nicosia in its entirety. Thus, the unique geopolitical status of Nicosia, being a divided capital, introduces a significant complexity to the Municipality's efforts towards designing and implementing an effective climate change strategy. The city's division compromises the efforts of building a holistic understanding and managing critical climate risk factors specific to the urban fabric of Nicosia, such as the comprehensive mapping of UHIE or the coordinated planning of drainage systems that ideally should function across the entire city's continuum. Furthermore, achieving unified data collection on climate variables, planning interconnected green infrastructure, or establishing early warning systems for the entire Nicosia urban area becomes challenging, potentially limiting the overall effectiveness and resilience-building capacity of the climate adaptation and mitigation efforts. On the other hand, this unfortunate situation could raise an opportunity for collaboration, where climate action, being a shared existential threat, might serve as a neutral ground for fostering dialogue and practical cooperation between the Greek and Turkish Cypriot communities across the divide. Addressing shared environmental challenges like urban heat, flood management and water stress could build trust between the two communities and demonstrate the mutual benefits of working together for a more

resilient Nicosia. Also, the two communities could greatly benefit from sharing experiences, information, and effective solutions to identical climate change problems that both face by living in the same geographical area.

As temperatures rise, **proactive urban planning and adaptation strategies** will be critical to minimizing these impacts and protecting public health. Potential adaptation actions include:

- Creating cool urban environments through nature-based solutions: Cool urban environments, increase green spaces (tree planting, urban parks), improve energy efficiency of buildings, shading structures, solar panels for shading, cool materials, green roofs, etc.
- Increased Green Spaces: Expanding parks, green roofs, and tree coverage in the city can help absorb heat and provide cooling effects. These spaces also promote biodiversity and enhance residents' quality of life. The mayor of Nicosia promised to plant 100,000 trees inside the city strategically to mitigate the problem.
- Sustainable building practices, i.e., adapting present and future architectural designs to mitigate the effects of heat absorption by materials and increase the area of vertical reflective surfaces: Using cool roofing materials, reflective pavements, and better building designs can help reduce the heat absorption of structures. These can significantly reduce the UHIE.
- Smart Urban Planning: Designing cities with wind corridors, expanding vegetation, and encouraging the use of light-colored materials that reflect rather than absorb heat are effective UHI mitigation strategies.
- Widening riverbanks and upgrading drainage systems to manage flooding: Widen banks of the Pediaios river, upgrade drainage system capacity, green infrastructure to absorb rainwater, subsidence for flood-proof buildings, flood barriers, etc. The city's infrastructure needs updating to accommodate new rainfall patterns and prevent urban flooding.
- Promoting the use of drought-tolerant native plants in urban landscaping: Adaptation strategies, including the use of heat-tolerant crops and water-efficient irrigation, will be critical to reducing the impacts of prolonged heat on agriculture. Drought-tolerant plants/crops, water management, heat-resilient landscaping, urban planning prioritizing green infrastructure, etc.

Best practices will be collected during Phase 3 to determine the recommendations that are most suitable for the Municipality of Nicosia, including recommendations collected via a questionnaire to the local community as well as technical experts.

2.1.3 Participation and risk ownership

The stakeholder engagement diagram illustrates the governance ecosystem surrounding the CLIMAAX-NIC Project at the end of Phase 2. The project is positioned at the centre of the diagram, emphasizing its role as the coordinating core of a multi-level climate resilience network. The concentric circles represent varying levels of proximity, operational involvement, and institutional influence, while the arrows indicate active communication channels, collaboration pathways, influence relationships, and risk-sharing dynamics among stakeholders.

The color coding reflects the current engagement status of stakeholders:

Blue: stakeholders already contacted and actively engaged through communication, collaboration, meetings, or technical cooperation.

Yellow: stakeholders identified during the Phase 1 stakeholder mapping exercise that are expected to become more actively involved during Phase.

The diagram also reflects the project's approach to shared risk ownership, as defined during Phase 1. Climate-related risks are not managed solely by the Municipality of Nicosia but are distributed across municipal departments, national authorities, research institutions, private sector actors, and local communities. The arrows therefore represent not only communication and collaboration, but also the distribution of responsibilities, technical expertise, policy influence, and adaptation capacity among stakeholders.

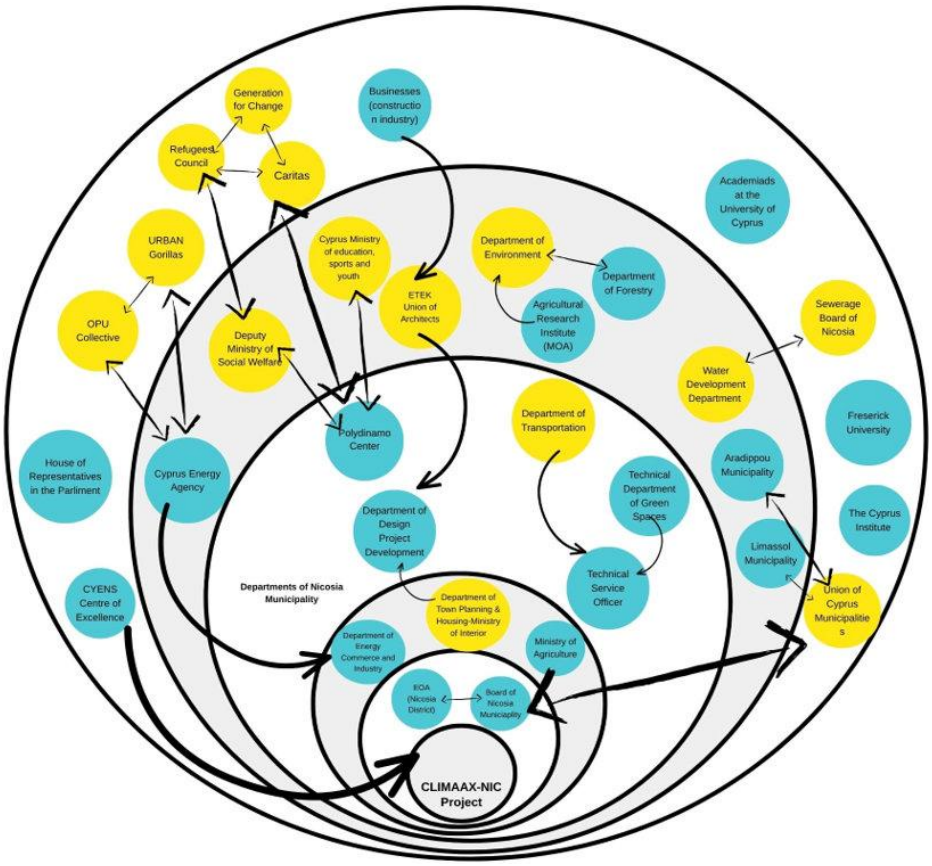


Figure 1 The stakeholder engagement organogram

a) Core Municipal Governance and Operational Stakeholders

The core municipal governance structure is led by the Board of Nicosia Municipality, which serves as the central decision-making authority responsible for coordinating climate adaptation and resilience actions. Municipal departments, including those responsible for energy, project development, technical services, and green spaces, form the operational backbone of adaptation implementation through urban planning, infrastructure upgrades, green infrastructure development, and climate-sensitive design.

Supporting this role is the Nicosia District Local Government Organisation (EOA) and has direct support and influence of the Nicosia Municipality. Also, the Ministry of Agriculture and the

Department of Forestry provide national-level support on environmental governance and ecosystem management. Additional governmental departments play a key role in the wellbeing of our communities such as the Deputy of social welfare and Cyprus Ministry of education, sports and youth which are directly responsible for the support to the Polydinamo Center.

Together, these stakeholders share responsibility for managing risks related to heatwaves, flooding, infrastructure vulnerability, and environmental degradation.

b) National Authorities and Sectoral Agencies

National authorities and sectoral agencies provide the regulatory, technical, and policy framework necessary for climate resilience. The Department of Town Planning and Housing supports the integration of adaptation measures into land-use planning and urban development, while the Department of Transportation contributes to sustainable mobility and transport resilience. The Department of Environment leads environmental governance and adaptation policy implementation, supported by the Department of Forestry through ecosystem protection and nature-based solutions. The Water Development Department plays a critical role in addressing water scarcity and drought resilience, while the Sewage Board of Nicosia supports climate-resilient drainage and flood management infrastructure. Collectively, these institutions share responsibility for managing environmental, infrastructure, and resource-related climate risks.

c) Research, Innovation and Academic Institutions

Research and academic institutions provide the scientific foundation for evidence-based climate adaptation planning. CYENS Centre of Excellence serves as the project's primary scientific and technological partner, offering expertise in climate modelling, digital innovation, and data analysis. The Cyprus Institute contributes climate projections and adaptation research, while academics from the University of Cyprus strengthen links between scientific knowledge and municipal decision-making. Frederick University and the Agricultural Research Institute further support technical expertise, educational outreach, ecosystem management, and environmental adaptation research. Together, these institutions enhance risk assessment, climate forecasting, knowledge dissemination, and informed policymaking.

d) Inter-Municipal and Regional Cooperation Stakeholders

Inter-municipal and regional stakeholders strengthen collaboration and knowledge exchange beyond the boundaries of Nicosia. The Union of Cyprus Municipalities facilitates coordination among local authorities, promoting the transfer of best practices and collective approaches to climate resilience. Municipalities such as Limassol and Aradippou provide opportunities for peer learning, networking, and future cooperation on adaptation initiatives. Their involvement supports the replication, scaling-up, and regional integration of resilience measures across Cyprus.

e) Private Sector and Professional Bodies

Private sector actors and professional organizations play an important role in implementing resilient urban development. Businesses within the construction industry contribute to the integration of climate-resilient infrastructure and sustainable building practices, while ETEK (the Union of Architects) provides professional expertise in planning, engineering, and architectural standards. These stakeholders support public-private collaboration, technical innovation, and the incorporation of climate resilience principles into future urban development projects.

f) Civil Society and Community Stakeholders

Civil society organizations contribute to participatory governance, social inclusion, and community engagement in climate adaptation processes. Organizations such as Urban Gorillas, OPU Collective, Caritas, Generation for Change, Refugee Council support citizen participation, co-design activities, awareness campaigns, and local engagement initiatives. Their involvement strengthens social innovation, community ownership of adaptation measures, and climate justice objectives by ensuring that vulnerable and underrepresented groups are actively included in resilience planning and decision-making.

g) Energy and Sustainability Support Organizations

The Cyprus Energy Agency acts as a key intermediary supporting sustainable energy transitions and climate resilience. Through the promotion of renewable energy, energy efficiency measures, and public awareness activities, the agency helps address energy-related vulnerabilities and contributes to reducing energy poverty among vulnerable households. Its role strengthens the connection between municipal adaptation efforts and broader sustainability objectives.

h) National Legislative Environment

The House of Representatives provides the broader legislative and policy framework that shapes climate governance in Cyprus. Through the development of laws, regulations, and policy support mechanisms, it influences the long-term institutional environment within which climate adaptation and resilience measures are implemented. Its role is essential for ensuring regulatory alignment, political support, and the sustainability of future climate resilience initiatives.

Overall, the diagram demonstrates that by the end of Phase 3, the CLIMAAX-NIC Project has evolved from an initial stakeholder mapping exercise into an increasingly interconnected governance and risk-sharing network. The arrows throughout the figure symbolize communication pathways, institutional influence, technical cooperation, shared responsibility, and collaborative management of climate risks.

Phase III is expected to further expand stakeholder participation, particularly among currently less-engaged actors shown in yellow. Additional municipalities, civil society organizations, sectoral authorities, vulnerable groups, and private sector actors will be more systematically involved through Phase III of the project. This gradual expansion aligns with the project's broader objectives of participatory climate adaptation, climate justice, social inclusion, and integrated urban resilience governance.

Risk ownership is a key and tricky component in any city s plans towards sustainability and climate resilience. By tricky, we mean that it is very difficult to embed general risk ownership into Nicosia s regulatory framework, for purposes of fairness, legal implications, enforcement, etc. Risk ownership is distributed across the municipality, private sector, and citizens, with the municipality of Nicosia playing a central regulatory role. The exact mechanisms depend on specific policies, but the approach emphasizes shared responsibility and adaptive governance. While each sector (e.g., health, energy, transportation, waste) entails different municipal policies, the following general principles apply regarding risk ownership for Nicosia:

a) Municipal responsibility: The Municipality of Nicosia acts as the primary regulator and coordinator of climate-related risks, ensuring:

- Policy Implementation: The municipality enforces climate adaptation and mitigation measures, assigning responsibilities to relevant departments.
- Stakeholder engagement: Collaboration with businesses, NGOs, and citizens to share risk ownership (e.g., through public-private partnerships).
- Compliance monitoring: Ensuring that municipal projects and private sector initiatives align with climate resilience goals.

b) Risk allocation in key sectors:

- Infrastructure and urban development: The municipality retains ownership of risks related to public infrastructure (e.g., flood defenses, green spaces) but may require private developers to integrate climate-resilient designs.
- Energy and transport: Risks associated with transitioning to renewable energy and sustainable transport are shared between the municipality, private sector, and national agencies. In Cyprus, it is national agencies (i.e., Department of Environment, Department of Transport) that define general policies which then the municipalities need to adhere to.

c) Public-Private Partnerships (PPPs):

- The municipality may enter agreements where private companies work on the mitigation of certain climate risks (e.g., renewable energy projects, green building standards). Insurance mechanisms and incentives could be used to distribute financial risks.

d) Citizen and community Involvement:

- Residents and community groups are encouraged to participate in local climate initiatives (e.g., urban greening, waste reduction), sharing responsibility for resilience. Awareness campaigns promote individual and collective risk mitigation.

e) Legal and regulatory framework:

- The municipality may introduce local ordinances mandating climate adaptation measures (e.g., water management, energy efficiency in buildings). Enforcement mechanisms (inspections, fines, or incentives) ensure compliance.

Nicosia does not explicitly define a quantified "**acceptable level of risk**" in terms of thresholds (e.g., specific flood probabilities or emission limits). Unacceptable risks are those that threaten life, critical infrastructure, or legal obligations. The municipality approaches acceptable risk" based on its alignment with EU and Cypriot climate adaptation standards, emphasizing:

- Avoidance of high-probability, high-impact risks (e.g., urban flooding, heatwaves) through infrastructure upgrades (drainage systems, green roofs).
- Tolerance of residual risks where mitigation is impractical (e.g., extreme weather events), managed via emergency response plans and insurance mechanisms.
- Progressive reduction targets (e.g., CO_2 emissions cuts by 40% by 2030), implying risks beyond these thresholds are unacceptable.

The municipality s risk tolerance is shaped by the precautionary principle, i.e., prioritizing proactive measures over reactive fixes (e.g., flooding protection measures in flood-prone areas). Risks may be acceptable only if mitigation costs exceed projected damage (e.g., minor flooding may not justify

expensive upgrades to riverbanks). Public consultations are a common practice of the municipality to ensure that risks align with community priorities (e.g., protecting cultural heritage sites from climate impacts).

We will communicate the project s results by leveraging various channels of communication so that each message category finds the most appropriate recipients. Both partners will apply the most effective strategy to deliver the messages by drawing from their dissemination capacity. Channels include emails and newsletters to local and European stakeholders, leaflets and posters in relevant local and European events and networking initiatives, newspaper articles, online news and stories at the main social media of Cyprus, press releases at different intervals of the project s lifetime, as well as exploiting the monthly meetings of the Union of Cyprus Municipalities, the scientific information days organized by Research and Innovation Foundation (RIF Cyprus) (*The Research and Innovation Foundation*, 2025) and by the Deputy Ministry of Research, Innovation and Digital Policy of the Republic of Cyprus (*Deputy Ministry of Research, Innovation and Digital Policy*, 2025). Our strategy is to use a variety of media (emails, leaflets, online and printed publications, webinars, workshops, science cafes and info days) to address the target groups of the project. An on-site conference will be organized near the end of the project, inviting all stakeholders to attend, expecting at least 100 participants. Our website and online social media pages, visited by tens of thousands of users per month, will help promote the project and build a community of stakeholders. Enticing narratives and successful stories will be produced, supported by data, to showcase how various risks affect different parts of the city based on different climatic projections, while various possible actions will be illustrated via narratives to inspire citizens and investors. In addition, web interfaces showing how various risks change in the city through space and time, visualized by means of geo-visualizations, will be produced, shared, and communicated to the public under a common online web portal.

The scientific partner of the project (CYENS) is committed to preparing and submitting at least two high-impact scientific publications in top-class journals, such as Nature Climate Change, Elsevier Global Environmental Change and Springer Mitigation and Adaptation Strategies for Global Change.

The Nicosia Municipality Multifunctional Foundation identified limited coordination among organizations supporting vulnerable groups as a key gap in service provision. To address this, NGOs and initiatives in Nicosia established the Solidarity Network Hub, which brings together organizations including Generation for Change, Caritas Cyprus, Hope for Children CRC Policy Center, Cyprus Red Cross Society, Systema Cyprus, Cyprus Refugee Council, and Ithaki Charity Organization to provide coordinated support to vulnerable populations. These organizations have been identified as key stakeholders and representatives of priority groups and will be engaged during Phase 3 to gather further information on the populations they support.

2.1.4 Application of principles

Although the Nicosia Municipality does not currently have a dedicated strategy, framework, or formal guidelines specifically addressing social justice, equity, and inclusivity across all aspects of municipal planning, these principles have consistently been prioritized in practice. The Mayor's Manifesto emphasizes the importance of youth participation through the establishment of a Youth Council, which actively contributes to discussions and decision-making processes. The manifesto also highlights the importance of understanding and addressing the needs of elderly people, while

the Nicosia Multipurpose Community Centre carries out activities that support vulnerable individuals and families within the community, especially those with low incomes.

As part of this project, a representative of the Nicosia Multipurpose Community Centre was consulted and shared valuable experiences, data, and insights regarding the communities living within the Municipality of Nicosia. These discussions helped inform the Phase III engagement strategy and guided the identification of key stakeholders and vulnerable groups that should be involved in the final assessment process.

The Municipality actively seeks to understand the needs of its residents and promotes inclusive participation through community engagement and consultation processes related to urban development and decision-making.

To further strengthen the integration of social justice, equity, and inclusivity considerations within the climate risk and vulnerability assessment, a stakeholder mapping exercise was undertaken. During this process, NGOs, community organizations, and social groups operating within the Municipality of Nicosia were identified, particularly those working with vulnerable populations such as immigrants/refugees, low-income households, people experiencing poverty, older adults, and persons with disabilities.

In Phase III of the project, targeted engagement activities will be conducted with these organizations and groups to gather information on their specific vulnerabilities, climate-related challenges, and adaptation needs. This information will be incorporated into the assessment to ensure that the perspectives and experiences of vulnerable populations are reflected in the analysis and considered in the development of adaptation measures.

Additionally, a questionnaire survey will be distributed to the general public, as well as to technical experts involved in urban development, including architects, engineers, and urban designers. This process aims to capture a broad range of perspectives, support inclusive participation, and ensure that adaptation planning is informed by both community knowledge and technical expertise.

Through these activities, the project seeks to promote equitable and inclusive climate resilience planning that recognizes the diverse needs and capacities of different population groups within Nicosia. By the end of Phase III, the ten priority adaptation recommendations will be identified and refined based on the evidence collected through stakeholder engagement, consultations, and survey responses. This process will ensure that the final recommendations not only address the identified climate risks but also reflect the needs, priorities, and perspectives of the wider community, contributing to a more inclusive, representative, and socially equitable adaptation strategy for Nicosia.

The precautionary approach is a principle where action is taken to prevent potential harm even when scientific evidence is incomplete or uncertain. In research (including climate studies), it means making conservative assumptions or policy recommendations to avoid serious or irreversible risks, rather than waiting for full proof.

We are exploiting the hotspots detected (flooding, UHI effect), to understand the reasons why they have been created, who they affect and potential impact, so that we can give recommendations or share best practices at Phase III. Our modelling tried not to overestimate the effects of the risks but provided conservative assumptions which would justify actions even before full proof is provided.

In our analysis, the principles of social justice, equity, and inclusivity were carefully considered throughout the CRA process. The study exploited detected hotspots, including areas affected by UHI effects, flooding, and vegetation stress due to drought, to investigate their causes, affected populations, and potential impacts. This approach enabled us to provide informed recommendations and identify best practices for mitigation in Phase III of the project. Importantly, no population subsets were excluded from the analysis; the CRA was conducted without geographical, demographic, or social selectivity. While priority was given to areas exhibiting recurring issues, such as frequently flooded zones, this was done purely to improve understanding of the underlying conditions rather than to exclude or disadvantage any groups. Vulnerable populations, including the elderly and young children, were explicitly considered in the assessment of risk and vulnerability.

The principle of quality and rigor was embedded in the modelling and analysis approach. All predictive models were validated against available ground-truth measurements, ensuring that results accurately reflected observed phenomena. Additionally, expert consultations were conducted to interpret the findings and understand the physical processes and dynamics driving the risks under study. This combination of empirical validation and expert review ensured that the analysis maintained high standards of scientific rigour and reliability, providing confidence in the conclusions drawn from the CRA.

Transparency was another cornerstone of the project. All results were made publicly available and communicated to stakeholders, including policymakers, to facilitate their practical exploitation. Efforts were made to ensure that findings were conveyed clearly and effectively, emphasizing actionable insights rather than technical complexity. Furthermore, the project actively engaged with the academic community, inviting fellow researchers to access and utilize the data and results. This openness promotes collaboration, peer scrutiny, and broader dissemination of knowledge, consistent with the CLIMAAX Framework s emphasis on transparent and accessible research.

The precautionary approach was consistently applied throughout the CRA. Modelling and predictions were tuned conservatively, aiming to present tendencies and risks without exaggeration or overstatement. This approach ensures that recommendations are justified even in the absence of complete proof, enabling timely and responsible decision-making by policymakers. By avoiding artificial inflation of risk magnitudes, the analysis provides credible guidance while maintaining scientific integrity and public trust.

By integrating these principles, the project ensures that the CRA not only identifies and quantifies climate-related risks but does so in a socially responsible, scientifically robust, and actionable manner. Social equity considerations guarantee that vulnerable populations are represented, while rigorous validation and expert consultation uphold the reliability of the findings. Transparency facilitates the practical use of the results, and the precautionary approach ensures that recommendations are grounded in conservative, credible assumptions rather than speculative exaggeration.

Overall, adherence to these principles strengthens the relevance, credibility, and usability of the CRA. The combination of inclusivity, rigour, transparency, and precaution ensures that the project delivers results that are scientifically sound, socially responsible, and immediately applicable for policy

development and mitigation planning. These principles collectively enhance the quality and impact of the climate risk assessments conducted for UHI, flooding, and vegetation stress, aligning the study with best practices in climate risk research.

2.1.5 Stakeholder engagement

Stakeholder engagement was carried out through targeted meetings and participation in regional events, ensuring continuous dialogue with key actors, experts, and priority groups.

At the local level, a series of meetings were conducted with representatives from the Nicosia Municipality, including the Technical Department of Green Spaces, the Department of Design and Project Development, and Technical Service Officers. These meetings focused on identifying key challenges, mitigation actions, and needs related to the three primary climatic risks addressed by the project: Urban Heat Island Effect (UHIE), flooding, and drought-induced vegetation loss. Participants included departmental heads and technical experts responsible for urban planning and infrastructure. We have been in contact with the head of the Polydynamo Center (Nicosia Multipurpose Community Centre) and held a meeting to gain insight into the vulnerable groups within the city, the support provided by the Center and the Nicosia Municipality, and any current actions being taken to mitigate the climate-related risks these groups may be facing.

These meetings also served to introduce the project objectives, communicate intermediate findings, and establish collaboration channels for Phase III, during which municipal departments are expected to contribute through a questionnaire which will enrich to the final list of recommendations that will be presented.

At the regional level, participation in a meeting of EU Member States, organised in the context of the Cyprus Presidency, provided an opportunity to present the CLIMAAX-NIC project, its methodology, and preliminary results. The meeting included representatives from regional authorities and experts from capital cities across the European Union. Project goals and intermediate results were communicated through a structured presentation, including UHIE risk findings and GIS-based flood mapping outputs, followed by an open discussion.

Very targeted meetings were executed with two other municipalities of Cyprus (Aradippou and Limassol), who participate at the Pathway2Resilience cascade funded projects. During those meetings, we shared our methodology and approaches to map and characterize climate risks. While Aradippou followed a different approach, based on more generic statistical information and surveys, Limassol municipality intends to replicate our approach for their region. This exercise will provide us with important insights about the generalization and adaptability of our risk modelling methods beyond the city of Nicosia.

Moreover, we interacted with stakeholders via the following opportunities that occurred within the period of Phase II:

- In April 2026, during the Cyprus Presidency, CYENS had a visit from the Attachés (Research and Innovation Attachés, approximately 60 attendees).
- In March 2026, our colleague Savvas Karatsiolis presented the UHI effect modelling at the Cyprus Computational Science Symposium: The Convergence of Physics-based Modeling with Data-driven Methods (CONVERGE), taking place on February 26–27, 2026, at the new buildings of the Engineering School of the University of Cyprus in Nicosia, organized by the Cyprus Institute and the University of Cyprus.

- In March 2026, our colleague Chirag Padubidri participated in a round table discussion at the international conference “Climate Neutral Blue Cities by 2030: Accelerating Local Change under the EU Cities and Ocean Missions, organised by the Municipality of Limassol, which took place at the Warehouse by IT Quarter, Limassol, Cyprus.
- In November 2025, our colleague Andreas Kamilaris participated as speaker at the Conference “Towards a Greener Future: European Innovation for Sustainable Cyprus”, which was held at the Royal Hall, Nicosia, supported by the Embassies of France and of the Kingdom of the Netherlands, in partnership with University of Limassol (UoL) and organized by Ideopsis Ltd.
- In April 2026 participated at Youth Fair organised by the University of Cyprus sharing information about CLIMAAX-NIC project objectives, up to now outcomes and next steps.
- In May 2026 joined the seven Centers of Excellences at the “Dooers Summit Festival” hosted in Limassol engaging local NGOs, small local businesses/startups, and research groups. (approximately 100 people)
- In May 2026, our colleague Noor Sajjad participated as a speaker at the Blended Intensive Programme (BIP) hosted in Cyprus, as part of a course designed to explore diversity and inclusion in depth through visual and artistically oriented methodologies. (approximately 20 people participated)
- In June 2026, our colleague Noor Sajjad participated as a speaker at the Presentation EWA GROW Programme in Cyprus, implemented by SocialTech Lab under the EIT Food initiative. (15 people participated)

Project goals and intermediate results were presented by means of banners, presentations, discussions in round tables as well as actual demonstrations for all the three risks modelled by the project (via a laptop for all three risks, while for UHI effect the sensing devices used for capturing temperature/wind were also presented to the public). The communication of project goals and intermediate results was carried out also through a structured scientific presentation, which included methodological explanations, modelling strategies, and key findings. The presentation introduced the proposed decomposition of UHI into a location-specific UHI potential (UHIp) and a weather-driven modulation term (UHIm), along with a learnable correction component addressing vehicle-induced convective bias. The results were presented in a comprehensive and analytical manner, providing clear explanations of the spatial and temporal dynamics of UHI in Nicosia. This approach facilitated an in-depth understanding of both the modelling framework and the physical interpretation of the results among participants.

We also generated QR codes and printed them on paper, placing them on our banners, inviting participants to scan the code and fill out our online questionnaires, which asked them questions relevant to the risks and any practices/measures they applied to address them. Project outputs were further disseminated by providing access to online resources and informing participants about upcoming research publications, which are expected to happen and be posted on the project’s website and online social media pages of the municipality and CYENS.

In general, the results were positively received by all participants, at local and regional level, and many of them expressed interest in the applicability of the methodology to other cities and countries. It is notable that many participants found their awareness raised about climatic risks, and they

recognized the importance of climatic risk modelling in their regions. Few participants expressed their viewpoint about the practical value of high-resolution, neighborhood-level insights for urban planning and climate adaptation, as this allows targeted and more effective measures with lower costs. Some participants found very interesting the spatial variability of climate risk within the city. Especially for the UHI effect, the fact that heat exposure differs significantly from one neighborhood to another. There was an overall positive reception of the AI-based approach, due to its interpretability and ability to support evidence-based decision-making rather than abstract climate indicators. It is worth mentioning that local experts considered the results credible and aligned with their on-the-ground experience. This was crucial for us to validate our results also via human experience and observations.

Stakeholders and expert engagement within the project were also achieved through participation in scientific dissemination events. In particular, the project team presented its work at the *Cyprus Computational Science Symposium: The Convergence of Physics-based Modeling with Data-driven Methods (CONVERGE)*. The presentation, titled *"Decomposing Urban Heat Islands: A Hybrid Physics-Inspired and Data-Driven Modeling Framework"*, focused on the UHI study conducted in Nicosia. The UHI effect modelling had strong interest from the local scientific community, which identified it as a novel and very interesting method to model this climate risk, with important benefits and advantages over more traditional methods. The primary participants in the symposium were scholars and researchers with expertise in computational science and related fields. The audience demonstrated significant interest in the presented work, particularly in relation to the observed UHI effects in areas familiar to them, such as their places of residence or work. Additional attention was given to the datasets generated during the study and the custom vehicle-mounted equipment developed for data acquisition. Specific aspects that attracted interest included the cost-effectiveness, usability, and scalability of the measurement system, as well as the novelty of the proposed UHI decomposition methodology.

Overall, the project outcomes were well received by the participants, with no notable difficulties or resistance encountered in communicating the results. Some initial scepticism regarding AI-driven models was largely addressed through elaborate explanation of methodology and validation results by means of various visuals. The clarity of the presented materials and the clear communication of the methodologies followed facilitated effective knowledge transfer, even within a demanding academic environment.

Some constructive feedback was provided on the importance of integrating citizen perspectives and local knowledge in future phases of the project, especially in relation to flooding and UHI effect, understanding people's perception about the climate risks and individual measures they take. Many questions revolved around the potential expansion of the methodology, including more data collection, real-time applications and visualizations, and particularly replication in other cities.

The overall positive reception suggests that the project's findings and methodological contributions have potential for further use by stakeholders, even the research community, particularly in the development of similar studies or the adaptation of the proposed framework to other urban contexts.

Participants did not provide much detail to us about how they would use the project outcomes in their region. However, via interaction with them and also through online questionnaires, it was evident that they plan to harness the outcomes via the following manners:

- Replication of our methodologies in their regions.
- Comparison between our methodologies and results with their methodologies/results at their regions
- Comparison of best practices and lessons for mitigating/adapting to climate risks, with practices/lessons from their regions
- Adoption of certain approaches/practices/lessons in their regions.

A noted limitation was the preliminary nature of the results at the time of presentation, as the project is still in progress. More comprehensive and conclusive findings are expected in Phase III, which will enable more detailed discussion and validation of the proposed approaches. Also, some technical details when communicated to a less technical audience (e.g., policymakers and decision-makers) were not easy, as they lacked technical knowledge.

See also the Limitations" section, where we elaborate on the technical challenges.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

During Phase 2 of the project, there were no new developments from what we described at proposal stage.

According to the CLIMAAX Phase 1 Climate Risk Assessment for the Municipality of Nicosia, three primary climate hazards have been identified as most critical for the region: heatwaves and the UHIE, river flooding, and drought. Nicosia already experienced peak summer temperatures frequently exceeding 43°C, a situation intensified by the UHIE due to the dense concentration of concrete, asphalt, and built surfaces that absorb and retain heat. Extreme heat poses serious public health risks, especially for the elderly, and drives heavy air conditioning use that strains the power grid and increases greenhouse gas emissions. River flooding, while historically low risk, is becoming increasingly severe due to more intense rainfall events, urban expansion, reduced green infrastructure, and aging drainage systems; vulnerable areas include the Pediaios, Klimou, and Kalogiros riverbeds, as well as districts such as Engomi, Agios Pavlos, Pallouriotissa, and Aglantzia. Drought compounds these challenges: Cyprus already has the highest water stress levels in Europe, and declining rainfall is expected to worsen water scarcity significantly, threatening agriculture (wheat, olives, citrus) and requiring expansion of energy-intensive desalination.

The CLIMAAX report team directly consulted the Copernicus Interactive Climate Atlas (C3S Atlas), using CMIP6 projections under the SSP2-4.5 scenario and comparing two reference periods (1981–2010 and 1991–2020) against two future target periods (2041–2060 and 2081–2100). Their findings, summarised in Table 2-1 of the report, show a consistent and accelerating deterioration across all key climate indicators. Maximum summertime temperatures are projected to rise by 2–3°C by mid-century and up to 3°C by end-of-century relative to the 1981–2010 baseline. The number of extremely hot days (above 40°C) is expected to increase by 13–18 days, while tropical nights (minimum temperatures above 20°C) are projected to grow by 20–30 additional nights per year. Precipitation is projected to decline by 12–20% in mean daily accumulation, and soil moisture is expected to fall by 0.75–1.5 kg/m². Notably, near-surface specific humidity is projected to rise by 15–25%, amplifying the perceived discomfort of heat. The report explicitly notes that all indicators

point in the same direction and that the pace of change appears to be accelerating, directly corroborating the choice of heatwaves and drought as Nicosia's priority hazards for in-depth risk analysis.

The CRA for the hazards in Nicosia is based on data we gathered during the second phase of the project.

Flooding. For the hazard characterization of river flooding, the project has access to hydrological simulation data, elevation models, grating/drainage infrastructure data, land use and land cover (LULC) datasets, and vegetation data. These inputs enable the spatial modelling of flood extent and depth across the municipality. In terms of vulnerability, the ideal dataset would capture the use of impermeable surface materials (such as asphalt and tile) that prevent water absorption, the adequacy of drainage infrastructure, and the presence of flood insurance or early warning systems, data that are not currently available to the team. In this work, vulnerability will be approximated using the spatial distribution of elderly and pregnant populations, sourced from WorldPopHub. These population groups are considered more vulnerable to flood impacts due to reduced mobility, increased health risks, and the greater challenges they may face during evacuation, access to emergency services, and post-flood recovery. Exposure is defined as the population density of Nicosia, for which spatial population data are available and will serve as the basis for the risk calculation.

Urban Heat Island (UHI) Effect. The hazard assessment for the UHI draws on a relatively rich set of meteorological and physical variables, including elevation, temperature (both measured at many locations in Nicosia and at the reference weather station) and humidity measurements, wind direction and intensity, solar irradiance, and atmospheric pressure data. Together, these allow the team to model the thermal landscape of Nicosia and identify hotspots of heat accumulation. For vulnerability, the ideal scenario would require data on the population density of elderly or low-income residents who lack access to air conditioning, the extent of tree canopy and green spaces, and the thermal insulation quality of buildings — none of which are fully available in the required spatial granularity. The real vulnerability proxy that will be used is the spatial distribution of the elderly population across the municipality, sourced from WorldPopHub. Exposure is defined as the human population density of Nicosia, for which population data are available and will serve as the basis for the risk calculation.

Drought and Extreme Heat. The hazard layer for drought and extreme heat is built upon multispectral satellite imagery and historical databases of crops cultivated within and around the city, as well as vegetation as urban green extracted via agricultural indices from multispectral satellite imagery (i.e., NDVI index). These sources allow the team to assess vegetation stress, land surface temperature anomalies, and the agricultural sensitivity of the area. Ideally, vulnerability assessment would require information on farmers' reliance on seasonal rainfall and on whether monoculture farming of high-water-demand crops is practiced — structural agricultural data that are not directly available. Instead, the actual vulnerability proxy to be used consists of crop type data for Nicosia's agricultural areas, sourced from CAPO Cyprus. The exposure layer combines agricultural plots and urban vegetation, for both of which spatial data are available. Risk for each component is computed through a multiplicative combination of hazard, vulnerability, and exposure.

The following table demonstrates the data used for the CRAs and the data we could further utilize to get more precise and rich results.

Table 1 Data overview (used or not available) for our CRAs.

Risk	*Hazard estimation data*	*Vulnerability data*	*Exposure data*
Flooding	Simulation, elevation, graters, LULC, vegetation	Ideal: Use of impermeable materials (asphalt/tile) preventing water absorption; inadequate drainage infrastructure; lack of flood insurance or early warning systems. Real: Elderly and Pregnant distribution of population (Source: WorldPopHub)	Population density
UHI Effect	Urban landscape, NDVI, elevation, temperature, humidity, wind	Ideal: High population density of elderly or low-income residents who lack access to air conditioning; insufficient tree canopy or green spaces; poor building insulation that traps heat. Real: Elderly and Pregnant distribution of population (Source: WorldPopHub)	Population density
Drought/Extreme heat	Multispectral satellite imagery, historical databases of crops cultivated in the city	Ideal: Reliance on seasonal rainfall; monoculture farming of high-water-demand crops Real: Types of crops (Source: CAPO Cyprus)	Agricultural plots, Urban vegetation

2.2.2 Scenarios chosen

Flooding:

As Nicosia is an inland municipality, the flood risk assessment focuses on riverine and pluvial flooding, while coastal flooding was not considered. To represent rainfall conditions capable of generating flood events, a set of rainfall scenarios was developed using Intensity–Duration–Frequency (IDF) curves obtained from the precipitation IDF dataset.

IDF curves are widely used in hydrology and describe the relationship between rainfall intensity, duration, and frequency (return period). A return period represents the average interval between rainfall events of a given magnitude. Events with shorter return periods occur more frequently,

whereas events with longer return periods are rarer but typically associated with higher rainfall intensities and more severe flooding. The IDF dataset provides rainfall estimates derived from long-term climate records and extreme value analysis. For this study, a 3-hour rainfall duration was selected to represent short-duration, high-intensity storms that are commonly associated with flooding in Mediterranean urban environments. Based on the available IDF data, rainfall scenarios corresponding to 2-, 5-, 10-, 25-, and 50-year return periods were considered.

These scenarios represent a progressive increase in rainfall severity, ranging from relatively frequent rainfall events to rare and more extreme storms. The use of IDF-based scenarios ensures that rainfall inputs are linked to statistically defined probabilities of occurrence rather than arbitrary rainfall intensities, providing a scientifically robust basis for flood hazard assessment. Furthermore, the selected return periods enable the evaluation of flooding under different levels of rainfall severity and support the subsequent development of a flood potential map that accounts for both the magnitude of flooding and the likelihood of the triggering rainfall events.

UHIE: The Urban Heat Island (UHI) of the Nicosia study area was projected under six future climate scenarios. The projections rely on the neural UHI model developed and trained on observations from August and September 2025, which predicts, for each of the 863 cells of a 200 m analysis grid, the temperature difference in degrees Celsius between that cell and the Athalassa reference weather station. The model was driven with six datasets containing environmental measurements predicted by the RCP4.5 and RCP8.5 emission pathways at the horizons 2045, 2065 and 2085, and its predictions were compared against a baseline computed from the real 2025 station measurements under an identical inference protocol. Three sets of results were produced containing the location identifier (0-862) and the time-averaged UHI: the 2025 baseline, the six scenarios driven by the RCP scenarios data and the six scenarios repeated with a wind bias correction. The reasons for producing the wind-corrected variant emerge naturally from the analysis and are explained below.

Drought and vegetation damage: We did not consider future climate conditions, as our study had a very good representation of actual conditions during the hot season around Cyprus (August 2025, after a prolonged period of drought at the island of Cyprus). Increases in maximum temperatures and low precipitation are expected to increase even further the water stress of urban vegetation, but this is something we did not investigate.

For the Nicosia **UHIE** case study, the future climate conditions considered were based on projections for the Eastern Mediterranean, one of the most climate-sensitive regions in Europe. Cyprus is expected to experience a substantial increase in average air temperatures, more frequent and intense heatwaves, and a reduction in summer precipitation over the coming decades. For urban heat island (UHI) analysis, these changes are particularly important because higher background temperatures amplify nighttime heat retention in densely built areas and increase the duration and intensity of thermal stress. The mid-to-high-emissions climate scenario (such as SSP2-4.5 or SSP5-8.5) captures the likely warming trend under continued global greenhouse gas emissions and provides a realistic estimate of future summer conditions in Nicosia. These scenarios indicate that by mid-century, Cyprus could experience several degrees of warming, making urban overheating a more significant environmental and public health concern.

Future socio-economic development was also considered, since urbanization strongly influences the magnitude of the urban heat island effect. Cyprus population increased from approximately 854,000 in 1995 to 1.352 million in 2024 and is projected to reach around 1.51 million by 2054 before

declining gradually to about 1.278 million by the end of the century. Cyprus Population growth over the next few decades is expected to increase housing demand, commercial development, transportation infrastructure, and energy consumption, particularly in and around Nicosia. Continued economic growth is likely to result in further expansion of impervious surfaces such as buildings, roads, and parking areas, while increasing the number of anthropogenic heat sources including vehicles, air-conditioning systems, and industrial activities. These factors reduce vegetation cover and increase heat storage and waste heat emissions, intensifying the urban heat island effect.

In addition, socio-economic changes such as higher living standards and changes in consumption patterns may lead to greater electricity demand for cooling during summer months. Food consumption and prices are also expected to be affected by climate change, particularly through increased irrigation demand and reduced agricultural productivity, although these factors have a more indirect impact on urban temperatures. Overall, the combination of rising temperatures, ongoing urbanization, and increased energy use makes Nicosia highly vulnerable to stronger urban heat island effects in the coming decades, highlighting the importance of climate-resilient urban planning and mitigation strategies such as increasing green spaces, improving building materials, and reducing waste heat emissions.

Future socio-economic development was not explicitly modeled within this study. However, if future socio-economic scenarios were considered, several factors relevant to flood risk would be evaluated. Population growth and continued urban development are expected to increase the extent of built-up areas within and around Nicosia. The expansion of residential, commercial, and transportation infrastructure typically increases the proportion of impervious surfaces such as roads, rooftops, and paved areas. These surfaces reduce infiltration and increase surface runoff during rainfall events, potentially leading to higher flood volumes and faster runoff generation. In addition, population growth increases the number of people, buildings, and critical infrastructure exposed to flooding. Urban expansion may also place new developments in areas that are currently undeveloped or naturally act as flood storage zones, further increasing flood vulnerability. Increased economic activity and infrastructure development can place additional pressure on existing drainage systems, which may become insufficient under future rainfall conditions.

Climate change and socio-economic development can therefore interact to amplify flood risk. While more intense rainfall events increase flood hazard, urbanization and population growth increase both exposure and potential impacts. Future assessments could incorporate population projections, land-use change scenarios, and urban growth forecasts to evaluate how flood risk may evolve under different development pathways and to support long-term urban planning and adaptation strategies.

The effects of rapid population growth have already been visible in the city's urban development. In recent years, there has been a noticeable increase in the construction of apartment buildings, especially in central areas and along major transport corridors. As land becomes more limited and expensive, developers are increasingly choosing higher-density residential projects instead of detached houses. This reflects a gradual change in the urban landscape, where apartment living is becoming more common than traditional single-family housing.

While higher-density development can provide housing for a growing population and make more efficient use of available land, it may also contribute to higher property prices and rental costs. At the same time, increased density can improve access to services, employment opportunities, and public transport, as more people live closer to the city center. However, if population growth

continues without adequate planning and infrastructure investment, issues such as traffic congestion, pressure on public spaces, and reduced environmental quality may become more significant. Therefore, the challenge for Nicosia will be to accommodate future growth while maintaining housing affordability, accessibility, and a good quality of life for residents.

In regard to **flooding**, the analysis was conducted using the historical baseline climate period (1976–2005) provided within the CLIMAAX precipitation IDF dataset. This period was selected to represent the current climatic conditions under which flood hazards are presently experienced and managed within the study area. Rather than assessing changes across multiple future climate horizons, the objective of this phase of the study was to establish a robust baseline flood hazard and flood potential assessment for Nicosia. The selected rainfall scenarios therefore represent the frequency and magnitude of extreme rainfall events expected under the historical climate conditions for the region. Future climate projections corresponding to near-term, mid-term, and long-term horizons (e.g., 2011–2040, 2041–2070, and 2071–2100) are available within the CLIMAAX dataset and could be incorporated in future analyses to evaluate the potential impacts of climate change on flood hazard. However, these future climate horizons were not considered within the scope of the present assessment, which focuses on establishing a baseline flood risk profile using historical climate conditions.

In regard to **UHI effect**, the analysis is considered medium-term (e.g., 20-30 years), as we do not expect dramatic changes to daily average temperatures in hot seasons beyond 1-2 degrees Celsius.

In regard to **drought and vegetation damage**, the analysis can also be considered short-to medium-term, as we cannot be certain whether prolonged drought and excessive heat, beyond the scenario we considered, would have more adverse effects on vegetation.

2.3 Regionalized Risk Analysis

2.3.1 UHI hazard - fine-tuning to local context

The Urban Heat Island (UHI) phenomenon is one of the most significant local manifestations of global climate change and rapid urbanization. It refers to the tendency of urban areas to experience substantially higher temperatures than their surrounding rural environments, primarily due to the concentration of impervious surfaces, dense building structures, limited vegetation, and anthropogenic heat emissions. The UHI effect has far-reaching consequences for cities, adversely affecting the quality of life and health of residents, particularly vulnerable populations such as the elderly and individuals with pre-existing medical conditions. It also leads to increased energy demand for cooling, higher greenhouse gas emissions, deterioration of air quality, and broader economic impacts associated with elevated operational costs and reduced urban productivity.

Although a vast body of research has investigated the UHI phenomenon over the past several decades, only in recent years have policymakers, urban planners, and architects begun to systematically incorporate UHI mitigation and adaptation strategies into urban design and planning processes. This growing interest reflects the recognition that urban heat is not merely an environmental issue, but a critical challenge for public health, energy security, and sustainable development.

At the same time, the manifestation and intensity of UHI are highly dependent on local conditions. Urban morphology, land cover, vegetation distribution, building materials, traffic patterns, and regional climatic characteristics interact through complex physical processes that vary significantly

from one location to another. As a result, findings and models developed for one city are often difficult to transfer directly to different urban environments without substantial recalibration. This spatial heterogeneity poses a major challenge to the development of generalized tools for urban heat assessment and mitigation.

With these considerations in mind, we set out to develop an ambitious yet practical UHI modeling framework that operates at the microscale, captures the unique characteristics of each urban area, and remains straightforward to implement in other cities. The proposed methodology is designed to provide high-resolution, area-specific insights while maintaining sufficient flexibility and scalability to support future applications across diverse urban contexts. By combining detailed local data with a transferable modeling approach, this framework aims to assist researchers, planners, and decision-makers in evaluating and mitigating urban heat more effectively. The UHI study has been submitted to the Urban Climate Journal on May 12, 2026 and is currently under review (Decomposing Urban Heat Islands at Micro-Level: A Hybrid Physics-Inspired and Data-Driven Modelling Framework by Savvas Karatsiolis, Panos Hadjinicolaou, Chirag Padubidri, Andreas Kamilaris :: SSRN).

2.3.1.1 Overall description of the UHI study

To study the UHI effect manifested in Nicosia, we discovered a novel approach to analysing the phenomenon. We developed a hybrid physics-inspired, data-driven framework that decomposes the canopy-layer urban-rural air temperature difference into a location specific Urban Heat Island potential (UHIp) and a weather-driven modulation (UHIm), with a learnable vehicle-induced convective bias correction. The framework was applied to Nicosia, a compact, hot semi-arid Mediterranean city, using 700,000 measurements acquired during August-September 2025 from custom sensors on the Municipality of Nicosia's operational fleet, referenced to the Athalassa meteorological station. Learned embeddings over 863 grid cells of 200 × 200 m implicitly encode local morphology, while a 92-hour antecedent meteorological record drives UHIm estimation. Validation against six independent stations yields a MAE of 0.25-1.09◦C. The model recovers a physically coherent diurnal reversal: a morning cool-island regime (mean ΔT of −0.7 to −1.3◦C) transitions to a city-wide heat island in the afternoon (+2.4 to +3.1◦C) that persists nocturnally (+1.4 to +1.6◦C). UHIp correlates with surface and terrain characteristics, confirming physical interpretability. Local Climate Zone stratification reveals the highest UHIp in compact low-rise zones and the lowest in open low-rise, with realised urban-rural differences reaching 3-4◦C midafternoon. Crucially, during the 42◦C+ heatwave of 9-11 August, UHIm approaches zero, indicating that extreme atmospheric overheating suppresses the urban-rural differential precisely when thermal stress peaks. Trained on opportunistic municipal fleet data, this physics-inspired decomposition yields interpretable, high-resolution micro-scale UHI characterisation, directly relevant to urban planning and climate-resilience strategies in Mediterranean cities. In the following sections, we provide details about our methodology and results

2.3.1.2 Local adaptation and data basis

The study focuses on Nicosia during August and September 2025. The hazard is defined as the potential of an area to manifest a temperature difference from a reference station outside the urban fabric. The reference is the Athalassa meteorological station, located in a sparsely built landscape with many trees and fields, and therefore suitable as a local non-urban comparison point. The modelling domain is divided into 200 by 200 m grid cells, a scale selected to represent

neighbourhood-level microclimates where built form, surface materials, vegetation, and other local characteristics are relatively homogeneous. The data acquisition process provided multiple temperature measurements for 863 grid cells, shown in the following figure.

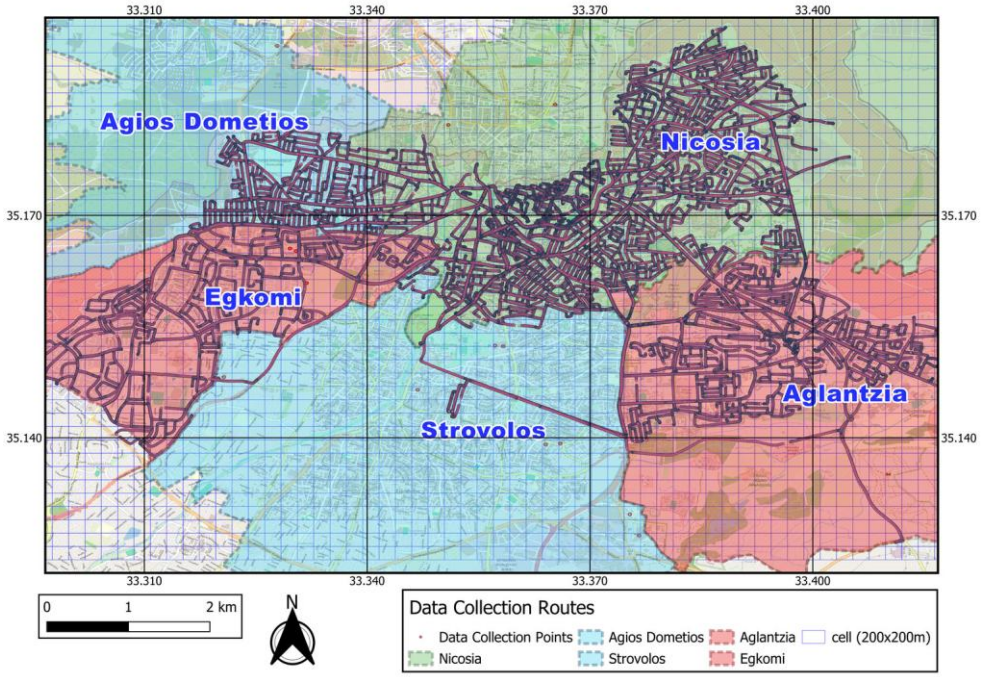


Figure 2 Map of Nicosia showing the vehicle-mounted temperature measurements acquired during August-September 2025.

The method adapts the UHI assessment to Nicosia by replacing a generic city-scale estimate with a local, micro-scale modelling framework. Instead of representing the city with one UHI value, the model estimates how the urban-rural temperature difference varies by location, hour, day, month, and recent meteorological history. This is important because UHI intensity depends on both the physical character of each urban cell and the environmental conditions that activate or suppress the local heat-island effect.

Local data are integrated at several levels. Urban air-temperature observations are collected from custom vehicle-mounted devices installed on the Municipality of Nicosia's operational fleet. The measurements are collected opportunistically while municipal crews perform their normal duties, rather than through fully planned transects. Two devices support two daily acquisition periods: 08:00-15:00 and 18:00-23:30. The acquisition interval is one second, producing approximately 700,000 data points over August and September 2025 across approximately 8 square kilometres. Data coverage is irregular because vehicle routes and stops follow municipal operations; the model therefore relies on generalisation to mitigate uneven spatial and temporal sampling.

The reference meteorological data come from the Cyprus Department of Meteorology at Athalassa. The weather station provides measurements every 10 minutes. The model uses temperature, humidity, wind speed at 2 m and 10 m above ground, wind direction, atmospheric pressure, and solar radiation. These local reference data are used not only at the time of each urban measurement but also as a 92-hour historical record, approximately four days, so that the model can represent heat accumulation, cooling trends, wind effects, and solar variability before the prediction time.

Local urban context is used for interpretation and assessment of the learned model. NDVI is derived from Sentinel-2 imagery as a proxy for vegetation. Building fraction is computed from building-footprint data as the fraction of each 200 by 200 m cell covered by structures. Elevation is provided by the measurement equipment during acquisition. Local Climate Zone (LCZ) data are retrieved from the LCZ Generator website, and the dominant LCZ class of each grid cell is assigned according to the class with the highest pixel count within the cell. The three dominant LCZs in the study area are compact low-rise, large low-rise, and open low-rise, accounting together for 96.9% of cells.

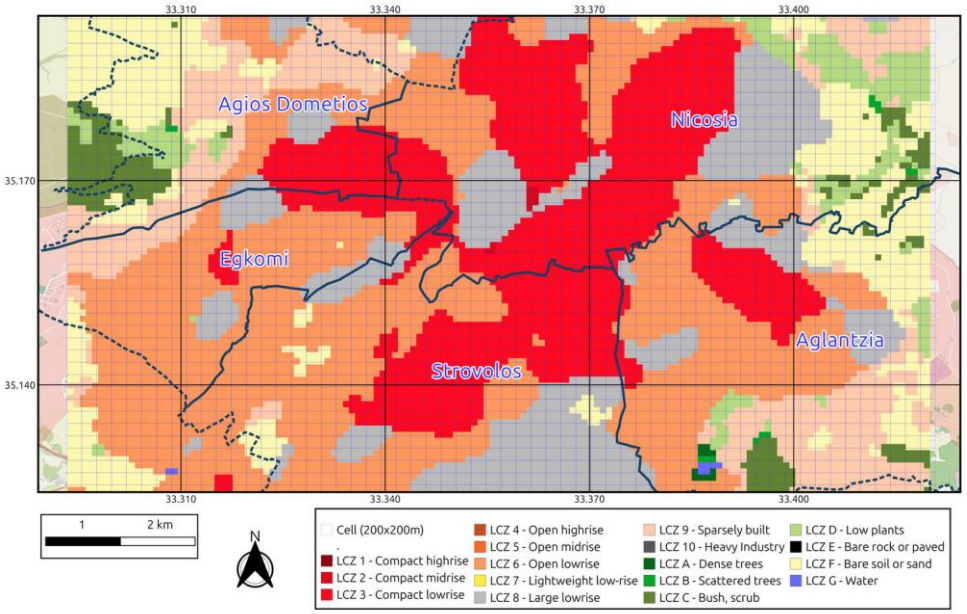


Figure 3 Local Climate Zone map of the Nicosia study area.

2.3.1.3 Vehicle-mounted measurement system

The vehicle-mounted equipment is a key part of the methodology. It allows large-scale air-temperature sampling without installing hundreds of fixed sensors. Each device is a compact, self-contained system with separate compartments for sensors, processing, storage, power, positioning, and timekeeping. A Raspberry Pi 4 controls data acquisition, timestamps measurements, and stores observations locally on a microSD card. GPS provides geolocation at 1 Hz with a circular error probable of 2.5 m, and an RV-8803 real-time clock provides reliable timing when network connectivity is unavailable.

Temperature is measured using three TMP117 high-precision digital sensors. The source reports an accuracy of +/-0.1 degrees Celsius over the -20 to +50 degrees Celsius range and 16-bit resolution. The three sensor readings are averaged during data processing to produce one representative temperature for each observation and reduce random noise. Wind speed is measured with a DFRobot SEN0170 cup anemometer, which reports wind speeds from 0 to 30 m/s. Since the Raspberry Pi has no native analog input, an ADS1015 12-bit analog-to-digital converter digitises the anemometer signal, and a voltage divider conditions the sensor output to the ADC input range.

The enclosure is designed specifically for mobile outdoor operation. The temperature sensors and anemometer are placed in an upper compartment with a front air inlet, honeycomb flow straightener, and outlet. This arrangement reduces turbulence, separates the sensors from heat-generating electronics, shields temperature sensors from direct solar radiation, and positions the sensors to

sample airflow representative of the surrounding environment. Operators can monitor acquisition through a locally hosted web interface on a phone or tablet. The following figure shows the internal diagram of the device, and the next figure shows the assembled device.

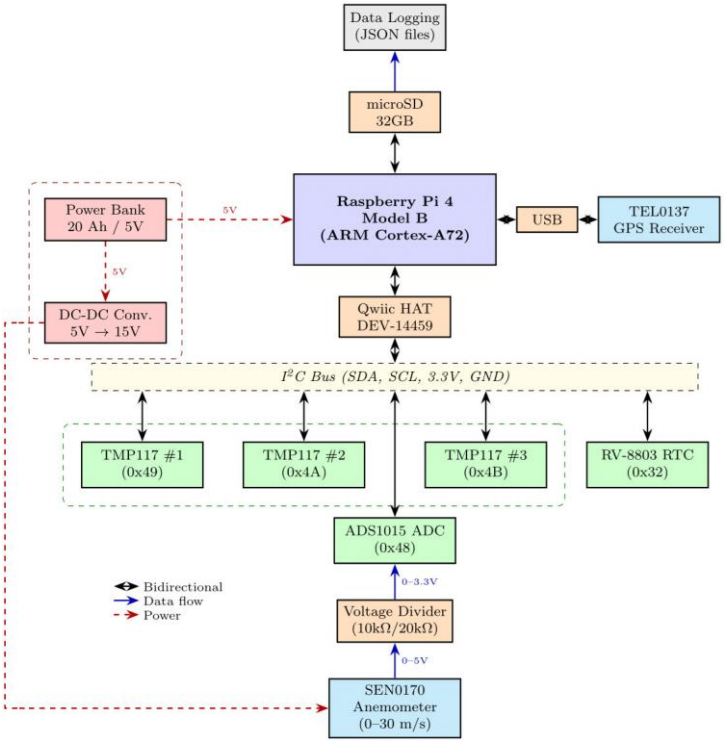


Figure 4 System block diagram of the vehicle-mounted environmental sensing platform.

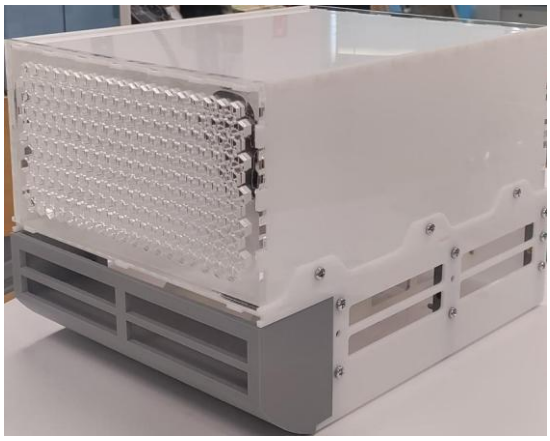


Figure 5 Photograph of the assembled vehicle-mounted data acquisition device.

2.3.1.4 UHI decomposition model

The central modelling decision is to decompose the urban-rural temperature difference into two interpretable components: UHI potential, UHIp, and UHI modulation, UHIm. UHIp represents the location-specific capacity of a 200 by 200 m cell to alter local temperature. It is intended to capture local characteristics such as morphology, surface materials, building density, vegetation, elevation, and other spatial attributes. The model constrains UHIp to the interval [-1, +1]. A positive value indicates a tendency to be warmer than the reference, while a negative value indicates a local cool-

island tendency. UHIm represents the weather-driven excitation of that local potential. It is computed from the recent environmental history at the Athalassa reference station. The model constrains UHIm to be non-negative, so it can amplify or suppress the inherent behaviour of a location but does not reverse its sign. The basic decomposition is:

$$\Delta T = UHIp \times UHIm$$

where ΔT is the temperature difference between an urban grid cell and the reference station outside the urban fabric.

This structure is important methodologically because it separates spatial potential from meteorological forcing. A cell can have a high positive potential but show a smaller realised temperature difference when environmental modulation is weak. Conversely, the same meteorological conditions can produce different urban-rural differences in cells with different learned potentials.

Because the urban measurements are collected from moving vehicles, airflow around the equipment can bias temperature readings because convective cooling is enhanced. This bias is significant because its magnitude can be comparable to the UHI signal itself. To address this, the learning objective includes a wind-correction term:

$$\Delta T = UHIp \times UHIm - b(1 - \exp(-aW))$$

Here, W is the wind speed measured by the vehicle-mounted device, and a and b are learnable parameters. The correction term represents the negative temperature bias produced by airflow-induced convective cooling and is subtracted during training. The function is exponentially saturating: there is no correction at zero wind speed, and the correction grows with wind speed before approaching saturation. The parameter *b* is constrained to 0-3 and *a* to 0.1-1.0 using sigmoid transformations of raw learnable parameters. During inference and evaluation, W is set to zero so the model estimates the physical decomposition $\Delta T = UHIp \times UHIm$. The correction is therefore used to learn from biased mobile measurements, not to represent a physical urban-climate process during final UHI estimation. The behavior of the correction function is shown below.

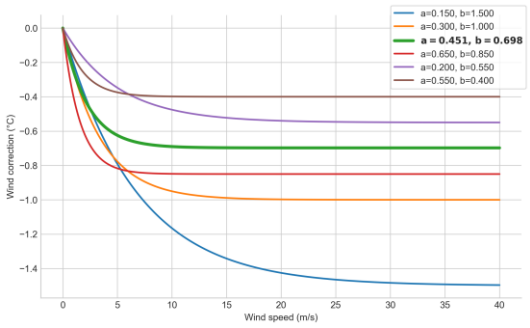


Figure 6 Wind-correction function for different a and b values. In bold, the values learned by the model.

2.3.1.5 Model inputs and architecture

The AI model predicts the temperature difference between each urban cell and the Athalassa reference station. Its inputs include the grid-cell ID, altitude, date and time, reference meteorological history, and vehicle-measured wind speed for training the correction term. The observed urban temperature from the vehicle is not used as an input to the decomposition equation; it is used to construct the ground-truth ΔT against which the model is trained.

Each 200 by 200 m cell is represented by a learned embedding. The embedding size is 64, and embeddings are learned for all 863 cells. These embeddings allow the model to encode location-specific spatial characteristics that are not directly supplied as variables.

The model computes UHIm from a 92-hour reference-weather history. With observations every 10 minutes, this corresponds to 552-time steps. The source describes the historical input as 8 x 92 x 6 values, where six observations per hour are available for each quantity. History is processed by 20 linear layers, each forming a different temporal summary. These summaries allow the model to learn whether different parts of the recent meteorological history, such as the last 6, 12, 24, or intermediate hours, are important for UHI modulation.

Two fully connected neural networks compute UHIp and UHIm. Each has one hidden layer of size 128 and uses ReLU activation. The UHIp network uses a hyperbolic tangent (tanh) output to constrain the potential to [-1, +1]. The UHIm network uses a Rectified Linear Unit (ReLU) output to ensure non-negative modulation. Date, time, and wind direction are cyclically encoded using sine and cosine terms so that periodic variables do not contain artificial discontinuities at cycle boundaries, such as 23:59 to 00:00 or 359 degrees to 0 degrees.

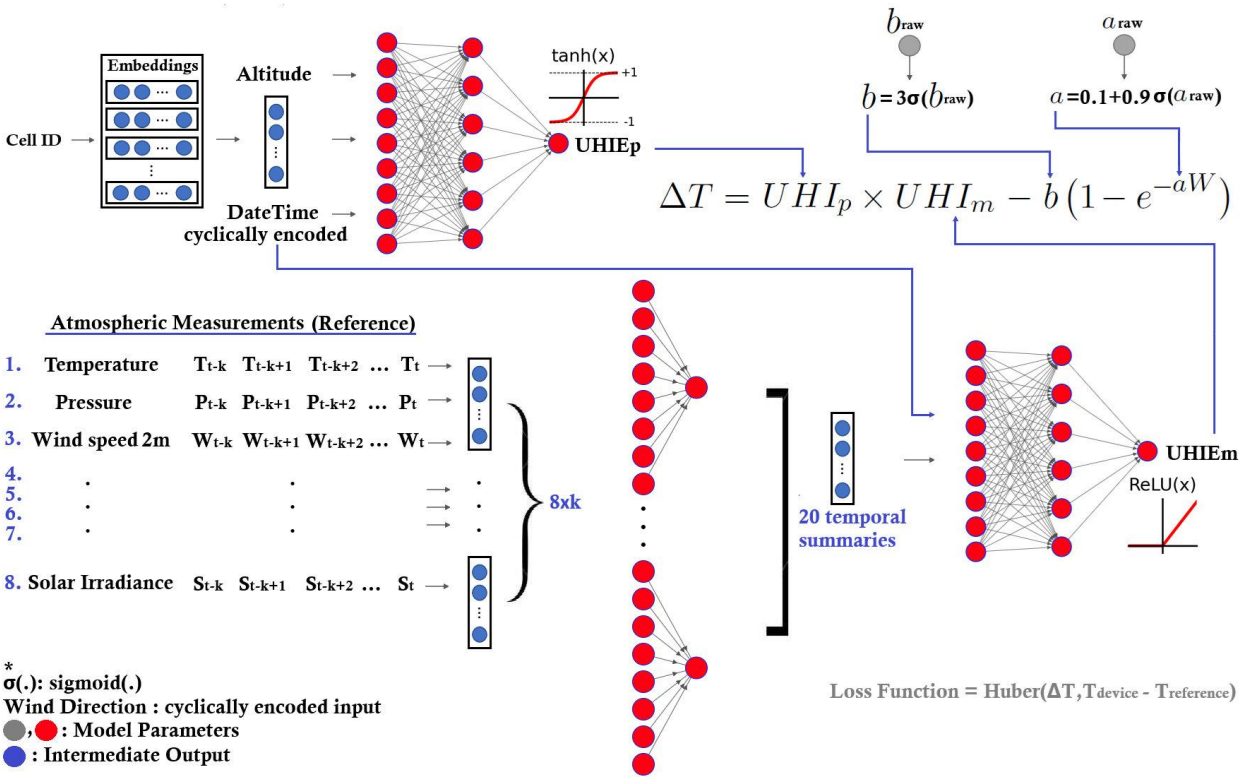


Figure 7 AI model architecture showing inputs, embeddings, meteorological summaries, UHIp, UHIm, wind correction, and predicted ΔT.

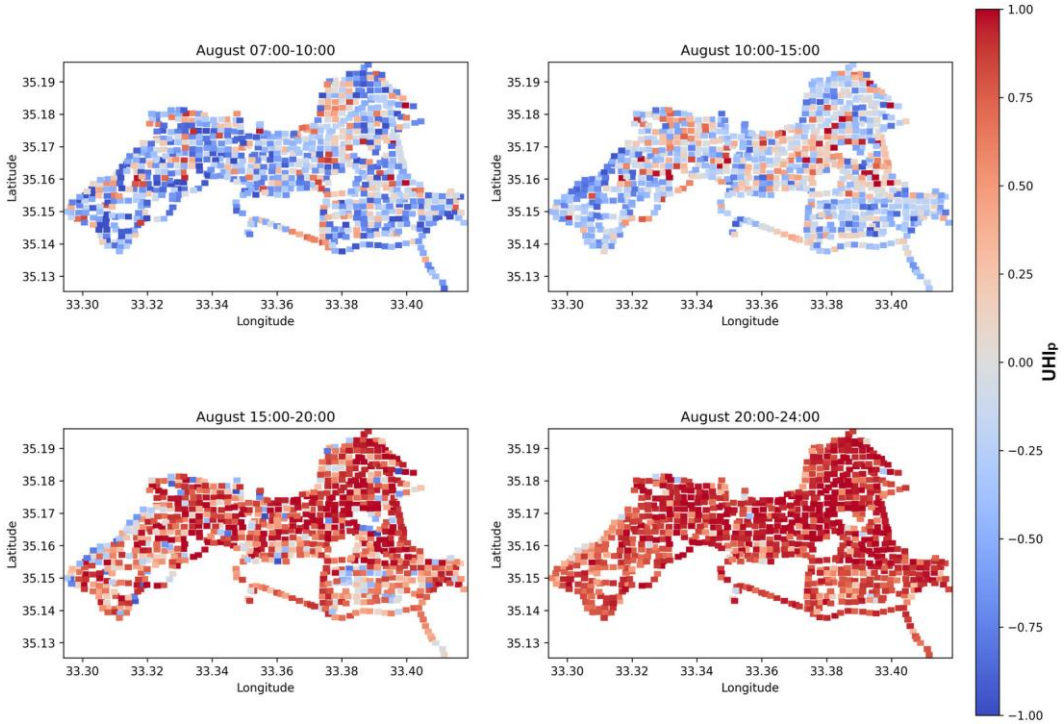
2.3.1.6 Preprocessing and training

The vehicle measurements and reference weather-station measurements are min-max normalised to the interval 0-1. This keeps heterogeneous sensor variables on comparable scales and supports stable optimisation. Cells with fewer than 10 measurements are removed, reducing the domain from 982 to 863 cells.

Training uses AdamW with a learning rate of 0.001 and weight decay of 0.0002. The loss function is Huber loss between predicted and ground-truth ΔT, selected because it is less sensitive to outliers than mean squared error. The dataset is split at the individual one-second measurement level, with 90 percent for training and 10 percent for validation. The source explicitly cautions that this validation split tests held-out individual measurements, not generalisation to unseen cells, unseen days, or unseen routes, because recurring routes can place training and validation samples in the same cells and overlapping time windows. The trained model reaches a Huber training loss of 0.13 and validation loss of 0.145. The 20 temporal summaries of meteorological history show high diversity, reaching 40.5 in the final epoch, suggesting that the model uses distinct aspects of the 92-hour environmental record.

2.3.1.7 UHI maps and signatures

After training, the model was used to compute UHI_p for all 863 cells from August 1 to September 30 between 07:00 and 23:00. The outputs are summarised as spatial heatmaps, city-wide daily signatures, LCZ-stratified signatures, realised temperature-difference signatures, and modulation profiles. Spatial UHI_p heatmaps are produced for August and September by averaging UHI_p over four intervals: 07:00-10:00, 10:00-15:00, 15:00-20:00, and 20:00-24:00. These maps show potential rather than realised temperature difference. Realised UHI depends on multiplication by UHI_m. City-wide UHI_p signatures are computed by averaging UHI_p over all locations and days at hourly intervals. LCZ-specific signatures are computed by grouping cells according to dominant LCZ.



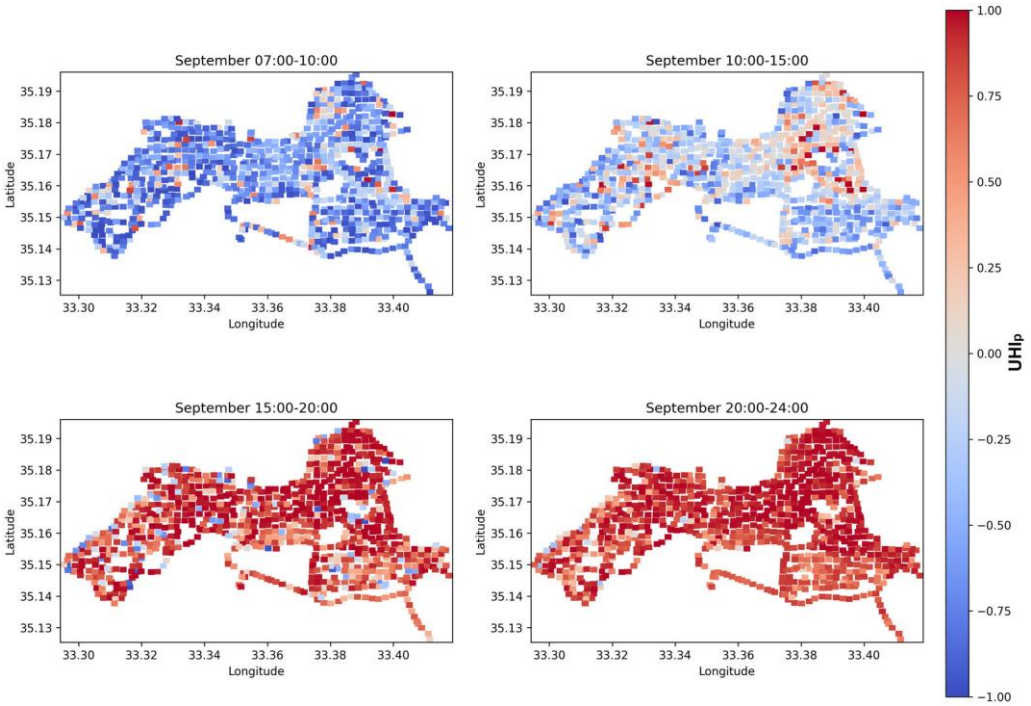


Figure 8 August and September spatial distribution of estimated UHIp by time interval.

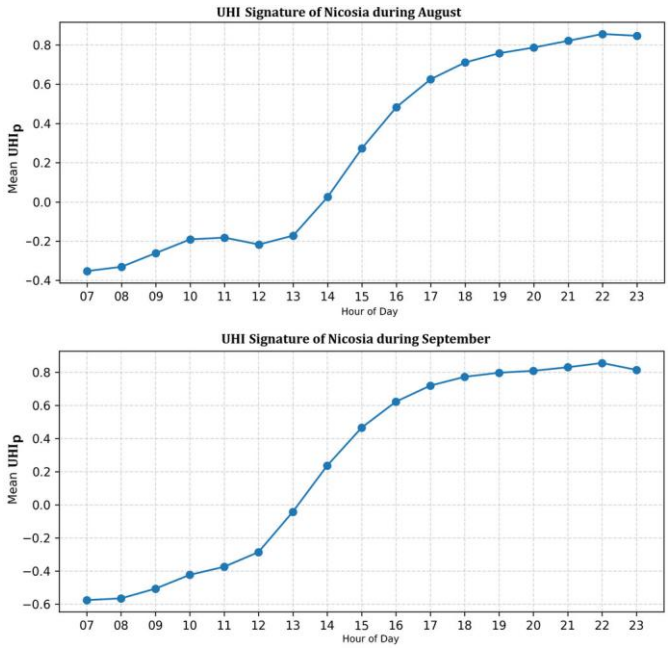


Figure 9 Citywide UHIp signature for the months of August and September.

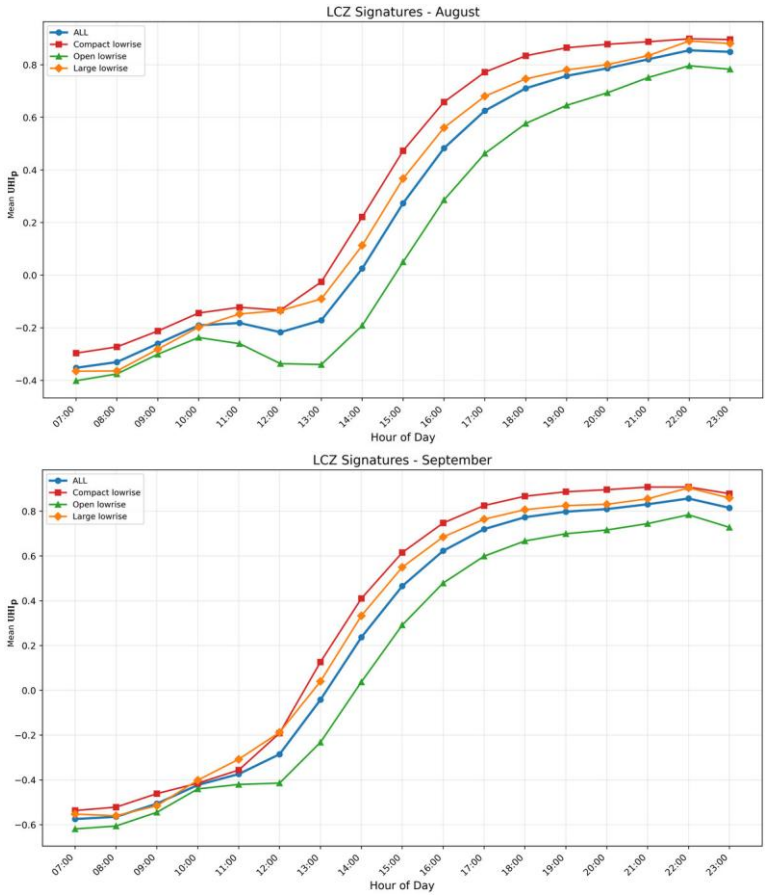


Figure 10 Citywide UHIp signature for the months of August and September per LCZ.

The model recovers a clear diurnal reversal. Mean realised UHI values, defined as ΔT between urban cells and Athalassa, are negative in the morning and positive later in the day. In August, the mean UHI is -0.71 degrees Celsius during 07:00-10:00, -0.47 degrees Celsius during 10:00-15:00, +2.44 degrees Celsius during 15:00-20:00, and +1.41 degrees Celsius during 20:00-24:00. In September, the corresponding values are -1.32, -0.47, +3.14, and +1.55 degrees Celsius.

The UHIp maps show predominantly negative potential across most of the city in the morning, retreat of cool-island cells and emergence of warm clusters during 10:00-15:00, near city-wide heat-island potential during 15:00-20:00, and strong coherent positive potential during 20:00-24:00. The largest August-September differences occur in morning and afternoon-evening intervals, while nocturnal behaviour is similar between the two months. The city-wide UHIp signature is negative in the morning, crosses from negative to positive between approximately 12:00 and 16:00, and stabilises around 0.80-0.85 from about 17:00 onward.

LCZ results show that compact low-rise areas have the highest UHIp intensity, followed by large low-rise areas, with open low-rise areas showing the lowest intensity. The source attributes higher compact low-rise potential to dense buildings, narrow street canyons, reduced sky view factor, limited ventilation, and high thermal mass. Realised UHI signatures by LCZ confirm the morning cooling effect, post-noon heating, and positive temperature differences that persist into the late evening and nighttime. Although UHIm peaks late in the day, lower UHIm values cap the realised nighttime temperature difference.

2.3.1.8 Relationship between learned UHIp and local urban characteristics

The study evaluates whether the learned UHIp is physically meaningful by comparing hourly averaged UHIp, denoted P-bar, with six local predictors: NDVI, building fraction, elevation, compact low-rise LCZ membership, large low-rise LCZ membership, and open low-rise LCZ membership. The analysis uses Pearson and Spearman correlations with Bonferroni correction, decile-binned summaries for continuous variables, grouped comparisons for LCZ indicators, and a multiple linear regression with all six predictors. Five of the six predictors have significant bivariate associations after Bonferroni correction. NDVI has a negative Spearman correlation rs = -0.213, p = 2.7 x 10^-10. Building fraction has a positive correlation, rs = +0.287, p = 7.9 x 10^-18. Elevation has a negative correlation, rs = -0.305, p = 5.5 x 10^-20. Compact low-rise has a positive association, rs = +0.298, p = 3.4 x 10^-19, while open low-rise has the strongest bivariate association, rs = -0.310, p = 1.3 x 10^-20. Large low-rise has only a weak association, rs = +0.064, which is not significant after Bonferroni correction.

The binned analysis supports the same interpretation. Mean P declines from 0.35 at the second NDVI decile to 0.11 in the highest NDVI decile. For building fraction, mean P rises from 0.096 in the lowest decile to 0.361 in the highest. For elevation, P declines from 0.36 to the lowest elevations to 0.10 at the highest. Compact low-rise cells have higher mean P than non-members, 0.345 versus 0.189; large low-rise cells show a smaller increase, 0.293 versus 0.244; and open low-rise cells have lower mean P, 0.147 versus 0.316. The multiple regression with all six predictors explains 16.3 percent of the variance in P, with R2 = 0.163 and adjusted R2 = 0.157. The model is statistically significant, F(6,856) = 27.83, p = 1.9 x 10^-30. Compact low-rise is the strongest independent predictor with beta = +0.393, followed by large low-rise, elevation, open low-rise, building fraction, and NDVI. The source notes that the inclusion of LCZ indicators attenuates the building-fraction effect because building fraction is strongly correlated with compact low-rise membership.

The methodological implication is that the learned embeddings capture meaningful local spatial information. Vegetation, building fraction, and LCZ are not provided directly to the AI model, yet the learned UHI_p field correlates with them in physically expected directions.

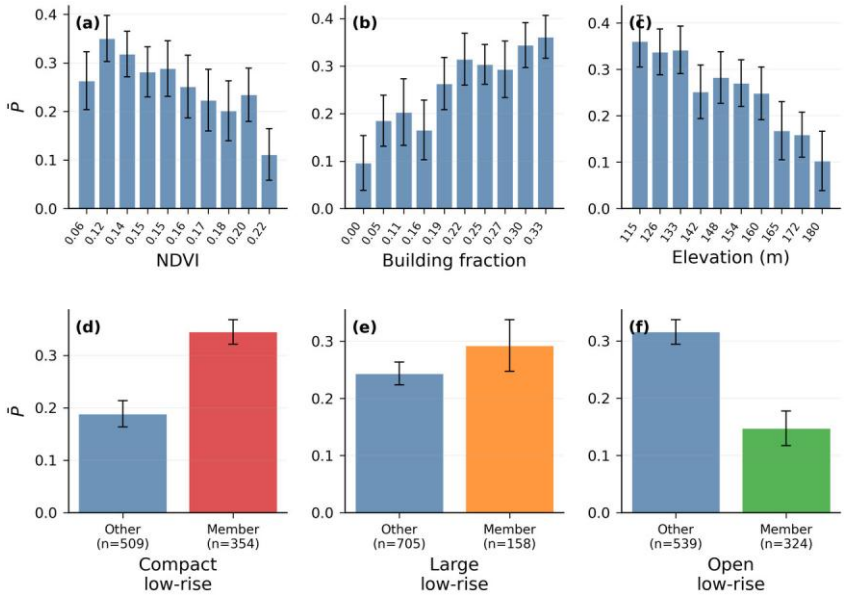


Figure 11 Citywide UHIp signature for the months of August and September per LCZ.

2.3.1.9 Environmental modulation and heatwave behaviour

The model's UHI_m component is analysed by averaging modulation outputs across all cells at hourly intervals. In both August and September, the average modulation follows a unimodal daytime profile (see Figure below). It starts around 2.2-2.5 at 07:00, rises to approximately 7.8-8.0 at 14:00, and declines to approximately 1.8-1.9 around 22:00. The two months have nearly identical average modulation profiles, with only small differences during the morning build-up phase.

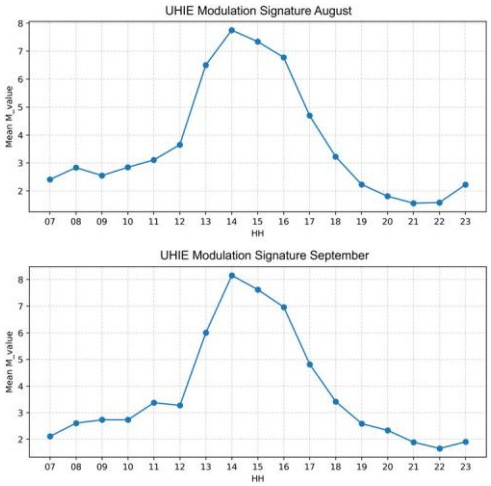


Figure 12 Average UHIm during daily hours in August and September.

From our analysis, wind, temperature trend, and solar variability as the main factors associated with out-of-the-ordinary average modulation values. High average modulation is associated with calm wind below 1.5 m/s, sustained multi-day heat buildup, and sharp solar gradients such as cloud-clear sky cycles. Low average modulation is associated with wind above 3.5 m/s, cooling trends or extreme temperature plateaus, and prolonged low radiation. An important result is that extreme heat does not necessarily imply high UHI modulation. During the 9-11 August heatwave, with temperatures above 42 degrees Celsius, average modulation was often very low because strong winds or uniform overheating of both the urban area and rural reference compressed the urban-rural differential. On August 10, average modulation was approximately zero at 13:00 during the heatwave. On August 11, average modulation peaked at 08:00, then dropped sharply after wind speed increased. By contrast, September 3 produced the highest peak, approximately 14.38 at 14:38, under very low daily wind and a strong solar radiation drop associated with cloud passage. September 25 and 30 had mild peaks, approximately 5.4 and 6.1, during cool and windy conditions with a cooling trend in the 92-hour history. Figure below shows the average UHI_m values for the days mentioned in the above analysis.

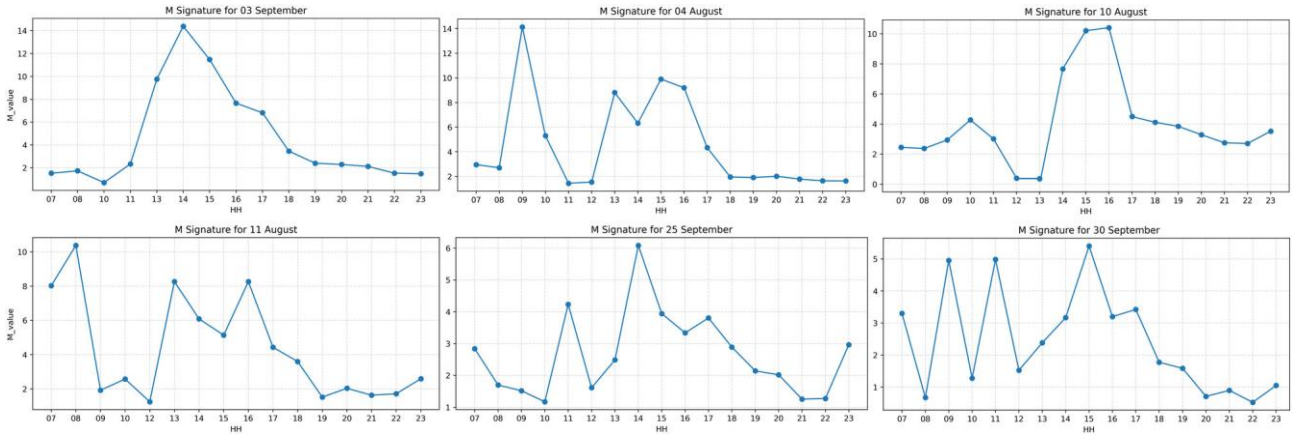


Figure 13 Average UHIm during daily hours on certain days of August and September.

2.3.1.10 Independent validation

The model is validated with public third-party station data from Weather Underground's WunderMap platform. Six stations are selected from eleven available stations because they are located in grid cells visited by the vehicle-mounted acquisition system: IAGLAN3, IENGOM5, IENGOMI3, INICOS12, ISTROV12, and ISTROV17. WunderMap provides measurements roughly every five minutes. The validation uses approximately 11,700 measurements per station during the 07:30-23:30 daily window over August and September 2025. For validation, station wind speeds, station altitudes, Athalassa reference weather data, and timestamps are used to infer ground-truth temperature differences relative to Athalassa, following the same model methodology. Reported prediction MAE values are 0.3425 degrees Celsius for IAGLAN3, 0.6273 for IENGOM5, 1.0923 for IENGOMI3, 0.6090 for INICOS12, 1.0907 for ISTROV12, and 0.2471 for ISTROV17. Mean bias is positive for all six stations: 0.34, 0.63, 1.09, 0.36, 1.09, and 0.25 degrees Celsius. The validation therefore shows systematic overestimation rather than random disagreement. The source explains this as physically plausible because the model is trained primarily on vehicle measurements along asphalted road networks, while third-party stations are typically away from asphalt. The model has therefore learned the warmer road-surface context. The wind correction is also tailored to the vehicle-mounted equipment and is not intended for stationary station sensors.

2.3.1.11 UHI hazard assessment

The climate hazard associated with the Urban Heat Island (UHI) phenomenon arises directly from the tendency of certain urban areas to exhibit significantly higher temperatures than their surrounding environments or less built-up regions. These localized “hot spots” are primarily driven by factors such as densely built infrastructure, limited vegetation, high surface heat retention, and concentrated anthropogenic heat emissions. As a result, residents within these areas are often exposed to more severe and prolonged thermal stress compared to individuals living or working in cooler parts of the same city or in nearby rural zones.

This uneven distribution of heat has important implications for public health, as elevated ambient temperatures increase the risk of heat-related illnesses, exacerbate cardiovascular and respiratory conditions, and place additional strain on vulnerable populations. Importantly, these risks are highly localized, meaning that even within a single city, exposure levels can vary significantly over short distances.

However, many existing alerting and early-warning systems for extreme temperatures rely on coarse spatial data or regional weather station measurements. These systems often fail to capture fine-scale thermal variability within urban environments. Consequently, localized UHI hotspots may be underrepresented or entirely overlooked, leading to situations where alerts are delayed, not issued, or underestimate the true level of risk experienced by specific urban populations.

In addition, the UHI effect has significant implications for urban energy systems. Elevated local temperatures increase the demand for electricity, primarily due to widespread use of cooling technologies such as air conditioning. This demand is not uniformly distributed but is instead amplified in UHI-affected zones, where residents experience higher thermal stress. As a result, utility providers and energy authorities may not fully anticipate or accurately model these localized peaks in consumption, potentially leading to underestimation of peak load requirements, increased operational stress on the grid, and reduced efficiency in energy planning and resource allocation.

We address these challenges by computing a more granular hazard, estimated on neighborhood level that can capture intra-urban temperature variability (UHI_p). We are especially interested in areas that exhibit a high UHI_p which means that the temperature tends to be several degrees higher than other areas. To build a single hazard layer we use the predicted UHI_p values averaged across the area of Nicosia (per 200 by 200 m cell).

2.3.1.12 Risk assessment

The risk for the UHI phenomenon is calculated by multiplying the hazard spatial map (averaged UHI_p across space for months August and September) with the vulnerability and the exposure maps, i.e.,

Risk = Hazard x Exposure x Vulnerability.

For the vulnerability index in an area (200 by 200 m cell), we consider the portion of the vulnerable population over the total population of the specific area. As a vulnerable population, we consider the members of the population that are more susceptible to the effects of extreme heat conditions, especially because of their physical condition or their inability to take countermeasures. Such population categories are pregnant women and elderly persons to whom extreme heat can lead to health complications. Another vulnerable population category is infants that solely rely on their parents' care and protection from extreme heat. We aggregate these population categories and compute the ratio as follows:

Vulnerability = (Pregnant Women + Infants + Elderly) / Total_People_in_the_ area .

Exposure reflects how many people are in the path of a certain area's risk. It is a representative quantity of the absolute population in an area.

Concretely, we define the risk as a product of the following definitions:

- Hazard: how dangerous is the place itself (UHI potential)
- Exposure: how many people are in the path of that danger (absolute population)
- Vulnerability: how susceptible those people are (demographic composition)

Since the UHIp values have a range between −1 and +1, we standardize them in the range [0,1] to avoid multiplication with negative numbers that would result in a negative risk. We opted for this value range because it is more robust and explainable. Standardization is also useful for the Exposure multiplier to bring it to the same scale. We apply standardization with $x_{scaled} = (x - x_{min})/ ($

$x_{max} - x_{min}$) where x is the original value, x_{min} is the minimum value of x and x_{max} is the maximum value of x. For vulnerability we do not need to standardize the values because the ratio of vulnerable population is in the correct range. Before standardizing the Exposure values, we apply a logarithmic transformation to reduce the effect that diverse population values have on risk computation. For example, in areas where the population is dense, the resulting risk can be biased towards extreme high values compared to areas of very low population. By applying the transformation **Exposure = ln(Total_People_in_the_ area +1),** where ln is the logarithm with base e, we mitigate this exaggerating effect. The +1 term makes sure that areas with zero population result in Exposure=0.

The data for exposure and vulnerability were retrieved from the Worldpop platform (https://www.worldpop.org/).

Table 2 Data overview for UHI risk

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
UHI potential	*Portion of pregnant, infants and elderly population over Total Population*	*Total Population in an area (logarithmic)*	*Hazard x Exposure x Vulnerability*

The described processing results in the heatmaps (Hazard, Exposure, Vulnerability) shown in the following figures.

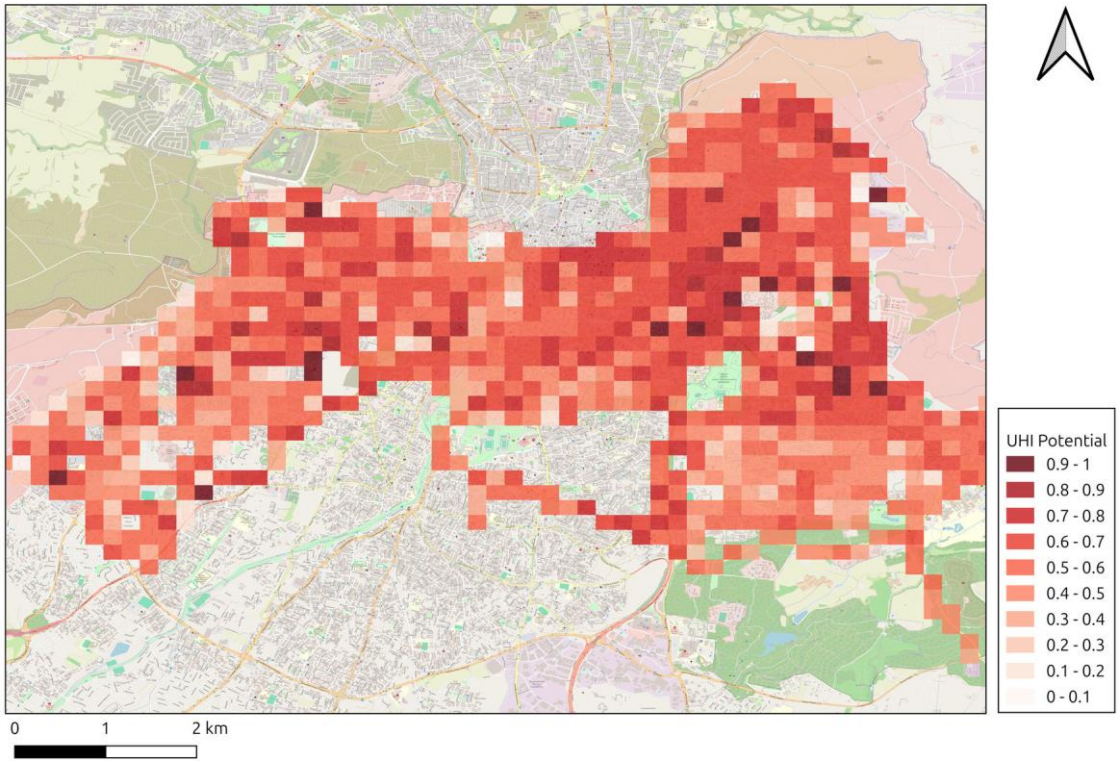


Figure 14 The UHI potential heatmap of months August and September in the Municipality of Nicosia.

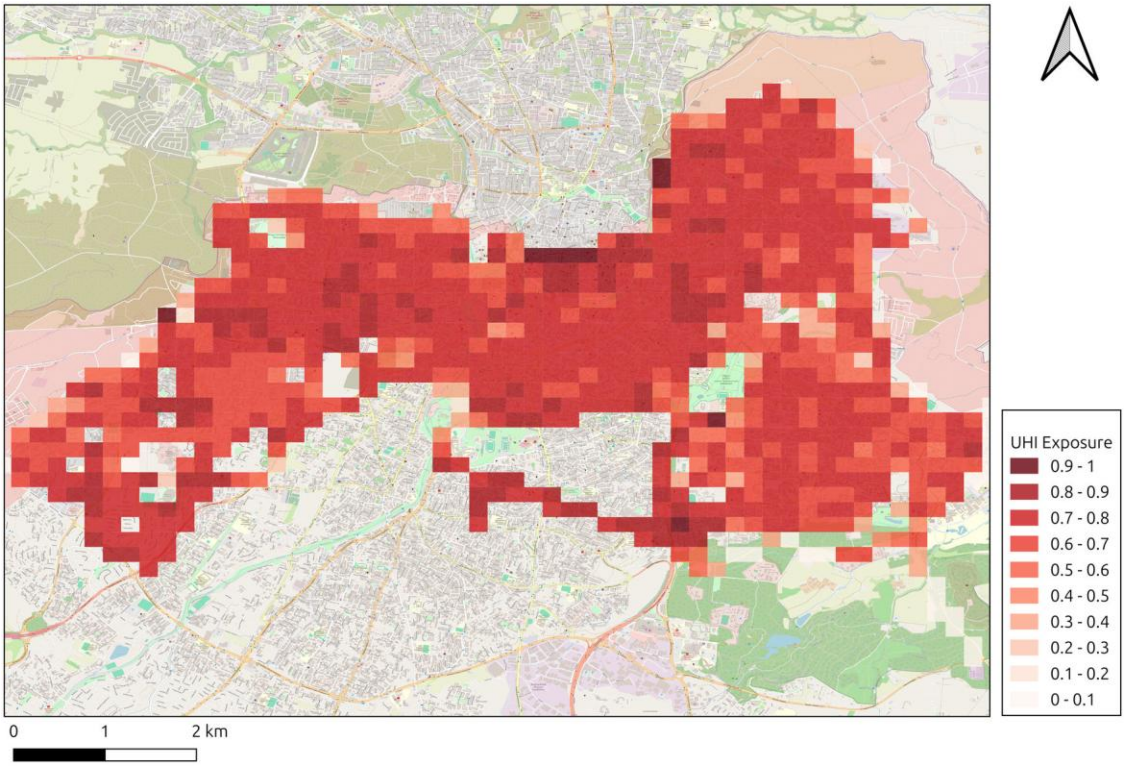


Figure 15 The population exposure in the Municipality of Nicosia.

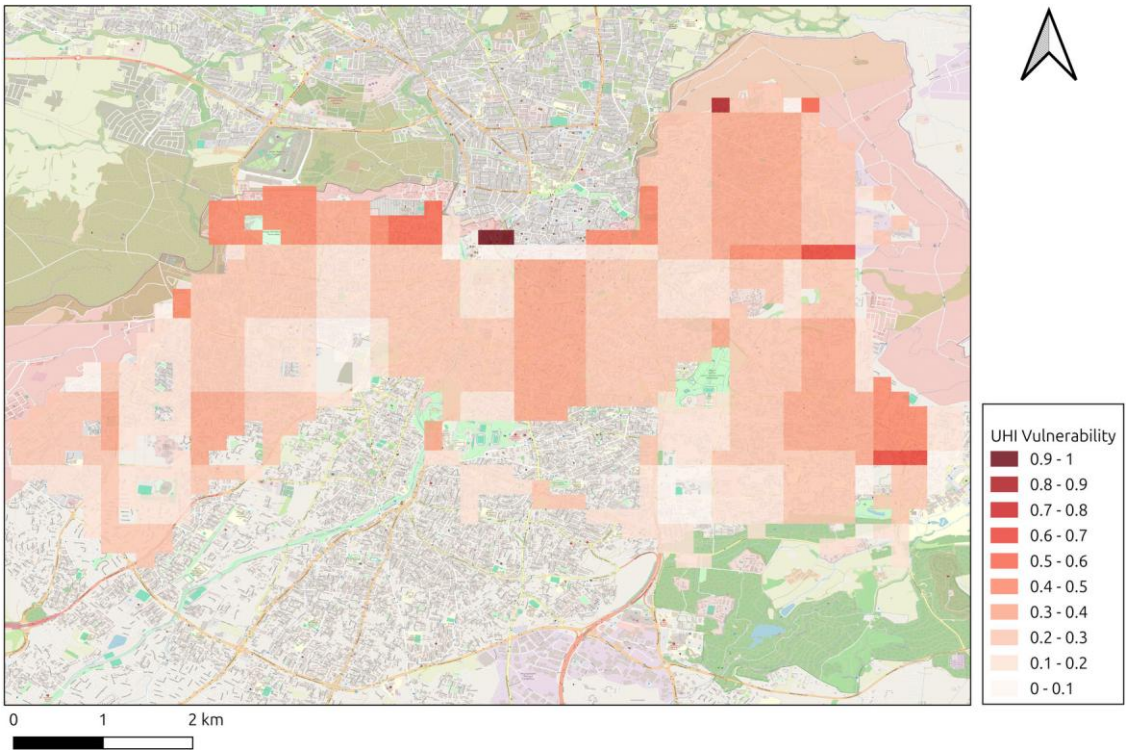
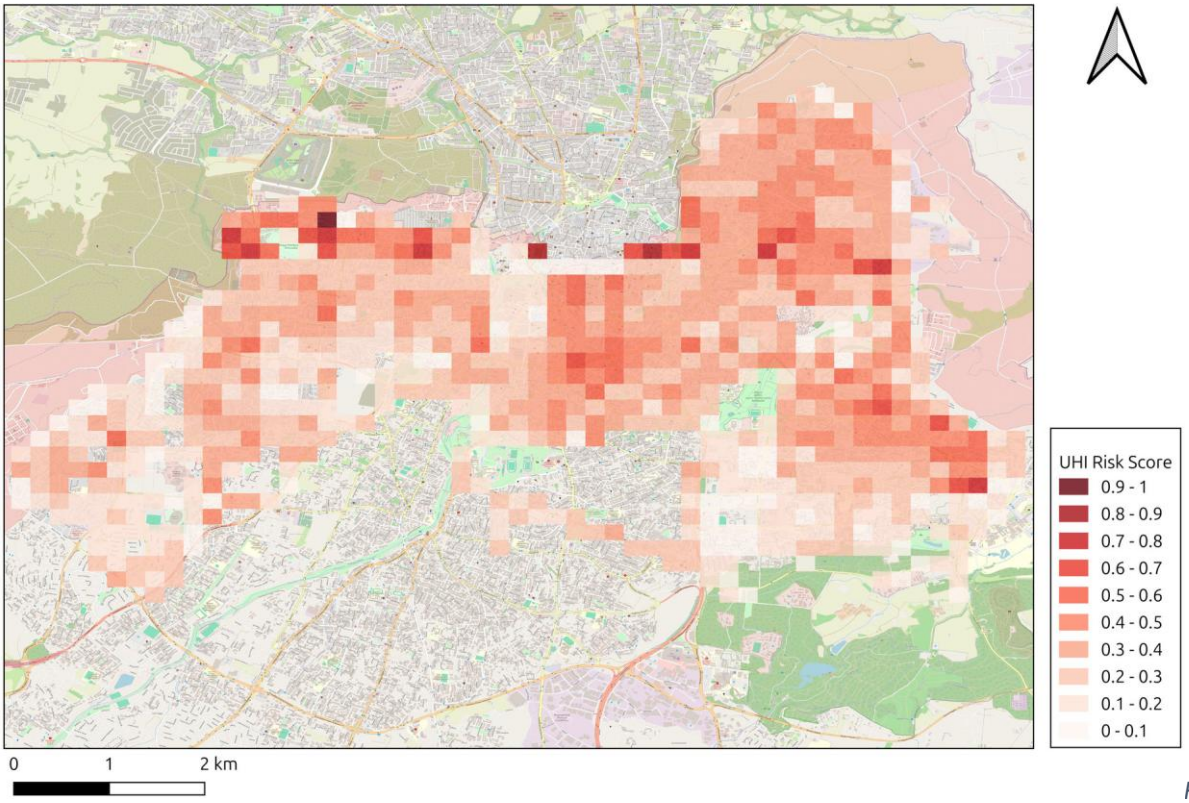


Figure 16 The vulnerability heatmap in the Municipality of Nicosia.

The computed risk map for the UHI hazard is shown in the following figure.



Figure

Figure 17 The final UHI risk heatmap for the Municipality of Nicosia.

To ensure comparability across spatial units, all three components are aligned to the same 200 by 200 m grid resolution. This harmonization is essential because mismatched spatial supports

between hazard, exposure, and vulnerability layers can introduce aggregation bias and distort localized risk estimates. The selected resolution represents a trade-off between computational feasibility and the ability to capture fine-grained urban heterogeneity, particularly in densely built environments where UHI effects can vary significantly over short distances.

In addition, the multiplicative structure of the risk model implies that low values in any single component can substantially reduce overall risk. This reflects the intended interpretation that high UHI risk emerges only when high heat hazard coincides with both high population presence and high demographic susceptibility. However, this formulation also introduces sensitivity to extreme values, particularly in exposure-dense urban cores, which necessitates careful interpretation when comparing across heterogeneous urban and peri-urban zones.

Temporal representativeness is also embedded in the hazard component, which is derived from averaged UHIp values for August and September. This period corresponds to the peak summer thermal stress window in the study region, thereby capturing the most relevant conditions for heat-related health impacts. Nevertheless, inter-annual variability is not explicitly modeled in this formulation, meaning that the resulting risk estimates should be interpreted as climatological risk under typical peak-summer conditions rather than event-specific extremes.

Finally, the resulting composite risk map provides a spatially explicit decision-support layer that can be used for urban planning and public health prioritization. Areas with consistently high risk values indicate co-location of persistent heat accumulation, high population density, and elevated demographic vulnerability, and may therefore be prioritized for mitigation strategies such as urban greening, cooling centers, or heat-health early warning systems.

2.3.1.13 Future Projections UHIE

2.3.1.13 .1 UHIE Model description: inputs and outputs

The UHI model expresses the temperature difference between a grid cell and the reference station as the product of two learned terms plus a wind correction, DT = P * M + C. The first term, P, is the UHI potential of the location: a small neural network derives it from a learned 64-dimensional embedding of the location identifier, the cyclically encoded date and time

(sine and cosine of the day of year and of the second day) and the cell's altitude. This term carries the spatial signature of the urban heat island, i.e. which neighbourhoods run hot and which run cool. The second term, M, modulates that potential according to the recent environmental history: twenty learned temporal summaries are extracted from each of eight measurement channels covering the preceding 92 hours at 10-minute resolution, namely air temperature, atmospheric pressure, relative humidity, the cosine and sine of the wind direction, the wind speed at 10 m and at 2 m, and global solar radiation. The final term, C, is an attenuation driven by the local wind speed. Consistent with the intended use of the model, the wind-correction input was set to zero in every run reported here, so that all results describe the zero-wind (worst-case) UHI. The model outputs the temperature difference directly in degrees Celsius.

The training-side data consist of the Athalassa station record from 1 July to 30 September 2025 at 10-minute cadence (16,974 records), min-max scaled to the unit interval using fixed ranges stored alongside the model (for example 12.0-44.8 degrees Celsius for temperature, 980.7-1002.1 hPa for pressure, 0-7.9 m/s for the 10 m wind speed and 0-1047 W/m2 for solar radiation), and the training

dataset of 642,943 grid-cell temperature observations, which was used here to obtain the mean altitude of each cell and to establish at which times of day the model was actually trained. The environmental measurements' predictions according to RCP4.5 and RCP8.5 for various years (2045, 2065 and 2085), was retrieved from the Copernicus Climate Data Store (CDS) and specifically the publicly available dataset "CORDEX regional climate model data on single levels" (https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=download). The data retrieved consists of six files, each containing a single simulated season from 1 August to 30 September at 3-hour resolution for one climate-model grid point near the study area, with 2 m air temperature, 2 m relative humidity, mean sea-level pressure, downward surface solar radiation and 10 m wind speed. The units of all variables match the training data exactly, so no unit conversion was required.

2.3.1.13.2 Preparing the scenario data for the model

Bridging the gap between what the climate files provide and what the model expects requires a series of documented decisions. The scenario data are available in 3-hour intervals, while the model consumes 10-minute histories, so every channel was linearly interpolated to the 10-minute grid before the 92-hour history matrices were assembled; it should be kept in mind that this interpolation smooths away the short-term variability that the model experienced during training. A subtlety was discovered in the pressure data: although the training column is nominally sea-level pressure, its values (980.7 to 1002.1 hPa) are only consistent with station-level pressure at the station's elevation of roughly 160 m, whereas the scenario files contain true mean sea-level pressure (998 to 1019 hPa). A single constant offset of 18.23 hPa, the difference between the mean over all six scenario files and the Athalassa mean of 990.58 hPa, was therefore subtracted from the scenario pressure. Using one common offset rather than per-file adjustments preserves whatever pressure differences exist between the scenarios.

Two of the eight measurement channels are absent from the climate files altogether. The wind direction rows were filled with their training-set mean scaled values (0.537 for the cosine and 0.227 for the sine channel), which is the same convention the training data feeder applies to missing values. The 2 m wind speed was estimated from the 10 m wind speed through the relation = 0.826 , the slope of a regression through the origin fitted on the raw 2025 station data. All channels were then scaled with the exact training ranges; occasional scenario values outside those ranges (winds up to 14.2 m/s against a training maximum of 7.9 m/s) were passed to the model without clipping so as not to distort the climate signal.

The choice of inference timestamps followed the training coverage. The model was trained on observations falling roughly between 06:40 and 15:20 and between 20:20 and 23:50 local time; of the 3-hourly slots available in the scenario files, only 09:00, 12:00, 15:00 and 21:00 lie inside these well-covered windows. Combined with the requirement that a full 92-hour history be available within each file, every run uses the same 229 timestamps between 4 August 21:00 and 30 September 21:00. For each run the model was evaluated at all 863 locations for each of the 229 timestamps and the predictions were averaged over time, yielding one UHI value per location. The 2025 baseline was produced with exactly the same protocol, the same calendar window and the same daily slots applied to the real station measurements, the only difference being that the baseline naturally uses the measured wind direction and 2 m wind speed rather than fills.

2.3.1.13.3 Results

The 2025 baseline yields a mean UHI of +2.29 degrees Celsius across 863 cells, with individual cells ranging from about -3.3 to +5.8 degrees Celsius and 91% of cells showing a positive heat island. Driven by the scenario forcing as delivered, the six scenarios produce lower means of +0.87 to +1.46 degrees Celsius (RCP4.5: +1.42, +0.87 and +1.11 degrees Celsius for 2045, 2065 and 2085; RCP8.5: +1.20, +1.46 and +1.22 degrees Celsius respectively) as shown in the table below.

Table 3 The UHI predicted by our model for various years under the two RCP scenarios (no wind correction).

	RCP4.5	**RCP8.5**
2045	+1.42	+1.2
2065	+0.87	+1.46
2085	+1.11	+1.22

The most robust feature of the results is the stability of the spatial pattern. The correlation between each scenario and the baseline across the 863 cells is 0.95 to 0.97 (Spearman rank correlation 0.96 to 0.98), the six scenarios agree with one another at correlations of at least 0.994, and of the twenty hottest cells in the 2025 baseline, nineteen or twenty are also the hottest in every scenario. In other words, the map of where the heat island is strong or weak, which is dominated by the learned location embedding, is essentially unchanged under all scenarios. What does change is the amplitude: regressing each scenario against the baseline gives slopes between 0.35 and 0.66 (with R2 of 0.90 to 0.95), meaning the scenario runs compress the urban-rural contrast rather than rearrange it.

The ordering of the scenarios did not match the natural expectation that the UHI should grow along 2025 < 2045 < 2065 < 2085 and be larger under RCP8.5 than under RCP4.5. Investigation of the retrieved environmental data from Copernicus Climate Data Store revealed the following: First, the inputs themselves are not monotonic: the seasonal-mean temperature at the inference slots is 31.0, 30.3 and 33.0 degrees Celsius for RCP4.5 at 2045, 2065 and 2085, and 32.5, 33.5 and 33.3 degrees Celsius for RCP8.5. Each file contains a single simulated season, and the year-to-year weather variability of one to two degrees exceeds the two-decade climate increment, although RCP8.5 is consistently warmer than RCP4.5 at matching horizons. Second, and more importantly, the predicted mean UHI across the six scenarios correlates with the seasonal-mean wind speed at r = -0.94 but only weakly with temperature (r = +0.45): the windier the simulated season, the lower the predicted heat island. Wind, not temperature, controls the ordering of these results.

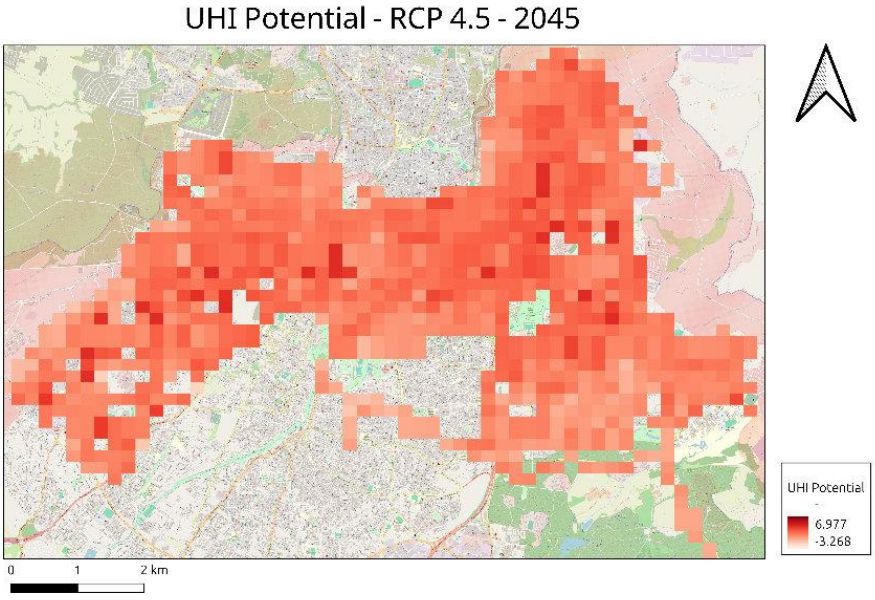
This finding motivated the wind-corrected variant. The scenario winds are grid-cell averages from a climate model and average 3.63 m/s over the six files, whereas the sheltered station anemometer the model was trained on averaged 2.28 m/s in 2025; a large part of the difference is a mismatch

between data sources rather than a projected increase in wind. The 10 m wind of every scenario was therefore multiplied by the single global factor 0.627 (the ratio of the two means) before scaling, with the 2 m wind derived from the rescaled values; one common factor aligns the wind climatology with the training source while preserving all differences between and within the scenarios. The correction raises every scenario by 0.35 to 0.53 degrees Celsius, to means of +1.91, +1.32 and +1.64 degrees Celsius for RCP4.5 and +1.69, +1.81 and +1.68 degrees Celsius for RCP8.5 at 2045, 2065 and 2085 respectively, closing roughly half of the gap to the baseline while leaving the spatial correlations essentially unchanged (0.94 to 0.96). After applying wind correction, RCP8.5 exceeds RCP4.5 at the 2065 and 2085 horizons, though not in 2045, and the ordering across years remains non-monotonic, as expected: the rescaling removes the source bias but cannot remove the weather noise of single simulated seasons.

Table 4 The UHI predicted by our model for various years under the two RCP scenarios with wind correction.

	RCP4.5	**RCP8.5**
2045	+1.91	+1.69
2065	+1.32	+1.81
2085	+1.64	+1.68

The heatmaps showing the future UHI predictions are shown below. The first set of predictions reflects the results without wind rescaling. The second set show the results for all scenarios and years using wind rescaling.



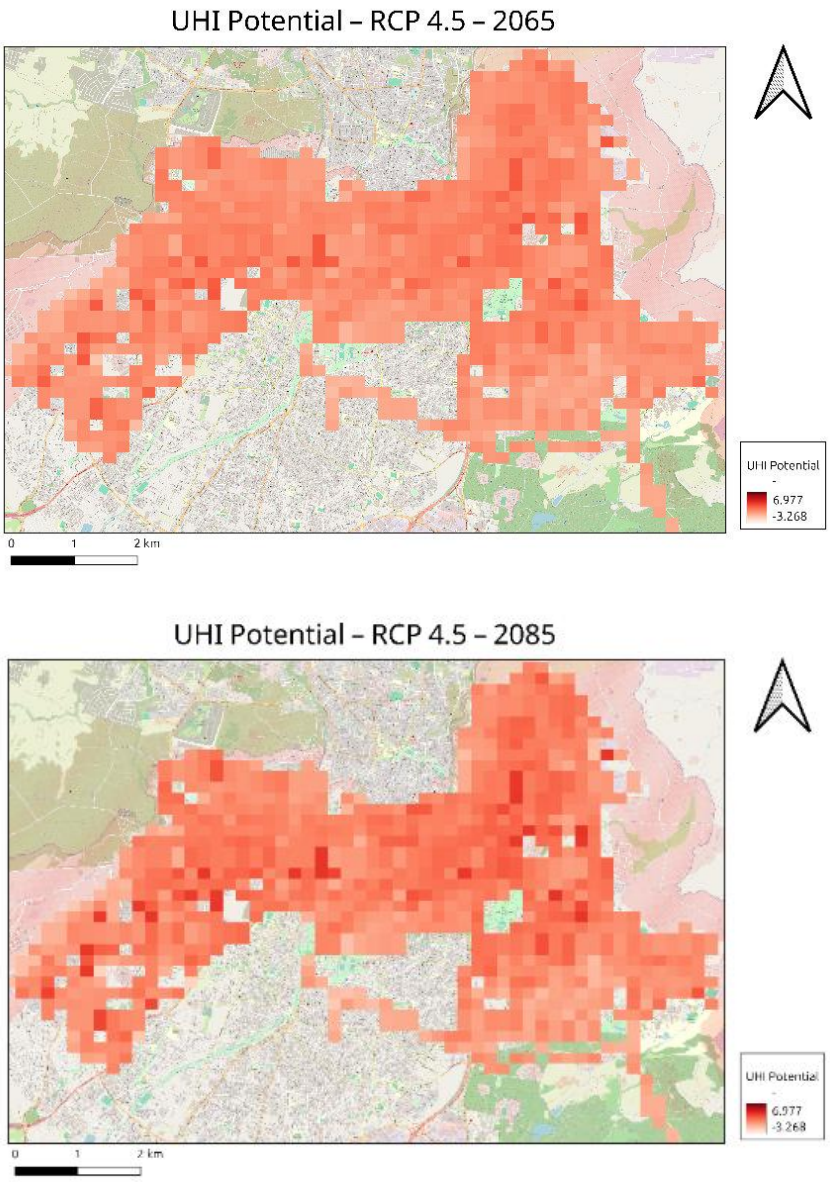
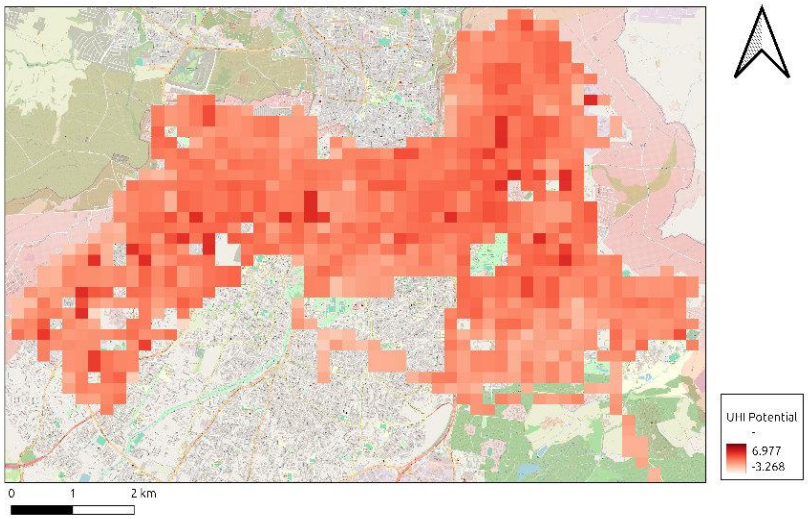
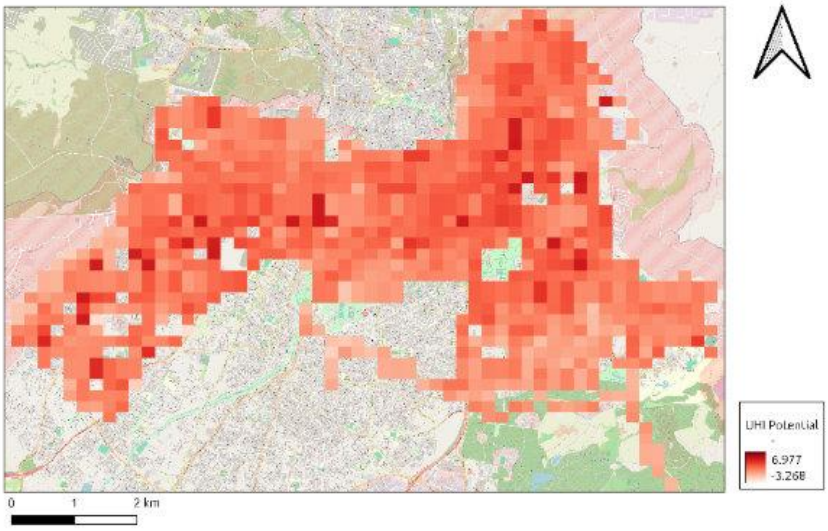


Figure 18 The UHI predicted by our model (without wind rescaling) for various years under the two RCP scenarios.

UHI Potential – RCP 8.5 – 2045



UHI Potential – RCP 8.5 – 2065



UHI Potential – RCP 8.5 – 2085

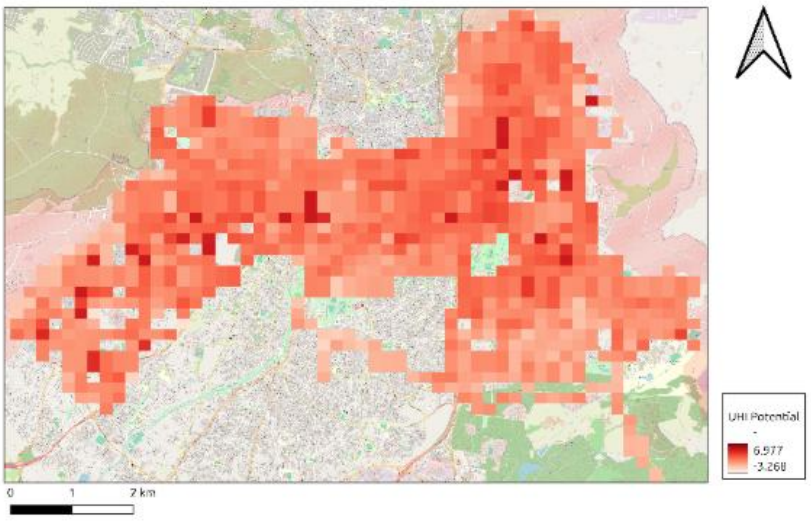


Figure 19 The UHI predicted by our model (with wind rescaling) for various years under the two RCP scenarios.

2.3.1.13.4 Conclusions on Future UHI risks

Three considerations frame the interpretation of these results. The first is that the UHI is a differential quantity, the difference between a cell and the reference station, and a uniformly warmer background climate raises both without necessarily widening the gap; indeed, within the 2025 baseline the day-to-day mean UHI correlates only weakly with the concurrent temperature (r = +0.21). The absolute temperatures do rise along the emission pathways in the forcing data; the heat island superimposed on them is governed in this model chiefly by wind. The second is that part of the level difference between the scenarios and the baseline is methodological rather than climatic: beyond the wind-source mismatch addressed by the rescaled variant, the interpolation from 3-hourly to 10-minute resolution smooths the histories, and the wind-direction and 2 m wind channels had to be filled or estimated. Differences of the order of 0.3 degrees Celsius between individual scenarios should therefore be regarded as within the noise of the method. The third is that single-season forcing files fundamentally cannot resolve a two-decade climate trend in the UHI; multi-year forcing per horizon would be required for that question.

The conclusions that the results do support are the following. The spatial ranking of the urban heat island across the 863 cells, that is, the identification of the hottest and coolest neighbourhoods, is highly robust: it is reproduced almost identically under every scenario, corrected or not, and can be used with confidence. The wind-rescaled runs constitute the

fairer like-for-like comparison with the 2025 baseline and should be preferred when absolute magnitudes are quoted. Under that variant the scenario heat islands average between +1.3 and +1.9 degrees Celsius over the study area against +2.3 degrees Celsius in 2025, with the differences from the baseline and between scenarios reflecting, to a substantial degree, the wind conditions of the particular simulated seasons rather than a systematic climate signal in the heat island itself.

2.3.2 Flooding hazard - fine-tuning to local context

Flooding in urban environments is strongly influenced by local terrain characteristics, land cover, drainage infrastructure, and rainfall patterns. Consequently, flood hazard assessments developed for one region cannot be directly transferred to another without considering local environmental and urban conditions. Nicosia presents a unique combination of dense urban development, impervious surfaces, modified drainage pathways, and localized topographic variations that significantly influence flood generation and flow propagation.

To account for these local characteristics, a flood assessment framework was developed using datasets and assumptions representative of the study area. High-resolution topographic data was used to capture local terrain variations and surface flow pathways, while information on roads, buildings, and vegetation was incorporated to represent the varying hydraulic resistance of different land-cover types. In addition, hydraulic flood models typically require information on stormwater drainage infrastructure. As detailed drainage network data were not available, drainage gratings were represented using simplified engineering assumptions along the road network as an exploratory approximation of urban drainage processes. Rainfall scenarios were selected using Intensity–Duration–Frequency (IDF) relationships representative of the region. Multiple return

periods were considered to capture a range of rainfall severities, from relatively frequent events to rare extreme storms. This approach enables the assessment of flood behaviour under different rainfall conditions while accounting for the probability of occurrence of each event.

The resulting framework combines local terrain, land-cover, infrastructure, and demographic information to produce a flood hazard and risk assessment tailored to the conditions of Nicosia. By incorporating local datasets and region-specific assumptions, the methodology provides a more realistic representation of flood processes than would be achieved through the direct application of generic flood assessment approaches.

2.3.2.1 Overall description of the flood study

Flooding is one of the most significant climate-related hazards affecting urban areas. Intense rainfall can generate substantial surface runoff, overwhelm urban drainage systems, and lead to localized inundation of roads, buildings, and critical infrastructure. The impacts of flooding include damage to property and infrastructure, disruption of transportation and public services, economic losses, and risks to human safety. In urban environments, flood behavior is strongly influenced by local terrain characteristics, land cover, drainage infrastructure, and the spatial distribution of impervious surfaces.

To assess flood hazard in Nicosia, a scenario-based hydraulic modelling framework was developed using locally relevant geospatial datasets and rainfall conditions representative of the study area. The methodology combines terrain information, land-cover characteristics, drainage assumptions, and rainfall scenarios derived from Intensity–Duration–Frequency (IDF) relationships to estimate flood depth under a range of rainfall severities. The resulting flood simulations are subsequently combined into a flood potential layer that incorporates both flood magnitude and the probability of the triggering rainfall events. The final outputs provide high-resolution flood hazard and risk information suitable for urban planning and climate resilience applications.

2.3.2.2 Local adaptation and data basis

The flood assessment focuses on the municipality of Nicosia and considers riverine and pluvial flooding processes relevant to an inland urban environment. The modelling domain was represented using a high-resolution (10m) Digital Elevation Model (DEM), which serves as the primary dataset controlling overland flow routing and flood propagation. To represent the influence of the urban environment on surface-water movement, local land-cover datasets including roads, buildings, and vegetation were incorporated into the modelling framework. These datasets were used to derive spatially distributed Manning roughness coefficients that influence flow velocity and flood extent. Roads were assumed to provide preferential flow pathways, while buildings act as physical barriers to flow propagation.

The influence of urban drainage infrastructure was represented through drainage grating locations distributed along the road network. Due to the absence of a complete drainage asset inventory, drainage inlets were represented using a simplified engineering assumption of regularly spaced grating locations along roads. This approach allows the model to account for the effect of stormwater capture on flood generation and propagation while maintaining a computationally efficient representation of the drainage network. Rainfall forcing was derived from regional Intensity–Duration–Frequency (IDF) data. A 3-hour storm duration was selected to represent short-

duration, high-intensity rainfall events capable of generating urban flooding. Rainfall scenarios corresponding to return periods of 2, 5, 10, 25, and 50 years were considered.

LISFLOOD-FP Hydraulic Model

Flood simulations were performed using LISFLOOD-FP[1], a two-dimensional hydraulic flood inundation model developed by the School of Geographical Sciences at the University of Bristol. The model was originally designed to simulate riverine flooding over large spatial domains while maintaining computational efficiency and has since been widely applied in flood hazard, flood risk, and climate adaptation studies worldwide. LISFLOOD-FP combines physically based representations of water movement with efficient numerical solvers, enabling the simulation of flood extent, water depth, and flow dynamics across complex landscapes.

The model uses topographic information to represent the movement of water across the terrain and can incorporate additional hydraulic parameters such as surface roughness, channel networks, and rainfall inputs. Due to its ability to simulate both fluvial and pluvial flooding, LISFLOOD-FP has become one of the most widely used open-source flood modelling frameworks in research and operational applications. The model has undergone continuous development for more than two decades and has been applied in numerous studies ranging from local urban flood assessments to continental-scale flood hazard mapping.

In this study, LISFLOOD-FP was selected because it provides an appropriate balance between computational efficiency and physical realism while allowing for the integration of locally available datasets, including terrain, land-cover, and rainfall information. Additional information regarding the model, documentation, and development history is available through the official LISFLOOD-FP website[2] and associated scientific publications[3].

2.3.2.3 Rainfall scenario development

To represent a range of potential flood-generating rainfall conditions, multiple rainfall scenarios were developed using Intensity–Duration–Frequency (IDF) curves. IDF relationships describe the statistical relationship between rainfall intensity, duration, and frequency (return period), and are widely used in hydrological and engineering applications to characterize extreme precipitation events. The IDF data used in this study were obtained from the CLIMAAX *Precipitation pre-calculated IDF* dataset[4], which provides Europe-wide rainfall estimates derived from CORDEX regional climate model simulations and extreme value analysis.

For Nicosia, rainfall intensities were extracted from the IDF dataset and used to define a set of independent flood simulation scenarios. A 3-hour duration was selected because it is representative of short-duration, high-intensity rainfall events that are commonly associated with urban and riverine flooding in Mediterranean environments. Five return periods were considered: 2, 5, 10, 25, and 50

LISFLOOD : https://ec-jrc.github.io/lisflood-model/

[2] LISFLOOD: https://ec-jrc.github.io/lisflood-model/

[3] De Roo, A.P.J., Wesseling, C.G. and Van Deursen, W.P.A. (2000), Physically based river basin modelling within a GIS: the LISFLOOD model. Hydrol. Process., 14: 1981-1992. https://doi.org/10.1002/1099-1085(20000815/30)14:11/12<1981::AID-HYP49>3.0.CO;2-F

Precipitation pre-calculated IDF :
https://handbook.climaax.eu/resources/datasets/precipitation_idf_europe.html

years. These return periods represent a progressive increase in rainfall severity, ranging from relatively frequent events to rare and more extreme storms. The corresponding rainfall intensities used in the simulations are presented in Table 3. The selected scenarios provide a representative range of flood-generating rainfall conditions while remaining relevant for urban planning, resilience assessment, and flood risk management applications. Return periods greater than 50 years were not considered in the present study to focus the analysis on events with greater practical relevance and lower uncertainty.

Each return period was simulated independently to evaluate the sensitivity of flood behavior to increase rainfall severity. The resulting flood depth maps were subsequently used to construct a flood potential layer that accounts for both the magnitude of flooding and the probability of occurrence of the rainfall events. This scenario-based approach provides a scientifically robust framework for assessing flood hazards under a range of plausible rainfall conditions.

Table 5 Rainfall scenarios used for flood modelling in Nicosia derived from the CLIMAAX Precipitation IDF Europe dataset.

Scenario	Rain Intensity (mm/hr)	Return Period
S1	3.57	2-year
S2	4.49	5-year
S3	5.23	10-year
S4	6.35	25-year
S5	7.32	50-year

2.3.2.4 Flood potential assessment

Individual flood simulations provide flood depth maps associated with specific rainfall return periods. However, a single flood hazard layer is required for subsequent risk assessment. To achieve this, the flood depth maps generated for each rainfall scenario were combined into a flood potential layer using probability-based weighting.

The weighting factors were derived from return-period intervals and represent the probability of occurrence within each interval rather than the probability of an individual return period. The flood potential was calculated as (Figure 18):

$$\textbf{Flood Potential} = \Sigma(\textbf{Depth} \times \textbf{Probability Interval})$$

Where the probability interval is derived from the annual exceedance of probabilities associated with consecutive return periods.

This approach enables both the magnitude of flooding and the likelihood of the triggering rainfall events to be incorporated into a single hazard layer. Areas that experience deep flooding under multiple rainfall scenarios receive higher flood potential values than areas that only flood during rare extreme events.

2.3.2.5 Flood risk assessment

The climate hazard associated with flooding arises from the accumulation and movement of surface water following intense rainfall events. Flooding can disrupt transportation networks, damage buildings and infrastructure, affect economic activities, and pose direct risks to human safety. The severity of flood impacts is not determined solely by the depth of flooding but also by the likelihood of the event occurring and the characteristics of the exposed population.

To capture both the magnitude and probability of flooding, a flood potential layer was developed by combining flood depth maps generated from multiple rainfall return-period scenarios. The resulting flood potential represents the expected flooding conditions across the study area by accounting for both the magnitude of flooding and the probability of occurrence of the rainfall events that generate it. Areas with high flood potential are therefore locations that are more likely to experience significant flooding under a range of rainfall conditions.

For the flood risk assessment, hazard, exposure, and vulnerability layers were combined according to the following relationship:

$$\textbf{Risk} = \textbf{Hazard} \times \textbf{Exposure} \times \textbf{Vulnerability}$$

In this framework, the hazard layer is represented by the flood potential map derived from the hydraulic simulations. Exposure reflects the number of people that may be affected by flooding within a specific location, while vulnerability captures the susceptibility of the exposed population to flood impacts.

Similar to the UHI risk assessment, the exposure and vulnerability components are derived using the same demographic datasets and methodological framework. For the vulnerability index within each 200 m × 200 m grid cell (Figure 20), we consider population groups that are generally more susceptible to flood-related impacts and evacuation challenges. These include pregnant women, infants, and elderly persons. The vulnerability is therefore defined as:

$$\textbf{Vulnerability} = (\textbf{Pregnant Women} + \textbf{Infants} + \textbf{Elderly}) / \textbf{Total Population}$$

This formulation produces values in the range [0,1], where higher values indicate a greater proportion of vulnerable individuals within the population.

Exposure is represented by the total population within each grid cell (Figure 19). To reduce the influence of highly populated areas and avoid disproportionately large risk values, a logarithmic transformation is applied:

$$\textbf{Exposure} = \ln(\textbf{Total Population} + 1)$$

where ln denotes the natural logarithm. The addition of one ensures that areas with zero population result in an exposure value of zero.

Following the transformation, both the hazard and exposure layers are standardized to the range [0,1] using min-max normalization:

$$x_{scaled} = (x - x_{min}) / (x_{max} - x_{min})$$

Where x is the original value, xmin is the minimum value, and xmax is the maximum value observed within the study area. The vulnerability layer does not require additional standardization because it is already expressed as a ratio between 0 and 1.

Population, elderly population, infant population, and pregnancy-related demographic data were obtained from the WorldPop platform and spatially aggregated to the common 200 m × 200 m analysis grid. The resulting processing chain produces spatially explicit maps of Flood Potential (Hazard) (Figure 18), Exposure (Figure 19), Vulnerability (Figure 20), and Flood Risk (Figure 21), allowing the identification of areas where flood impacts are expected to be most significant. The final risk maps provide a spatial representation of locations where severe flooding coincides with high population concentrations and elevated vulnerability, supporting prioritization of adaptation and resilience measures.

Table 6 Data overview of the flooding study

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Flood Potential	Portion of pregnant women, infants and elderly population over Total Population	Total Population in an area (logarithmic)	Hazard × Exposure × Vulnerability

The described processing results in the heatmaps (Hazard, Exposure, Vulnerability) shown in the following figures.

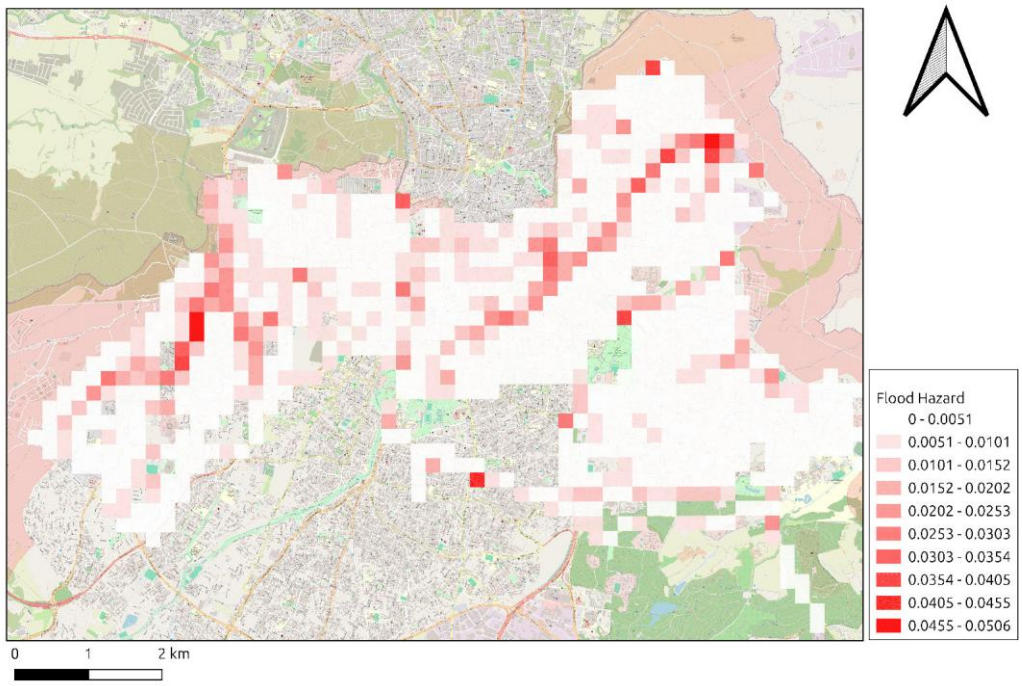


Figure 20 The Flood potential heatmap in the Municipality of Nicosia.

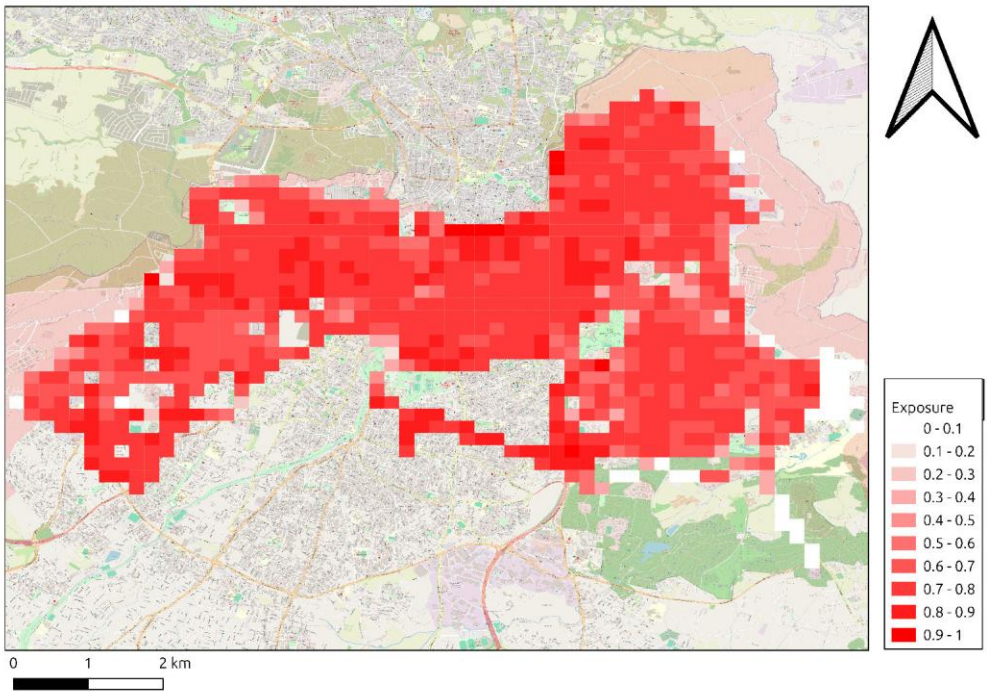


Figure 21 The population exposure in the Municipality of Nicosia.

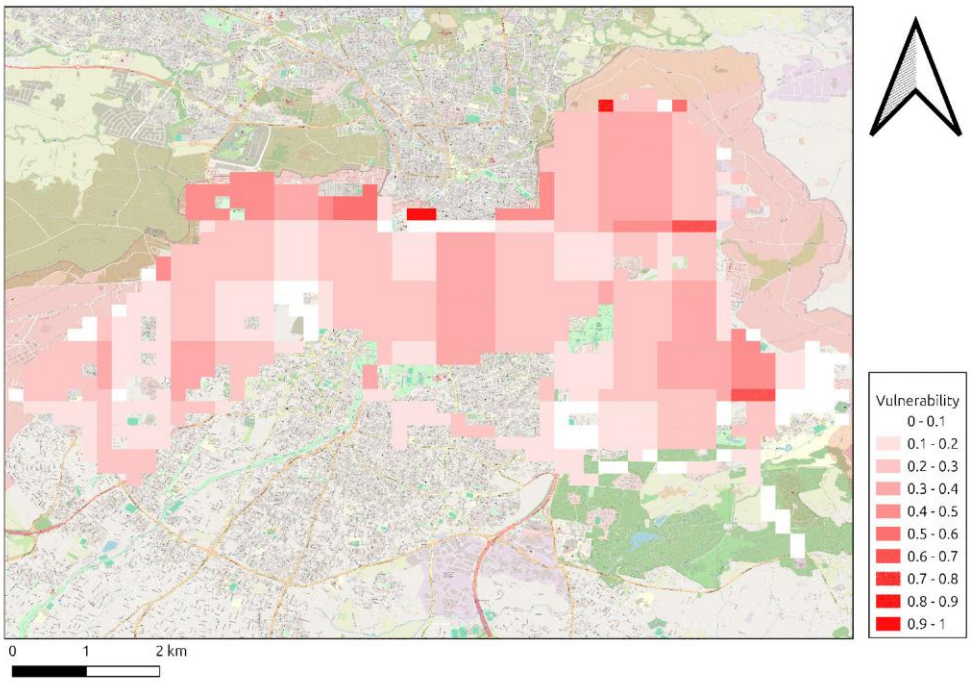


Figure 22 The vulnerability heatmap in the Municipality of Nicosia.

The computed risk map for the Flood hazard is shown in the following figure.

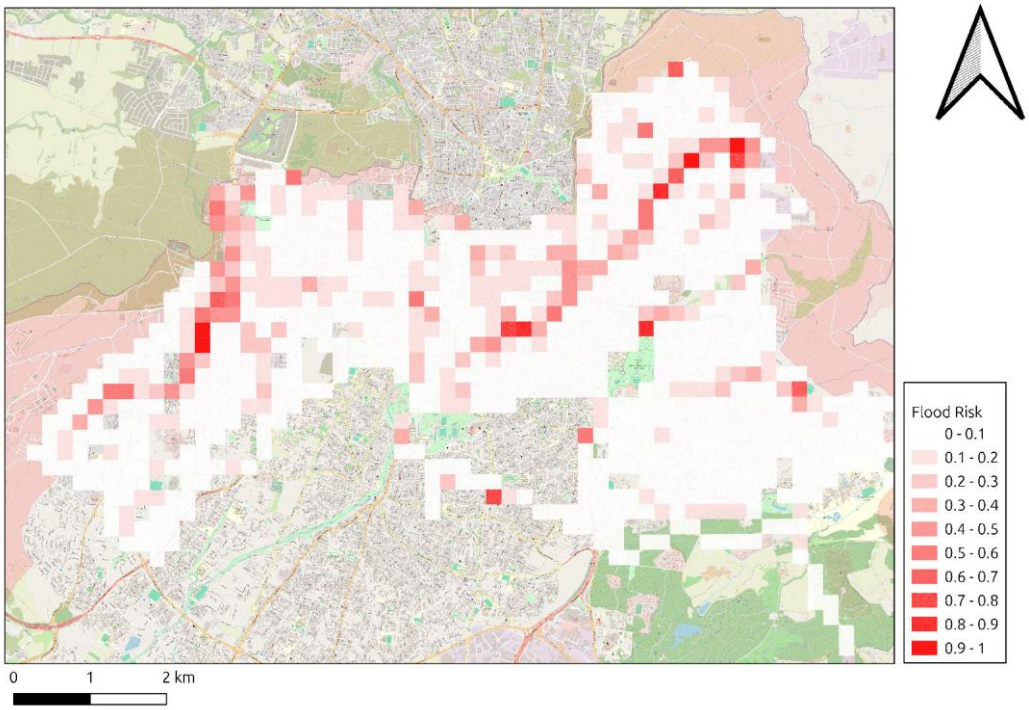


Figure 23 The final flood risk heatmap for the Municipality of Nicosia.

2.3.2.6 Future Flood Scenarios

2.3.2.6.1 Introduction

Future flood behaviour was evaluated using five rainfall scenarios representing progressively increasing storm severities. The rainfall inputs were derived from the CLIMAAX Precipitation Intensity–Duration–Frequency (IDF) dataset, which provides Europe-wide rainfall estimates based on CORDEX regional climate model simulations and extreme value analysis. For the Nicosia study area, a 3-hour storm duration was selected to represent short-duration, high-intensity rainfall events commonly associated with urban flooding. Five return periods (2, 5, 10, 25 and 50 years) were considered, representing a progression from relatively frequent rainfall events to rare and more extreme storms.

2.3.2.6.2 Model description: inputs and outputs

The future flood scenarios were simulated using LISFLOOD-FP, a two-dimensional hydraulic flood inundation model that computes the movement and accumulation of surface water across the terrain. The model represents overland flow using a high-resolution Digital Elevation Model (DEM) together with spatially distributed hydraulic parameters describing surface roughness and drainage characteristics. For this study, the model was configured using a 30 m Digital Elevation Model, a Manning's roughness layer derived from land-use/land-cover data, the river network, and a synthetic drainage network represented by preferential flow paths along the road network. Rainfall forcing was supplied using 3-hour design storms derived from the CLIMAAX Precipitation IDF dataset, with independent simulations performed for the 2-, 5-, 10-, 25-, and 50-year return periods.

The hydraulic model calculates the spatial distribution of flood water throughout the simulation

period and produces a maximum flood depth raster representing the greatest water depth reached at each 30 m grid cell during the rainfall event. These maximum flood depth maps constitute the primary output used in this study. For subsequent analysis, the raster outputs were aggregated to the common 200 m × 200 m analysis grid, where flood statistics, including mean flood depth, maximum flood depth, flooded area, and flood potential, were derived for each grid cell.

2.3.2.6.3 Preparing the rainfall scenarios

Rainfall forcing for the hydraulic simulations was derived from the CLIMAAX Precipitation IDF dataset, which provides rainfall intensity estimates for different return periods across Europe based on regional climate model simulations and extreme value analysis. A 3-hour storm duration was selected to represent intense rainfall events capable of generating urban flooding. Five independent rainfall scenarios corresponding to 2-, 5-, 10-, 25-, and 50-year return periods were simulated. All model parameters, terrain data, and hydraulic characteristics were kept identical across the simulations, with rainfall intensity being the only varying input. This approach allows the influence of increasing rainfall severity on flood depth and inundation extent to be evaluated while maintaining a consistent modelling framework.

2.3.2.6.4 Flood Scenario Summary

The overall characteristics of the simulated flood scenarios are summarized below. As expected, increasing rainfall return periods produce progressively larger flood extents, greater average flood depths, and higher maximum flood depths.

Scenario	Return Period	Mean Flood Depth (m)	Maximum Flood Depth (m)	Flooded Area (%)
S1	2-year	0.234	5.692	7.42
S2	5-year	0.260	6.351	8.75
S3	10-year	0.280	6.803	9.63
S4	25-year	0.309	7.442	10.87
S5	50-year	0.333	7.821	11.77

2.3.2.6.5 Results

The simulations demonstrate a consistent increase in flood severity with increasing rainfall return period. The 2-year rainfall event (S1) represents relatively frequent flooding, with approximately 7.4% of the study area experiencing inundation above the selected flood threshold. The mean flood depth for flooded areas is 0.234 m, while the maximum simulated flood depth reaches 5.69 m.

As rainfall intensity increases, both the depth and spatial extent of flooding increase steadily. The 5-year and 10-year scenarios show a moderate expansion of inundated areas, with flooded area increasing to 8.75% and 9.63%, respectively. Mean flood depth also increases from 0.260 m to 0.280 m, while maximum flood depths exceed 6 m in both scenarios.

The largest changes are observed for the 25-year and 50-year rainfall events. Under the 25-year

scenario, approximately 10.9% of the study area becomes flooded, increasing further to 11.8% under the 50-year scenario. Mean flood depth increases to 0.309 m and 0.333 m, respectively, while the maximum simulated flood depth reaches 7.82 m for the 50-year event.

Although flood depth and inundation extent increase with rainfall severity, the overall spatial distribution of flooding remains largely unchanged across all scenarios. Areas identified as flood-prone during the more frequent rainfall events continue to experience the greatest flooding under the more extreme scenarios. Increasing rainfall intensity primarily amplifies the depth and extent of flooding rather than introducing entirely new flood-prone locations. This indicates that local terrain, land cover, and drainage characteristics are the dominant controls governing the spatial distribution of flooding, while rainfall intensity determines the magnitude of flood impacts.

2.3.2.6.6 Flood Depth Maps

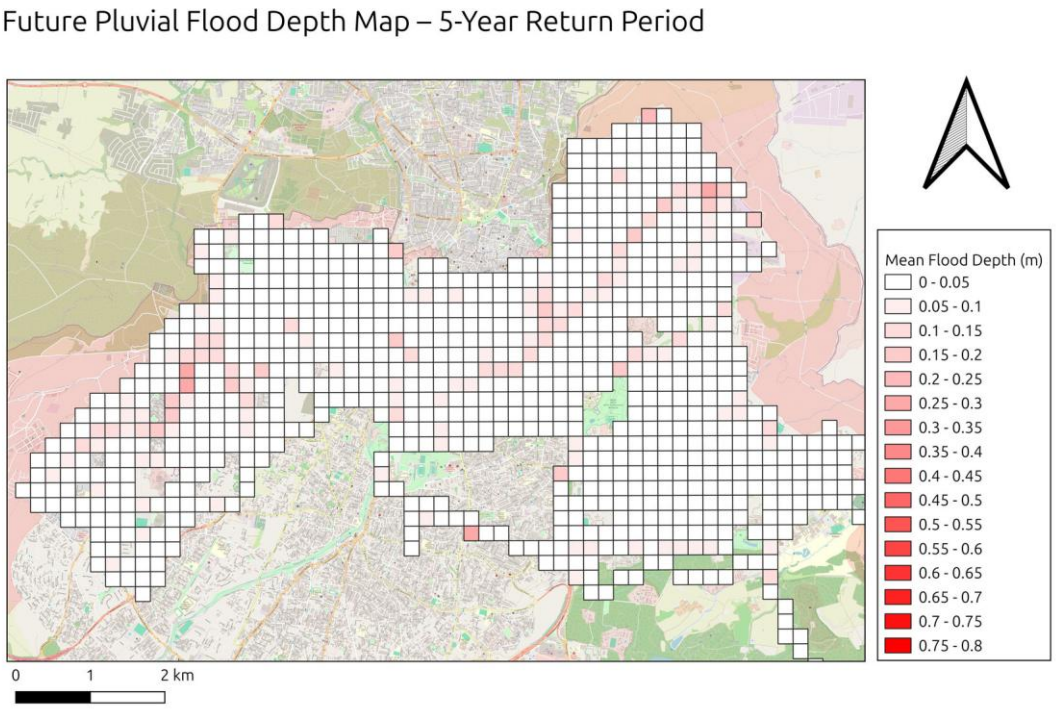


Figure 24 Maximum flood depth simulated for the 2-year rainfall event.

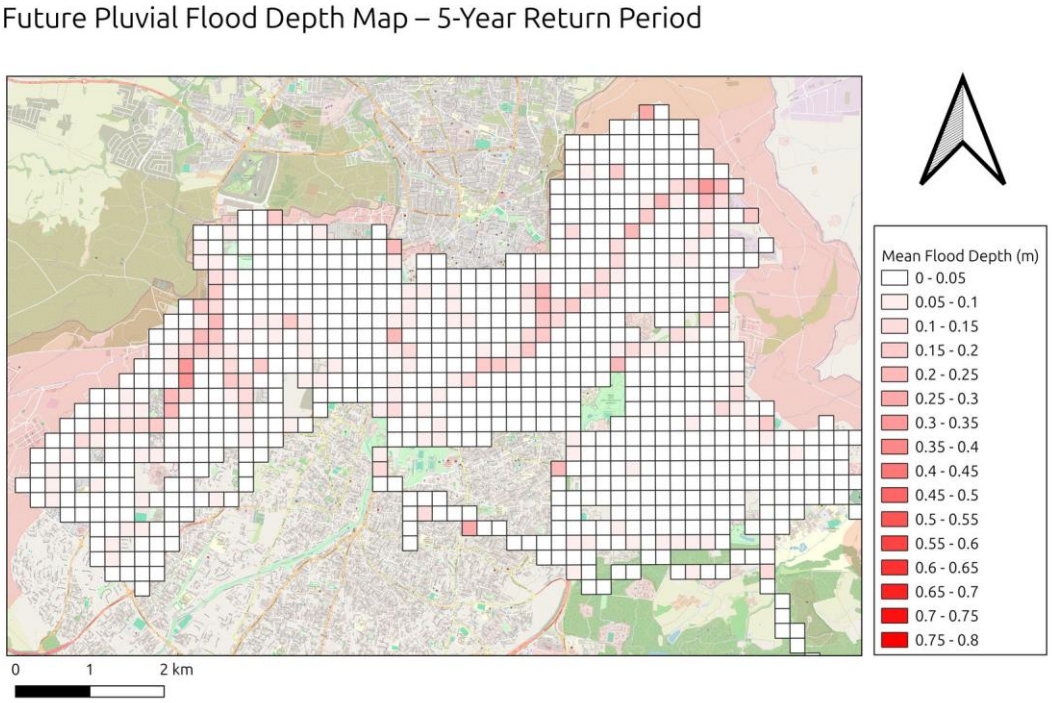


Figure 25 Maximum flood depth simulated for the 5-year rainfall event.

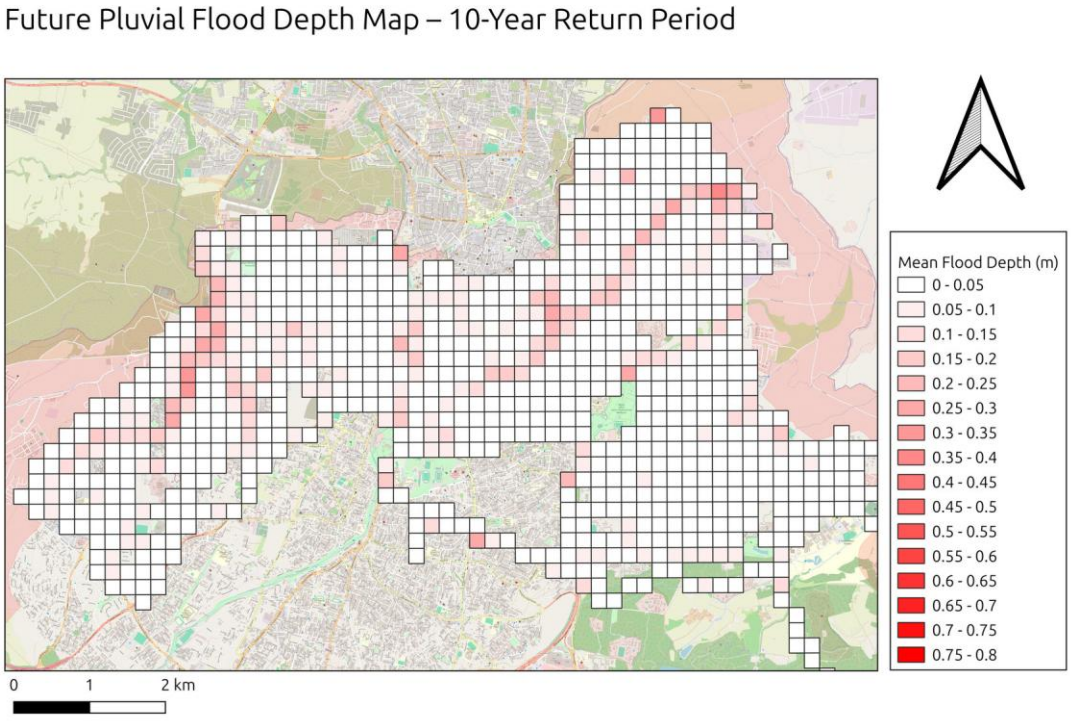


Figure 26 Maximum flood depth simulated for the 10-year rainfall event.

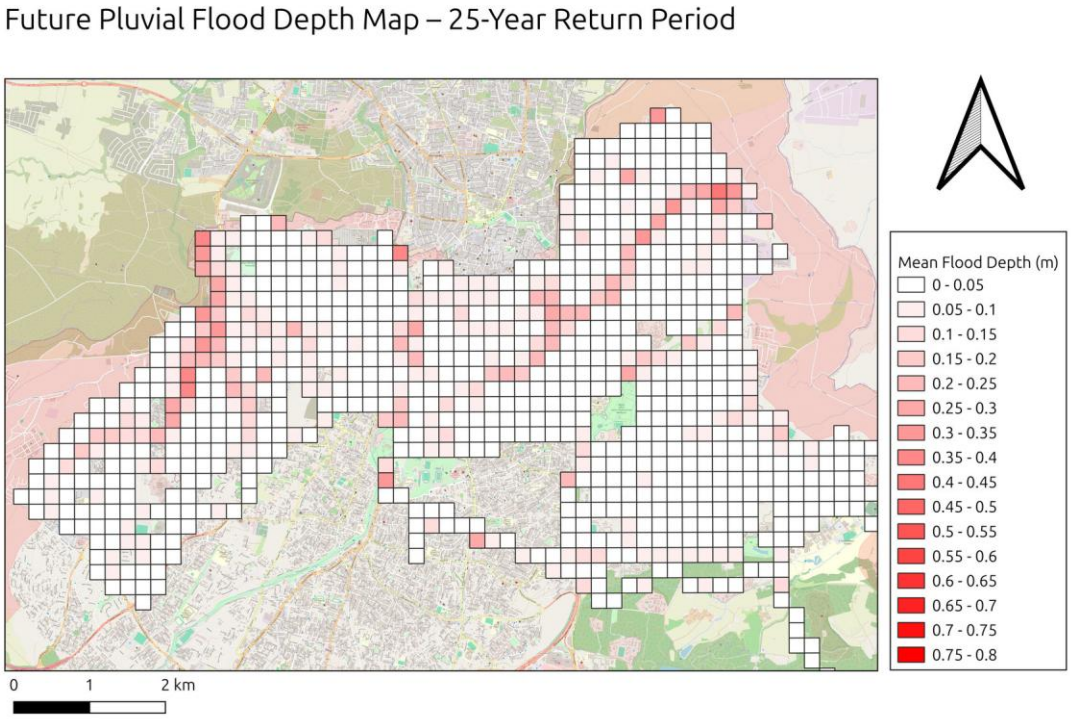


Figure 27 Maximum flood depth simulated for the 25-year rainfall event.

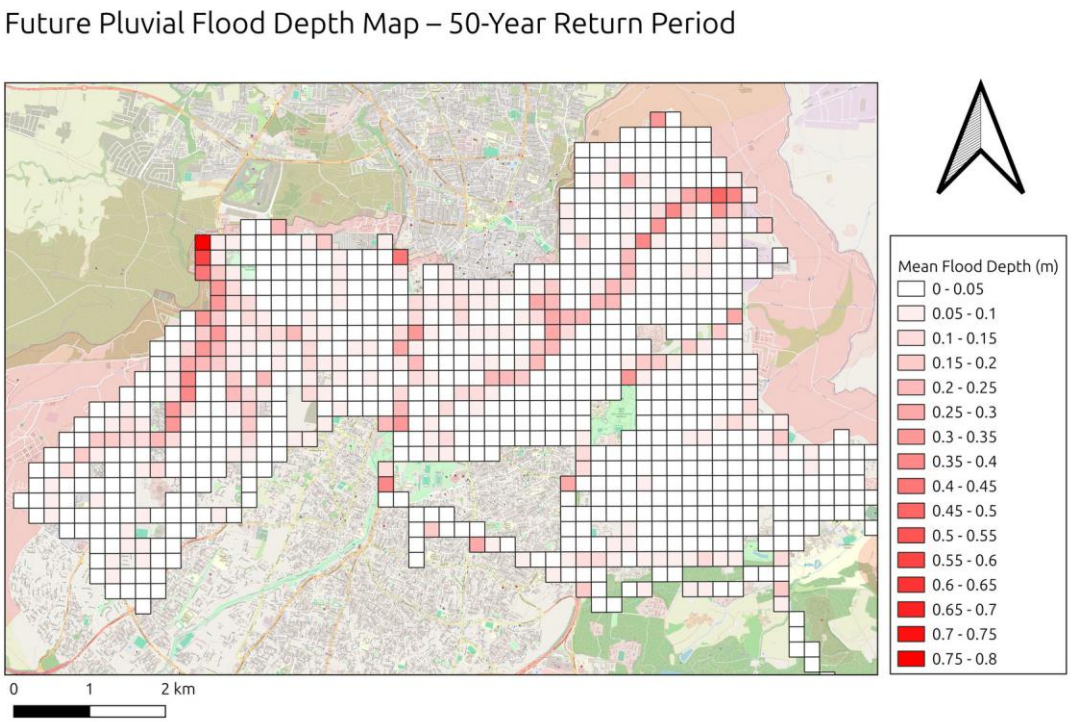


Figure 28 Maximum flood depth simulated for the 50-year rainfall event.

2.3.2.7 Discussion and Conclusions

The scenario-based simulations demonstrate the sensitivity of urban flooding to increasing rainfall intensity. While the magnitude and spatial extent of flooding increase with return period, the principal flood pathways remain consistent across all scenarios. This suggests that local topography, land cover and drainage characteristics primarily determine where flooding occurs, whereas rainfall intensity controls the severity of flooding. These results provide a robust basis for developing flood potential, hazard and risk maps for climate resilience and urban planning applications.

2.3.3 Drought and vegetation-stress

Drought and vegetation stress are gradually emerging with climate change impacts and the growth of cities, and the dry and hot regions like the eastern Mediterranean are affected by this the most. Unlike a flood or a storm, this kind of stress builds slowly, as the heat lasts and water runs short, plants lose their health and dry out, and the damage adds up over time, especially in summer. In and around cities the problem gets worse because there is so much paved surface, green areas are small and scattered, and water is in short supply. When healthy plants are lost, the city loses the shade and cooling they give, the air gets worse, more water is needed for irrigation, and people feel the heat.

Factors that contribute the most to the vegetation stress, in urban and peri-urban environments, are local land cover, surface composition, vegetation distribution, and the seasonal evolution of plant cover. Vegetation condition assessments developed for one region cannot be transferred directly to another without accounting for local environmental and urban conditions. Nicosia has a particular combination of dense urban development, substantial impervious surfaces, green vegetation, and a hot semi-arid Mediterranean climate that exposes the vegetation in the city to seasonal water stress, especially during the summer months.

Considering these local characteristics, we developed a framework that uses satellite imagery for drought and vegetation stress across Municipality of Nicosia and turns this into a clear map of drought and vegetation-stress hazard and risk to help with city planning and climate resilience.

2.3.3.1 Overall description of the vegetation-stress study

Drought and vegetation stress are among the most relevant slow-onset climate-related hazards affecting semi-arid urban regions. Prolonged dry periods and elevated temperatures reduce vegetation vigor and canopy moisture, diminishing the cooling, shading, and air-quality benefits that urban green spaces provide. In urban environments, vegetation conditions are strongly influenced by local land cover, the spatial distribution of green and built-up surfaces, and the availability of canopy moisture.

To assess vegetation conditions in Nicosia, a remote-sensing framework was developed using locally relevant satellite imagery and a seasonal observation window representative of the study area. The methodology combines multispectral data acquisition, per-scene cloud screening, monthly median compositing, and the computation of two vegetation indices to characterize greenness, and canopy moisture status across the whole of Cyprus. From the resultant layers, the geographical region of Nicosia is extracted. The resulting index layers are then used to map

vegetation cover and to classify water stress and overall vegetation condition. In the following sections, we provide details about our methodology and results.

2.3.3.2 Local adaptation and data basis

The study focuses on Nicosia during August 2025, one of the hottest and driest parts of the summer. The hazard is defined as water stress, exposure is the potential area of Nicosia, and exposure is the green vegetation within Nicosia.

The analysis is built on Sentinel 2 surface-reflectance (COPERNICUS/S2_SR_HARMONIZED collection 5), which provides the spectral bands required to characterize vegetation greenness, moisture, and chlorophyll content at a spatial resolution appropriate for analysis. Spectral imagery is processed over the whole of Cyprus and is then extracted for the defined administrative boundary of Nicosia Municipality.

Instead of using a single satellite photo, we used all the clear images with cloud coverage, less than 30% for the whole month and averaged them into one. This gives a clean, average single layer.

2.3.3.3 Satellite data acquisition and monthly compositing

In this project, satellite data from Sentinel-2 is used. Sentinel-2 is a pair of Earth-observation satellites operated under the European Copernicus Program. Together, the satellites provide global coverage, capturing high-resolution images of the Earth's land surfaces, inland waters, and coastal regions. They revisit the same location approximately every five days, and even more frequently at higher latitudes. The Sentinel-2 surface-reflectance collection is filtered for the Cyprus region for August 2025, and the tiles with the cloud coverage of less than 30% are selected. Residual clouds, cloud shadows, and other unreliable pixels are removed from each scene using the Sentinel-2 scene-classification layer[6]. Pixels labelled as cloud shadow, unclassified, medium- and high-probability cloud, thin cirrus, or snow are masked out, so that only clear-sky observations contribute to the result.

After the data cleaning in next step B04 (red, Central Wavelength of 665nm), B08 (NIR, Central Wavelength = 842nm), B11 (SWIR 1, Central Wavelength = 1610nm) are selected for vegetation indices calculation. Data acquisition and preprocessing are performed on the Google Earth Engine platform*7*. Monthly compositing helps in noise reduction and makes readings more robust.

2.3.3.4 Vegetation index computation and masking

Vegetation indices are mathematical combinations of two or more spectral bands from satellite or drone imagery used to remotely measure the density, greenness, and health of plant canopies. Plants reflect and absorb different colors (wavelengths) of light in characteristic ways which tell about the status or the health of the plant.

5https://handbook.climaax.eu/resources/datasets/precipitation_idf_europe.html

[6] Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-2A (SR) | Earth Engine Data Catalog | Google for Developers

7 https://www.researchgate.net/figure/Sen2Cor-Scene-classification-classes-for-Sentinel-2_tbl2_334403171

In this study, we use two indices as shown in figure below. Each one is a normalized, ranging between −1 and +1:

- **Normalized Difference Vegetation Index (NDVI):**

  NDVI is a remote sensing index that quantifies the density and health of green vegetation by exploiting the contrast between how plants reflect near-infrared (NIR) light and absorb red light. Healthy vegetation strongly absorbs red light for photosynthesis while reflecting NIR strongly, so the difference between these bands is large for vigorous plant cover.

- **Normalized Difference Moisture Index (NDMI):**

  NDMI is a remote sensing index that estimates the water content held within vegetation canopies, using the contrast between near-infrared (NIR) reflectance and short-wave infrared (SWIR) reflectance. Leaf water absorbs SWIR radiation, so well-hydrated canopies show lower SWIR reflectance, producing higher index values.

The two indices are calculated as:

- NDVI = (NIR − Red) / (NIR + Red)
- NDMI = (NIR − SWIR) / (NIR + SWIR)

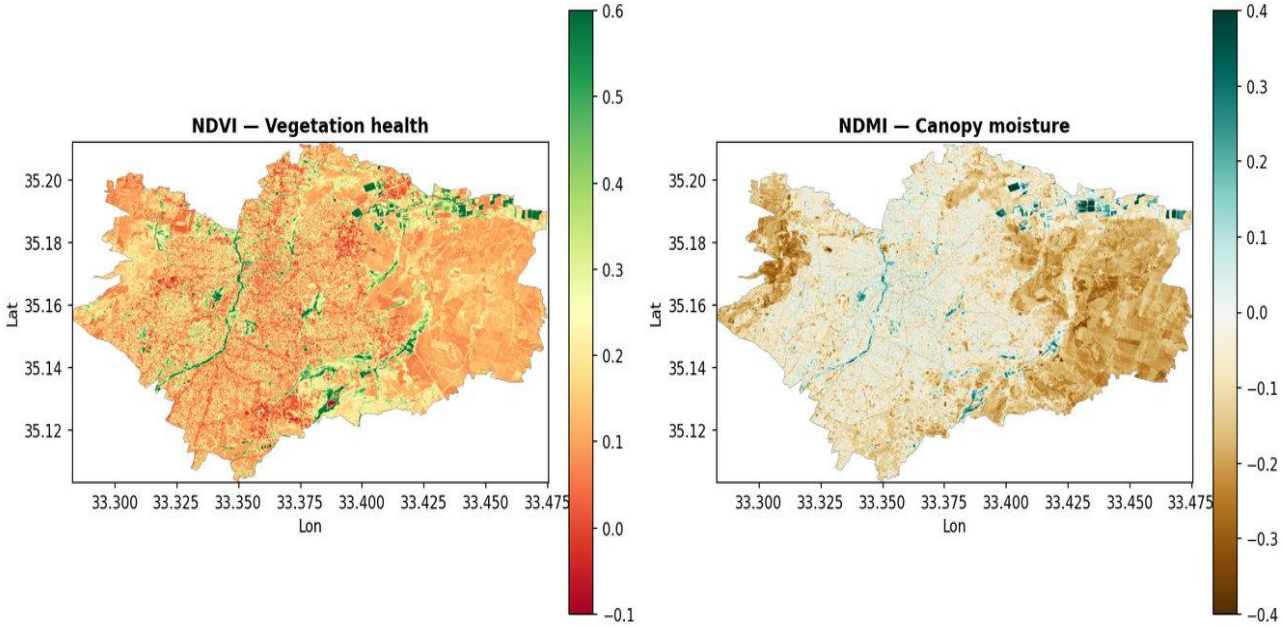


Figure 29 Vegetation indices NDVI, NDMI August 2025.

Vegetation indices are computed on each cloud-masked layer, combined into the monthly median composite, and exported as GeoTIFF layers at 10 m resolution in a geographic coordinate reference system (EPSG:4326).

To separate vegetated surfaces from bare soil, impervious surfaces, and water, a vegetation mask is constructed by retaining only pixels with NDVI greater than 0.2[8]. The vegetation only layer is generated and masked-out pixels are assigned to no-data value and excluded from all statistics.

2.3.3.5 Vegetation-index results and vegetation cover

NDVI and NDMI were mapped over the Nicosia study area for August 2025. The NDVI field is low overall, with a mean of 0.16 and a median of 0.13, consistent with the sparse, largely senescent vegetation expected across a semi-arid city at the height of summer. The highest NDVI values are confined to irrigated agricultural parcels in the north-east and to scattered well-watered patches, while the dense urban core and the eastern fallow lands show low greenness.

The NDMI field is predominantly negative, indicating low canopy and surface moisture across most of the study area. Positive NDMI values, denoting higher moisture content, are largely limited to a small number of irrigated fields and water bodies in the north-east.

Applying the NDVI > 0.2 vegetation threshold as shown in figure below, only 393,993 pixels (24.9 percent of the study area) are classified as vegetated, while the remaining 1,190,036 pixels are non-vegetated. Vegetated surfaces are concentrated along agricultural belts and green corridors, confirming that genuine vegetation occupies a minority of urban fabric in late summer.

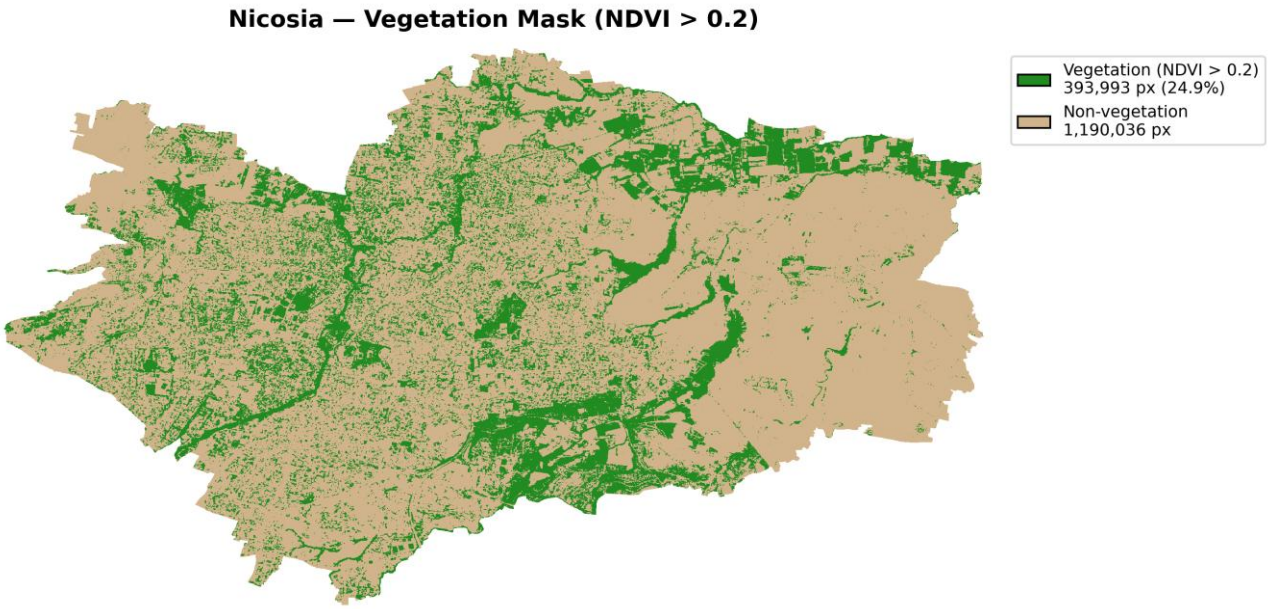


Figure 30 Vegetation mask

2.3.3.6 Water-stress and vegetation-condition classification

To translate the continuous indices into interpretable categories, NDMI was classified into water-stress classes[9], and the NDVI - NDMI relationship was used to classify overall vegetation condition. Across the full study area, majority of pixels fall in the mid-low canopy, high water-stress class (NDMI between −0.2 and 0.0) and a further 31.5 percent in the average-canopy high water-stress class (0.0

[8] Google Earth Engine: Planetary-scale geospatial analysis for everyone - ScienceDirect

[9] https://www.usgs.gov/special-topics/remote-sensing-phenology/science/ndvi-foundation-remote-sensing-phenology

to 0.2), while only 0.9 percent show no water stress (0.4 to 0.6) and effectively none indicate waterlogging.

Restricting the classification to vegetated pixels, water stress remains dominant: 56.5 percent of vegetation falls in the high water-stress class, as shown in Figure below.

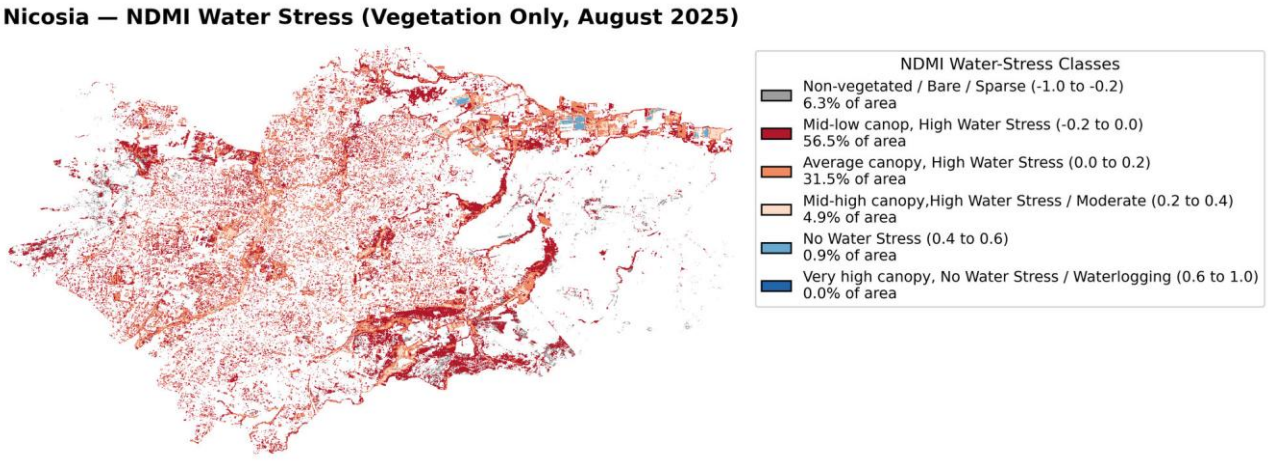


Figure 31 NDMI water-stress classes over vegetated pixels only, August 2025.

A summary of the vegetation pixels reinforces the diagnosis: 94.3 percent of vegetated pixels lie below the NDMI = 0.2 moisture-stress line, and by greenness 77 percent of vegetation is sparse or grassland (NDVI 0.20–0.40), 17 percent is moderate (0.40–0.60), and only 6 percent is dense (NDVI above 0.60)[10] as shown in the figure below.

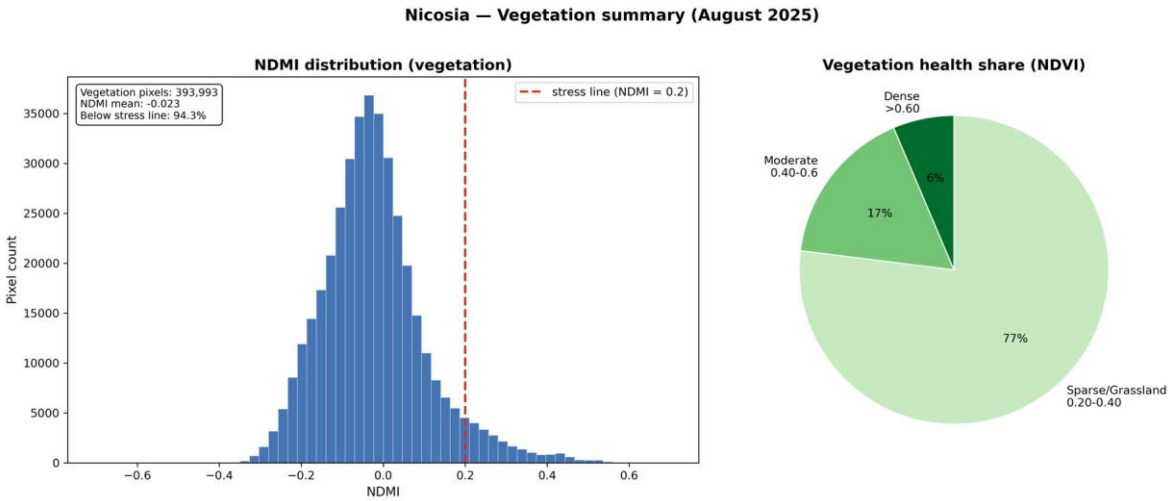


Figure 32 Vegetation summary: NDMI distribution, and NDVI-based vegetation-density share.

Overlaying NDMI on high-resolution imagery allows the spatial pattern to be interpreted against land use. Comparatively higher moisture is associated with dense tree cover and healthy irrigated agricultural fields, principally in the north-east, sparse urban vegetation shows moderate values, and the eastern agricultural and fallow lands display the lowest moisture as shown in the figure below.

[10] 1. https://eos.com/make-an-analysis/ndmi/ 2.https://www.lifeingis.com/using-the-normalized-difference-moisture-index/

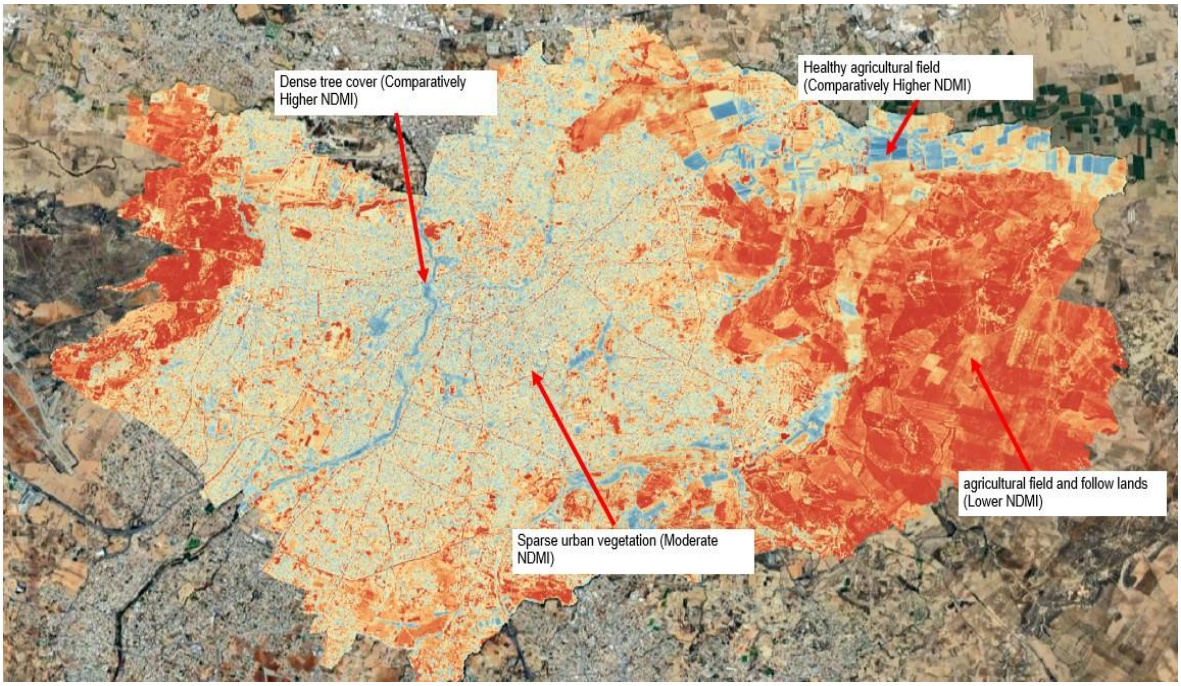


Figure 33 Annotated NDMI interpretation over satellite imagery of the Nicosia area.

2.3.3.7 Hazard assessment

The drought and vegetation-stress hazard come from the fact that some parts of a city keep weaker, drier, and less healthy plants than others, which means less cooling, shade, and clean air. The August 2025 results show a high hazard over most of Nicosia. Real plants cover only about a quarter of the area, and most of those plants are stressed. The majority of vegetation sits below the moisture-stress line.

We turn these results into one hazard value for each neighborhood. Because lower greenness and lower moisture mean more stress, the measures are set up so that a higher hazard value means drier, more stressed plants. The pattern makes sense, the city center and the dry eastern fields carry the highest hazard, while the watered farms and tree cover in the north-east are lower hazard spots. The places to worry about most are those that mix thin, stressed plants with dense buildings, where the loss of plant cover meets the parts of the city least able to cope with summer heat.

2.3.3.8 Risk assessment

Here the risk is about the plants themselves, which parts of Nicosia have vegetation most at risk from drought. We build it straight from the drought analysis by combining three things how dry the area is, how much green vegetation it holds, and how much of the area is involved using

Risk = Hazard × Exposure × Vulnerability.

Hazard is water stress. It comes from the NDMI water-stress results, the drier in the area (lower NDMI), the higher the hazard. As shown earlier, most Nicosia falls in the high water-stress classes, so the hazard is high across most areas of the city. Vegetation in the geographical area of Nicosia is classified as exposure.

Vulnerability is green vegetation. The green vegetation is at high risk because of the drought. Cells with more green cover (higher NDVI, above the 0.2 vegetation line) are more vulnerable, because

there is more living plant cover that could be damaged or lost; bare soil, buildings, and paved ground have little or nothing to lose. Vegetation in the geographical area of Nicosia is exposed to this hazard.

The result is a map that points to the green parts of Nicosia most threatened by summer drought, where drying, stressed vegetation and genuine plant cover come together. These areas are the first natural targets for steps such as targeted watering, protecting existing trees, or choosing more drought-resilient planting.

Table 8 Data overview of the drought risk

Hazard data	Vulnerability data	Exposure data	Impact metrics / Risk output
Water stress	Green vegetation	Vegetation in geographical area of Nicosia	Hazard × Exposure × Vulnerability

2.3.3.8 Future risk assessment for drought

Introduction

Future agricultural drought conditions in the Nicosia study area were evaluated using the Standardized Precipitation-Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010) derived from regional climate model projections. The index combines precipitation with an estimate of atmospheric evaporative demand, so it responds to changes in temperature as well as rainfall. The analysis was performed at a 3-month accumulation period (SPEI-3), a timescale commonly used as an indicator of short-term agricultural drought.

Climate forcing was taken from a single EURO-CORDEX EUR-11 model combination (global model MPI-M-MPI-ESM-LR downscaled with the regional model CLMcom-CCLM4-8-17) with simulations for the historical period and two emission pathways, RCP4.5 and RCP8.5, over 1950-2100. Drought conditions were standardised against the 1971-2000 reference climate and summarised for a baseline period and three future horizons (2045, 2065 and 2085) under the two RCP pathways. The methods, the preparation of the scenario data and the results are described below.

2.3.3.9 Inputs and outputs

The SPEI is a multi-scalar drought index based on the climatic water balance, defined as the difference between precipitation (P) and potential evapotranspiration (PET). For each month, the water balance is accumulated over the preceding three months, and the resulting series is transformed into a standardised index by fitting a probability distribution and converting the cumulative probabilities to standard normal values. An SPEI value of zero corresponds to the median conditions of the reference period, negative values indicate conditions drier than normal and positive values wetter than normal.

The model inputs consisted of three monthly variables from the CORDEX simulation: precipitation (pr), monthly mean daily maximum near-surface air temperature (tasmax) and monthly mean daily minimum near-surface air temperature (tasmin), each for the historical, RCP4.5 and RCP8.5 experiments. The area of interest (AOI) was defined by the boundaries of the following five municipalities: Lefkosia, Agios Dometios, Aglantzia, Egkomi and Strovolos. The EUR-11 grid has a resolution of approximately 12 km, and the cells overlapping the AOI were used in the analysis.

Potential evapotranspiration was estimated with the Hargreaves method (Hargreaves and Samani, 1985; Allen et al., 1998), a temperature-based approach used to estimate reference or potential evapotranspiration. It requires maximum and minimum temperature and the latitude of the site. Precipitation and PET were converted to mm/day and the monthly climatic water balance was computed as P - PET. The SPEI-3 was then calculated with the xclim library, fitting a three-parameter log-logistic distribution separately for each calendar month by maximum likelihood. The distribution parameters were estimated on the 30-year period 1971-2000, in line with the recommended reference period of at least 30 years (Lindenlaub et al., 2026), and applied to the full 1950-2100 series, so that future values are expressed relative to the climate of the reference period. The index was bounded at 3.

The SPEI-3 results are presented for the 1971-2000 baseline and for three future projections, 2045, 2065 and 2085, under each RCP scenario. For these projections, SPEI-3 maps were also produced, including a version showing agricultural and vegetated land (pasture, agriculture and forest) based on CORINE Land Cover.

2.3.3.10 Preparing the drought scenarios

The historical simulation provides data up to 2005, and the RCP simulations continue from 2006 to 2100. For each RCP, the two were joined into one continuous monthly record. The historical part is the same for both scenarios and all other settings were kept identical, so RCP4.5 and RCP8.5 share the same baseline. Differences between the scenarios reflect the emission pathway together with the natural variability of the two model runs.

Future drought was summarised for three horizons centred on 2045, 2065 and 2085, each over an 11-year window (the target year 5 years), and compared with the 1971-2000 baseline. For each period and scenario, the mean SPEI-3 and the frequency of moderately dry or drier (SPEI < -1.0), severely dry or drier (SPEI < -1.5) and extremely dry (SPEI < -2.0) months were calculated. The values were interpreted using the drought categories in Table 1.

Table 9 SPEI categories

SPEI-3 range	Drought category
2.00 and above	Extremely Wet
1.50 to 1.99	Severely Wet
1.00 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.00 to -1.49	Moderately Dry
-1.50 to -1.99	Severely Dry
-2.00 and below	Extremely Dry

2.3.3.11 Drought Scenario Summary

The mean SPEI-3 for each scenario and future horizon is shown in the table below. The mean over the 1971-2000 baseline is -0.03.

Table 10 Mean SPEI-3 for Nicosia under the two RCP scenarios (11-year windows).

	RCP4.5	RCP8.5
2045	-0.55	-0.44
2065	-0.69	-0.69
2085	-0.37	-1.24

2.3.3.12 Results

Over the 1971-2000 baseline, the mean SPEI-3 is -0.03, close to zero as expected because the index was calibrated on this period. The baseline is the same for both scenarios because the historical record is common to both.

Under RCP4.5, the mean SPEI-3 is -0.55 in 2045, -0.69 in 2065 and -0.37 in 2085. All three horizons are drier than the baseline, with the driest conditions in 2065. The 2085 horizon is less dry than 2065 but remains drier than the baseline.

Under RCP8.5, the mean SPEI-3 is -0.44 in 2045, -0.69 in 2065 and -1.24 in 2085, and conditions become drier with each horizon. By 2085, the mean SPEI-3 falls in the moderately dry category.

The two scenarios are similar in 2045 and 2065, with mean SPEI-3 values within 0.11 of each other, and differ clearly in 2085, when the mean SPEI-3 under RCP8.5 (-1.24) is lower than under RCP4.5 (-0.37).

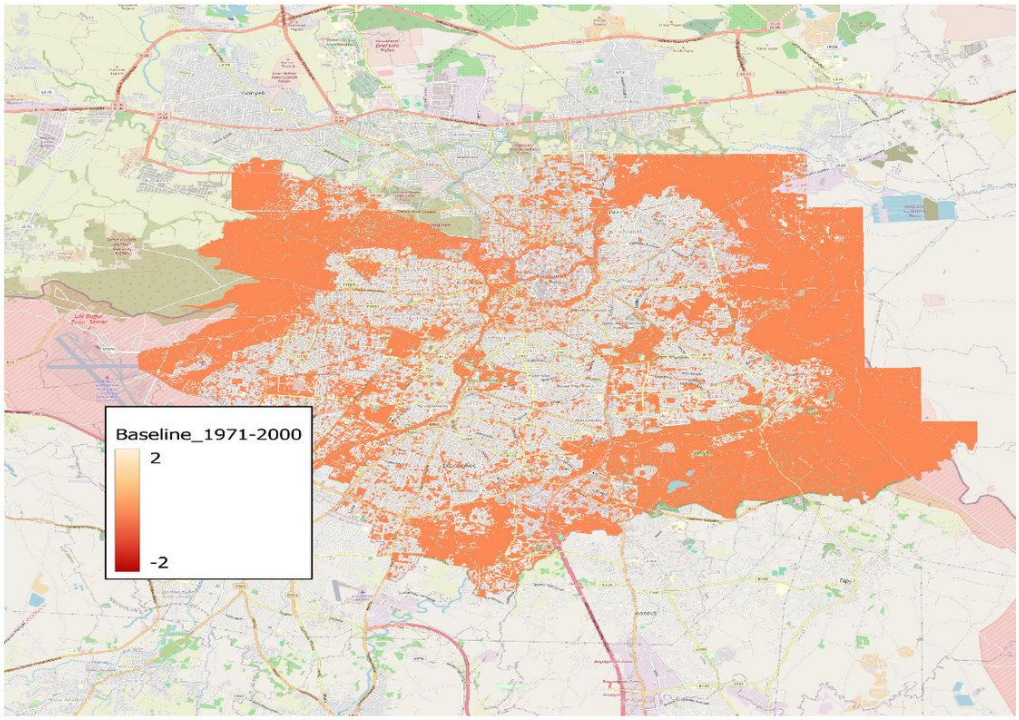


Figure 34 Baseline from 1971-2000

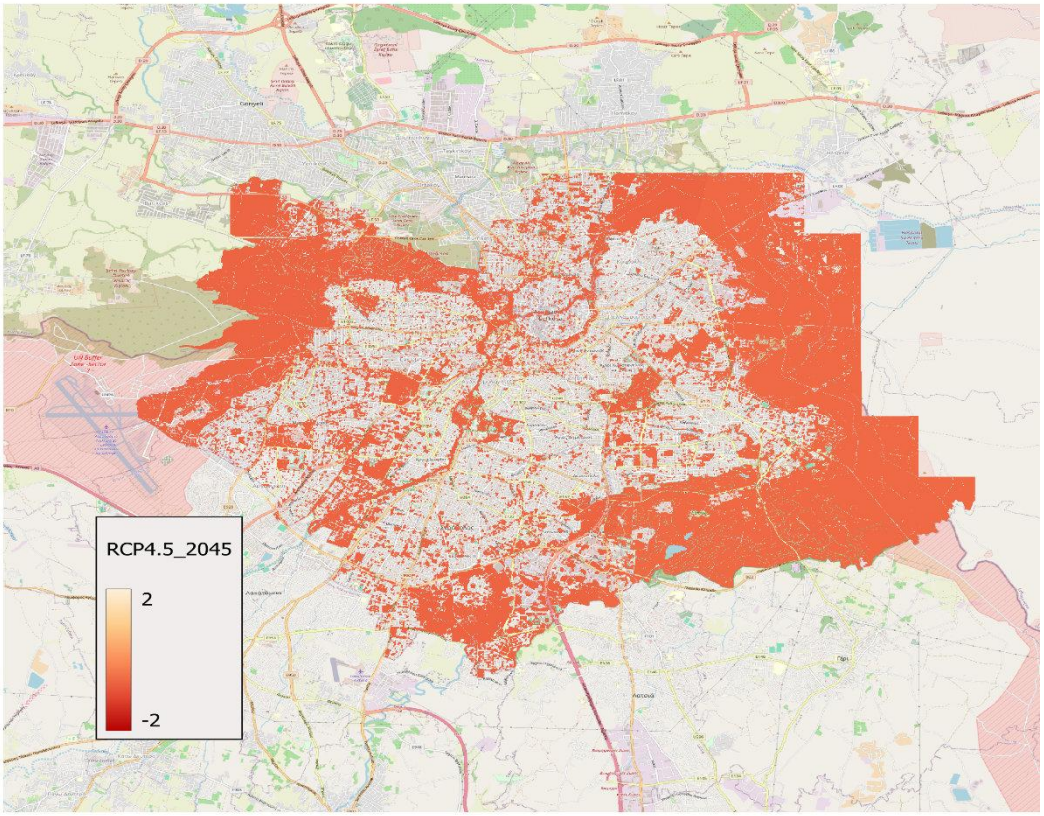


Figure 35: SPEI-3 for Nicosia in 2045 under RCP4.5.

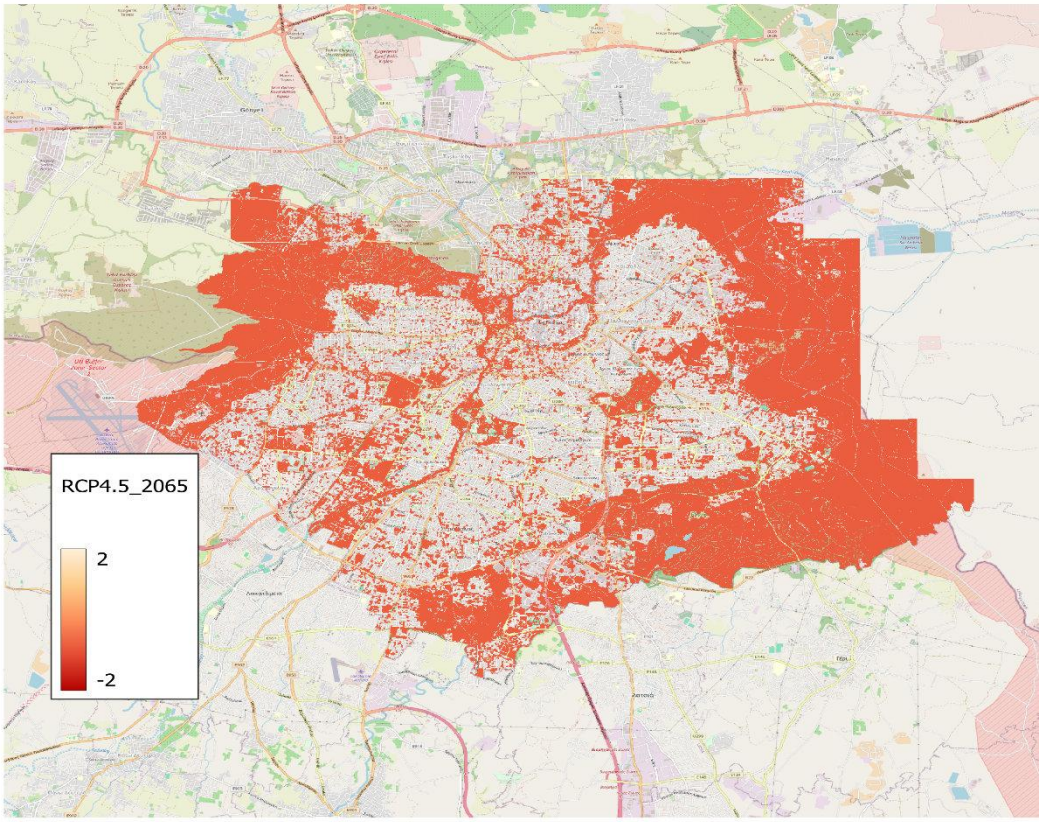


Figure 36: SPEI-3 for Nicosia in 2065 under RCP4.5.

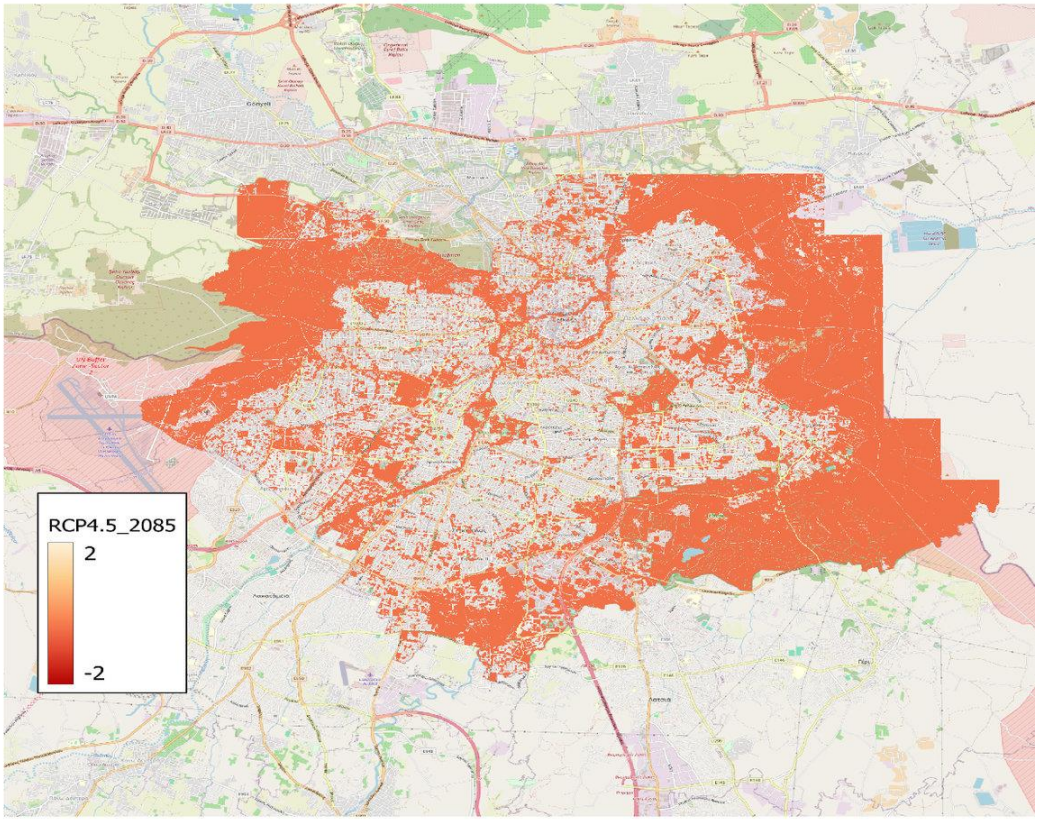


Figure 37: SPEI-3 for Nicosia in 2085 under RCP4.5.

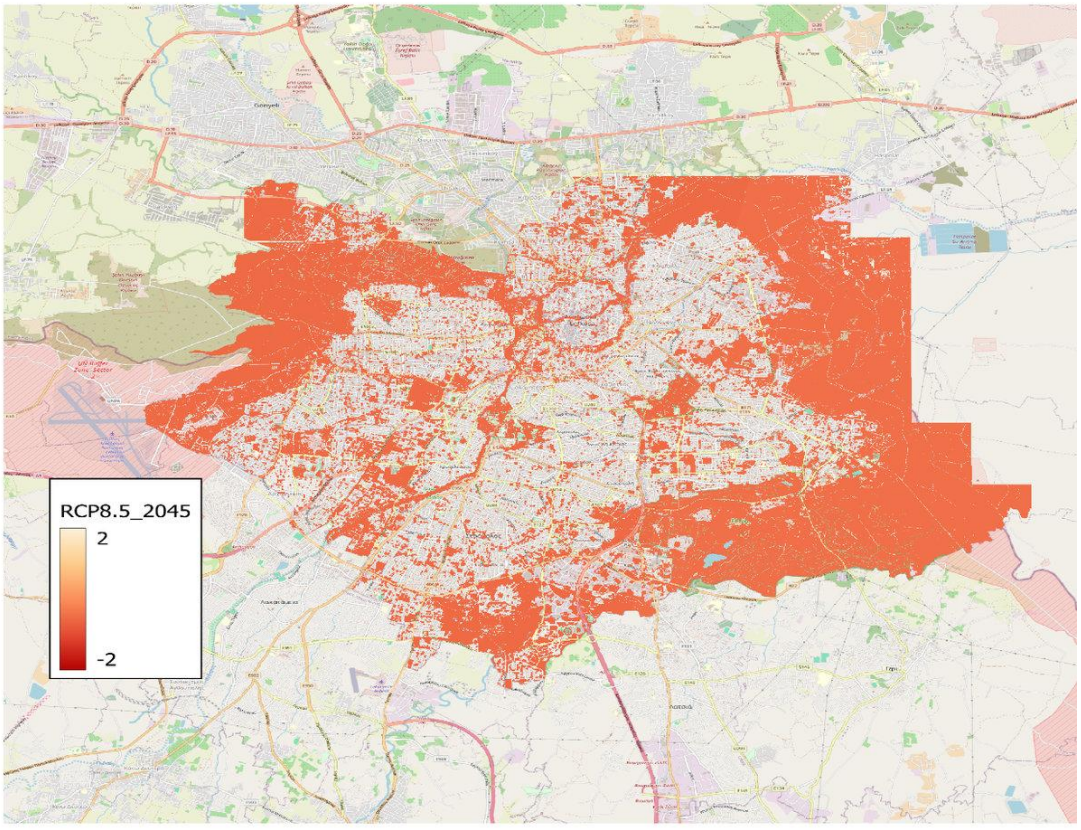


Figure 38 SPEI-3 for Nicosia in 2045 under RCP8.5.

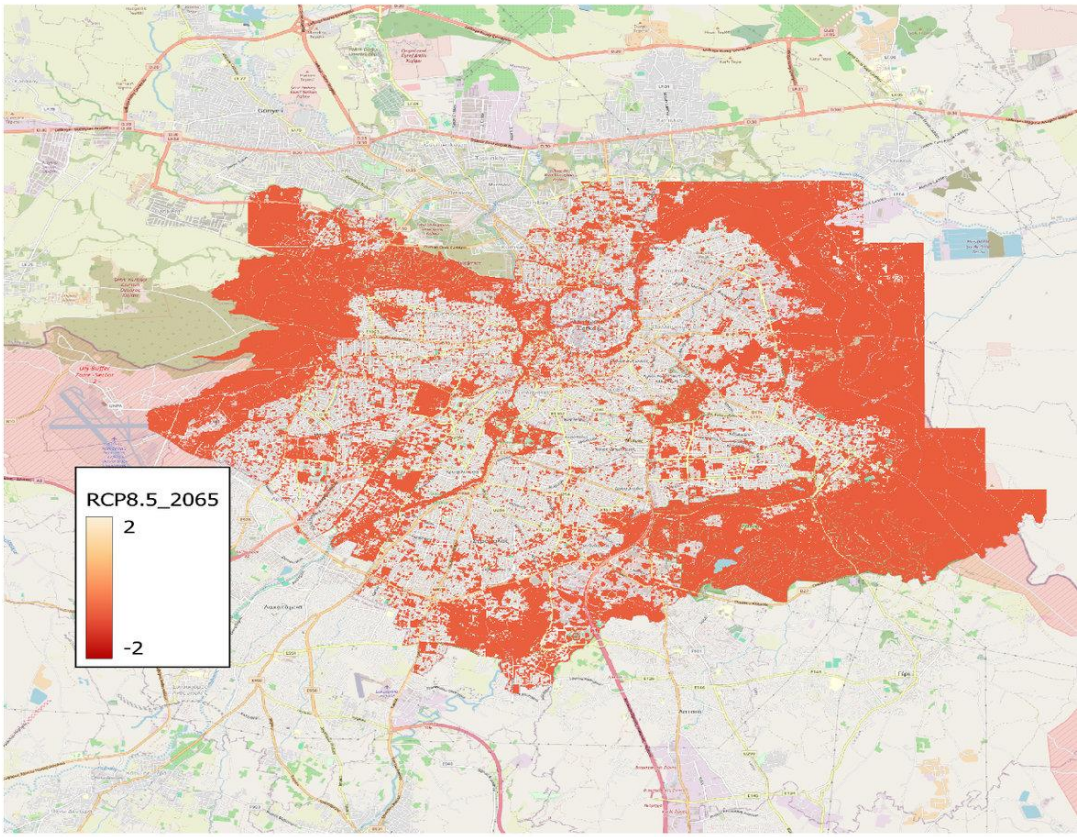


Figure 39 SPEI-3 for Nicosia in 2065 under RCP8.5.

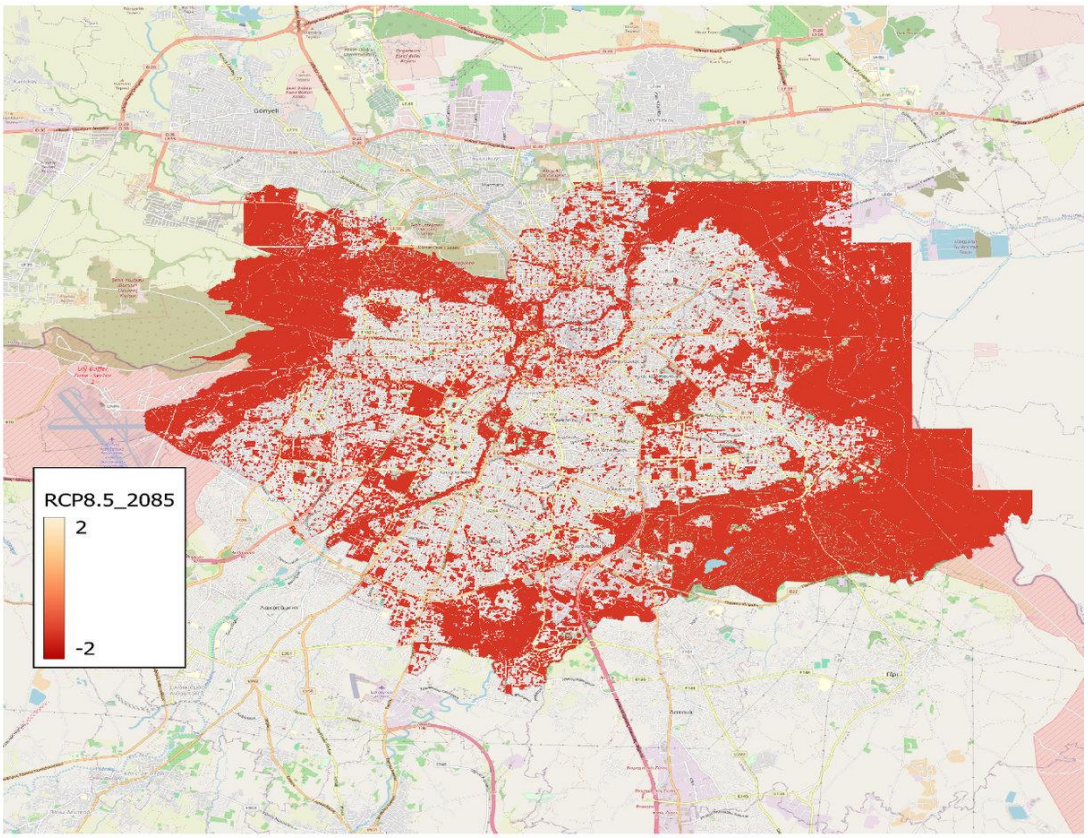


Figure 40 SPEI-3 for Nicosia in 2085 under RCP8.5.

2.3.3.12 Discussion and Conclusions

Under both scenarios, all three future horizons are drier than the 1971-2000 baseline. Under RCP8.5, conditions become drier with each horizon and the mean SPEI-3 reaches the moderately dry category by 2085. Under RCP4.5, the driest horizon is 2065. The two scenarios are similar up to 2065 and differ clearly by 2085.

These results are based on one GCM-RCM combination and describe SPEI-3 conditions for Nicosia as a whole, relative to the 1971-2000 baseline. They provide an input to drought hazard assessment for Nicosia and can be complemented with results from additional climate models.

2.4 Key Risk Assessment Findings

Table 11 Risk assessment severity, urgency, capacity and priority

Risk	**Severity**		***Urgency***	***Capacity***	***Risk priority***
	C	**F**		**Resilience/CRM**	
Drought and vegetation damage	Substantial	Critical	Immediate action needed	Low	Very High
Flooding	Moderate	Substantial	More action needed	Substantial	Moderate
Urban Heat Island effect	Moderate	Moderate	More action needed	Low	Moderate

2.4.1 Mode of engagement for participation

During Phase 2 of the CLIMAAX-NIC Project, engagement activities focused primarily on the stakeholders already identified and contacted during the stakeholder mapping exercise of Phase 1 which it was further updated in Phase 2 adding more stakeholders as well as prioritising the engagement and the relationship with each stakeholder within the next steps of the project. The engagement process was mainly informal and based on direct communication, meetings, and continuous information exchange with municipal departments, public authorities, technical experts, and institutional stakeholders relevant to climate adaptation and resilience planning.

The meetings and discussions played an important role in helping the project team better understand the hierarchical structure of the institutions involved, the governance mechanisms through which decisions are made, and the operational processes followed by the different departments and authorities. Through these interactions, the project gained a clearer understanding of how responsibilities are distributed across sectors, how departments cooperate with each other,

and the practical difficulties often faced during implementation processes, even in cases where regulations and policy frameworks are already established.

The engagement activities mainly aimed to support the ongoing climate risk evaluation process by sharing information, identifying the responsible departments and institutional actors related to different climate risks, and mapping them within the stakeholder network of the project. The meetings also supported the collection of technical, operational, and institutional information necessary for the development of the project methodology and the overall progress of the project. Communication was conducted mainly through informal meetings, discussions, and email exchanges used for coordination and meeting arrangements, while internal minutes and records of discussions were shared among project partners to support data collection and methodological development.

Overall, the engagement activities carried out during Phase 2 helped strengthen communication channels with key stakeholders, improve understanding of governance structures and implementation challenges, support the project's climate risk evaluation process, and establish a stronger foundation for the more structured participatory activities planned for Phase 3.

2.4.2 Gather output from Risk Analysis step

We used geospatial maps at high spatial granularity/resolution, to identify hotspots and geographical areas of concern, for all three risks. In detail, we observed at least 5 hotspots of UHI effect around Nicosia, almost all public parks having heavily affected by drought (high water stress), while we observed flooding risks in multiple locations, especially close to the main river of Nicosia (Pediaios) and the smaller river of Aglantzia.

2.4.3 Assess Severity

The maps, graphs, and evaluation dashboard developed during Phase 2 of the project provided a comprehensive assessment of the current and future severity of the three identified climate risks affecting the Municipality of Nicosia: drought and vegetation damage, flooding, and the Urban Heat Island Effect (UHIE). The assessment was conducted by considering existing conditions, projected climate impacts, stakeholder input, municipal operational capacities, and the potential environmental, social, and economic consequences associated with each risk.

The assessment identified drought and vegetation damage as the most severe climate risk facing Nicosia, with a current severity classified as Substantial and a future severity classified as Critical. The municipality contains a significant amount of urban greenery, including public parks, green corridors, and private residential gardens, which contribute positively to urban liveability and environmental quality. However, prolonged periods of high temperatures and reduced precipitation are already placing considerable stress on vegetation throughout the city. The Department of Greenery highlighted that the municipality's expansion following the Local Government Reform has significantly increased the area requiring maintenance, while the current irrigation and maintenance system remains largely dependent on manual practices, limited human resources and little to non-consultation during development infrastructure projects. As a result, the municipality is increasingly challenged in maintaining healthy green spaces under current climatic conditions. Future projections indicate that longer drought periods, higher temperatures, and increasing water scarcity will further accelerate vegetation degradation and biodiversity loss. The potential decline of urban green infrastructure could lead to irreversible environmental consequences, including the loss of

mature vegetation, reduced ecosystem services, and diminished urban cooling capacity. Furthermore, vegetation loss may generate cascading effects by intensifying Urban Heat Island conditions, increasing water demand, and reducing the overall resilience of the city to climate change. Stakeholder discussions also revealed concerns regarding the limited coordination between the Municipality of Nicosia and the Department of Forestry, which is responsible for several green areas within the municipality's boundaries. This lack of coordination may further increase the vulnerability of urban ecosystems and supports the classification of drought and vegetation damage as a critical future risk requiring immediate action.

Flooding was assessed as having a Moderate current severity and a Substantial future severity. Although flooding remains a significant concern, particularly in areas surrounding the Pedieos River corridor, the municipality has already undertaken several measures to reduce flood-related impacts. Flood risk considerations have been incorporated into the city's master planning framework, and adaptation measures are being implemented through ongoing projects and inter-municipal collaborations. The municipality, together with neighbouring municipalities, is currently planning the upgrading and maintenance of the Pediaios linear river corridor to improve accessibility and resilience. These initiatives have contributed to reducing the current severity of flood impacts. However, climate projections indicate that future extreme rainfall events may become more frequent and intense, potentially increasing flood occurrence and affecting larger areas of the city. Such events could disrupt transport networks, damage infrastructure, affect economic activities, and compromise public safety. Following the Local Government Reform, responsibility for underground drainage systems no longer falls under the municipality's direct jurisdiction, which may limit its capacity to address some aspects of flood risk management. While stakeholders generally recognised that progress has been made in flood preparedness and mitigation, they also acknowledged that continued investment and coordination will be necessary to prevent future flood impacts from becoming more severe.

The Urban Heat Island Effect was assessed as having a Moderate severity under both current and future conditions. Increasing summer temperatures and prolonged heatwaves already affect urban comfort and can create health risks for vulnerable population groups, particularly during extended periods of extreme heat. While the impacts are not currently considered as severe as those associated with drought and vegetation damage, stakeholders recognised that heat-related challenges are becoming increasingly important within the municipality. The assessment identified limited institutional expertise, fragmented data management, and a lack of specialised knowledge regarding Urban Heat Island mitigation measures as key constraints affecting the municipality's adaptive capacity. These limitations reduce the municipality's ability to fully understand and address heat-related risks. Discussions with municipal stakeholders indicated that decision-makers are aware of the growing importance of climate adaptation but require additional technical knowledge, integrated data systems, and strategic planning tools to strengthen resilience. Nevertheless, the municipality has demonstrated a strong commitment to improving its climate governance through the development of a Climate City Contract and efforts to consolidate urban information into a centralised system. These initiatives are expected to improve understanding of climate risks and support more effective adaptation planning. Although the future severity of the Urban Heat Island Effect remains classified as moderate, the assessment highlights the need for additional interventions to protect communities, improve urban cooling, and strengthen long-term climate resilience.

Overall, the severity assessment demonstrates that drought and vegetation damage represent the most critical long-term climate threat to Nicosia due to their extensive environmental impacts, potential irreversible consequences, and interaction with other climate risks. Flooding remains an important risk requiring continued adaptation efforts, while the Urban Heat Island Effect highlights the need for increased institutional capacity and proactive planning. These findings provide the basis for prioritising climate actions and engaging relevant stakeholders in the next phase of the project.

2.4.4 Assess Urgency

The urgency assessment considered the severity of current and projected impacts, the municipality's ability to respond effectively, and the timeframe within which action is required to avoid further climate-related consequences. The findings indicate that drought and vegetation damage represent the most urgent climate risk for the Municipality of Nicosia and therefore require immediate action. The assessment identified increasing pressure on urban green infrastructure resulting from prolonged periods of drought, rising temperatures, and declining water availability. These pressures are already affecting public and private green spaces throughout the municipality and are expected to intensify under future climate conditions. Stakeholder consultations with the Department of Greenery highlighted that the municipality's current maintenance approach relies heavily on manual irrigation practices and limited human resources, while the expansion of municipal boundaries has significantly increased the area requiring management. Furthermore, insufficient consultation between municipal departments during infrastructure development projects and limited coordination with the Department of Forestry further increases the urgency of intervention. Without immediate action, the continued degradation of vegetation may lead to irreversible environmental impacts, reduced urban cooling capacity, biodiversity loss, and increased vulnerability to other climate-related hazards, particularly the Urban Heat Island Effect.

Flooding was assessed as requiring additional action, although its urgency is considered lower than that of drought and vegetation damage. The municipality has already incorporated flood risk considerations into planning processes and has implemented several mitigation measures through ongoing projects and collaborations with neighboring municipalities. Planned upgrades and maintenance work along the Pedieos River corridor demonstrate that flood risk is already being addressed through proactive measures. Nevertheless, projected increases in the frequency and intensity of extreme rainfall events mean that continued investment and adaptation efforts remain necessary. The urgency is therefore linked primarily to ensuring that existing measures are maintained and strengthened to accommodate future climate conditions and prevent the escalation of flood-related impacts.

The Urban Heat Island Effect was also assessed as requiring additional action. Although its severity remains moderate, increasing temperatures and more frequent heatwaves pose growing challenges for public health, urban comfort, and community wellbeing. Stakeholder discussions highlighted that limited technical expertise, fragmented climate data, and the absence of a coordinated heat adaptation strategy reduce the municipality's preparedness to address future heat-related risks. The urgency of action therefore lies in strengthening institutional knowledge, improving data collection and monitoring systems, and integrating heat mitigation measures into future urban planning initiatives. The municipality's ongoing efforts to develop a Climate City Contract and establish a

more integrated approach to climate governance with the use of this data that provides a great opportunity to address these gaps before impacts become more severe.

2.4.5 Understand Resilience Capacity

The assessment of resilient capacity examined the municipality's ability to anticipate, manage, and adapt to climate-related risks through existing institutional structures, resources, knowledge, governance arrangements, and stakeholder collaboration mechanisms. The findings reveal considerable variation in resilience capacity across the three assessed risks.

For drought and vegetation damage, the municipality's resilience capacity was assessed as low. Although the Department of Greenery possesses valuable operational knowledge and experience, existing resources are insufficient to manage the increasing pressures associated with climate change and municipal expansion. The maintenance of green spaces remains heavily dependent on manual irrigation and labor-intensive practices (e.g. watering plants manually), while staffing levels are not adequate to meet the growing needs of the enlarged municipality. Stakeholder consultations also identified limited integration of green infrastructure considerations within infrastructure development projects and insufficient coordination between the municipality and the Department of Forestry regarding the management of the national parks/ or larger green spaces falling under different administrative responsibilities. These institutional and operational limitations significantly constrain the municipality's capacity to build resilience against drought conditions and vegetation degradation, thereby contributing to the risk's very high-priority ranking.

Flooding demonstrated a comparatively stronger resilience capacity, which was assessed as substantial. Existing planning frameworks already incorporate flood risk considerations, and several adaptation measures have been implemented or are currently under development. The municipality actively collaborates with neighboring municipalities on flood-related initiatives, particularly regarding the Pediaios River corridor, demonstrating a level of governance coordination that supports resilience building. However, following the Local Government Reform, responsibility for underground drainage infrastructure no longer falls under municipal jurisdiction. While this limits direct control over certain flood management functions, the municipality continues to integrate flood resilience considerations into urban development projects and planning processes. As a result, existing institutional arrangements provide a stronger foundation for managing flood risks compared with the other assessed climate hazards.

The resilience capacity associated with the Urban Heat Island Effect was assessed as low. Stakeholder consultations identified limited technical expertise, fragmented data management systems, and a lack of specialised knowledge regarding heat adaptation measures as key barriers to effective climate resilience. Although decision-makers recognise the increasing importance of heat-related risks, the municipality currently lacks a comprehensive framework for monitoring, assessing, and addressing Urban Heat Island impacts. These gaps reduce the municipality's ability to proactively implement adaptation measures and protect vulnerable populations during prolonged heat events. Nevertheless, the municipality has demonstrated a strong willingness to strengthen its climate resilience through the development of a Climate City Contract, the consolidation of city-wide information into a unified system, and the integration of climate considerations into its new ten-year development and sustainability strategy. These initiatives provide an important foundation for improving future resilience capacity and supporting more effective climate risk management across the municipality.

2.4.6 Deciding on Risk Priority

The prioritisation of climate risks was undertaken using the Evaluation Dashboard developed during Phase 2 of the project. The dashboard provided a structured and evidence-based framework for comparing the identified risks by combining the results of the severity, urgency, and resilience capacity assessments. The process enabled the Municipality of Nicosia and relevant stakeholders to evaluate not only the magnitude of current and future impacts but also the municipality's ability to respond effectively to each risk. The prioritisation exercise was informed by the spatial analysis, risk maps, stakeholder consultations, technical discussions with municipal departments, and the assessment matrix developed throughout the project.

The evaluation demonstrated that drought and vegetation damage should be assigned as the highest priority. This risk was assessed as having a substantial current severity and a critical future severity, reflecting the significant and increasing impacts of prolonged drought periods, rising temperatures, and water scarcity on urban green infrastructure. The urgency assessment further identified the need for immediate action due to the ongoing degradation of green spaces and the potential for irreversible environmental consequences. In addition, the municipality's resilience capacity was assessed as low because of limited human resources, reliance on manual maintenance practices, insufficient integration of green infrastructure considerations within development projects, and limited coordination with external stakeholders responsible for green space management. The combination of high severity, immediate urgency, and low adaptive capacity resulted in a very high overall risk priority, making drought and vegetation damage the most critical climate challenge requiring immediate intervention.

Flooding was assigned a moderate priority despite its substantial future severity. The evaluation dashboard showed that while flooding remains a significant climate risk, particularly in areas surrounding the Pedieos River corridor, the municipality has already implemented several mitigation measures and incorporated flood risk considerations into planning processes. Furthermore, the resilience capacity assessment indicated a substantial capacity to manage flooding through existing governance arrangements, inter-municipal cooperation, and ongoing infrastructure improvement projects. As a result, although additional action is required to address future increases in flood intensity and frequency, the presence of existing adaptation measures reduces the overall priority compared with drought and vegetation damage.

The Urban Heat Island Effect was also assigned as a moderate priority. The dashboard assessment identified moderate current and future severity levels, reflecting the growing but comparatively less immediate impacts of increasing urban temperatures. However, the resilience capacity assessment highlighted important institutional gaps, including limited technical expertise, fragmented climate data, and the absence of a comprehensive heat adaptation framework. While these limitations increase vulnerability, stakeholder consultations recognised that the municipality has already initiated efforts to strengthen climate governance through the development of a Climate City Contract and the integration of climate considerations into its long-term development strategy. Consequently, although further action is required to strengthen preparedness and resilience, the overall priority remains lower than that assigned to drought and vegetation damage.

The prioritisation process provided a transparent basis for decision-making and resource allocation by ensuring that risks were assessed not only according to their potential impacts but also according to the urgency of required actions and the municipality's existing capacity to respond. The results of

the Evaluation Dashboard therefore establish drought and vegetation damage as the primary climate adaptation priority for the Municipality of Nicosia; while flooding and the Urban Heat Island Effect remain important risks that require continued monitoring, investment, and integration into future planning and resilience-building initiatives.

2.5 Monitoring and Evaluation

Urban Heat Island effect: The second phase of the climate risk assessment significantly improved the understanding of UHI risk in Nicosia by moving from a general recognition of heat stress to a spatially explicit, neighbourhood-level risk characterisation. The assessment showed that UHI risk is not uniform across the municipality: the combination of high UHI potential, population exposure and vulnerable groups creates distinct hotspots, with at least five areas of concern identified through the high-resolution geospatial outputs. The most important learning was that heat risk depends not only on the occurrence of very high air temperatures, but also on local urban morphology, building density, surface materials, vegetation, elevation, wind conditions, time of day and the distribution of vulnerable populations. The UHI model also showed a clear daily cycle, with cooler conditions in the morning and stronger heat-island behaviour in the afternoon and evening, when heat retained by dense urban surfaces can prolong thermal stress.

The main difficulties were related to data availability, representativeness and operational constraints. The UHI dataset was generated through vehicle-mounted sensors on the municipal fleet, which allowed broad and cost-efficient spatial coverage, but also produced measurements that were sparse in time and space, concentrated along the road network, and influenced by asphalt surfaces and vehicle-induced convective effects. The campaign was limited to August and September, which are highly relevant months for peak summer heat stress in Cyprus, but they do not yet support a full year-round assessment. Data collection was also limited mainly to municipal working patterns and did not cover the late-night and early-morning period from 00:00 to 07:00, although nocturnal heat retention is important for public health and recovery from daytime heat. These limitations were addressed as far as possible through the AI-based UHI decomposition model and validation against independent stations, but they remain important considerations for interpreting the findings and designing future monitoring.

Stakeholders play a central role in monitoring and evaluation because the UHI results are intended to support municipal planning, prioritization of adaptation measures, and future policy decisions. Engagement with the Municipality of Nicosia, including technical departments responsible for green spaces, design, project development, infrastructure and public services, helped confirm that the identified hotspots and spatial variability are relevant to practical urban management. Feedback from local and regional stakeholders was generally positive, especially regarding the usefulness of high-resolution, neighbourhood-level maps for targeted action instead of city-wide average indicators. Stakeholders also highlighted the need to integrate citizen perspectives and local knowledge in the next phase, particularly to understand how residents perceive heat risk, how vulnerable groups cope during heat events, and which adaptation measures are considered feasible and acceptable.

Learning is ensured through a combination of technical documentation, reproducible geospatial outputs, stakeholder feedback and planned follow-up activities in Phase 3. The modelling process, assumptions, validation metrics, identified limitations and hotspot maps provide a structured

evidence base that can be reviewed, updated and compared with future data collection. The project team will use the UHI findings to support recommendations and best practices in Phase III, including measures such as increasing tree canopy and shaded public spaces, using cool materials, improving urban ventilation, prioritising compact low-rise hotspots, and aligning interventions with areas where exposure and vulnerability are also high. Learning will be strengthened through structured questionnaires and discussions with municipal departments and other stakeholders, so that scientific outputs are connected with implementation capacity, maintenance responsibilities, and policy instruments.

New data are now available for the UHI risk assessment, including approximately 700,000 mobile measurements collected during August and September 2025, reference meteorological data from the Athalassa station, model outputs for 863 grid cells of 200 m by 200 m, UHI potential and realised UHI maps, and risk layers combining hazard, exposure and vulnerability. However, further data are needed to understand the risk better and to make the monitoring system operational. Priorities include repeated data collection across additional seasons and years, automatic or extended-hour measurements during 00:00-07:00, fixed sensors in selected hotspot and cool-reference areas, improved information on tree canopy, shade, building materials, building insulation, access to air conditioning, electricity demand during heat events, health outcomes, and finer demographic indicators for vulnerable groups. Cooperation across the wider urban area would also improve the interpretation of UHI patterns, especially given the divided urban context of Nicosia.

The final UHI outcomes are communicated in formats that serve both technical and policy audiences. The technical report and the published paper document the methodology, assumptions, validation results, limitations and interpretation of UHI risk. For decision makers and municipal departments, the most useful products are the hotspot maps, ranked priority areas, short policy briefs, GIS layers, and adaptation-oriented summaries that connect each hotspot with possible measures and responsible departments. Public communication should use accessible maps, infographics and presentations to explain why heat exposure differs between neighbourhoods and how targeted interventions can reduce risk. The outcomes targeting technical audience have been mostly generated during this project Phase (Phase 2). Some of the outcomes targeting policy audiences have also been created, but Phase 3 will ensure the completeness of these outcomes.

At present, Nicosia does not yet have a sufficient UHI monitoring system covering the analysed risk in real time. Nevertheless, the Phase 2 work provides the technical basis for such a system by demonstrating a scalable approach that combines municipal fleet measurements, reference meteorological data, AI modelling and geospatial risk mapping. What worked well was the efficient use of existing municipal resources: the vehicle-mounted system made it possible to collect a large dataset at relatively low cost and without installing a dense fixed-sensor network, while the modelling approach converted sparse measurements into interpretable city-wide outputs. What worked less well was the limited temporal completeness of the campaign, the road-surface bias, the lack of direct social and health data, and the need for stronger integration of citizen experience. Overall, resources were used efficiently in terms of staff time, equipment cost and data yield, but efficiency also created some trade-offs because opportunistic fleet-based monitoring cannot fully replace systematic continuous monitoring. The impact of the CRA is therefore substantial: it improves institutional understanding of UHI risk, supports evidence-based prioritisation of adaptation investments, raises awareness of neighbourhood-scale heat inequalities, and creates a

practical foundation for Phase 3 recommendations and future monitoring. Most of the weaknesses identified will be dealt with during Phase 3.

Flooding: The second phase of the flood climate risk assessment significantly improved the understanding of flood risk within Nicosia by moving from a general awareness of flooding concerns to a spatially explicit assessment of flood hazard, exposure, vulnerability, and risk. The assessment demonstrated that flood risk is highly localized and strongly influenced by terrain characteristics, land cover, urban infrastructure, and rainfall severity. The development of multiple rainfall scenarios based on Intensity–Duration–Frequency (IDF) relationships enabled the identification of areas that are susceptible to flooding under both frequent and more extreme rainfall events. The probability-weighted flood potential approach also provided a more comprehensive representation of flood hazard than would be achieved through the analysis of a single rainfall scenario.

The main difficulties encountered during the assessment were related to data availability and model validation. Detailed information regarding the stormwater drainage network, including drainage inlet locations, pipe connectivity, hydraulic capacities, maintenance status, and blockage conditions, was not available and therefore had to be approximated through simplified assumptions. Additional uncertainty arises from the use of a 10 m Digital Elevation Model, which cannot fully capture fine-scale urban features that influence flood routing, and from building datasets that may not fully reflect recent urban development. Another important challenge was the limited availability of documented historical flood observations and flood extent records. Although efforts were made to collect information on past flood events, the available data was often incomplete, inconsistent, or lacked the spatial detail required for systematic model validation. Consequently, the identified flood hotspots should be considered indicative and will require future field inspections, stakeholder consultations, and targeted ground-truth data collection to verify the results and better understand the local causes of flooding.

Stakeholders play an important role in the monitoring and evaluation process, particularly municipal engineers, urban planners, civil protection authorities, and infrastructure managers. The flood hazard, flood potential, and flood risk maps provide valuable information for identifying priority intervention areas, supporting planning decisions, and improving preparedness for future flood events. The final outcomes will be communicated through stakeholder presentations, and an online resilience portal that allows users to explore the spatial distribution of flood hazards and risks.

The assessment generated new flood hazard, flood potential, and flood risk datasets for Nicosia and provides a valuable first step towards understanding flood risk at the municipal scale. Additional information, including detailed drainage network data, documented flood-event observations, and field-based validation of identified hotspots, would further improve confidence in the results. Despite these limitations, the methodology efficiently combined climate, geospatial, and demographic datasets to produce actionable flood-risk information. The CRA improves institutional understanding of flood risk, supports evidence-based adaptation planning, and identifies priority areas for intervention. The resulting outputs establish a strong foundation for future monitoring and decision-making, while Phase 3 will focus on validating flood hotspots, incorporating additional local data, and refining the assessment framework.

For **Drought and vegetation stress**, this phase covered the period (August 2025), using satellite indices (NDVI, NDMI) to map vegetation and water stress across Nicosia. The main lesson is that these indices map the vegetation stress well with fine details, but the assessment based on ground-

truth labelling, which was the main difficulty, crop-type labels from the Cyprus Agricultural Payments Organization (CAPO) are based on farmer's self-declarations rather than independent or remote-sensing verification, so they may be inconsistent, and very few labelled fields existed in Nicosia. To reduce this, the analysis used all vegetation across the city instead of only labelled parcels.

The intended way to communicate the outcomes is through the hazard and risk maps, the figures and summary statistics in this report, and a briefing for the municipality and relevant authorities. What worked well was the index-based, whole-vegetation approach, which gave broad spatial coverage and reduced reliance on the sparse, uncertain field labels. What worked less well was the labelled crop data, which was limited in quantity and accuracy. In terms of resources, the approach was efficient in time, staff, and cost because it relied on free satellite imagery and cloud-based processing rather than fieldwork. On this basis, the CRA can be seen as a step toward an improved understanding of where drought and vegetation stress concentrate in Nicosia, with potential to support public awareness, institutional capacity, and the case for investment in urban greening and water management.

2.7 Work plan Phase 3

By understanding the dominant risks of Nicosia, the municipality will make more informed decisions and shape better policies which embrace climate risks into the local policy frameworks and include specific actions and solutions to mitigate those risks or perform adaptation measures. Based on the characterization of the main climate risks of the city at high granularity and detail, Nicosia will investigate and record best practices and promising solutions, which would serve as significant adaptation, resilience and/or mitigation measures. Various best practices will be considered and assessed, trying to quantify them in terms of cost and impact as much as possible. Best practices and solutions will be linked directly with the hotspots of climatic risks, as indicated by the risk characterization process of Phase II. At least 10 specific risk adaptation and mitigation actions and solutions will be identified and assessed by the end of the project.

Climate risk characterization will be accompanied by site visits to examine extreme cases that constitute hotspots or/and cold spots. These visits will help identify, through field observations, the factors contributing to increased or decreased climatic risks in these locations. At least 10 site visits to selected hotspots and cold spots are planned. In addition, meetings with key stakeholders (see organogram) will be conducted to further assess the impacts of the three climatic risks on local communities through a series of interviews (five interviews in total). Further dissemination activities will promote the maps developed for the three climatic risks through the 18 information points located within the municipality of Nicosia, with the aim of raising awareness and collecting best practices and experiences from local communities. These insights will also support the development of the final 10 climate risk adaptation recommendations.

The outcomes of this project will become an integral part of the Nicosia Municipality Sustainable Energy and Climate Action Plan 2021-2030. Right now, this plan does not include information about climate risks, thus it is urgent to run actions such as this one, to assess the risks of the city and derive mitigation strategies. We plan to align the best adaptation responses into local planning and regional policies, in the near future.

The outcomes of the project will improve the existing strategic master plan of the Republic of Cyprus, named ZENON. While this plan currently contains a report on disaster risk management in

Cyprus (https://tinyurl.com/vyw5nzps), this report only lists various physical risks and climate change-related impacts.

We will dedicate some effort to make Nicosia an exemplar for other cities, to characterize climate risks of the island. The risk characterization followed by Nicosia is expected to be followed also by the Municipality of Limassol, to characterize its own climatic risks. CLIMAAX-NIC will assist Limassol in these efforts.

We plan to raise awareness to stakeholders and beneficiaries, especially citizens of the municipality of Nicosia and citizens of Cyprus in general, with the aim of shifting the general attitude towards taking actions about climate resilience and increasing climate awareness. A conference will be organized near the end of the project, to present the overall results, findings and outputs to the citizens as well as policy and decision makers in our region.

We intend to articulate data-supported narratives and stories about the climate risk characterization and the key findings of Phase II of the project and create press releases to widely disseminate this information to the public.

Finally, we are in the process of developing an online platform, which would visualize and report on the climate risk characterization performed in Phase II of the project, visualizing all the three risks modelled, including the hazard maps, vulnerability and exposure GIS layers, plus explanations about the risks and the methodologies followed. Users would be able to navigate through the maps and understand the risks in their local area.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of the CLIMAAX-NIC climate risk assessment advanced the work from the broad scoping and risk screening completed in Phase 1 to a localized, evidence-based assessment for the Municipality of Nicosia. The main conclusion is that the three priority risks selected for the project, Urban Heat Island Effect, flooding, and drought-related vegetation stress, are not evenly distributed across the municipality. They vary strongly by neighbourhood, land cover, terrain, population distribution, infrastructure conditions, vegetation conditions, and local institutional capacity. This phase therefore provides a practical spatial evidence base for targeted adaptation planning rather than relying on city-wide averages or generic risk descriptions.

A key achievement of this phase was the refinement of the CLIMAAX workflows with local data, local modelling assumptions, and stakeholder input. The assessment produced hazard, exposure, vulnerability, and risk layers for all three hazards, allowing areas of concern to be identified at a finer scale. It also strengthened the link between technical analysis and municipal decision-making by engaging municipal departments, technical experts, social-support organisations, other Cypriot municipalities, and wider public audiences through meetings, presentations, questionnaires, and dissemination events. These activities helped confirm that the project outputs are relevant for urban planning, public health, green-space management, infrastructure planning, and climate-resilience policy.

For the Urban Heat Island Effect, Phase 2 demonstrated that heat risk in Nicosia is strongly shaped by local urban form and time of day. The vehicle-mounted sensing campaign generated approximately 700,000 temperature and wind measurements during August and September 2025 and enabled a physics-inspired artificial intelligence model to estimate UHI potential across 200 m

by 200 m grid cells. The results identified at least five areas of concern and showed a clear daily pattern: cooler conditions in the morning shift to strong heat-island behaviour in the afternoon and evening, with realised urban-rural temperature differences of about 2.4-3.1 degrees Celsius in the afternoon and 1.4-1.6 degrees Celsius in the evening. Compact low-rise areas showed the highest UHI potential, while vegetation, elevation, building density, wind, and recent meteorological conditions were important factors in the spatial and temporal expression of heat risk. The model was validated against independent weather-station data and provides a useful basis for targeted heat mitigation, especially where heat hotspots coincide with high population exposure and vulnerable groups.

For flooding, Phase 2 concluded that flood risk in Nicosia is localized and depends on terrain, land cover, flow pathways, drainage assumptions, and rainfall severity. The assessment used a scenario-based hydraulic modelling approach with rainfall return periods of 2, 5, 10, 25, and 50 years, and combined the individual simulations into a probability-weighted flood potential layer. This approach allowed flood-prone areas to be identified under both more frequent and more extreme rainfall conditions. The results point to areas of concern around the Pediaios river corridor and the smaller river of Aglantzia, while also showing that flood impacts are likely to be most relevant where flood hazard overlaps with population exposure and vulnerable groups. Flooding was assessed as an important risk that requires continued action, although existing planning activities, inter-municipal cooperation, and ongoing works along river corridors provide stronger response capacity than for the other two risks.

For drought and vegetation stress, Phase 2 concluded that this is the highest-priority climate risk for Nicosia. Sentinel-2 imagery for August 2025, processed through NDVI and NDMI indicators, showed that only 24.9 percent of the study area was classified as vegetated during the assessment period. Among vegetated pixels, 56.5 percent were in the high water-stress class, and 94.3 percent were below the moisture-stress line. The highest concern occurs where stressed vegetation coincides with dense urban areas, because the loss of vegetation can reduce shade, cooling, air-quality benefits, biodiversity, and overall urban livability. Irrigated agricultural areas and tree cover in the north-east showed lower stress, while the city centre and dry eastern fields showed higher drought and vegetation-stress hazard. The risk evaluation classified drought and vegetation damage as very high priority because current severity is substantial, future severity is critical, immediate action is needed, and resilience capacity is low.

Several challenges were addressed during this phase. The limited usefulness of generic or pan-European datasets for a small municipality was partly overcome by collecting local measurements, integrating municipal and geospatial datasets, adapting workflows, developing local models, and using remote-sensing methods. Sparse and uneven UHI measurements were addressed through model generalisation and independent validation. The lack of reliable crop labels for drought assessment was reduced by analysing all vegetation across the municipality rather than relying only on labelled agricultural parcels. For flooding, the absence of a complete drainage inventory was handled through simplified engineering assumptions that made an exploratory local flood assessment possible.

Several challenges remain unresolved and should guide the final phase. The UHI assessment does not yet provide year-round coverage, has limited measurements between midnight and early morning, and remains affected by road-surface bias because the mobile sensors collected data mainly along asphalted routes. The flood assessment still requires detailed drainage-network data,

documented flood-event observations, field validation of hotspots, and future climate and land-use scenarios. The drought and vegetation-stress assessment require stronger ground-truth validation, better crop and irrigation information, and closer connection with operational green-space management data. Indirect impacts, cascading effects, health outcomes, electricity demand, water-system constraints, and long-term socio-economic change were not fully quantified in this phase.

Overall, Phase 2 established a credible and usable foundation for climate risk management in Nicosia. The main takeaway is that drought and vegetation damage require immediate prioritisation, while flooding and Urban Heat Island Effect require continued monitoring, data improvement, and targeted adaptation. The generated maps, datasets, stakeholder knowledge, and evaluation dashboard provide a basis for Phase 3 activities, including hotspot validation, site visits, stakeholder interviews, public engagement, and the identification of at least 10 specific adaptation and mitigation actions. The value of the assessment lies in its capacity to connect climate evidence with practical municipal decisions, supporting future integration into local planning, resilience investment, and public communication.

4 Progress evaluation

Table 12 Overview key performance indicators

Key performance indicators	*Progress*
At least 3 workflows successfully applied on Deliverable 1 (Phase 1)	All workflows were successfully developed and recorded on Deliverable 1
At least 100 local stakeholder entities identified by Deliverable 1 (Phase 1)	All local stakeholders identified. More than 200 local specific stakeholder entities identified and recorded (list updated in Phase 2).
At least 3 refinements of the workflows applied to Deliverable 2 (Phase 2)	All workflows were successfully developed and recorded on Deliverable 2

Key performance indicators	*Progress*
At least 200 local stakeholders are involved in the activities of the project (Phase 3)	In progress • Meetings with responsible departments of Nicosia Municipality to collect information that will support Phase III of the project including best practices and identifying other stakeholders to reach out to. • Prepared questionnaire that will reach the public in Nicosia Municipality to identify their exposure to the climatic risks and mitigation actions that should decrease their exposure. (Phase III of the project) • Prepared questionnaire that will reach stakeholders identified and added in the list to collect information about the master plan of the city, development and mitigation actions to reduce the three climatic risks exposure. (Phase III of the project) • Meeting with Mr Charalambos Theopemptou Representative of Nicosia constituency in the Parliament to discuss the legal framework in Cyprus and best practices that can support Phase III.

Key performance indicators	*Progress*
At least 10 communication actions taken to share results with the stakeholders by the end of the project (Phase 3)	In progress 1. Invited by the METACITIES project to present our work and to discuss with experts from local municipalities about the impact of the UHIE on cities. 2. Booth at the Regional meeting of EU member states organised due to Cyprus Presidency to present CLIMAAX-NIC project, methodology. 3. Invited by the University of Cyprus at the Cyprus Computational Science Symposium and presented the modeling framework used and results collected for UHIE on cities. 4. Online meeting with Aradippou Municipality, presented the CLIMAAX- NIC project and the results of UHIE. 5. Invited by the Limassol Municipality at the Climate Neutral Blue Cities by 2030 conference to present and do a workshop. 6. Participation and presentation of CLIMAAX-NIC project at Attachés (Research and Innovation Attachés), EU Presidency. 7. Participation at University of Cyprus Youth Fair sharing information about CLIMAAX-NIC project objectives, up to now outcomes and next steps. 8. Participation at the Dooers Summit Festival, engaged with local NGOs, small local businesses/startups, research groups and share the importance of connecting research with key stakeholders' involvement, using CLIMAAX- NIC as an example of effective collaboration. 9. Participation in a Blended Intensive Programme (BIP) hosted in Cyprus, where the project was presented to postgraduate students as an example of participatory and inclusive climate resilience planning, highlighting stakeholder engagement, social inclusion, and community-oriented urban adaptation. 10. Presentation about CLIMAAX results in the EWA GROW Programme in Cyprus, implemented by SocialTech Lab under the EIT Food initiative.
At least 2 scientific publications by the end of the project (Phase 3)	To be done UHIE research paper prepared and in review process
At least 10 notes for policy makers by the end of the project (Phase 3)	To be done

Key performance indicators	*Progress*
At least 10 specific risk adaptation and mitigation actions and solutions identified and assessed by the end of the project (Phase 3)	In progress (Preparation of Questionnaire and template for the collection of best practices that will be showcased as part of the Phase 3)
At least 5 articles in regional media mentioning the project (Phase 3)	In progress 1. Article at local magazine (Insider. Phileleftheros) in the section Environmental Actions with the title "Transition to a Green and Sustainable Future" introducing CLIMAAX Project by Nicosia Municipality.
At least 3 spatiotemporal maps of risks published by the end of the project (Phase 3)	To be done
At least 3 models of risk estimation will be published by the end of the project (Phase 3)	In progress

Table 8 Overview of milestones

Milestones	*Progress*
M1: Dissemination and Communication Plan developed (Month 3)	The plan has been developed, and it is being followed.
M2: Subcontracting done (Month 3)	The subcontracting process has been set into motion. The partner CYENS is already contributing significantly to the project.

Milestones	*Progress*
M3: Attended the CLIMAAX workshop held in Barcelona (Months 3-4)	Representatives of both the Municipality of Nicosia and CYENS attended the CLIMAAX workshop and shared our vision and concepts for the project. It was an excellent networking opportunity.
M4: Identification of all relevant local stakeholders done (Month 6)	All relevant local stakeholders have been identified, and a list of more than 200 specific stakeholders has been created. (List updated)
M5: Multi-risk climate assessment performed for the three targeted risks based on the CLIMAAX common methodology, workflows successfully applied (Month 6)	Climate assessment based on the three targeted risks and based on the CLIMAAX methodology and workflows has been done. It is low resolution, and limited conclusions can be extracted; thus, we look forward to Phase II of the project, where higher granularity is expected.
M6: Refined regional/local multi-risk assessment implemented for the three targeted risks (Month 14)	Regarding the UHI effect risk in particular, we have developed sensory devices that measure temperature with high accuracy, placing these sensor devices on municipal vehicles that move opportunistically within the city of Nicosia. This will allow us to understand heat conditions all around the city, creating spatial maps of the UHI effect risk eventually. We have experimented and collected data in Phase II during the pick heat periods in August and September.
M7: Refined spatiotemporal maps of risk published (Month 16)	UHIE maps have been published.
M8: Adaptation strategies studied and assessed (Month 20)	In progress Collection of information from departments of Nicosia Municipality. Active participation in the development of the new strategy of Nicosia Municipality for the funding period 2028-2034.
M9: Presentation of results to policy and decision makers in our region (Month 20)	To be done
M10: Improved risk management plans developed (Month 22)	To be done
M11: Attended the final CLIMAAX workshop held in Brussels (Month 22).	To be done

5 Supporting documentation

All supporting documentation has been uploaded to the Zenodo Repository (Deliverable Phase 2 – Climate risk assessment Climate Risk Assessment in Nicosia, Cyprus via the CLIMAAX Framework (CLIMAAX-NIC) | Zenodo)

Table 9 List of supporting documentation.

Description	*Filename*
Article	Article_Insider_CLIMAAX project_NICMUN.pdf
List of stakeholders (updated)	CLIMAAX-NIC_Stakeholder List Phase 2.pdf
Photos from dissemination actions	Dissemination Actions_Phase 2.zip
Report Phase 2	CLIMAAXNIC_Phase 2 report_V2.pdf
Risk Maps and Figures	UHIE_Maps&figures.zip
Risk Maps and Figures	Floodings_UHIE_Maps&Figures.zip
Risk Maps and Figures	Drought_heatmaps.zip
Stakeholders' interactions	CLIMAAX_Organogram.png
Stakeholders' meetings	CLIMAAX-NICStakeholdersMeetings_Phase 2.zip
UHIE study figures and plots	Repository_UHIE.zip
Flood study GIS deliverables (vulnerability, exposure, risk)	FLOOD-GIS.zip
UHIE study GIS deliverables (vulnerability, exposure, risk)	UHIE-GIS.zip
This report	ReportFinal_V4.docx
This report in PDF	ReportFinal_V4.pdf