Driving Urban Transitions

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MAIN CODE

urban climate shelters in schoolyards

Report D3.1

Comprehensive map of vulnerability in Turin and Halandri

WP 3 | Implementing UCS in Turin and Halandri pilot schoolyards
Task 3.1 | Map the climate and social vulnerability in Turin and Halandri

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Comprehensive map of vulnerability in Turin and Halandri

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1. Introduction: What is the Document About

Work Package 3 (WP3), led by COMMONSPACE and co-led by ULAB, focuses on the implementation of Urban Climate Shelters (UCS) in the pilot schoolyards of Turin and Halandri. The participating school communities are envisaged as pivotal hubs for climate change adaptation, bridging the gap between existing and emerging knowledge about UCS, and translating these insights into practical and context-specific applications to foster active community engagement. **Task 3.1** initiates this process by **mapping the social and physical vulnerability of Turin and Halandri to climate hazards, and in particular to extreme heat.** The aim is to **identify the most vulnerable areas within the two cities, thereby supporting the selection of schoolyards for the pilot implementation** (Figure 1).

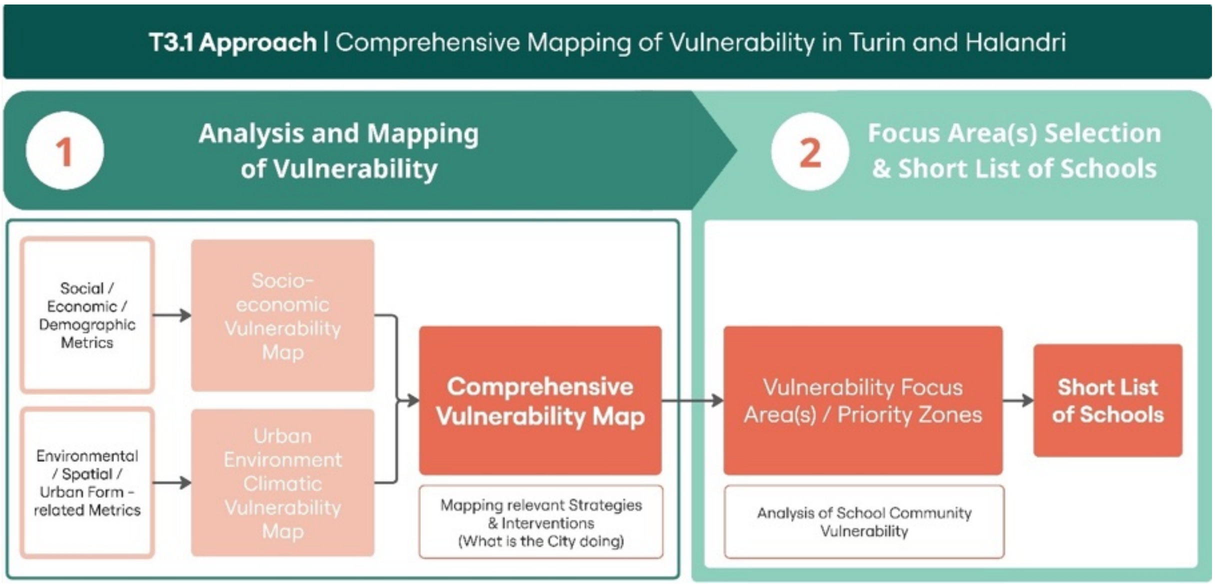

Figure 1 | MAINCODE T3.1 methodological approach diagram (Source: Authors elaboration)

More specifically, the **main D3.1 objectives are**:

- In-depth analysis, understanding, and **mapping of socio-economic and climate-related environmental aspects of vulnerability** in the two cities
- **Identification of the focus area(s)**, as priority zone(s) for climate action.
- **Evidence-based determination of a shortlist of schools** that serve as the pool for future final selection.

By identifying priority zones for intervention in Turin and Halandri, the **comprehensive vulnerability mapping carried out in D3.1 represents one of the six key criteria for the final school selection,** that are outlined in the MAINCODE project. These are: (i) the focus on primary schools; (ii) location in areas with high climate hazard exposure and social vulnerability; (iii) schoolyards with open community access; (iv) current non-sustainable conditions; (v) sufficient size; and (vi) willingness of the school community to participate in the MAINCODE project.

A. What is the comprehensive vulnerability map?

The concept of a **comprehensive vulnerability map** builds on the recognition that vulnerability to climate hazards, particularly to extreme heat in urban environments, is shaped by a complex interplay of social, environmental, and structural factors. Existing studies has examined this from different perspectives, while relevant literature reviews on urban heat vulnerability stress the existence of multiple critical indicators and categories of metrics for its assessment (Mah et al., 2023; Qian & Liu, 2025). These stands of research highlight that no single set of indicators is universally valid; instead, **context-based approaches are essential to capture the drivers of vulnerability in each urban setting** (McCullagh et al., 2025).

Vulnerability is often understood as “the degree to which populations are susceptible to natural hazards and their capacity to respond and recover from impacts” (Fitton et al., 2021, cited in McCullagh et al., 2025). In the case of heat, this involves assessing how individuals, communities, or urban systems are exposed to elevated temperatures, how sensitive they are to those conditions, and how well they can adapt. **Exposure** refers to the spatial and temporal extent of contact with high temperatures, frequently intensified by the urban heat island effect. **Sensitivity** encompasses the socio-demographic, health-related, and ecological factors that make some groups more at risk than others, including for instance age, pre-existing conditions, income level (Mah et al., 2023). **Adaptive capacity** relates to the individual or collective resources, institutions, and infrastructures that enable preparation, coping, and recovery. From this perspective, vulnerability emerges as a multidimensional phenomenon shaped by the interaction of physical risks and social inequalities. (Amorim-Maia et al., 2023). Recent work emphasizes that vulnerability must be seen through an intersectional lens, as it is shaped by overlapping historical, socioeconomic, and material conditions (ibid). These jointly determine exposure, sensitivity, and adaptive capacity Therefore, **mapping vulnerability requires an integrated framework that moves beyond purely physical risk assessment and incorporates the social and economic dimensions of urban life.**

In the context of the MAINCODE project, this approach is operationalized through **the combination of the socio-economic dimension with structural and environmental climate-related aspects and the creation of a comprehensive vulnerability map.** This tool integrates indicators such as population density, age distribution, socio-economic status, land surface temperature, green space availability, and urban morphology. As shown from existing studies and pilot applications, the creation of UCS in schools is considered an innovative and effective measure to address vulnerability to heatwaves (Pene, 2024). By layering spatial, social, and environmental climate-related data, the MAINCODE Vulnerability Map in Turin and Halandri provides evidence-based guidance for the UCS implementation in areas where they can deliver the greatest benefit. In doing so, it ensures that adaptation measures are not only technically effective but also socially equitable, thereby supporting more resilient and inclusive cities.

B. Structure of the report

After this introduction, **Chapter 2 provides the conceptual methodological framework** guiding the vulnerability mapping. It sets out the logic of the approach and explains the main steps followed, starting from data collection and processing, through the development of vulnerability metrics, to the integration of socio-economic and environmental dimensions, and finally the production of the comprehensive map of vulnerability and the identification of priority areas and schools most exposed to climate risks, especially heat.

Following, **Chapter 3 forms the analytical core of the report and it focuses on the analysis and mapping of urban vulnerability to extreme heat in Turin and Halandri**. It explores the socio-economic and urban environment climatic dimensions of urban vulnerability in each city, beginning with a contextual overview. For Turin and Halandri alike, the chapter presents thematic maps, interprets vulnerability patterns, and produces comprehensive maps of urban heat vulnerability. Additionally, it presents how the two cities respond to the identified vulnerabilities, by outlining ongoing urban initiatives and climate adaptation strategies, that can build synergies with the Urban Climate Shelter (UCS) concept.

In Chapter 4 the focus shifts to schools and priority areas. Based on the vulnerability maps, the most exposed urban zones are identified, and within them, a shortlist of schools is proposed as candidates for UCS pilot implementation. The school's level of vulnerability is considered alongside further aspects such as schoolyard environmental and structural features and accessibility. This step narrows down the options and sets the stage for the next phases of MAINCODE, where the final selection will be made and the selected schools will host the UCS. Finally, **Chapter 5 outlines the basic commonalities and differences of the two cases of analysis**, summarising the key findings.

2. Methodology for the Comprehensive Vulnerability Map

As stated in the introduction, this Report aims to map the vulnerability to extreme heat in the cities of Turin and Halandri by applying a common methodological framework that ensures comparability while allowing for deviations and local adaptations. The overarching goal is to identify priority areas where climate-related risks intersect with social disadvantage, and thereby support evidence-based decisions regarding the selection of the schoolyards that will host the pilot implementation of UCS. The two cities follow a **common methodology, adapted to local data availability, different urban scale and further context-specific peculiarities**. This structured process ensures comparability between Turin and Halandri while allowing flexibility to accommodate differences in data sources, resolution, and indicators. The process unfolds in four main stages (Figure 2):

A. **Data collection**: socio-economic, demographic, environmental, and climate-related datasets from official sources.
B. **Data processing and development of metrics:** transformation of raw data into meaningful indicators of vulnerability, using a common geospatial framework.

C. **Data synthesis:** integration of the socio-economic and environmental, urban form-related dimensions into **composite vulnerability measures.**
D. **Identification of focus areas and priority schools:** interpretation of results to define the most vulnerable urban areas and the shortlist of schools for pilot implementation.

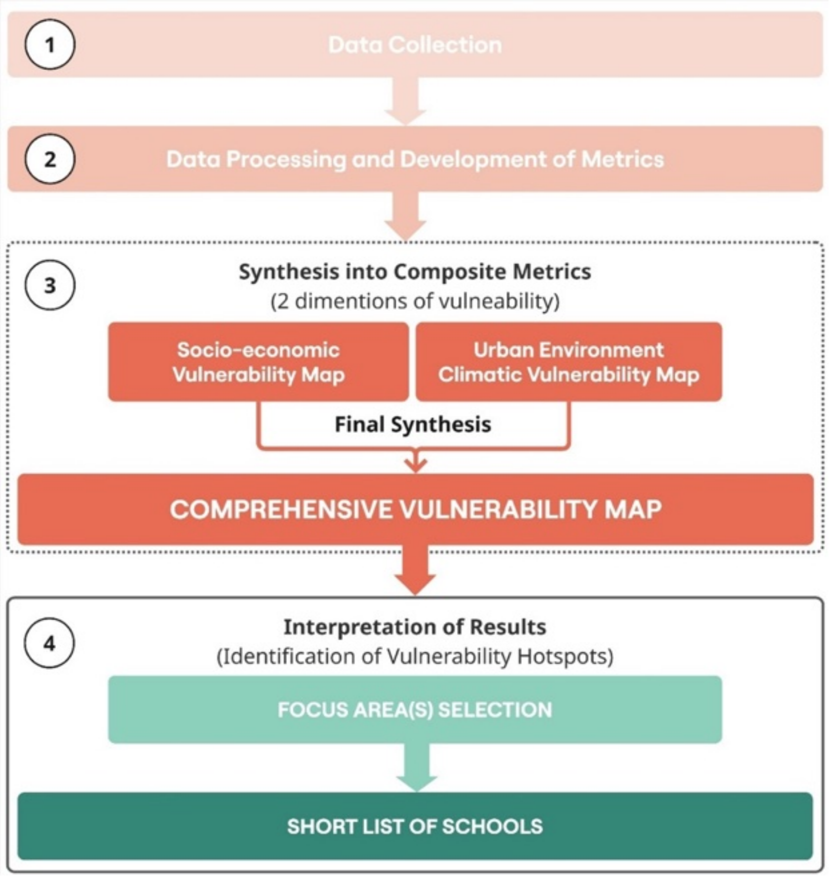

Figure 2 | Methodology for the comprehensive map of vulnerability (Source: Authors elaboration)

A. Data collection: sources and type of data

The choice of data was guided by established social vulnerability indices, relevant academic literature (McCullagh et.al., 2025; Mah et.al., 2023; Sun et al., 2022) and, crucially, by the availability of reliable, good-quality datasets. The analysis was structured around three main categories of datasets:

- **Socio-demographic data:** including population density, social composition of the population (e.g. age distribution, nationality, education, occupational status, etc), income, housing conditions, and household structure. These datasets capture sensitivity and adaptive capacity of the population to extreme heat.
- **Urban structure and land use data:** including built density, impervious surfaces, green and blue areas, mobility infrastructure, and further urban features related to climate adaptation (e.g. fountains). These reflect the physical conditions that shape exposure to heat.

- **Environmental and climate-related data:** including land surface temperature (LST), vegetation indices (NDVI), tree cover density, and Urban Heat Island (UHI), these datasets capture microclimatic variations and environmental regulating capacity.

These datasets were drawn from a range of sources. Census data are provided by the Italian National Statistical Institute (ISTAT) for Turin and the Hellenic Statistical Authority (ELSTAT) for Halandri. Complementary spatial layers are obtained through remote sensing and Earth Observation, including the Copernicus Urban Atlas, imperviousness and vegetation layers, and thermal satellite imagery. Municipal geospatial databases and existing climate adaptation plans and assessments further enrich the analysis, offering planning, and environmental information from the municipalities of Turin and Halandri.

B. Data processing and methods

The vulnerability mapping is conceptually framed around two complementary dimensions:

1. **Socio-economic vulnerability,** reflecting the sensitivity of urban populations to heat and their capacity to adapt.
2. **Urban environmental-climatic vulnerability,** addressing the structural and environmental characteristics of the urban fabric that determine exposure to heat.

All data processing is conducted **within a GIS environment** to transform raw datasets into spatially consistent and comparable vulnerability metrics. The workflow consisted of the following steps:

- **Pre-processing and harmonization** of datasets in terms of projection, resolution, and spatial extent, and **development of relevant metrics.**
- Employment of **hexagonal tessellation grid** as the spatial unit of analysis[1] and **spatial aggregation** of the produced metrics into the hexagonal grid using population-weighted interpolation for socio-demographic variables and area-weighted interpolation for environmental and land-use variables. The aim is to enable spatial comparability between heterogeneous datasets and avoid biases.
- **Normalization of values to a 0–100 scale and composite measures,** since the indicators were expressed in different units and scales. Higher values consistently represent higher vulnerability.

C. Data synthesis: production of the comprehensive vulnerability map

The processed normalized indicators are synthesized into the two analytical dimensions (socio-economic and urban environment climatic) by averaging their normalised scores. These two dimensions are then integrated into a **composite vulnerability measure** by calculating the mean of the socio-economic and environmental scores for each hexagon. **The outcome of the process is the comprehensive vulnerability map, which integrates social and environmental climate-related factors into a single spatial visualization.** The

[1] The size of the hexagonal grid is defined separately in each city, to facilitate balance between spatial detail and interpretability. Specifically, each hexagon approximates the size of three urban blocks in Halandri, with a proportionally scaled surface applied to Turin. The grid covers the area within the administrative boundaries, with special treatment applied at the edges to reduce boundary effects.

composite measure is classified to highlight relative levels of vulnerability, from very low to very high, while a common colour palette is applied in both cities to enable visual comparability of the results. This synthesis not only identifies broad patterns (e.g., central vs. peripheral disparities) but also reveals localized hotspots of vulnerability embedded within generally lower-risk areas. This integrated approach captures on the one hand the sensitivity and adaptive capacity of the population to urban heat based on its socio-economic characteristics. On the other hand, it takes into consideration the regulating role of vegetation, water, and urban morphology, providing a nuanced picture of both strengths and weaknesses in urban adaptation capacity.

D. Identification of focus area(s) and short list of schools

Finally, the mapping of social and climate vulnerability at the city scale in Turin and Halandri leads to the **identification of heat vulnerability hotspots in both cities**, that serve as the focus areas for interventions and indicate a preliminary shortlist of schools. **The preliminary shortlist of primary schools represents the schools located in high-vulnerability zones where the benefits of urban climate shelters are expected to be most significant.** This list is not a final selection but a starting point for the determination of the schools that will participate in the MAINCODE project. Within these priority zones, schools are mapped and cross-referenced with further available information about their physical characteristics provided by municipal education datasets. By combining the various identified MAINCODE criteria and taking into consideration the fulfilment of most of them, the final selection will take place at the next phase of the project.

3. Analysis and Mapping of Vulnerability

This Chapter addresses the core objective of the D3.1 document: analysing and mapping the overall vulnerability of the two cities, Turin and Halandri. It begins with a brief overview of each city's urban profile, followed by the mapping of their **socio-economic and urban environmental-climatic vulnerabilities.** These two key dimensions are then integrated into a **comprehensive urban heat vulnerability map** for both cities. The chapter concludes by presenting important climate adaptation programs and related interventions designed to reduce the identified vulnerabilities and likely to build synergies with the MAINCODE urban climate shelter approach.

3.1 Analysis and Mapping of Vulnerability in Turin

Turin, the capital of Piedmont region in north-western Italy, exemplifies the climate adaptation challenges facing many European metropolitan areas. With 872,316 inhabitants across 130.17 km^2[2], the city sits at the convergence of four major waterways within a complex hydrological system that extends from the Alpine foothills to the Po Valley plains.[3]

Urban transformation and emerging vulnerabilities

The city's remarkable transformation from an industrial powerhouse to a hub for technology, education, and culture has created both opportunities and new vulnerabilities. The conversion of approximately 10 million square meters of abandoned industrial land into green infrastructure since the 1990s has positioned **Turin as one of Italy's greenest cities**, with over 55 m^2 of green space per resident.[4]

However, this urban evolution has also exposed specific climate risks. The **heavily urbanized flat areas**, particularly former industrial zones with vast impermeable surfaces, have become heat island hotspots. Climate monitoring data from ARPA Piemonte (2003-2019) confirms a significant warming trend, with **maximum temperatures increasing by 0.6°C per decade** and the city having already experienced emergency situations related to heat waves, notably the 2003 event which saw a marked increase in mortality rates.[5]

The challenge of a warming climate: Trends and projections for Turin

Turin's continental climate, characterized by hot summers and cold winters, is experiencing significant changes that amplify urban heat stress. Located in the Po Valley with Alpine influences, the city sits at approximately 240m elevation, creating a unique microclimate within the broader regional context. The urban morphology, combining dense historical districts with extensive former industrial areas, creates varying degrees of heat exposure across neighbourhoods.

ARPA Piemonte data reveals a clear warming pattern, climate projections indicate this trend will intensify, with scenarios predicting temperature increases of 3-6°C by 2100. This translates into critical heat stress trends:

- **Tropical days** (Tmax >30°C) are expected to increase by 35-51 additional days per year.
- **Heat wave duration** could extend from the current 4-5 days to as long as 16-47 days.
- These heat effects are compounded by changing precipitation patterns, which point toward increased **drought risk and water stress**.

Strategic framework for climate action

Turin's response to these challenges is guided by a multi-level strategic framework that translates European commitments into targeted local action.

- **European Commitment: The Climate City Contract (CCC).** As part of the EU Mission for "100 Climate-Neutral and Smart Cities by 2030," Turin's Climate City Contract anchors its climate ambitions at a continental scale. This agreement establishes ambitious decarbonization and adaptation targets across all urban sectors—energy,

[2] Turin Climate Resilience Plan, Chapter 4.1
[3] Turin Climate Resilience Plan, Chapter 3
[4] Turin Climate Resilience Plan, Chapter 6
[5] Turin Climate Resilience Plan, Chapter 4.1

buildings, waste, and transport—positioning Turin within a network of pioneering cities.
- **City-Wide Vision: The Turin 2030 Strategic Plan.** This plan integrates climate resilience as a fundamental pillar of the city's development, alongside sustainable mobility, circular economy, and social inclusion. It ensures that climate adaptation is not a confined objective but is embedded within broader urban goals, maximizing co-benefits and guiding coherent investment strategies.
- **Operational Tool: The Climate Resilience Plan (PRC).** The PRC is the primary instrument for translating high-level commitments into on-ground interventions. Developed through an interdisciplinary process, the plan provides the analytical foundation for action, identifying specific vulnerabilities and defining adaptation priorities for the most at-risk neighbourhoods.

Schools as a strategic response to climate risks

In this context, developing **Urban Climate Shelters** becomes a key strategy, connecting the city's high-level climate plans (the Climate City Contract) with the concrete actions laid out in its Climate Resilience Plan. Schools, as trusted and distributed community assets, are uniquely positioned to serve a dual function: maintaining their educational mission while providing safe, accessible refuges during extreme weather events. This dual-use approach represents a practical implementation of Turin's integrated strategy, translating high-level planning into a tangible network of community support that builds long-term urban resilience.

3.1.1 Socio-economic vulnerability in Turin

Socio-economic vulnerability refers to the way in which **individual and household characteristics interact with climate-related hazards**, particularly extreme heat events. This includes demographic factors (such as age, gender, and household composition), economic conditions (income levels and housing quality), and social factors (community networks and access to resources). Research has established which population groups face the highest risks during heat waves - primarily elderly people, young children, women, low-income households, and recent immigrants. This analysis aims to map where these vulnerable groups are concentrated in Turin's neighbourhoods. By selecting data indicators that correspond to these known risk factors and combining them spatially, we identify which areas of the city have the highest concentrations of heat-vulnerable residents.
For Turin's climate shelter strategy, **understanding the spatial distribution of socio-economic vulnerability is essential to ensure that interventions are located where they can serve the greatest number of people most at risk during extreme heat events.**

Socio-economic vulnerability indicators

Methodological note to data selection: The socio-economic analysis uses official population and income statistics to understand which people and families face the greatest challenges during extreme heat events. 2021 census data (which counts all residents neighbourhood by neighbourhood) were combined with 2021 income data (organized by postal codes) to create a comprehensive picture of social vulnerability across Turin.

SOCIO-ECONOMIC VULNERABILITY				
Map	**Data Source**	**What the Data Shows**	**How It Was Processed**	**Why It Matters for Heat Vulnerability**
Population Density	ISTAT Census 2021	Number of people living in each neighborhood area	Raw population counts divided by neighborhood area to show density per km²	Areas with more people need more cooling resources and represent priority zones for climate shelters
Female Population Density	ISTAT Census 2021	Concentration of women in each neighborhood	Female population counts divided by area, mapped as density per km²	Research shows women face higher heat-related health risks due to physiological and social factors
Children Density (Under 14)	ISTAT Census 2021	Where families with young children live most densely	Child population counts divided by area, shown as density per km²	Children cannot regulate body temperature as well as adults and depend on others for protection during heat waves
Elderly Density (Over 65)	ISTAT Census 2021	Concentration of older adults in each area	Senior population counts divided by area, mapped as density per km²	Older adults have reduced ability to cope with extreme heat and higher risk of heat-related illness
Foreign Population Percentage	ISTAT Census 2021	Percentage of non-Italian residents in each neighborhood	Foreign residents divided by total population, shown as percentage by area	Recent immigrants often have lower incomes, language barriers, and less knowledge about local cooling resources
Per Capita Income	Ministry of Economics and Finance 2021	Average yearly income per person by postal zone	Tax return data averaged across each postal code area	Lower income families often live in poorly insulated homes without air conditioning and cannot afford private cooling solutions

Table 1 | List of metrics used in mapping of Socio-economic vulnerability in Turin

Socio-economic vulnerability map

The socio-economic vulnerability analysis reveals a heterogeneous pattern across Turin, with the **highest vulnerability concentrations in peripheral areas**, particularly in the northern and southern districts. These areas are characterized by high population density combined with significant presence of vulnerable demographic groups.

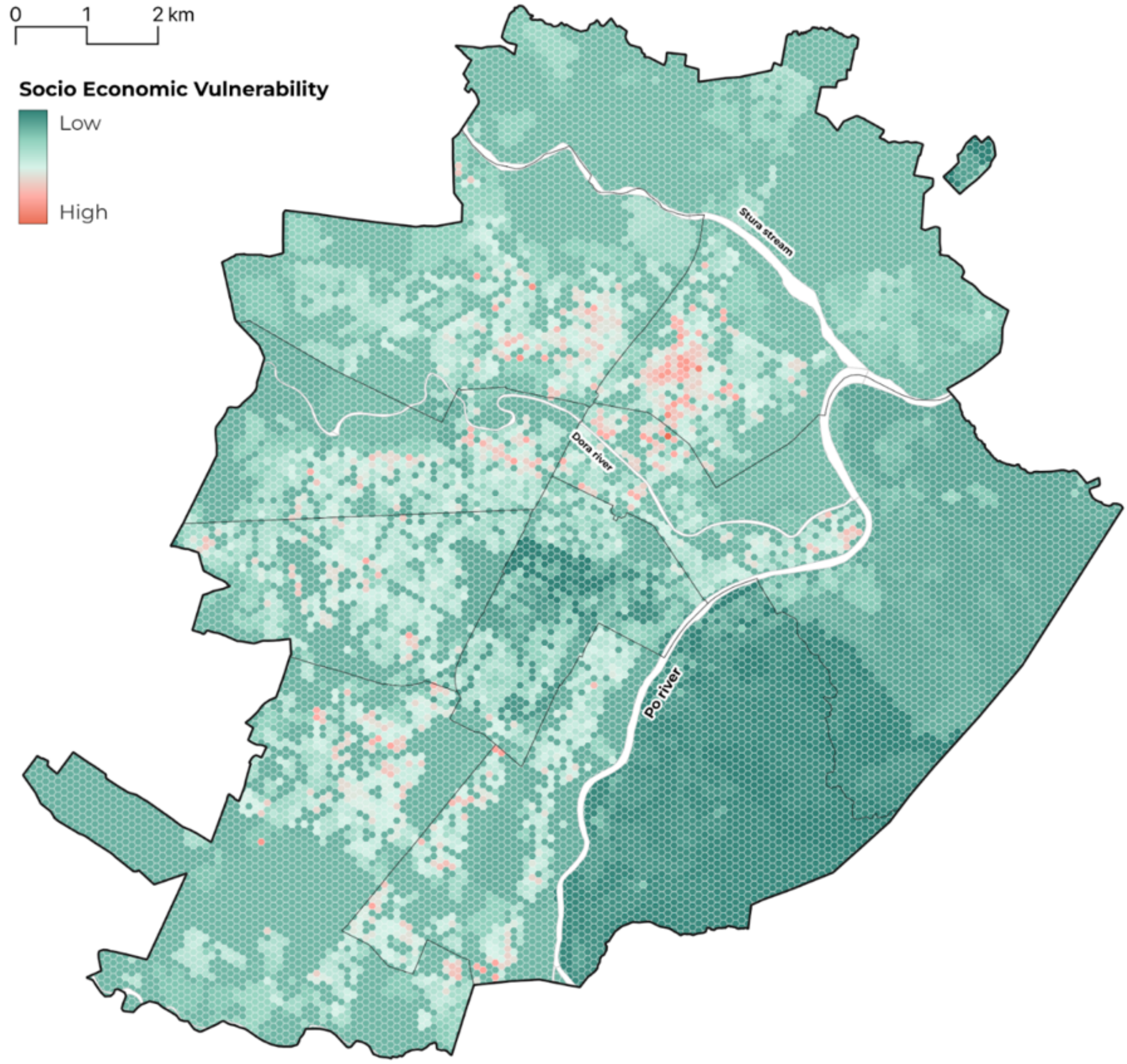

Figure 3 | Map of socio-economic vulnerability in Turin. (Source: Authors elaboration. Data Source: ISTAT Census 2021, Ministry of Economics and Finance 2021)

Northern periphery: The northern districts show the most critical socio-economic vulnerability profile, combining high density of young families (high percentage of under-14 population), significant foreign resident populations, and the lowest per capita income levels in the city. This combination creates compound vulnerability where multiple risk factors intersect.

Southern areas and Dora corridor: The southern periphery and areas along the Dora River present a different vulnerability profile, characterized by higher concentrations of elderly population (over 65) alongside moderate income levels. While economically less disadvantaged than the north, these areas face age-related climate vulnerabilities.

Central and hillside areas: The city centre and hillside districts generally show lower socio-economic vulnerability, with higher income levels, lower population density, and demographic profiles that include fewer of the most heat-vulnerable age groups.

At the end, **the spatial distribution of income inequality creates a clear north-south divide, with the lowest-income postal codes concentrated in the northern districts, where young, economically vulnerable families with children are most prevalent**. This pattern suggests that climate shelter interventions in northern areas could serve both high-density populations and those with the greatest socio-economic barriers to private cooling solutions.

3.1.2 Urban environmental-climatic vulnerability in Turin

Urban environmental-climatic vulnerability refers to the way in which the physical and environmental characteristics of the city interact with climate-related hazards, particularly extreme heat events and heat stress. This includes **structural aspects of the urban fabric** (such as the extent of built-up areas, the distribution of green spaces, or surface materials that absorb heat), as well as **factors related to accessibility to cooling services and infrastructures** (such as proximity to green spaces, public fountains, or shaded mobility networks). The purpose of this analysis is to map where these heat-amplifying or heat-mitigating conditions are distributed across Turin. By selecting data indicators that correspond to these known environmental risk and protective factors and combining them spatially, it is possible to identify which areas of the city face the greatest climate-related heat stress. For Turin's climate shelter strategy, understanding the spatial distribution of urban environmental-climatic vulnerability helps identify where the physical environment itself creates the most dangerous heat conditions.

Urban environmental-climatic vulnerability indicators

Methodological notes to data selection: The climate analysis examines Turin's physical environment to identify areas where extreme heat poses the greatest risks. We combined city infrastructure databases, satellite images that measure vegetation health, official climate studies, and accessibility calculations (measuring how far people must walk to reach cooling resources) to understand where the city's landscape makes heat waves more dangerous.

URBAN ENVIRONMENTAL-CLIMATIC VULNERABILITY				
Map	**Data Source**	**What the Data Shows**	**How It Was Processed**	**Why It Matters for Heat Vulnerability**
NDVI (Vegetation Health)	Satellite imagery analysis 2025	How healthy and dense vegetation is across the city	Satellite sensors measure how much vegetation reflects light, creating a "greenness" score for each area	More vegetation means more shade and natural cooling through evaporation from leaves, reducing local temperatures
Urban Heat Islands	Turin Climate Resilience Plan / ARPA Piemonte	Areas where temperatures are hotter than surrounding zones	Climate scientists identified zones that trap more heat based on surface materials and building density	These "heat island" areas become dangerously hot during heat waves, requiring priority attention for cooling solutions
Urbanized Areas	Land use analysis 2025	Which parts of the city are covered by buildings and pavement versus natural surfaces	City mapping data classified as either built-up (concrete, asphalt) or natural (soil, vegetation) surfaces	Sealed surfaces absorb and store heat all day, then release it at night, making these areas much hotter than natural areas
Access to Urban Green Spaces	Municipal green space database 2025	How close residents live to parks and natural areas	Calculated walking distance from each neighborhood to nearest accessible green area (within 300 meters)	Parks and green spaces stay cooler than built areas and provide refuge during heat waves, but only if people can easily reach them
Access to Public Fountains	Municipal fountain database 2025	How close residents live to public water sources	Mapped all public fountains and calculated 300-meter walking access zones around each one	During heat waves, access to free drinking water is essential for preventing dehydration and as a cooling source to prevent heat strokes
Pedestrian Network Access	Municipal infrastructure mapping 2025	Which neighborhoods connect to safe walking paths	Identified pedestrian areas and calculated 300-meter access zones	People need safe places to walk to reach cooling resources, especially during heat when staying indoors may not be possible

Shaded Pedestrian Network Access	Municipal tree database 2024 + infrastructure mapping 2023	Which walking areas have tree cover or other shade	Combined pedestrian paths with tree locations to identify shaded versus sun-exposed walking routes	Walking in direct sun during heat waves can be dangerous; shaded paths enable safe movement to cooling areas
Cycling Network Access	Municipal cycling infrastructure 2025	Which areas connect to bicycle paths	Mapped bicycle lanes and paths with 300-meter access calculation	Cycling can be faster than walking to reach cooling resources, but only where safe bike infrastructure exists
Shaded Cycling Network Access	Municipal tree + cycling databases 2024/2025	Which bike paths have natural shade coverage	Combined cycling infrastructure with tree canopy data to show protected versus exposed routes	Like walking, cycling in extreme heat requires shade protection to prevent heat-related illness during travel

Table 2 | List of metrics used in mapping of urban environmental-climatic vulnerability in Turin

Urban environmental-climatic vulnerability map

The urban environmental-climatic vulnerability analysis reveals distinct patterns across Turin's urban fabric, with vulnerability concentrations in industrial zones, dense urban areas with limited vegetation, and districts with poor access to cooling infrastructure.

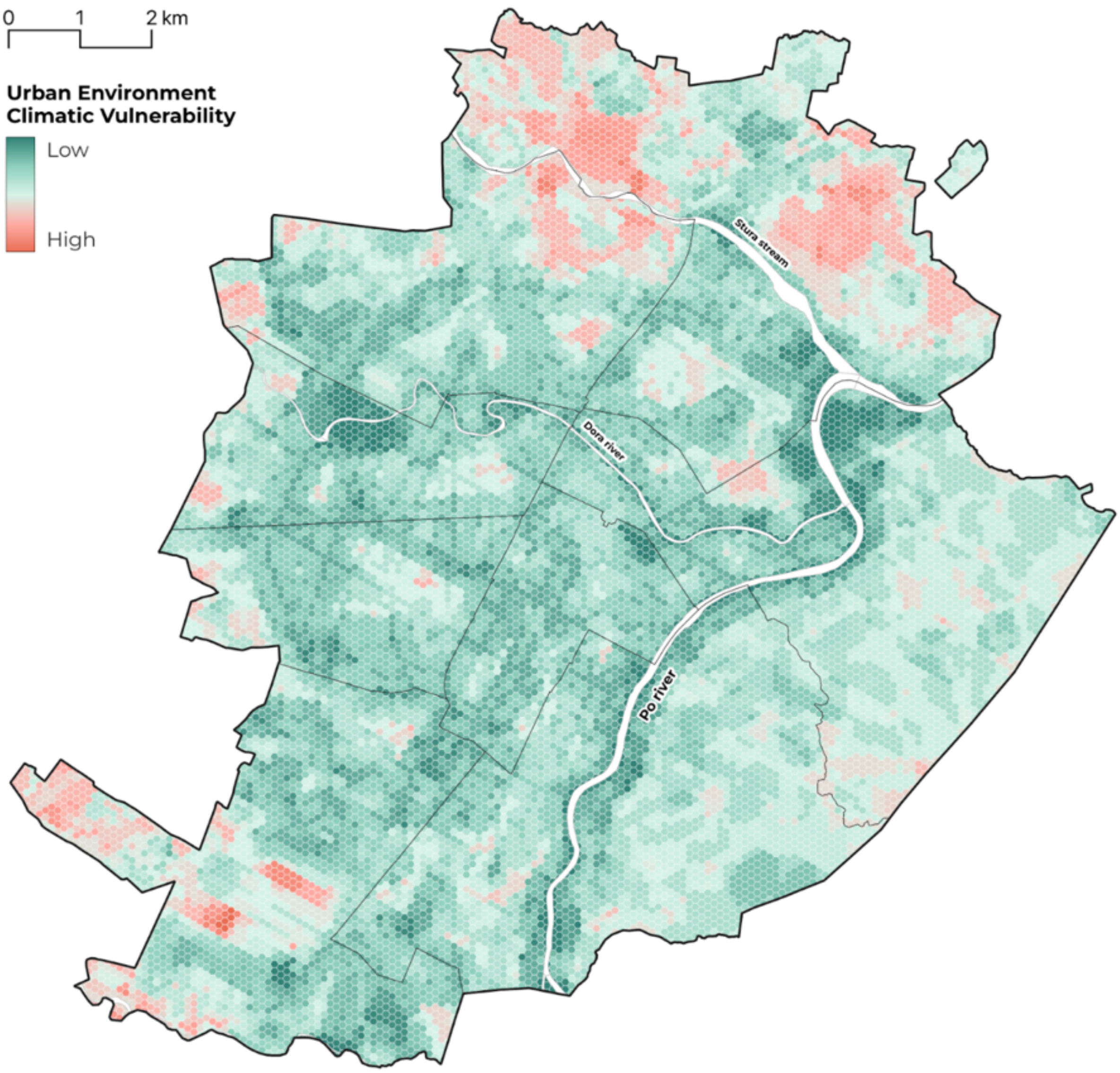

Figure 4 | Map of urban environmental-climatic vulnerability in Turin (Source: Authors elaboration. Data Source: Municipal Database)

Industrial and dense urban areas: The highest urban environmental-climatic vulnerability occurs in Turin's industrial zones and densely built areas with extensive impermeable surfaces. These areas experience the most severe urban heat island effects, with temperatures significantly higher than the city average during heat events. The northern industrial districts and large southern industrial complexes show particular vulnerability due to vast sealed surfaces and minimal vegetation cover.

Vegetation and cooling access disparities: Areas along the Dora River, despite being classified as low-risk for urban heat islands, show poor vegetation quality (low NDVI values), indicating limited natural cooling capacity. The analysis reveals significant variations in green space access, with excellent coverage in the historic center and hillside areas (East side of the Po River), contrasting sharply with limited access in northern peripheral districts.

Infrastructure and accessibility gaps: Public fountain distribution shows good citywide coverage with notable gaps in northern areas and some industrial zones. The cycling and pedestrian network provides reasonable shaded access through tree-lined corridors, but gaps exist in connecting peripheral areas to cooling resources.

Northern districts critical profile: The northern areas emerge as climatically vulnerable zones linked to moderate to high heat island risk, limited vegetation coverage, reduced fountain access, and significant impermeable surface coverage. The areas beyond Stura show high climatic vulnerability partly due to their distinctive urban fabric—a heterogeneous mix of peri-urban agriculture, large industrial zones, and scattered urban fringe developments that differ significantly from the rest of the municipal territory. In contrast, the densely populated residential areas between the Dora River and Stura torrent face different vulnerability challenges related to their urban density and concentration of vulnerable populations. Both zones lack adequate natural and built cooling infrastructure compared to other parts of the city.

Hillside and central areas resilience: The hillside districts demonstrate the lowest urban environmental-climatic vulnerability due to extensive vegetation coverage, natural topography providing cooling, and good access to green spaces. Similarly, the historic center benefits from tree-lined streets, fountain networks, and proximity to major parks, though some areas show lower lever of permeability.

The spatial pattern of urban environmental-climatic vulnerability creates clear priority zones for climate shelter interventions, with the northern periphery representing the confluence of multiple risk factors requiring immediate attention for heat adaptation measures.

3.1.3 Comprehensive map of vulnerability in Turin

The comprehensive vulnerability mapping in urban areas cannot be understood by simply adding together social and environmental risks. Instead, **socio-economic and urban environmental-climatic vulnerabilities interact through complex compensation mechanisms** that either amplify or reduce overall risk depending on how they combine spatially.

The fundamental concept is one of **cross-compensations**: residents with higher incomes living in climatically risky areas (such as heat islands) can often afford better housing with insulation and air conditioning, effectively reducing their actual heat exposure despite the challenging environmental conditions. Conversely, socio-economically vulnerable residents living in areas with good environmental conditions (such as near parks with natural cooling) may benefit from these public cooling resources that partially compensate for their inability to afford private cooling solutions.

This creates four distinct risk scenarios across Turin:

- **Compound Risk:** High socio-economic vulnerability + high urban environmental-climatic vulnerability = maximum danger

- **Environmental Compensation:** High socio-economic vulnerability + low urban environmental-climatic vulnerability = reduced risk through environmental protection
- **Economic Compensation:** Low socio-economic vulnerability + high urban environmental-climatic vulnerability = reduced risk through economic resources
- **Optimal Condition:** Low socio-economic vulnerability + low urban environmental-climatic vulnerability = minimum risk

Understanding these interactions is crucial for climate shelter placement, as areas with compound risks require immediate attention, while areas with compensation mechanisms may need different intervention approaches.

Vulnerability pattern recap

The socio-economic vulnerability analysis identified highest concentrations of vulnerable populations in northern peripheral districts (young families, foreign residents, low income) and Southern/Dora corridor areas (elderly populations, moderate income). Meanwhile, the urban environmental-climatic analysis revealed highest environmental risks in industrial zones and densely built areas with limited vegetation and cooling infrastructure.

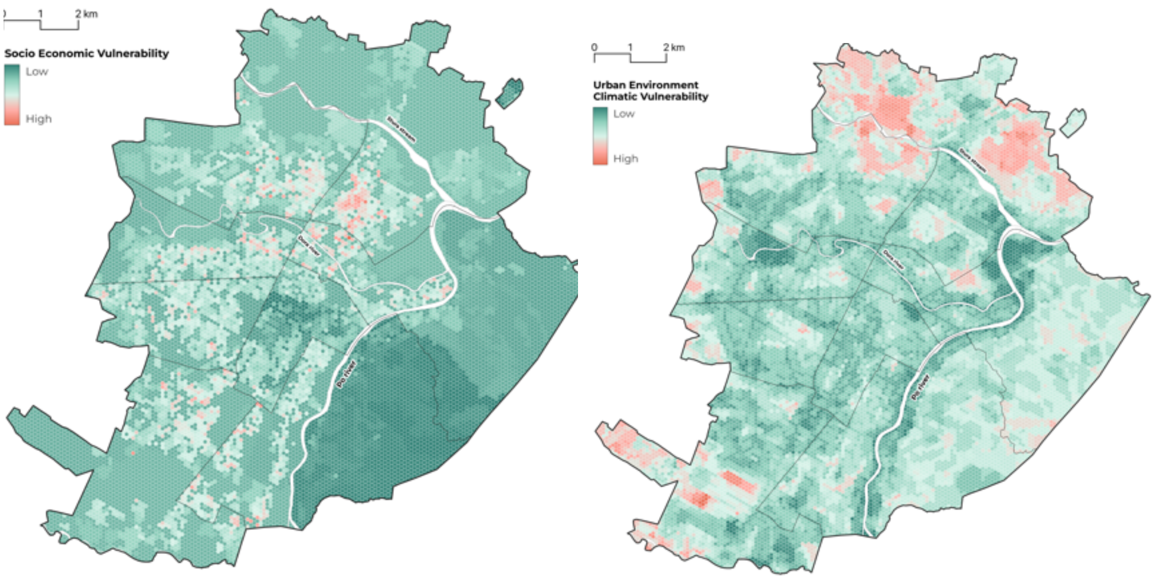

Figure 5 | Maps of socio-economic (left) and urban environmental-climatic vulnerability (right) to urban heat in Turin (Source: Authors elaboration)

Comprehensive vulnerability mapping

The comprehensive vulnerability map combines both analyses using weighted aggregation that accounts for the interaction effects described above. Rather than simple addition, the methodology recognizes that moderate levels of both vulnerabilities can create higher combined risk than high levels of just one type.

The comprehensive map demonstrates clear spatial clustering of highest-risk areas in Turin's northern periphery, where multiple vulnerability factors converge. This pattern provides strong evidence for prioritizing climate shelter interventions in these areas, where both environmental conditions and population characteristics create maximum need.

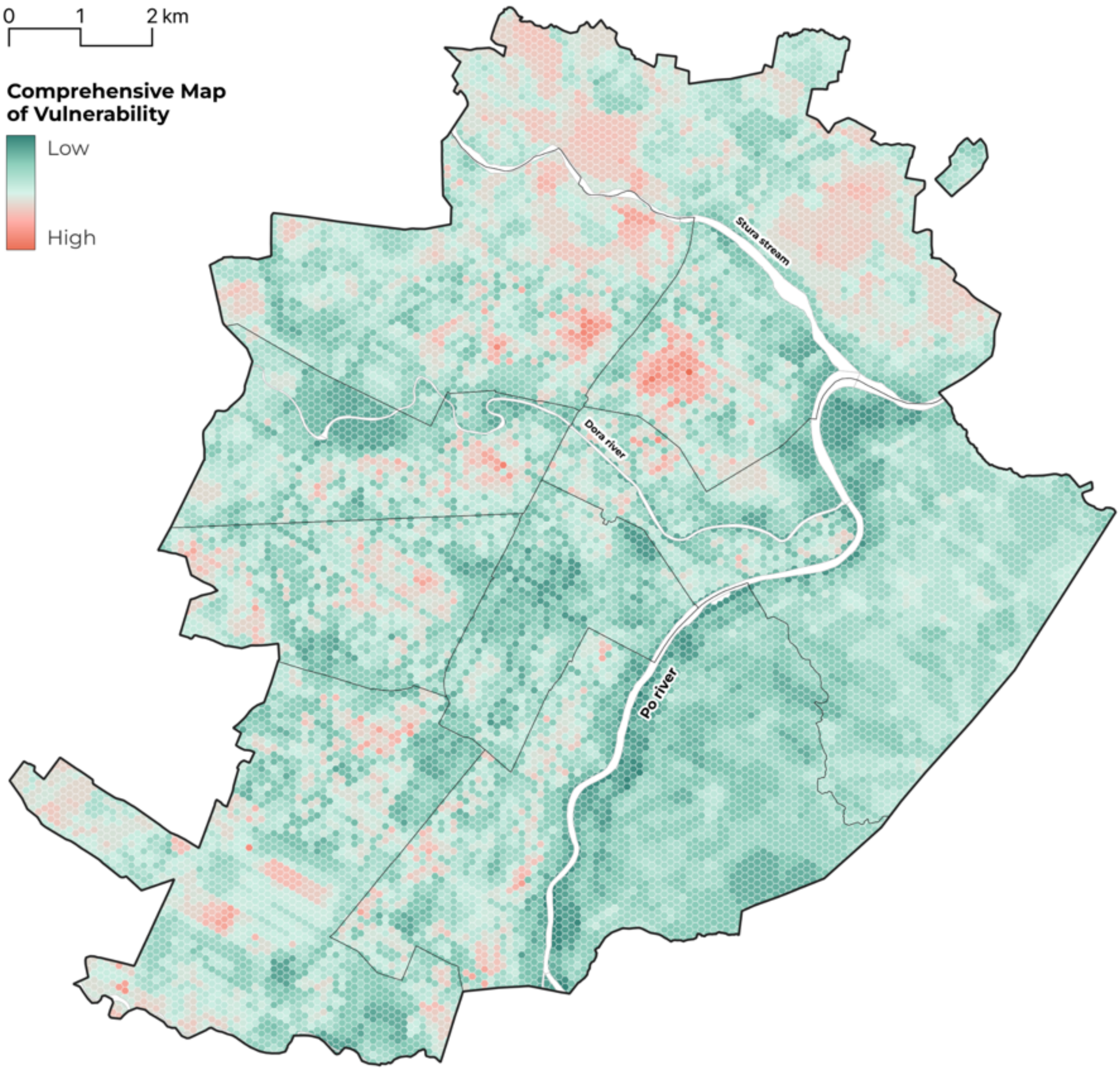

Figure 6 | Comprehensive vulnerability map in Turin (Source: Authors elaboration)

The resulting map reveals three critical patterns:

- **Hotspot zones - Northern Districts:** The most concerning areas emerge where Constituency 6 (northern periphery) shows the convergence of multiple risk factors. Here, high concentrations of young families with limited economic resources coincide with reduced access to cooling infrastructure, creating compound vulnerability requiring immediate climate shelter intervention.
- **Methodological considerations - Industrial Areas:** Some industrial zones show lower comprehensive vulnerability scores despite high climatic vulnerability (heat islands, sealed surfaces) due to minimal residential population. This apparent "low

risk" is a methodological artifact that requires critical interpretation—these areas significantly contribute to urban heat island formation and negatively impact surrounding residential neighbourhoods. The vulnerability maps must be read systemically, recognizing that industrial zones, while appearing as "low vulnerability" due to absence of residents, actually exacerbate climate hazards for adjacent populated areas. This underscores the importance of considering spatial spillover effects rather than treating each zone in isolation.

- **Surprising vulnerability - Hillside Edges:** Certain transitional areas between central and hillside districts reveal unexpected patterns where moderate socio-economic vulnerability intersects with reduced access to cooling resources, creating pockets of risk not immediately apparent from single-factor analyses.

3.1.4 Urban initiatives towards climate adaptation in Turin

For this study, we conducted a retrospective analysis of Turin's urban interventions, cataloguing **469 projects planned or implemented between 2014 and 2027** to assess their alignment with the identified climate vulnerabilities.

The implementation of these interventions is made possible by significant funding channels, while their strategic coherence is ensured by local planning instruments. In this context, a pivotal role is played by the **National Recovery and Resilience Plan (PNRR),** which has become the primary financial driver for more than half of the catalogued interventions, often integrating pre-existing funding lines. This financial framework empowers key local instruments, such as the **Strategic Green Infrastructure Plan** and the **Sustainable Urban Mobility Plan (PUMS),** to bridge the gap between strategic vision and on-ground implementation. These sectoral plans, in turn, inform both large-scale, structured implementation programs and targeted experimental projects designed to provide feedback and refine future strategies.

Analysis of urban interventions

A significant portion of these interventions is organized within specific **implementation programs**, which translate strategic guidelines into coordinated actions on the ground. These are complemented by **experimental projects**, which serve as living labs to test innovative solutions before wider application.

Main implementation programs

These multi-year programs represent the structural implementation of the city's policies, channelling significant municipal, national, and European funds.

MAIN IMPLEMENTATION PROGRAMS RELATED TO CLIMATE VULNERABILITY FACTORS				
Program	**Interventions (% of Total)**	**Implementation Period**	**Climate Vulnerability Potential Contribution**	**Funding Source**
Safe Schools Program (Scuole Sicure)	148 (31.6%)	2020-2026	Improves building envelopes and courtyards, creating potential climate shelters for vulnerable groups.	PNRR, Municipal funds
Integrated Urban Plan (PUI)	66 (14.1%)	2021-2027	Regenerates public spaces and services in disadvantaged areas, increasing access to cool areas.	PON Metro REACT EU
Torino 2030 (Città Vivibile Initiative)	23 (4.9%)	2021-2024	Upgrades public spaces which can be designed to reduce heat island effects and serve as cooling areas.	React EU
Sustainable Mobility Plan (Biciplan)	22 (4.7%)	2021-2027	Creates shaded mobility corridors, providing safe access to cooling resources for residents.	PON Metro Plus

Table 3 | List of the main implementation programs related to climate vulnerability factors in Turin 2017-2030 (Source: Municipal Official Website, Torinocambia Webpage)

Experimental and feedback projects

These initiatives are designed to pilot innovative approaches and provide evidence to inform and improve the city's overarching strategic plans.

EXPERIMENTAL AND FEEDBACK PROJECTS RELATED TO CLIMATE VULNERABILITY FACTORS				
Project	**Interventions (% of Total)**	**Implementation Period**	**Climate Vulnerability Potential Contribution**	**Funding Source**
proGIreg	34 (7.3%)	2018-2023	Directly implements nature-based solutions to reduce urban heat and manage stormwater.	Horizon 2020
City Water Circles (CWC)	7 (1.5%)	2021-2024	Addresses water stress by piloting improved water management and creating potential cooling effects.	Interreg

Table 4 | List of the main implementation programs related to climate vulnerability factors in Turin 2017-2030 (Source: Municipal Official Website, Torinocambia Webpage, European Programs Official Webpages)

The remaining **169 interventions (representing 36% of the total)** form a widespread constellation of projects outside of these specific programs. This group largely consists of new constructions and extraordinary maintenance projects focused on safety improvements, modernization, and functional requalification of public assets, which are nevertheless consistent with the city's strategic guidelines for resilience and sustainability.

Interventions by climate vulnerability impact

For the purposes of this study, we categorized the 469 identified interventions into seven thematic groups to assess their potential contribution to climate adaptation. This categorization has the main purpose to help understand how existing and planned urban projects might influence the climate vulnerabilities identified in sections 3.1.1-3.1.3, even when climate adaptation was not their primary objective.

Green infrastructure and Nature-Based Solutions (90 interventions, 19.2%)

These interventions aim to reduce urban heat island effects through vegetation-based strategies. Typologies include:

- Tree planting campaigns (27 interventions, 2018-2027) for shade provision and evapotranspiration
- Green area rehabilitation (11 interventions, 2020-2025) in existing parks and gardens
- Green walls (4), green roofs (3), and rain gardens (2) implemented 2021-2024
- Urban forestry projects (6 interventions, 2022-2026) for carbon sequestration and temperature reduction
- Biodiversity and pollinator-friendly interventions (10 projects, 2020-2024)

Potential climate adaptation contribution: These projects can help reduce heat island effects identified in the climatic vulnerability analysis while providing public cooling spaces in neighbourhoods with limited private cooling options.

School infrastructure (93 interventions, 19.8%)

This category represents the largest share of interventions, focusing on educational facility upgrades (2020-2026):

- Building envelope improvements for thermal regulation (55 extraordinary maintenance projects, primarily 2023-2026)
- Safety upgrades for extreme weather events (28 fire safety adaptations, 2022-2026)
- Courtyard transformations with green elements (5 projects, 2021-2024)
- New educational facilities (5 projects, 2022-2025)

Potential climate adaptation contribution: Schools can function as both educational facilities and potential climate refuges in neighbourhoods with high concentrations of vulnerable populations (see sections 3.1.1-3.1.2).

Sustainable mobility and accessibility (80 interventions, 17.1%)

Mobility interventions focus on infrastructure for accessing cooling resources during heat events:

- Protected cycling network expansion (39 projects) for alternative transportation
- Pedestrianization and traffic calming (20 school squares and pedestrian areas)

- Safe intersection improvements (11 projects) for vulnerable road users
- Traffic flow redesign and 30 km/h zones (10 projects)

Vulnerability response: Provides shaded pathways to cooling resources, relevant for populations with limited mobility identified in the socio-economic analysis.

Permeable surfaces and water management (50 interventions, 10.7%)

These interventions address surface heating and stormwater management:

- Permeable pavement installations (35 projects) to reduce surface temperatures
- Water management systems (8 projects) for evaporative cooling
- River corridor rehabilitation (3 projects) along natural cooling corridors
- Hydraulic infrastructure improvements (4 projects)

Vulnerability response: Targets urban heat island areas identified in section 3.1.2 while addressing precipitation management.

Public spaces and services (85 interventions, 18.1%)

Upgrades to public facilities and spaces that can serve as community resources:

- Library rehabilitations (16 projects) with climate control systems
- Sports facility improvements (10 projects) for year-round use
- Market area upgrades (11 projects) for food distribution continuity
- Public space redesign and rehabilitation (20 projects)
- Building renovations and restorations (28 projects)

Potential climate adaptation contribution: These facilities could serve as public cooling spaces in neighbourhoods where residents lack private cooling options, as identified in the socio-economic vulnerability analysis.

Energy efficiency in buildings (39 interventions, 8.3%)

Building retrofits to reduce energy consumption and improve thermal performance:

- Energy retrofits (29 projects) including insulation and HVAC upgrades
- Cool roof and wall installations (6 projects) to reduce heat absorption
- Social housing efficiency improvements targeting low-income residents

Vulnerability response: Aims to reduce cooling costs for low-income households identified in section 3.1.1 while decreasing overall heat generation.

Urban agriculture and food security (27 interventions, 5.8%)

Local food production initiatives in urban areas:

- Educational gardens in schools (17 projects) for climate education
- Community urban gardens (10 projects) for local food access
- Aeroponic greenhouses and alternative growing systems

Vulnerability response: Provides green spaces in dense urban areas while supporting local food systems and community networks.

Spatial distribution and vulnerability alignment

The overlay of the 469 catalogued interventions on the comprehensive socio-climatic vulnerability map (Figure 3) reveals an uneven distribution across Turin's territory. While interventions appear throughout the city, their concentration does not consistently align with areas of highest comprehensive vulnerability (shown in lighter red tones). The spatial pattern suggests a complex relationship between intervention placement and vulnerability types, where projects address different dimensions of urban challenges beyond pure climate risk. Comparing the vulnerability dimensions reveals important nuances in intervention targeting:

- **Socio-economic vs climatic divergence**: Several intervention clusters appear in areas showing high climatic vulnerability (red) but low socio-economic vulnerability (green). These industrial and commercial zones, while lacking resident populations, generate heat that affects surrounding neighbourhoods. Interventions here—primarily permeable surfaces and green infrastructure—address source problems rather than direct human exposure. Conversely, some densely populated residential areas show high socio-economic vulnerability but moderate climatic stress. School infrastructure and public service improvements in these zones provide community resources that can serve dual adaptation functions even where environmental heat risk is not extreme.
- **Multi-dimensional hotspots**: Areas where both vulnerabilities converge (appearing as lighter red in the comprehensive vulnerability map) show variable intervention coverage. The northern periphery, despite high scores in both dimensions, demonstrates sparse coverage, while some central areas with similar combined scores show higher intervention density—suggesting factors beyond vulnerability drive investment decisions.

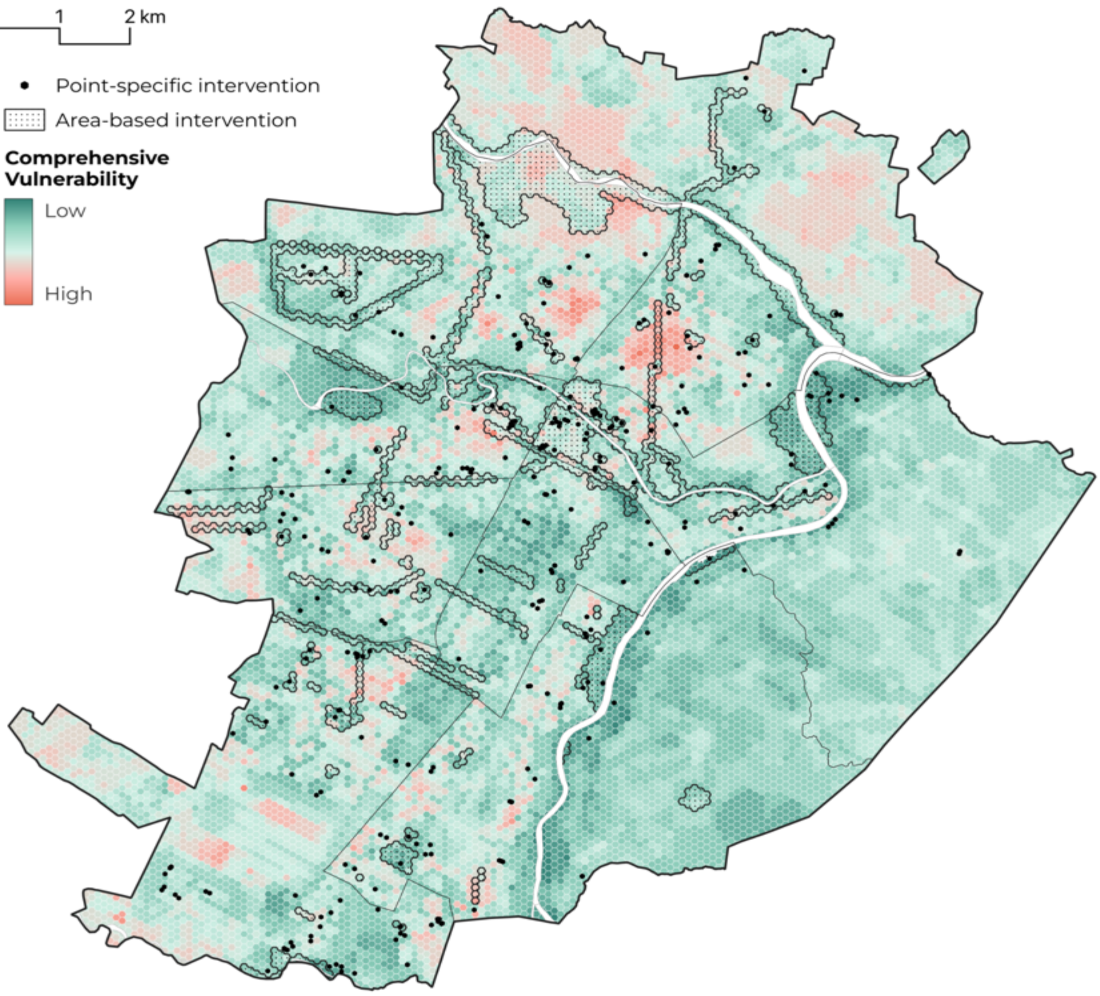

Figure 7 | Overlap of the city's interventions over the comprehensive map of vulnerability to urban heat in Turin (Source: Authors elaboration)

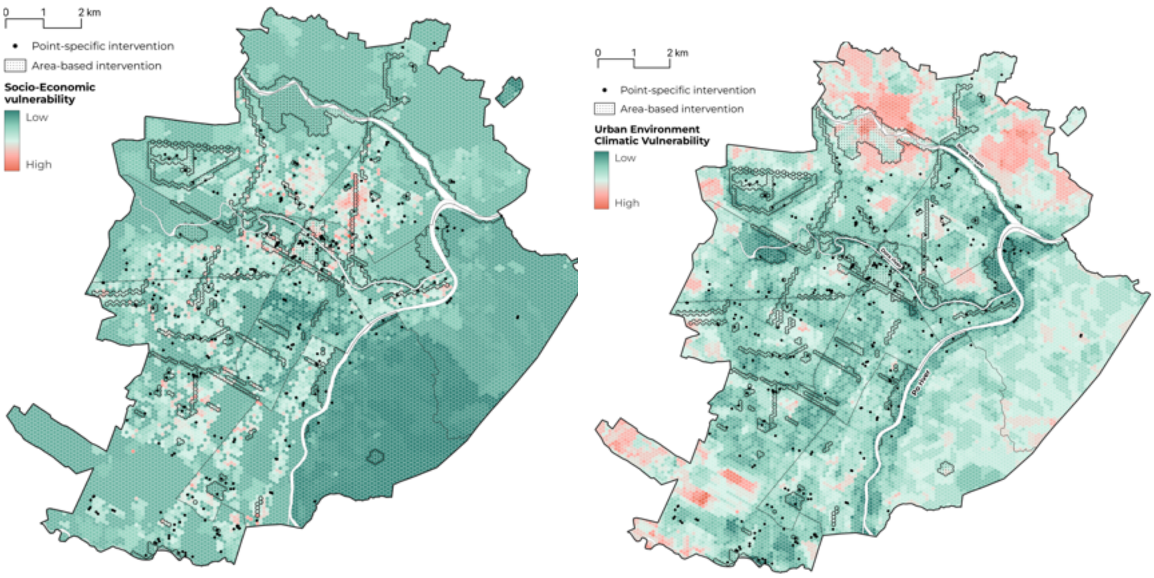

Figure 8 | Overlap of the city's interventions over the maps of socio-economic (left) and urban environmental-climatic vulnerability (right) to urban heat in Turin (Source: Authors elaboration)

Not all interventions in low-vulnerability areas represent misaligned investment:

Urban regeneration needs: Central districts showing lower vulnerability across all dimensions still receive substantial interventions, particularly in public space rehabilitation and mobility infrastructure. These projects often address urban decay, obsolete infrastructure, or changing land use patterns—legitimate urban needs independent of climate vulnerability.

Preventive interventions: Some green infrastructure projects in currently low-vulnerability areas may serve preventive functions, maintaining existing resilience rather than responding to acute stress. The concentration along river corridors exemplifies this approach, preserving natural cooling systems before they degrade and improving accessibility to the resource.

Network Connectivity: Mobility and infrastructure interventions in moderate-vulnerability zones often serve to connect high-vulnerability areas to resources, creating access corridors rather than place-based solutions. These linking interventions are essential for system-wide resilience even when located outside critical zones.

Critical Gaps and Opportunities

Constituency 6 paradox: This district exemplifies the complexity—showing high comprehensive vulnerability yet receiving limited interventions (50 total, 10.6%). However, the few large-scale area interventions present suggest recognition of need but insufficient follow-through with complementary point interventions.

Industrial zone opportunities: Areas with extreme climatic vulnerability but minimal socio-economic vulnerability (due to low residential density) represents strategic intervention points where heat island mitigation could benefit adjacent residential areas. Current intervention density in these zones remains insufficient given their systemic impact.

Adaptation vs transformation: The distribution pattern suggests Turin's interventions blend climate adaptation with broader urban transformation goals. While this integrated approach has merit, it may inadvertently underserve areas needing urgent climate-specific interventions, particularly where vulnerable populations cannot wait for comprehensive regeneration.

This spatial analysis reveals that intervention placement reflects multiple urban priorities beyond climate vulnerability alone. While this multi-objective approach has validity, the climate shelter initiative offers an opportunity to strategically supplement existing patterns with targeted interventions in underserved high-vulnerability areas, particularly southern Constituency 6 where vulnerable populations lack both adequate current infrastructure and pipeline projects.

3.2 Analysis and Mapping of Vulnerability in Halandri

The Municipality of Halandri, with 74,192 residents (ELSTAT, 2021 Census) and an area of 10.8 km², is the largest municipality in North Athens (Attica Region). Since the mid-1970s, it has undergone **steady urban transformation, characterised by expansion and significant densification of the built environment, but also differentiations in the social composition of the various districts**, as many residents relocated from central Athens to the northern and southern suburbs of the metropolitan area. Today, Halandri maintains a predominantly residential character with an overall moderate urban density of 7,589 residents/km², higher than its neighbouring municipalities but lower than central Athens, while facing typical contemporary **environmental pressures and climate risks of Mediterranean cities.**
Halandri is increasingly exposed to a combination of climate-related hazards, with **extreme heatwaves during the summer months** posing the most significant and escalating risk. The projected intensification of the Urban Heat Island (UHI) effect by 2050 in Europe (EEA, 2024) further amplifies the danger, placing the municipality's population under severe health and safety threats. At the same time, overlapping hazards such as urban flooding, as evidenced by major historical flood events (Figure 9), and the growing incidence of wildfires, exemplified by a large fire in 2023, underscore the municipality's heightened vulnerability to multiple, interacting climate risks.

These climate-related pressures are closely linked to Halandri' s urban morphology, where patterns of density, land use, and green–blue infrastructure shape the municipality's vulnerability, but also provide opportunities to apply climate adaptation strategies and enhance resilience. **Halandri's urban structure presents a spatial contrast**, with denser residential and mixed-use areas concentrated in the central and southern parts, while the northern zone presents more suburban features with newer developments. The municipality is framed on its eastern and western edges by major road arteries, which both connect it to the wider metropolitan area and act as physical boundaries. At its heart lies a vibrant commercial centre, organized around a network of pedestrian streets that support retail, leisure, and cultural activities. Cutting across this urban fabric, the **Stream of Halandri** forms a vital blue – green corridor, offering ecological, recreational, and climatic benefits that counterbalance the pressures of urban density. Linked to urban and physical morphology variations, heat exposure and thermal conditions are not uniform across the municipality. According to the climatic analysis of the Regional Climate Change Adaptation Plan of Attica (RePACC, 2020), the southern neighbourhoods of Halandri are consistently warmer than the northern parts of the municipality. As illustrated in Figure 10, South Halandri has recorded longer periods of high daily temperatures (above 35 °C) compared to the northern districts.

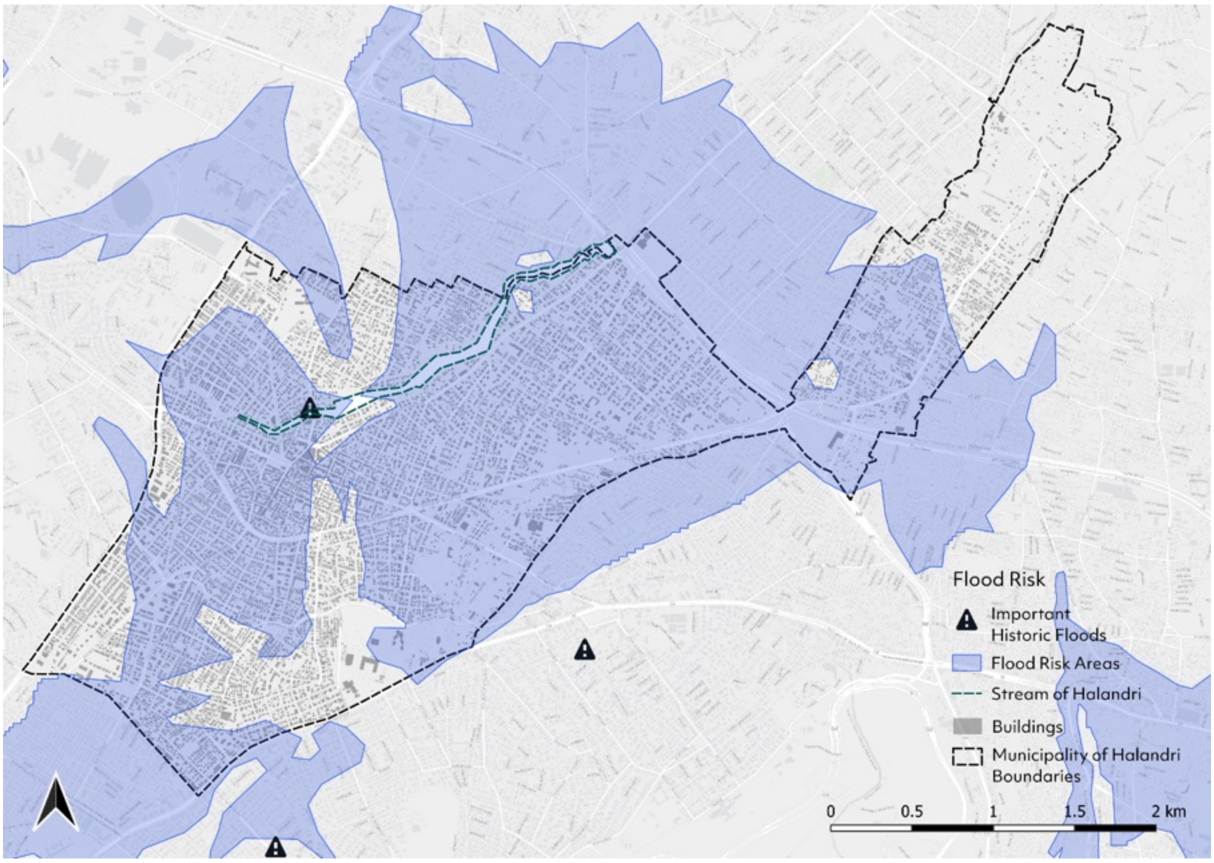

Figure 9 | Map of flood risk areas in Halandri. (Source: Authors elaboration. Data source: Ministry of Environment and Energy)

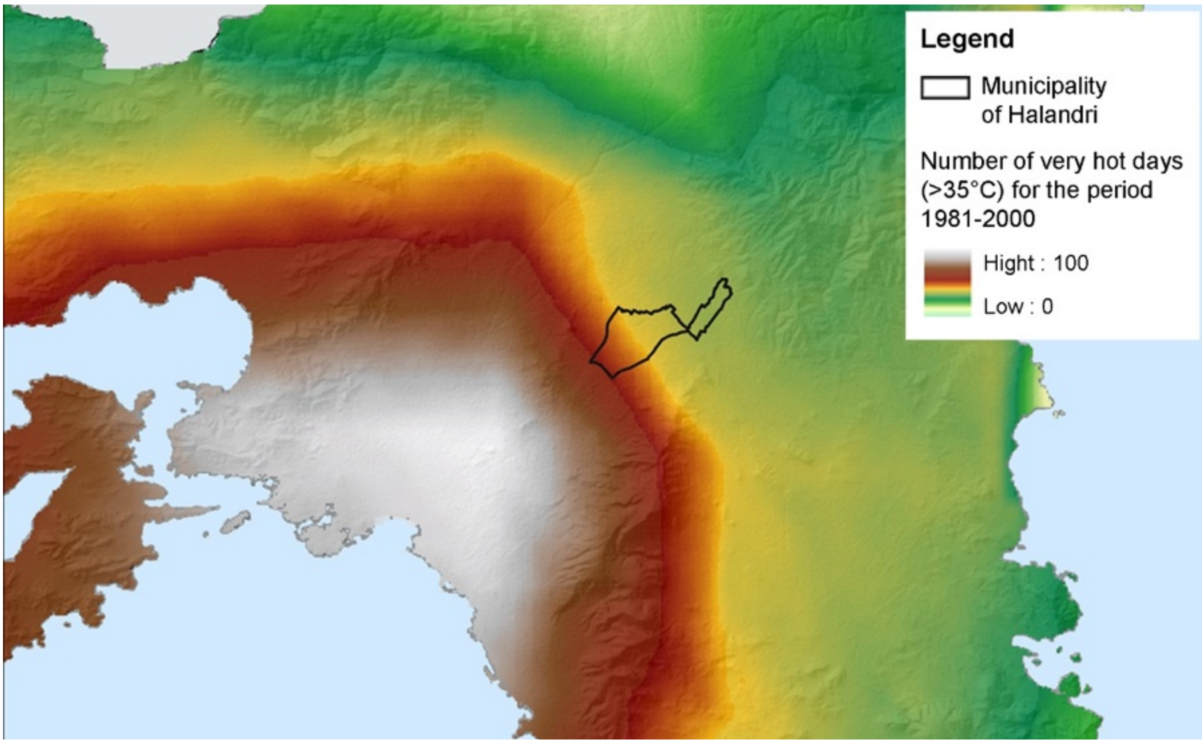

Figure 10 | Number of very hot days in the Region of Attica, including the Municipality of Halandri. (Source: Climate Change Adaptation Plan of Attica Region – RePACC 2020)

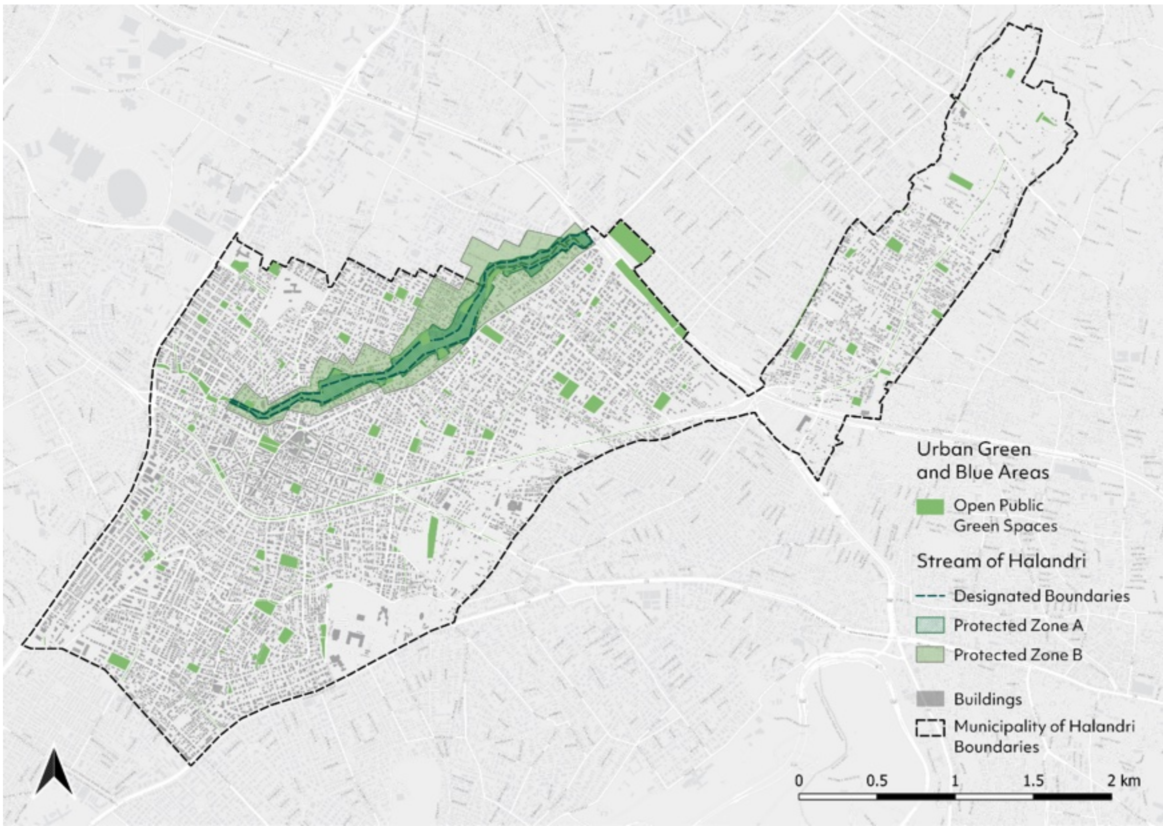

Figure 11 | Map of urban green and blue areas in Halandri. (Source: Authors elaboration. Data Source: Halandri Geospatial Portal)

In terms of environmental characteristics, **Halandri displays a mixed profile of both valuable natural assets and challenges.** The Stream of Halandri, originating on the southwestern slopes of Mount Penteli, is shaped by the merging of three tributaries and flows through Halandri. The distinct ecological value of Halandri Stream is highlighted by the existence of a special protection regulation, which has designated protected zones. (Figure 11). The semi-arid local climate has become hotter in recent years, with more frequent intense rainfall, making the stream's role in microclimate regulation increasingly important. Moreover, its flowing water and riparian vegetation provide natural cooling, mitigating urban heat and offering a buffer against flooding risks. Geomorphologically dynamic, with slopes ranging from 2% to 47%, it continuously reshapes its channel. The stream corridor hosts rich Mediterranean vegetation, including native and naturalized species such as plane trees and lentiscus, which enhance shade and evapotranspiration. It also serves as a permanent habitat and refuge for diverse bird species and a growing parrot population, highlighting its environmental value as both a biodiversity hotspot and a natural cooling source in Halandri's urban fabric [6]. At the same time, although Halandri hosts a green zone along Halandri Stream, and certain dispersed green areas, access to quality green infrastructure remains limited. An important challenge is the underutilization of the Stream, where some sections are being covered by unregulated vegetation and are

[6] Detailed information about the Stream of Halandri is provided in the Municipalities official website: https://www.chalandri.gr/yphresies/perivallon-aeiforia/rematia-xalandriou/

inaccessible. Furthermore, in recent years, Halandri's growth strategy has focused on market recovery and leisure-oriented development, with rapid expansion of restaurants, malls, and new transport links. While these investments boosted the local economy, they also strained urban resources, **increasing traffic, noise, and pressure on public and green spaces.** Indicatively, the city's park ratio is 2 sq.m. per resident, well below the metropolitan average[7], and walkability to accessible and well-maintained green areas is often weak. The characteristics outlined above provide a general profile of Halandri's socio-spatial trends and environmental climatic challenges. Building on this foundation, the following analysis of urban heat vulnerability adopts a more systematic approach. It first examines two key dimensions of vulnerability in Halandri: (a) the socio-economic vulnerability and (b) the urban environment climatic, that lead to the development of a comprehensive vulnerability map, produced through the methodological steps outlined in Chapter 2.

3.2.1 Socio-economic vulnerability in Halandri

The socio-economic vulnerability to urban heat refers to **how demographic, social and economic factors shape both the sensitivity of different population groups to extreme heat and their adaptive capacity to respond.** This assessment is essential because it reveals which communities are most exposed and least able to cope, thereby guiding targeted interventions for those who mostly need them.

The mapping of socio-economic vulnerability can be based on the combination of different factors depending on the context. In Halandri, eight (8) indicators were selected, informed on the one hand by established social vulnerability indices and relevant literature (McCullagh et al., 2025; Quian and Liu, 2025; Mah et al., 2023), and on the other hand by data availability[8]. The respective metrics were created through the processing of socio-demographic data from the latest Greek Census conducted by ELSTAT in 2021:

- **Population Density,** reflecting the extent to which larger concentrations of people are exposed to heat.
- **Age Dependency Ratio,** capturing the proportion of children and elderly, the age groups most sensitive to extreme heat.
- **Occupancy Density (m2 per resident),** used as a proxy for socio-economic status, refers both to adaptive capacity and to sensitivity to heat stress.
- **Non-EU Foreigner Population Ratio,** reflecting adaptive capacity
- **Population of Low Occupational Class Ratio,** reflecting adaptive capacity
- **Population without Tertiary Education Ratio,** reflecting adaptive capacity
- **Single-parent Households Ratio,** reflecting adaptive capacity
- **Households without Insulation Ratio,** reflecting adaptive capacity and revealing greater exposure to heat.

[7] The average parkland ratio in Athens is of 4.8 sq.m., as stated by the Municipality of Halandri, in the description of the area's challenges, here: https://culturalhidrant.eu/en/the-initiative/

[8] It is important to note at this point that income data were not available, and therefore we used other variables as proxies for the economic status.

The metrics used in the socio-economic vulnerability mapping in Halandri, along with the rationale of their selection, are outlined in Table 5, together with clarifications regarding the data processing for their creation in the GIS environment. In general terms, the GIS processing involved data initially provided at the urban block level, which were then aggregated onto a hexagonal grid, with each hexagon covering the area of approximately three urban blocks in Halandri. After the necessary preprocessing, the values for each metric were normalized to a common scale of 0–100 and subsequently combined into a composite index representing the socio-economic vulnerability of Halandri.

SOCIO-ECONOMIC VULNERABILITY				
	Indicator / Metric	**Data Source**	**Description & Data Processing**	**Rationale / Relevance to Heat Vulnerability**
1	**Population Density (n)**	ELSTAT - Greek Census 2021	Number of inhabitants per hexagonal cell.	High population density amplifies the impacts of extreme heat by increasing exposure. In densely populated areas, the combined effects of built-environment heat retention and social vulnerability further reduce adaptive capacity, thereby intensifying overall vulnerability to heat extremes.
2	**Age Dependency Ratio (n)**	ELSTAT - Greek Census 2021	The sum of the children (ages 0-14) and the elderly population (ages 65+) divided by the working-age population (ages 15-64).	By reflecting the share of children and elderly relative to the working-age population, this demographic indicator captures the age groups that are more sensitive to heat stress, and also and also more reliant on others for care and protection.
3	**Occupancy Density (m2 per resident)**	ELSTAT - Greek Census 2021	The available data of the living space per resident are categorical and report the number of residences per occupancy density category. An estimation metric was developed to approximate the sqm per resident. The range midpoint was used as representative value for each category. For the open-ended categories (less than 10 sqm and more than 80 sqm per resident) the values were approximated as 5 sqm per resident (half of the upper limit) and 160 sqm per resident (double the lower limit), respectively.	High occupancy density serves as a proxy for low economic status and housing precarity, reflecting limited adaptive capacity to heat. It also reveals physical sensitivity to heat, as overcrowding leads to higher thermal stress.

4	**Non-EU Foreigner Population Ratio (%)**	ELSTAT - Greek Census 2021	The number of non-EU foreigner population, divided by the total population.	Foreign nationals are likely to have less local knowledge and limited access to local information, due to language barriers. Higher values of non-EU foreigner residents in particular often indicate immigrant populations with lower average income, reflecting reduced adaptive capacity to heat.
5	**Population of Low Occupational Class Ratio (%)**	ELSTAT - Greek Census 2021	The sum of two occupational class categories: (1) Unskilled workers - manual labourers, and (2) industrial plants, machinery, and equipment operators, divided by the working population.	A high proportion of low occupational class population represents socioeconomic disadvantage, and therefore reduced adaptive capacity. It also indicates higher exposure and sensitivity, as such jobs often require outdoor or physically strenuous work, increasing vulnerability to extreme heat.
6	**Population without Tertiary Education Ratio (%)**	ELSTAT - Greek Census 2021	The number of up-to-secondary education holders (sum of relevant educational categories) divided by the total adult population.	Higher values reflect reduced adaptive capacity to heat, as lower education often limits access to, understanding of, and use of information about heat risks and protective measures, reinforcing socioeconomic disadvantage and sensitivity.
7	**Single-parent Households Ratio (%)**	ELSTAT - Greek Census 2021	The number of single-parent households divided by the total households within each hexagonal cell.	It often serves as a proxy for lower disposable income and higher caregiving burdens, reflecting reduced adaptive capacity to heat, as limited resources and responsibilities constrain access to cooling and safe refuge during extreme heat events.
8	**Households without Insulation Ratio (%)**	ELSTAT - Greek Census 2021	The number of households lacking thermal insulation divided by the total number of households within each hexagonal cell.	Higher values indicate greater physical sensitivity to heat, as poorly insulated homes experience higher indoor temperatures and limited protection during extreme heat events. It is considered a socio-economic indicator, as it reflects households' financial capacity to implement protective measures against heat.

Table 5 | List of metrics used in the mapping of socio-economic vulnerability in Halandri

A series of maps displaying the above-described metrics are included at the end of the document in the Appendix. Population density is lower along the eastern boundaries of Halandri, particularly in Nomismatokopeio, an area with generally limited housing. Metrics related to the population's social composition, such as age dependency ratio / age groups, non-EU residents, and educational and occupational characteristics, show little variation across Halandri and do not form clear spatial patterns. In contrast, the economic profile of the population reveals a distinct socio-spatial trend, with north-western Halandri (Patima) exhibiting greater financial resources, as indicated by higher average living space per resident and a lower proportion of households without insulation, a fact that reflects the area as a more recently developed, suburban district.

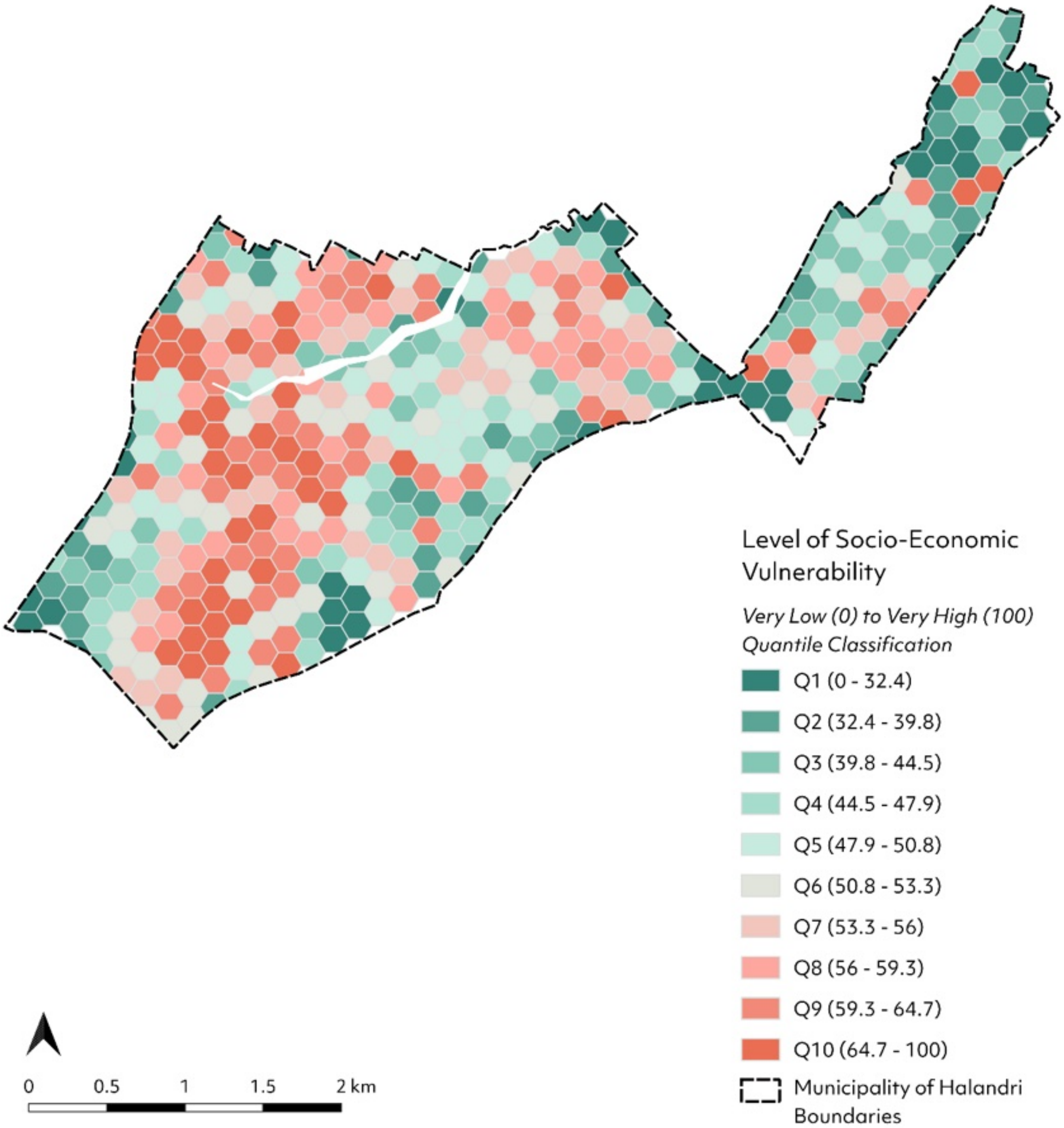

Figure 12 | Map of socio-economic vulnerability to urban heat in Halandri
(Source: Authors elaboration. Data source: ELSTAT - Greek Census 2021)

The map of socio-economic vulnerability in Halandri (Figure 12) that synthesizes these different variables, shows a concentration of higher values in the central and southern parts of the municipality, covering the entire Centre district, the eastern side of Kato Halandri, and, to a lesser extent, the Synoikismos district. A slightly weaker concentration of relatively high vulnerability is observed in the Toufa district in the north, while the lowest vulnerability values are found in the northern neighbourhood of Patima and along the peripheries of Halandri, particularly in the west-south and Nomismatokopeio areas. Overall, these results reveal **a distinct socio-spatial pattern, with lower vulnerability in north-western Halandri (Patima) and higher vulnerability concentrated in the central and southern neighbourhoods (Centre, Kato Halandri, Synoikismos).**

3.2.2 Urban environmental-climatic vulnerability in Halandri

The urban environment climatic vulnerability to heat addresses **the physical and environmental characteristics of the urban form that determine both the exposure of residents to high temperatures and the capacity of the built environment to mitigate them.** This dimension captures the spatial distribution of heat-related risks by considering factors such vegetation, surface material and imperviousness, density of the built fabric, and microclimatic conditions (e.g. land surface temperature). Mapping these characteristics reveals the neighbourhoods, that are structurally more exposed to extreme heat and where planning interventions that target climate adaptation, such as shading, greening, or improving surface permeability, can have the greatest impact.

The mapping of urban environment climatic vulnerability in Halandri is grounded in a set of place-based indicators that reflect the city's urban form and environmental features. Seven (7) metrics were selected in direct relation to the physical features and climatic conditions of Halandri, while also taking into account the availability of reliable of high-quality geospatial datasets. These metrics were derived primarily from Copernicus datasets and the Municipality of Halandri's Geospatial Portal and were processed within the GIS environment.

1. **Availability of Urban Green and Blue Areas (m² per resident),** representing the direct proximity of residents to accessible public green and blue spaces, weighted by population.
2. **Availability of Active streets (m per resident),** representing the presence of shaded and ventilated mobility networks, and calculated from the length of pedestrian streets and cycleways per resident.
3. **Floor Space Index (FSI),** quantifying the density of the built environment by combining land use intensity with building height.
4. **Impervious Density (IMD),** expressing the proportion of impervious surfaces (roads, pavements, buildings) within each unit.
5. **Normalized Difference Vegetation Index (NDVI),** indicating the density and health of vegetation as derived from satellite data.
6. **Land Surface Temperature (LST °C),** measuring the average surface temperature per unit, derived from satellite thermal data.
7. **Tree Cover Density (TCD %),** representing the ratio of area covered by tree canopy.

Table 6 presents the metrics used in the urban environment climatic vulnerability mapping in Halandri, their relevance to urban heat vulnerability, and details on the GIS processing. The several environmental and urban form-related data were aggregated onto the same hexagonal grid used for socio-economic vulnerability, and similarly the values for each metric were normalized to a common scale of 0–100 and then synthesized into a single measure reflecting the degree of climatic vulnerability of Halandri' s urban environment.

URBAN ENVIRONMENT CLIMATIC VULNERABILITY				
	Indicator / Metric	**Data Source**	**Description & Data Processing**	**Rationale / Relevance to Heat Vulnerability**
1	**Availability of Urban Green and Blue Areas (m^2 per resident)**	Municipality of Halandri Geospatial Portal	It represents the direct proximity of residents to public urban green and blue spaces. The total area (m^2) of accessible green and blue areas in Halandri is calculated from two spatial layers: (1) the Penteli–Halandri stream boundaries and (2) the Municipality's registered urban green spaces, and then weighted by the population to obtain per capita availability.	Higher availability of accessible urban green and blue areas reduces exposure to heat. These areas remain cooler than built environments and can serve as important refuges during heatwaves. In addition, vegetation and water bodies improve the local microclimate by reducing surface and air temperatures, enhancing shade, and mitigating the urban heat island effect.
2	**Availability of Active Streets (m per resident)**	Municipality of Halandri Geospatial Portal	It refers to the direct proximity to active street mobility network. The total length (m) of active streets derives from two layers: (1) the pedestrian streets (2) cycleways, and then it is weighted by the population to obtain per capita availability.	Availability of active streets contributes to lower heat exposure, as a higher density of pedestrian streets and cycleways provides shaded, ventilated routes, reduces local car traffic, and allows residents to move through cooler areas during heat events.
3	**Floor Space Index (FSI)**	Copernicus	Floor Space Index (FSI) is a measure of urban density that quantifies the ratio between the total floor area of buildings and the area of the land they occupy. For its calculation, the building height layer was assigned to Urban Atlas blocks (Copernicus). After the calculating the ratio of built-up area to total block area (GSI), the FSI was obtained by multiplying this ratio (GSI) by the mean building height, providing a measure that captures both horizontal and vertical built volume.	Higher FSI values indicate denser built environments, which are often associated with reduced natural ventilation, higher heat retention, and greater overall exposure to urban heat.
4	**Impervious Density IMD (%)**	Copernicus	Impervious density (%) refers to the proportion of land area covered by impervious surfaces, such as buildings, roads, and pavements. The data used were initially in raster format; they have been converted to vector polygons, representing the impervious surface density (%) for each hexagon.	Areas with high impervious density retain more heat and have reduced natural cooling from vegetation, resulting in elevated local temperatures, thereby indicating increased heat vulnerability for residents in these areas.

5	**Normalized Difference Vegetation Index (NDVI)**	Copernicus	NDVI is a broadly used satellite-derived metric for quantifying the health and density of vegetation. NDVI is a standardized index (–1 to +1), thus during data processing, no rescaling was applied. Raster data were converted into vector, areas with values ≥ 0 were extracted, and zonal statistics (MEAN) were calculated for each hexagon to find the average NDVI per spatial unit.	NDVI is a commonly used metric for the assessment of urban heat vulnerability. Higher NDVI values indicate more abundant and healthier vegetation, which contributes to natural cooling, shading, and improved microclimatic conditions, thereby reducing heat exposure and vulnerability for nearby populations.
6	**Land Surface Temperature LST (°C)**	Copernicus	LST derives from satellite thermal data and represents a specific time snapshot of the Earth's surface temperature. The LST raster data were converted to vector format, and zonal statistics (mean) were calculated for each hexagon to obtain the average values per unit.	As a measure of the Earth's surface temperature (soil, vegetation, buildings, etc.), LST is a key indicator of heat vulnerability. It highlights urban heat islands and areas where people are more exposed to heatwaves.
7	**Tree Cover Density TCD (%)**	Copernicus	Tree Cover Density (TCD) refers to the proportion of an area covered by tree canopy, expressed as a percentage. After converting data from raster to vector format, the average values were calculated for each cell.	TCD is an important metric in the assessment of heat vulnerability, as higher tree cover reduces exposure to heat through shading. Urban areas with low TCD are more susceptible to urban heat island effects and related health risks.

Table 6 | List of metrics used in mapping of urban environmental-climatic vulnerability in Halandri

The mapping of urban environmental-climatic vulnerability in Halandri provides important insights into how the city's physical and environmental characteristics shape exposure to heat and its spatial distribution. As demonstrated in the maps of the different metrics, available in the Appendix, **along the Halandri Stream, favourable values are recorded across several indicators, including accessibility to green–blue areas, proximity to active streets, tree cover density, NDVI, and land surface temperature (LST).** This finding reflects the cooling and regulating effect of this natural corridor. In contrast, **Patima performs poorly in terms of vegetation-related metrics and LST**, although the Floor Space Index (FSI) shows more favourable values due to the lower density of built structures. Elevated LST values are also clearly observed along the eastern boundaries of the municipality. Finally, the commercial centre, despite its relative proximity to the Stream, is marked by high impervious density (IMD) and low NDVI values, which decrease its climatic performance and underline the intensity of built-up pressure in this core urban zone.

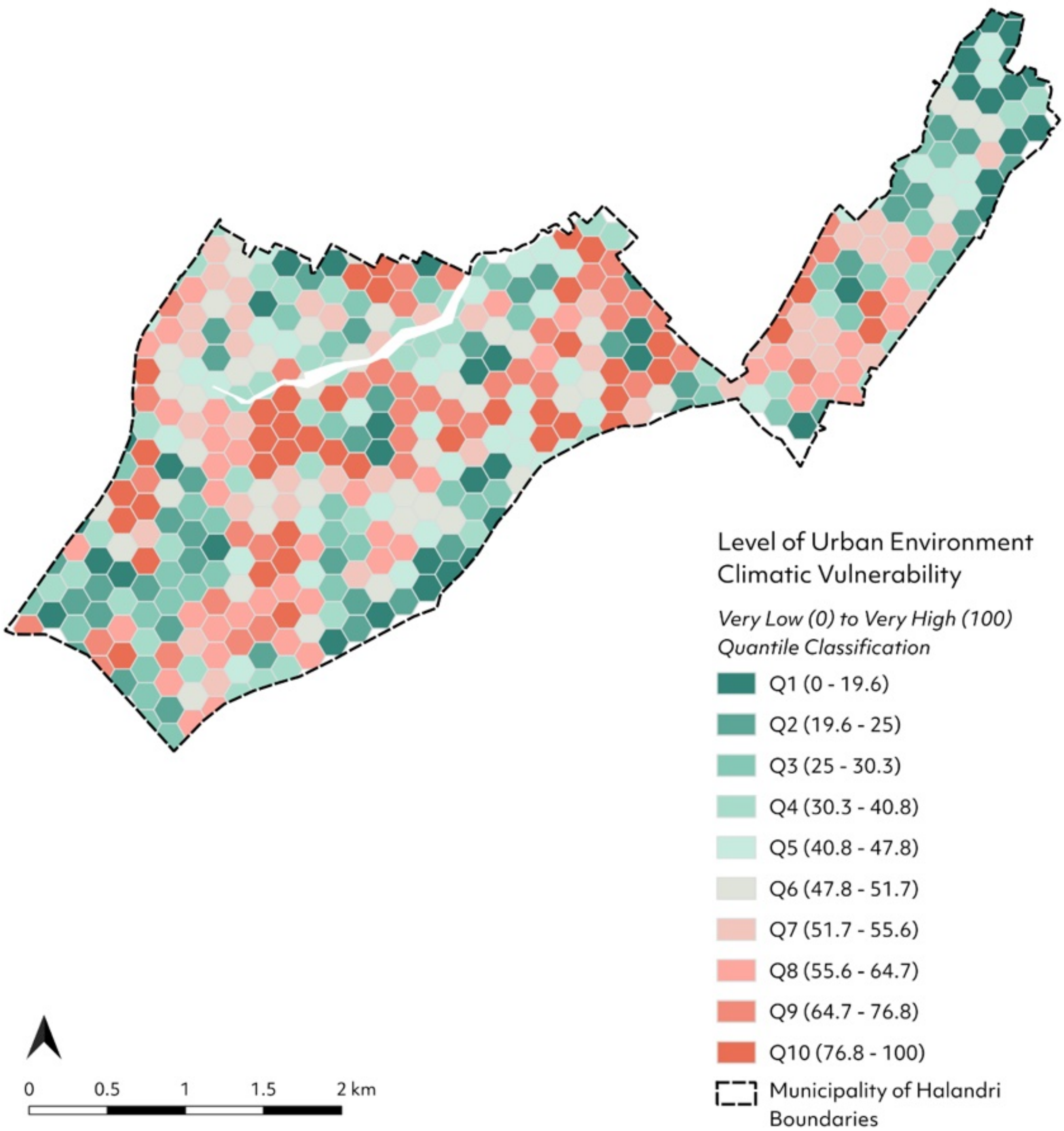

Figure 13 | Map of urban environmental-climatic vulnerability in Halandri
(Source: Authors elaboration. Data Source: Copernicus, Halandri Geospatial Portal)

The map of urban environment climatic vulnerability in Halandri (Figure 13), reveals a more complex and fragmented spatial distribution compared to the socio-economic dimension. Clusters of high vulnerability appear not only in the Centre, Kato Halandri, and Toufa, but also in Patima in the north. Furthermore, the distribution is far from uniform, with cells of high vulnerability emerging within generally low-vulnerability areas and vice versa. This patchwork pattern highlights the decisive role of local microclimatic conditions, where features such as the availability and quality of green spaces, or the presence of highly impervious surfaces, can strongly influence the immediate surroundings. The result is **a spatial mosaic of vulnerability driven from physical and spatial conditions, where even small-scale differences in urban form and environmental quality create sharp contrasts in exposure to heat across Halandri.**

3.2.3 Comprehensive map of vulnerability in Halandri

The comprehensive vulnerability map in Halandri synthesises the socio-economic and urban environmental-climatic dimensions discussed in the previous sections into one measure, allowing for a holistic assessment of urban heat risks in Halandri. Using the same hexagonal grid framework, the normalised scores of the two dimensions were averaged, producing a composite metric that ranges from very low (0) to very high (100) vulnerability. This approach ensures comparability across heterogeneous datasets while maintaining an appropriate spatial resolution. The resulting map classifies the municipality into ten quantiles, making visible the convergence of social and environmental factors in shaping exposure to extreme heat.

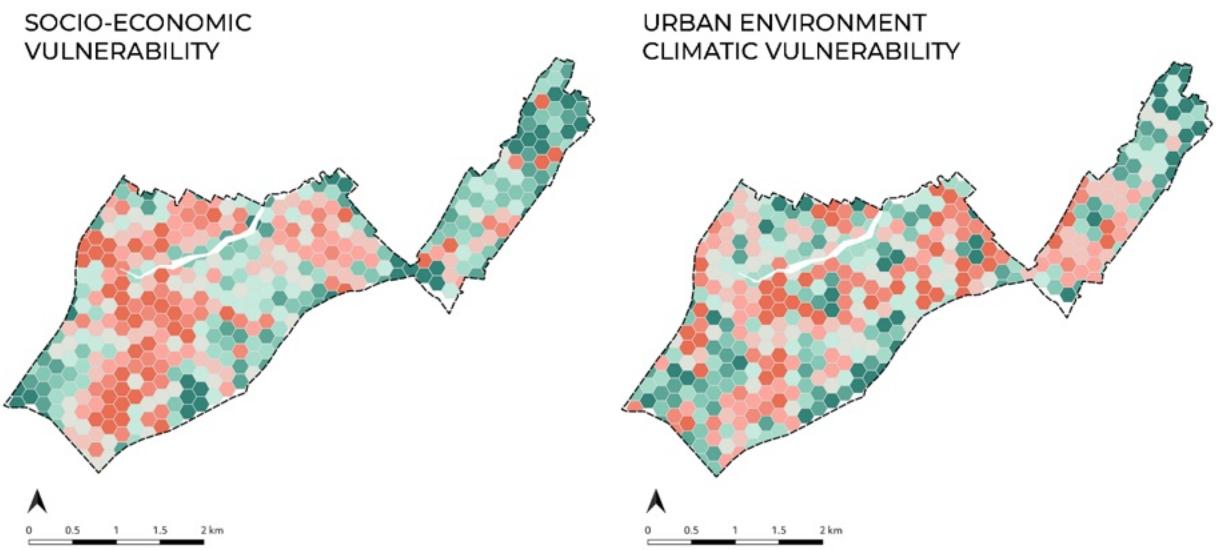

Figure 14 | The two key dimensions of Halandri's vulnerability to heat (Source: Authors elaboration).

The map reveals a pronounced clustering of high vulnerability values (Q8–Q10) in the central and southern districts, including the commercial Centre, parts Kato Halandri, and the east side of Synoikismos. These areas are characterized by both higher social vulnerability and adverse environmental conditions, such as dense built fabric and limited vegetation, which jointly amplify exposure to heat. Elevated vulnerability is also observed in the easternmost part of the municipality, in the district of Toufa, where impervious surfaces and high land surface temperatures prevail. In contrast, the lowest quantiles (Q1–Q3) are predominantly located in Patima, in the north-west, and in certain western peripheral areas in Nomismatokopeio, where a lower population density, more favourable socio-economic conditions and a less compact built form reduce overall vulnerability.

At the same time, **the spatial distribution is far from uniform, reflecting a mosaic-like pattern across the municipality.** High-vulnerability cells often emerge next to lower ones, particularly along transitional zones between the commercial core, the stream corridor, and residential neighbourhoods. This variability highlights the decisive role of local factors such as tree cover, green-blue infrastructures, land surface temperature, but also socio-demographic composition in shaping micro-scale vulnerability outcomes. **The patchwork**

nature of the results underlines the need for targeted, place-based interventions, as even within generally moderate or low-vulnerability zones, isolated hotspots of high risk persist. Finally, this finding also aligns with the MAINCODE upscaling approach that prioritizes the network of urban climate shelters across the city.

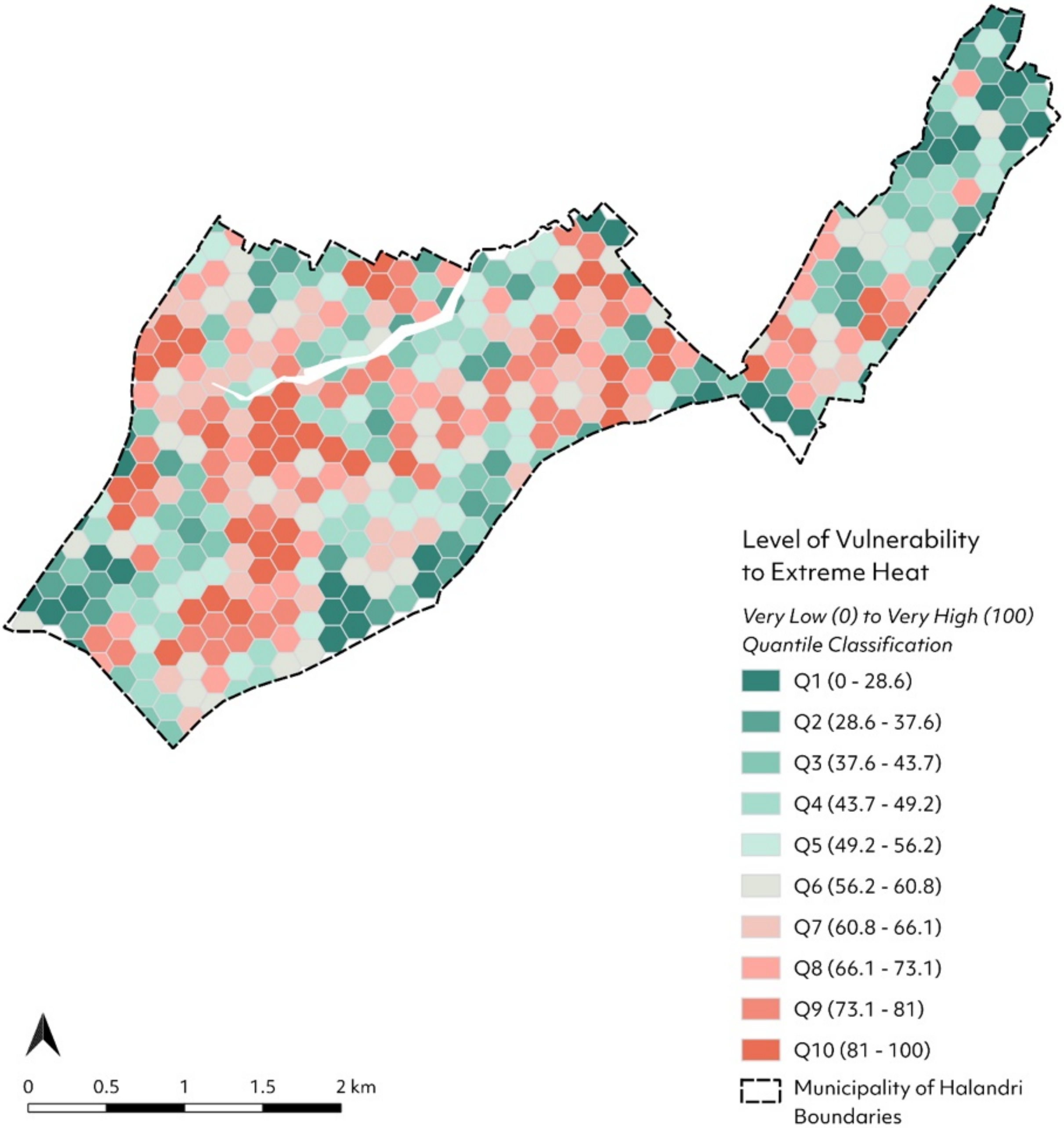

Figure 15 | Comprehensive map of vulnerability in Halandri (Source: Authors elaboration. Data source: ELSTAT - Greek Census 2021, Copernicus, Halandri Geospatial Portal)

3.2.4 Urban initiatives towards climate adaptation in Halandri

This subchapter presents the main urban initiatives of Halandri towards climate adaptation and resilience, with the aim to: (a) understand the strategic position of the Municipality regarding urban heat vulnerability, (b) examine the distribution of existing urban interventions, and (c) identify potential synergies to support the upscaling of MAINCODE

Urban Climate Shelter approach in Halandri. The various programs and projects listed and analysed below through a climate adaptation lens are identified through municipal databases and official websites, and discussions with key informants from the Municipality of Halandri.

In recent years, **the Municipality of Halandri is increasingly undertaking initiatives related to urban regeneration and climate adaptation**. Although Halandri doesn't have a local climate plan[9], the municipality has initiated numerous targeted practices and interventions focusing on sustainable mobility, NBS in urban regeneration, blue and green areas revitalization, waste management, energy efficiency, etc., that shape a coherent strategy towards sustainable urban development. Furthermore, Halandri is actively participating in relevant international and European urban networks that foster integrated development approaches to urban resilience, such as the European Energy Cities and URBACT Hydro-Heritage Cities.

The recently implemented and ongoing urban initiatives in Halandri that contribute in the reduction of the urban heat effects and climate-related vulnerability of the local population are listed in Table 7 below.

URBAN RESILIENCE INITIATIVES IN HALANDRI				
	Program / Project	**Implementation Stage**	**Funding Source**	**Scope / Area(s) of Focus**
1	Urban Sustainable Mobility Plan & Urban Accessibility Plan	Implemented	National - Green Fund (Ministry of Environment & Energy)	Mobility (pedestrian streets and cycleways, public transportation)
2	Cultural H.ID.RA.N.T.[10] - Hidden Identities ReAppear through Networks of water	Implemented	EU – European Regional Development Fund Urban Innovation Act (UIA)	Water Management, Cultural Hetitage, Participatory Urban Design, Urban Regeneration, NBS
3	Program 'Housing and employment for the homeless' (1st and 2nd Cycle)	Implemented (3rd Cycle ongoing)	National Fund (Ministry of the Interior)	Housing, Social Care
4	Public space (square) development in Patima	Implemented	Municipal Fund	Urban Regeneration, NBS
5	Bioclimatic urban regeneration of Halandri's commercial center	Ongoing	Recovery and Resilience Fund	Urban Regeneration
6	Sustainable Micromobility	Ongoing	National Fund 'Transport, Environment & Sustainability'	Mobility
7	Energy Efficiency Upgrades of Municipal Buildings (incl. public schools)	Ongoing	Regional Operational Programme of Attica	Sustainable Energy

[9] A strategic planning tool for integrating climate adaptation into local policies and actions has been developed at the regional level, the Climate Change Adaptation Plan of Attica Region (RePACC). This plan identifies the main climate threats and vulnerabilities of the broader region and proposes sector-specific adaptation actions, that affect the municipal context.

[10] https://culturalhidrant.eu/en/

8	Power Saving Check Goes Citizens	Ongoing	EU Program Erasmus+	Sustainable Energy, Citizen Participation
9	Green deal goes citizens	Ongoing	EU Program Erasmus+	Citizen Participation, Climate Crisis Awareness
10	Biowaste Management Initiatives & Pilot Actions for Separate Collection of Waste – "Pay as You Throw"	Ongoing	Recovery and Resilience Fund & National Fund 'Transport, Environment & Sustainability'	Waste Management
11	ToNoWaste[11] – Towards a new zero food waste mindset based on holistic assessment	Ongoing	EU Program HORIZON	Waste Management
12	Energy2Act[12]	Ongoing	EU - European Urban Initiative (EUI)	Sustainable Energy, Citizen Participation
13	URBACT Hydro-Heritage Cities[13]	Ongoing	URBACT Innovation Transfer Network	Water Management, NBS, Citizen Participation
14	Water Sensitive City[14] Thematic Partnership	Ongoing	Urban Agenda for the EU	Water Management, NBS, Citizen Participation
15	Douzeni Distillery Site: Revitalization of industrial Spaces	Ongoing	EU Program – Driving Urban Transitions (DUT)	Housing, NBS

Table 7 | List of urban initiatives in Halandri aimed to climate adaptation and urban resilience[15]

The identified interventions and programs in Halandri can be summarized into the following **key areas of urban action that advance climate adaptation**:

- **Development of a public spaces network through Nature-based Solutions (NbS) and green-Blue areas regeneration:** The most significant urban regeneration initiative in Halandri has been developed through the Cultural H.ID.RA.N.T. UIA project. This effort pursues a sustainable development path by fostering citizen participation, raising awareness of cultural and natural heritage, expanding walkable green areas, and introducing innovative blue–green infrastructure. At its core lies the regeneration of the Roman Hadrian Aqueduct, which is reintroduced into contemporary urban life as a resilient water-based system. More broadly, the project served as a pilot strategy for sustainable development in Halandri, that is further promoted through various urban interventions that followed. Building on the synergies and outcomes of Cultural H.ID.RA.N.T., an Integrated Territorial

[11] https://tonowaste.eu/
[12] https://www.urban-initiative.eu/calls-proposals/third-call-proposals-innovative-actions/selected-projects
[13] https://urbact.eu/networks/hydro-heritage-cities
[14] https://www.urbanagenda.urban-initiative.eu/partnerships/water-sensitive-city
[15] The is not an exhaustive collection of Halandri's planned urban interventions, but rather a selection of the latest relevant initiatives based on updated information by the Municipality of Halandri.

Investment (ITI) is currently being designed for the Hadrian Aqueduct, setting a strategic reference point at the metropolitan level.

- **Sustainable and active mobility:** Measures focus on redesigning streets with wider sidewalks, traffic calming, and street greening. In line with the Local Urban Plan for Sustainable Mobility, additional interventions include pedestrianization and the construction of bicycle lanes across the neighbourhoods of Halandri, as demonstrated in Figure 16. Highly relevant to MAINCODE is the ongoing establishment of a "green" walking route that links the district of Toufa (northern Halandri) with the city centre, connecting six school complexes and ensuring safe passage for students.
- **Energy efficiency:** Actions include the energy modernization of public buildings, including school facilities. Within this framework, the Municipality of Chalandri aims to establish an Energy Policy Implementation Office, in order to provide advice and measures for tackling energy poverty. At the same time, the Office will prepare a Municipal Climate Action Plan for Resilience and Adaptation through participatory and inclusive processes, recognising that this could become an essential tool for mobilizing financial instruments and funding sources connected to the Regional Climate Adaptation Plans.
- **Local community engagement and participation:** Citizen participation and co-production are recognized as key priorities, with growing community involvement in decision-making (e.g. participatory budgeting, public space and schoolyard co-design, promotion of citizen waste management initiatives, etc). This aspect is considered crucial in strengthening urban resilience and developing an integrated network of climate shelters.

The map in Figure 16 displays in a schematic way the spatial **distribution of the urban interventions toward climate adaptation in Halandri** on the one hand, and sketches their relation with the identified heat vulnerability hotspots in the city (Chapter 3.2.4) on the other hand, by overlaying them with the Comprehensive Vulnerability Map. It becomes evident that the recently implemented and ongoing actions are largely concentrated in areas most affected by climate threats, with a notable example being the dense network of designated pedestrian streets and greening practices in Central Halandri and other vulnerable parts of the city. In conclusion, while continued effort and coordinated planning are essential, **the stated initiatives undertaken in Halandri mark promising steps in addressing urban heat vulnerability, and present significant opportunities for synergies and upscaling through the MAINCODE Urban Climate Shelter approach.**

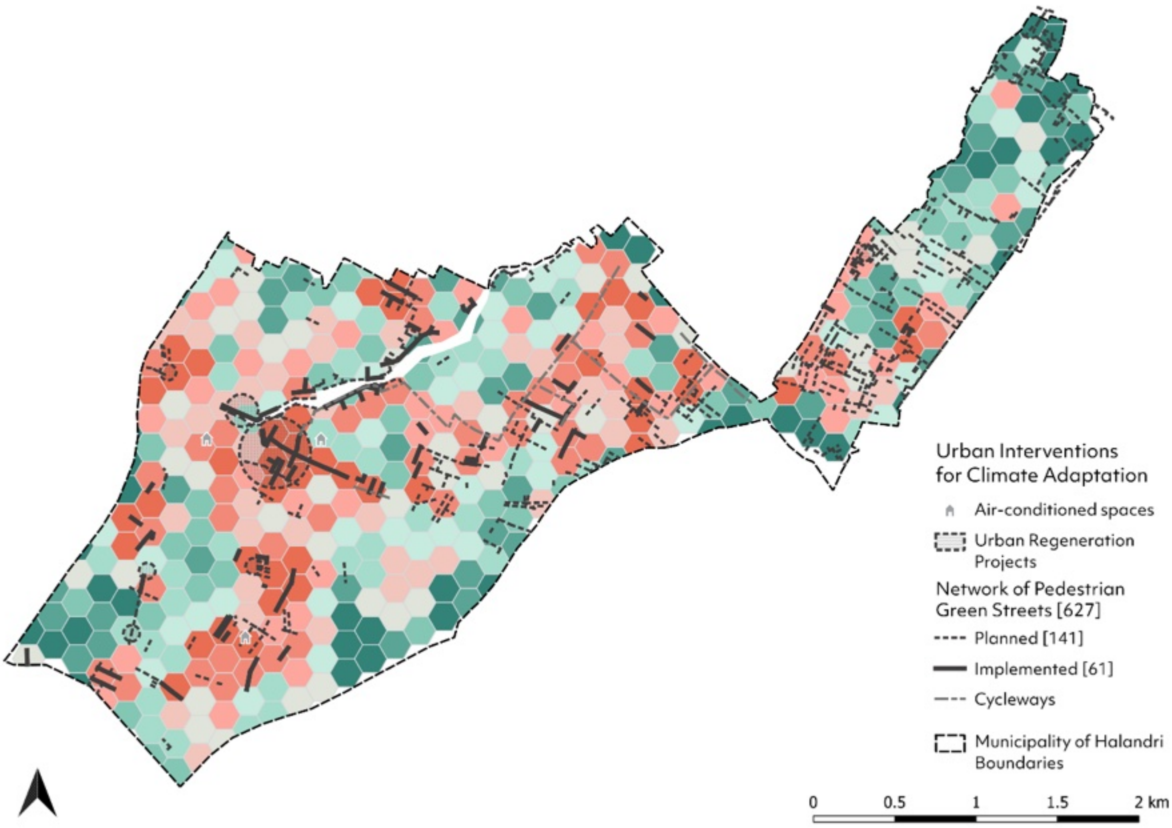

Figure 16 | Map of the recently implemented and ongoing urban interventions regarding climate adaptation in Halandri (Source: Authors elaboration. Data Source: Municipal Databases)

4. Focus Area(s) and Preliminary Shortlist of Schools

In Chapter 4, the focus is on identifying **a shortlist of primary schools in Turin and Halandri located within the focus areas**, namely the areas that are most vulnerable to urban heat. These priority zones, emerging from the comprehensive vulnerability mapping, serve as target areas for climate adaptation and specifically for UCS development within the MAINCODE context. The shortlisted schools within high-risk zones will be presented and analysed in terms of vulnerability, with additional information complementing the elements outlined in stakeholder mapping (D2.1). **This analysis will support the final school selection, which will also consider criteria such as accessibility, structural and environmental features of the schoolyard, and the willingness of the school community to cooperate, and will take place later in the MAINCODE project.**

4.1 Focus areas and preliminary shortlist of schools in Turin

Focus area(s) in Turin

The comprehensive vulnerability analysis presented in section 3.1.3 examined the intersection of socio-economic and climatic vulnerabilities across Turin's eight administrative districts (Constituencies). The synthesis of these analyses at district level provides clear evidence for prioritizing pilot interventions.

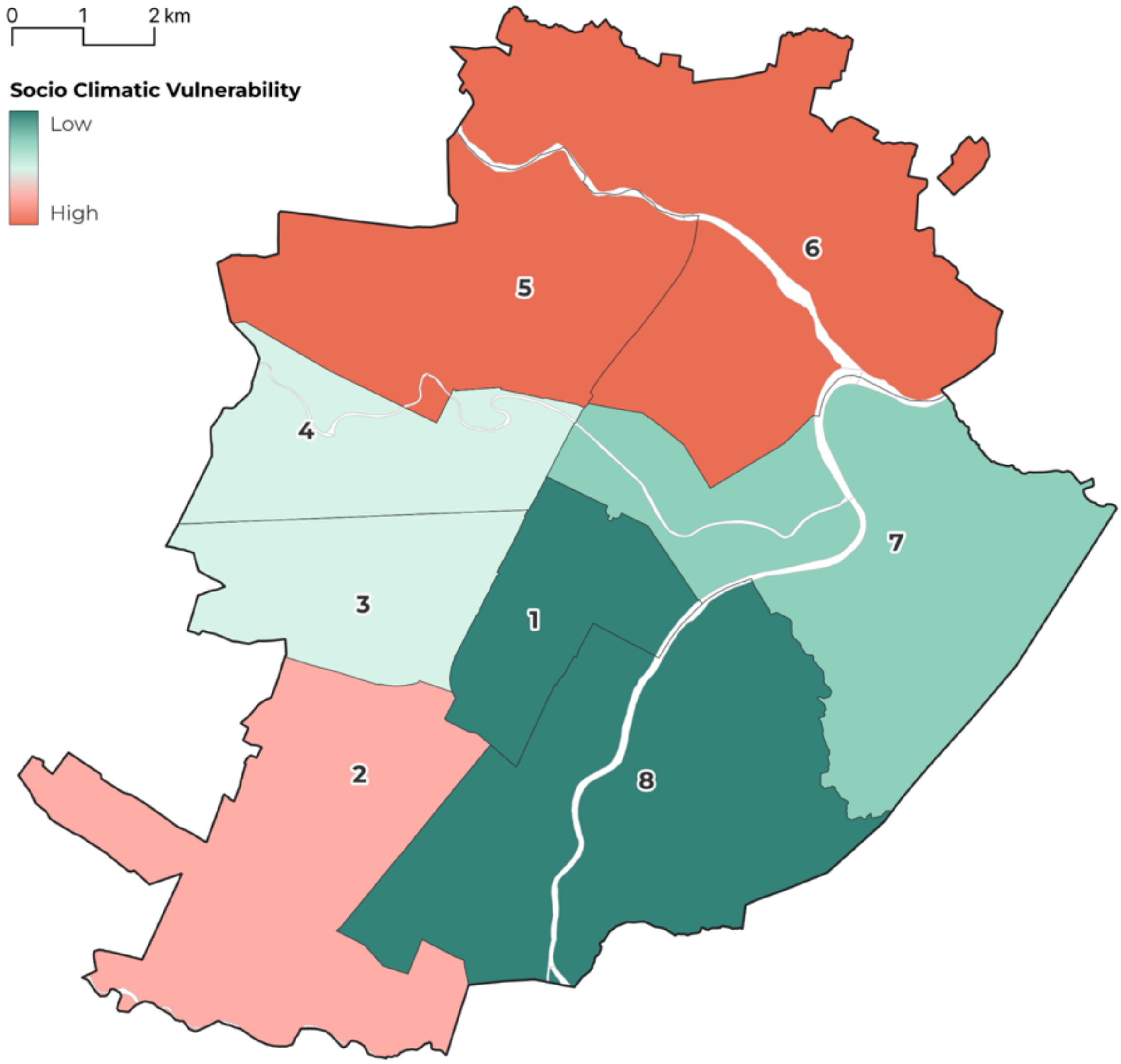

Figure 17 | Comprehensive map of vulnerability to urban heat in Turin - Constituencies aggregated data (Source: Authors elaboration)

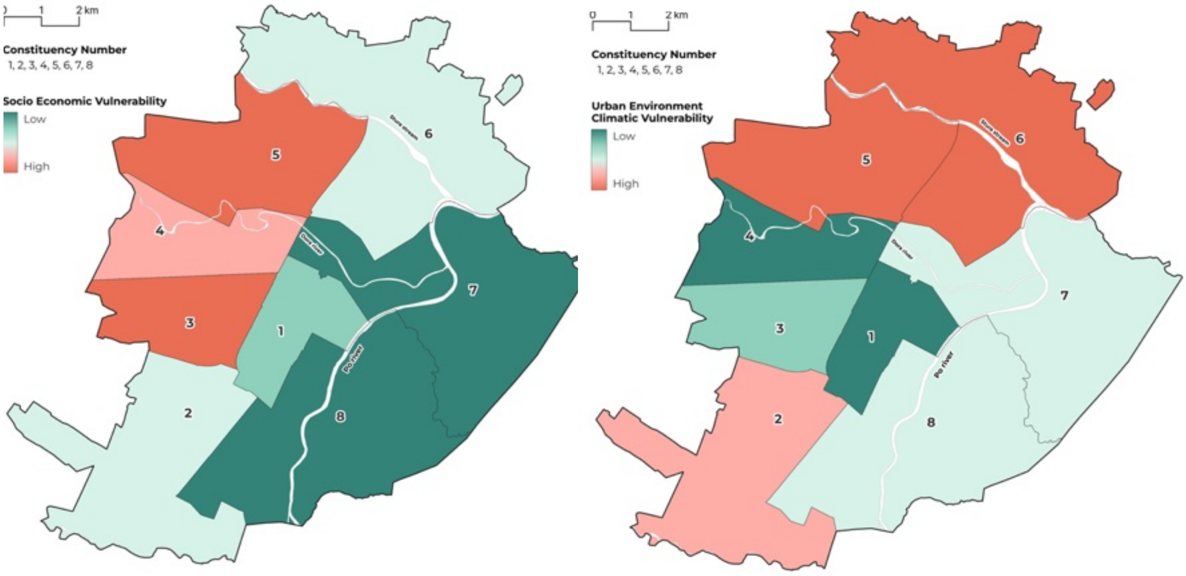

Figure 18 | Maps of socio-economic (left) and urban environmental-climatic vulnerability (right) to urban heat in Turin – Constituencies aggregated data (Source: Authors elaboration)

The district-level aggregation reveals that **Constituency 6** demonstrates the highest combined vulnerability score, resulting from the convergence of multiple risk factors:

- Highest concentration of young families with children under 14
- Significant foreign-born population with potential language and social barriers
- Lowest average income levels in the city
- Limited green infrastructure and high impermeability rates
- Reduced access to public cooling resources
- Moderate to high urban heat island effects

Geographic refinement of the focus area

Constituency 6 encompasses two distinctly different urban typologies divided by the Stura di Lanzo river:

North of Stura: This area comprises a heterogeneous landscape of peri-urban agriculture, natural areas, service-oriented industrial zones, and urban fringe developments. The sparse population distribution and mixed land use patterns present different adaptation challenges from dense urban areas.

South of Stura: This zone represents a predominantly urbanized fabric with significantly higher population density, continuous residential development, and typical urban infrastructure. This area concentrates the majority of the district's vulnerable population identified in our analysis.

For the purposes of this pilot study, **we focus exclusively on the urbanized area south of the Stura river,** where:

- Population density creates greater exposure to heat stress
- Limited private green spaces increase dependence on public cooling resources
- Concentrated vulnerable demographics align with climate shelter objectives
- Existing school infrastructure can serve larger catchment populations

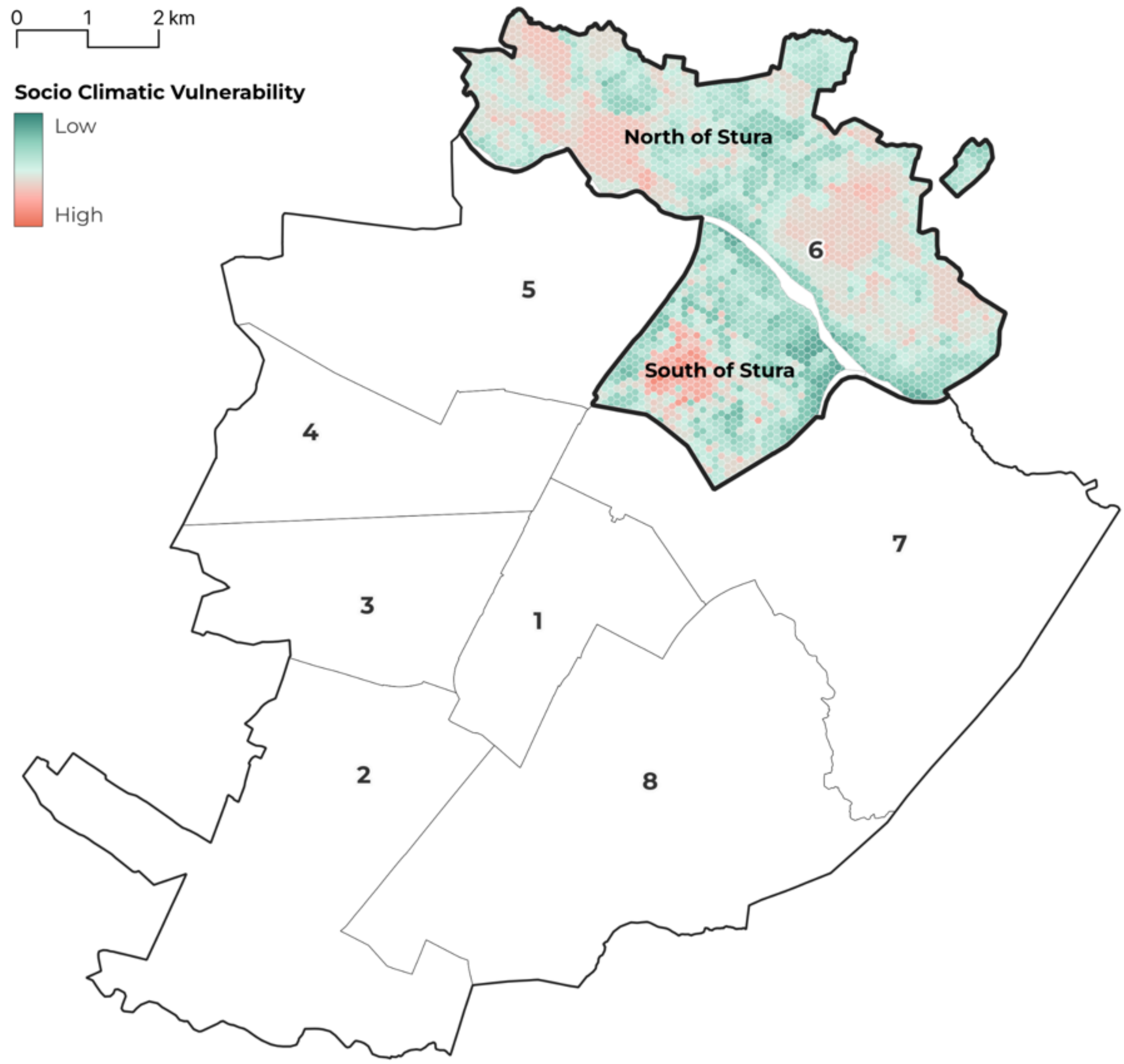

Figure 19 | Constituency 6 focus area selection, comprehensive Map of vulnerability to urban feat in Turin (Source: Authors elaboration)

Intervention landscape in the focus area

Our retrospective analysis of urban interventions (section 3.1.4) identified 50 projects within Constituency 6, representing 10.6% of citywide interventions despite the area's critical vulnerability status. The distribution of these interventions by category reveals:

- School infrastructure: 12 projects
- Green infrastructure: 8 projects
- Sustainable mobility: 7 projects
- Public spaces: 10 projects
- Other categories: 13 projects

This relatively low intervention density, combined with the high vulnerability scores, reinforces the selection of southern Constituency 6 as the priority area for climate shelter development. The existing projects provide a foundation that climate shelters can build upon while addressing critical gaps in heat adaptation infrastructure.

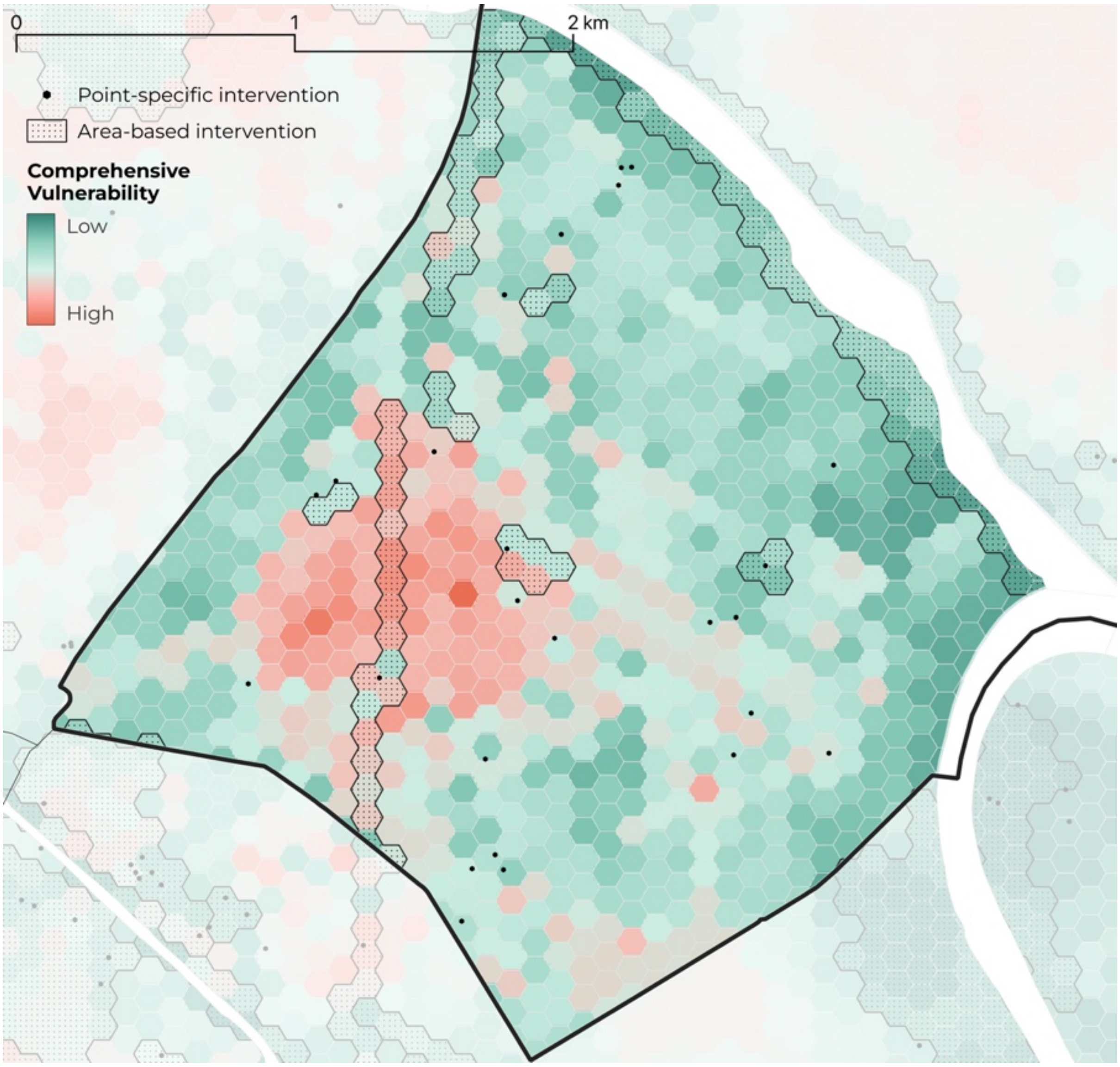

Figure 20 | Constituency 6 focus area zoom of the comprehensive map of vulnerability to urban heat in Turin, including catalogued city's interventions (Source: Authors elaboration)

Schools' vulnerability to climate hazards in Turin

The focus area contains 14 primary schools, of which 12 are public schools and 2 are private institutions. The 12 public schools are organized within 5 comprehensive educational districts (Istituti Comprensivi), which provide administrative and pedagogical coordination. These public facilities represent critical community infrastructure that, beyond their educational function, could serve as climate refuges for surrounding neighbourhoods during extreme heat events.

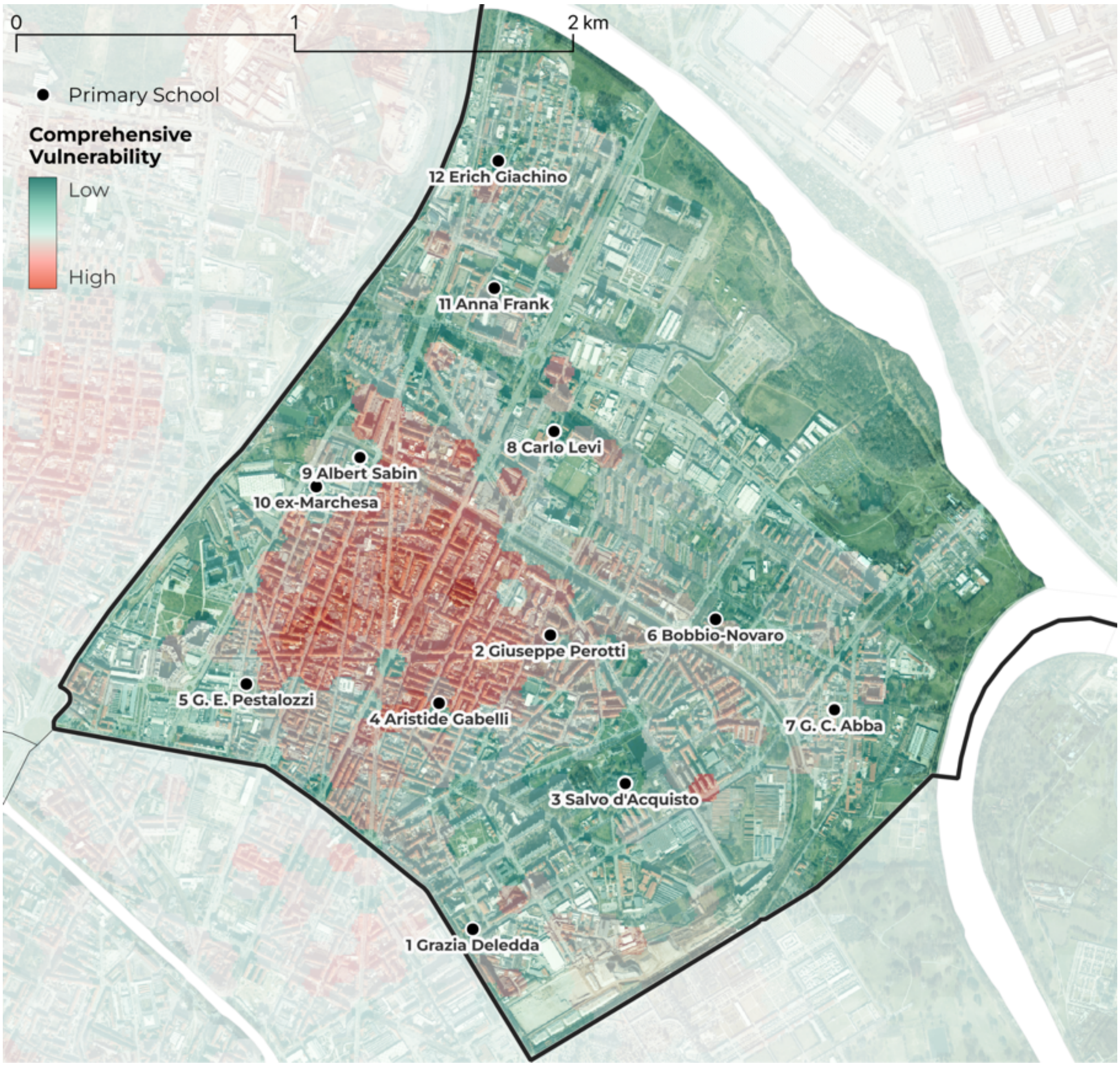

Figure 21 | Constituency 6 primary schools over comprehensive vulnerability orthophoto overlap (Source: Authors elaboration)

Multi-criteria assessment

The following assessment matrix applies the criteria established in the introduction of this chapter to evaluate the 12 public primary schools in the focus area. An important consideration for the Italian context is that **school grounds are typically restricted for security reasons, necessitating a focus on public schools only.** These 12 schools (out of 14 total primary schools in the area) operate under standardized municipal regulations that, once adapted for climate shelter purposes, can be replicated across the entire public school system. The 2 private schools in the area, operating under institution-specific policies, would limit the scalability of pilot interventions.

The organization of public schools within 5 Istituti Comprensivi (comprehensive educational districts) provides an additional advantage, as successful interventions can be more easily shared and replicated within and across these administrative structures.

CONSTITUENCY 6 PRIMARY SCHOOLS				
	Primary School Name	**Socio-Climate Vulnerability Index** (Low: 0; High:100)	**Yard Description**	**Yard Accessibility**
1	**Grazia Deledda**	58/100	Mixed: Green and concrete	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
2	**Giuseppe Perotti**	62/100	Mostly occupied by school's sport facilities	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
3	**Salvo d'Acquisto**	20/100	Mixed: Green areas partially occupied by school's sport facilities	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
4	**Aristide Gabelli**	79/100	Mixed: Green and concrete	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: Y Direct street access: Y
5	**Giovanni Enrico Pestalozzi**	43/100	Green area covered with adult trees	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
6	**Bobbio-Novaro**	33/100	Wide green areas partially covered with adult trees	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
7	**Giuseppe Cesare Abba**	38/100	Mostly sealed by concrete with few green areas	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
8	**Carlo Levi**	27/100	Mixed: Green and concrete. Presence of a green portion separated from the main courtyard.	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
9	**Albert Sabin**	44/100	Mixed: Green and concrete	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
10	**ex-Marchesa**	79/100	Occupied by school's sport facilities	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
11	**Anna Frank**	37/100	Wide green areas partially covered with adult trees	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y
12	**Erich Giachino**	26/100	Mostly sealed with concrete with few green areas	Separate entrance possible: Y Perimeter access feasible: Y Internal courtyard only: N Direct street access: Y

Table 8 | Primary schools located Into the selected focus area (Source: Municipal Official Website and Open Datasets - Geoportale)

Short list of schools

Based on the multi-criteria assessment, the following schools emerge as priority candidates for climate shelter development:

CONSTITUENCY 6 SHORTLISTED PRIMARY SCHOOLS		
	Primary School Name	**Key Strengths**
2	**Giuseppe Perotti**	Located in a high socio-climatic vulnerability area; features a large courtyard suitable for transformation and is supported by a very active school community.
4	**Aristide Gabelli**	Situated in one of the highest vulnerability hotspots; serves as a key reference point for a dense, multicultural neighbourhood and has strong, engaged leadership.
5	**Giovanni Enrico Pestalozzi**	High potential due to its large, tree-covered green area that provides existing natural cooling; the school leadership is exceptionally proactive on environmental issues.
6	**Bobbio-Novaro**	Possesses a very large courtyard with significant green spaces ideal for NBS interventions; benefits from proactive leadership interested in environmental education projects.
8	**Carlo Levi**	Features a distinct green area with potential for independent community access, a key feature for a climate shelter; the school is already engaged in environmental projects.
9	**Albert Sabin**	Serves a dense, multicultural area with high vulnerability; the school leadership has expressed strong preliminary interest and commitment to the project's goals.

Table 9 | Shortlisted primary schools located into the selected focus area (Source: Municipal Official Website and Open Datasets - Geoportale)

*Schools highlighted in colour indicate those that have expressed preliminary interest in the climate shelter project during initial consultations.

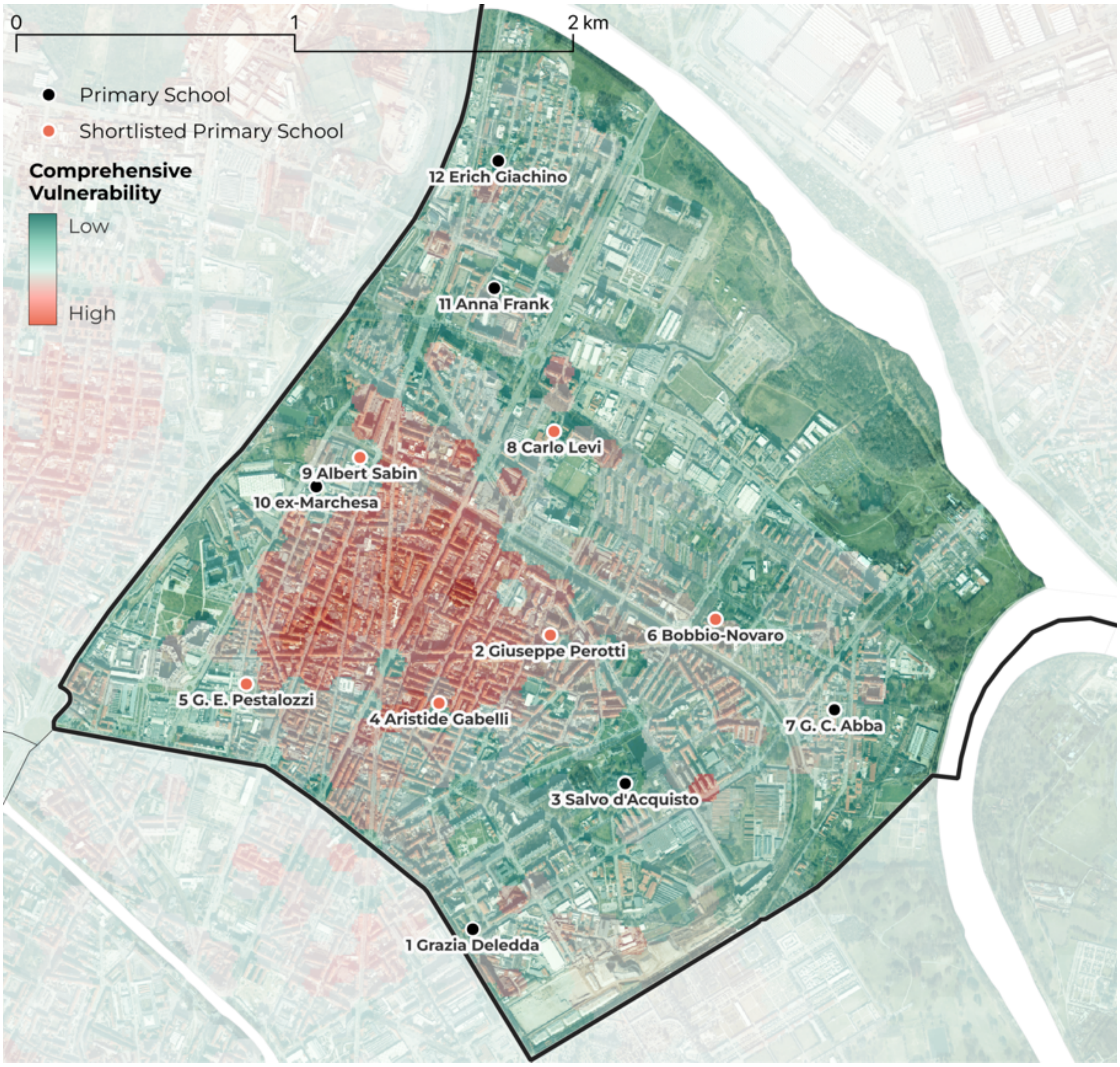

Figure 22 | Constituency 6 shortlisted primary schools over comprehensive vulnerability orthophoto overlap (Source: Authors elaboration)

The vulnerability assessment and preliminary school identification presented in this document (D3.1) provides the spatial and climate risk framework for focusing interventions in southern Constituency 6. This analysis will inform the stakeholder mapping process (D2.1 Comprehensive stakeholder map in Turin and Halandri), which will concentrate its detailed assessment on the short-listed schools identified here.

The final selection of pilot school(s) will be determined through the integration of:

- The climate vulnerability and physical suitability criteria established in this document (D3.1)
- The stakeholder readiness and engagement capacity assessment from the focused analysis (D2.1)

This two-pronged approach ensures that selected schools not only face significant climate risks and possess suitable physical infrastructure, but also have the institutional and community support necessary for successful climate shelter implementation and subsequent scaling across Turin's public-school network.

4.2 Focus areas and preliminary shortlist of schools in Halandri

Focus areas in Halandri

In the case of Halandri, **elementary school service areas** (Figure 23) **are used as the spatial framework for identifying the focus areas, i.e. the local-level vulnerability hotspots.** Halandri has 14 public primary schools and 12 school service areas[16]. These service areas correspond to the official school districts that delineate the residential catchment zones of students enrolled in certain elementary schools. This division is particularly meaningful, as it directly links vulnerability assessment to the actual populations that will be served by potential climate shelters[17]. By aligning the mapping of heat-related risks with the geographical areas from which each school draws its students, the approach ensures that the analysis captures both the spatial distribution of vulnerability and its implications for the school community. Finally, it enables the precise identification of which schools are situated in the most at-risk zones.

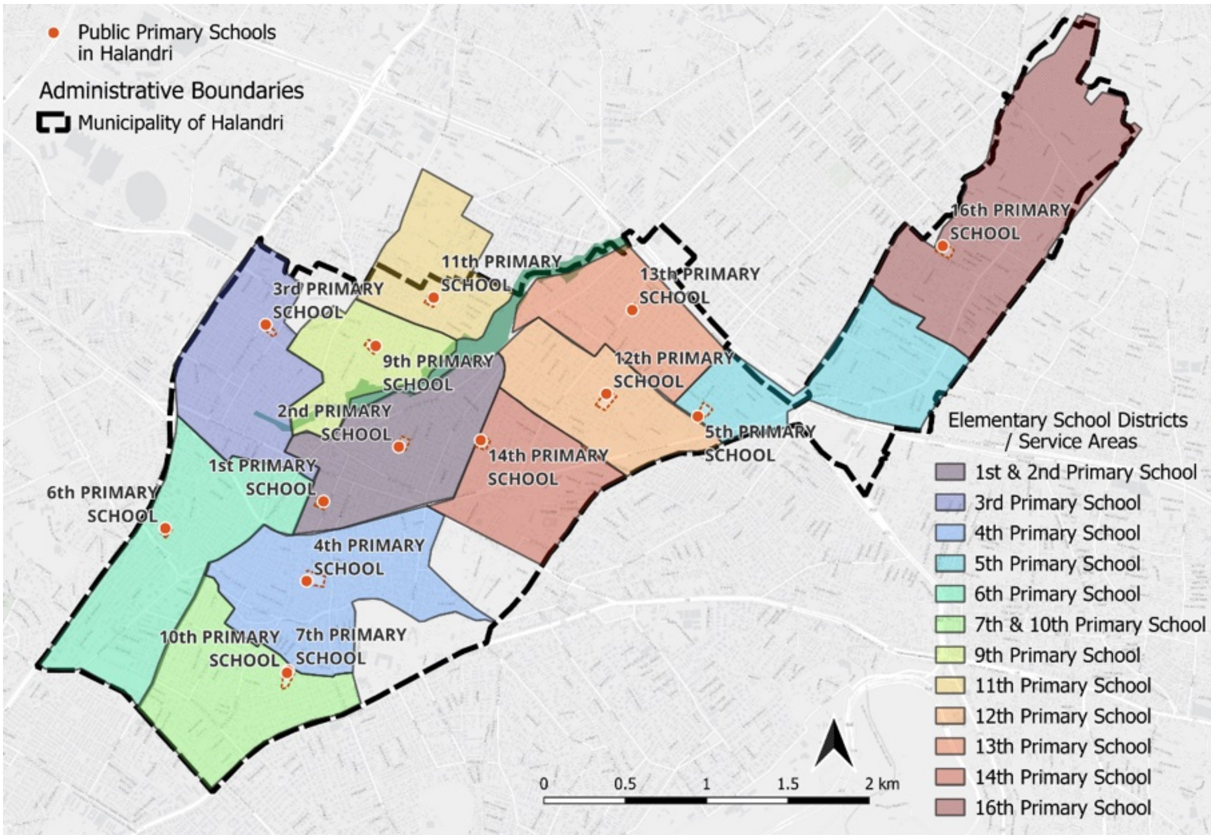

Figure 23 | Map of the 14 public primary schools in Halandri and their respective service areas (Source: Authors elaboration. Data source: Halandri Geospatial Portal)

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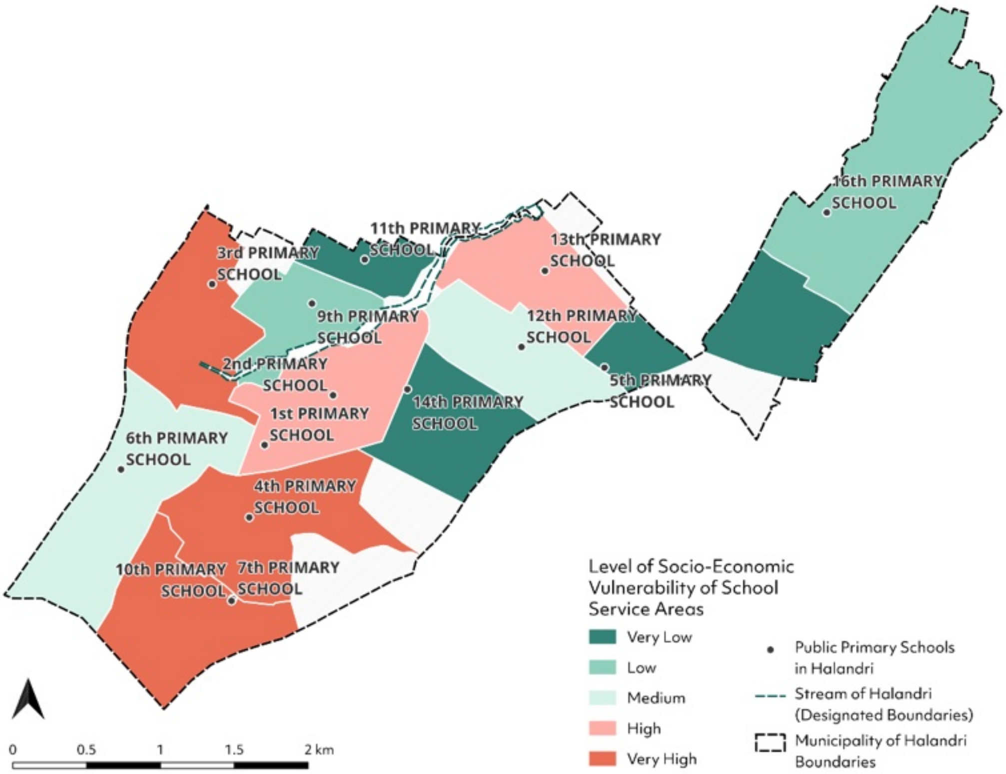
[16] In Halandri two public primary schools share the same yard (7th and 10th) and two are located close to each other at the central district (1st and 2nd), and therefore there are 12 service areas.

[17] Additionally, the non-residential segments of Halandri, such as Nomismatokopeio, that practically have very low or no population, are excluded from the analysis, since do not fall within the designated school service areas (see Figure 11).



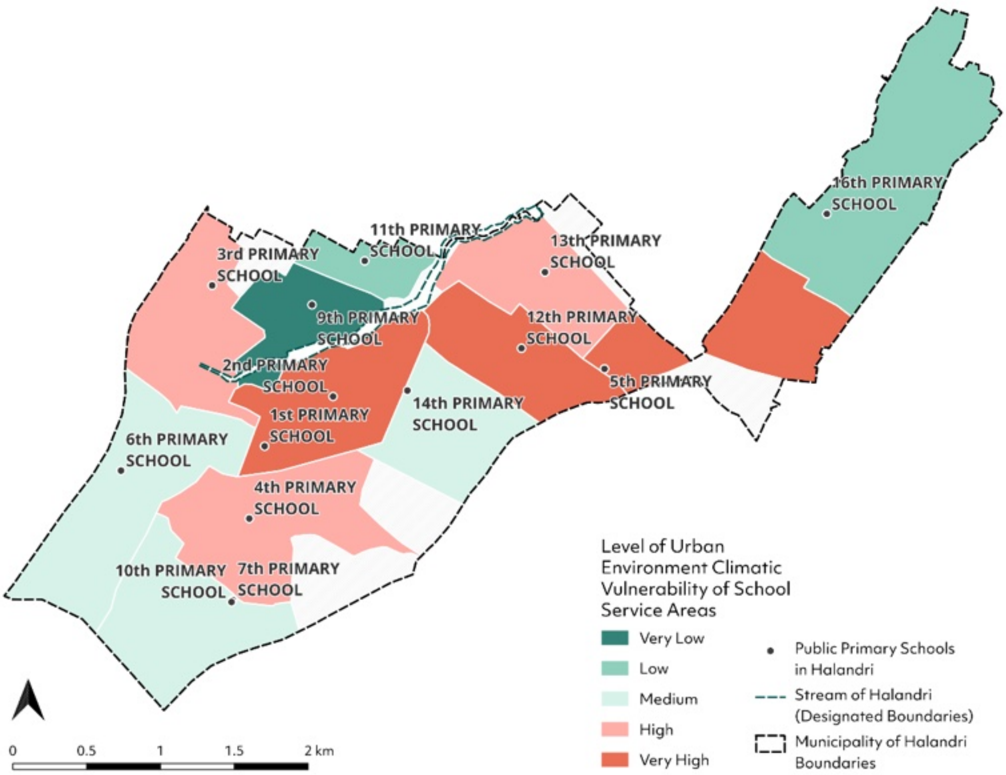


Figure 24 | Map of the two key vulnerability dimensions of the school service areas in Halandri (Source: Authors elaboration. Data source: ELSTAT - Greek Census 2021, Copernicus, Halandri Geospatial Portal)

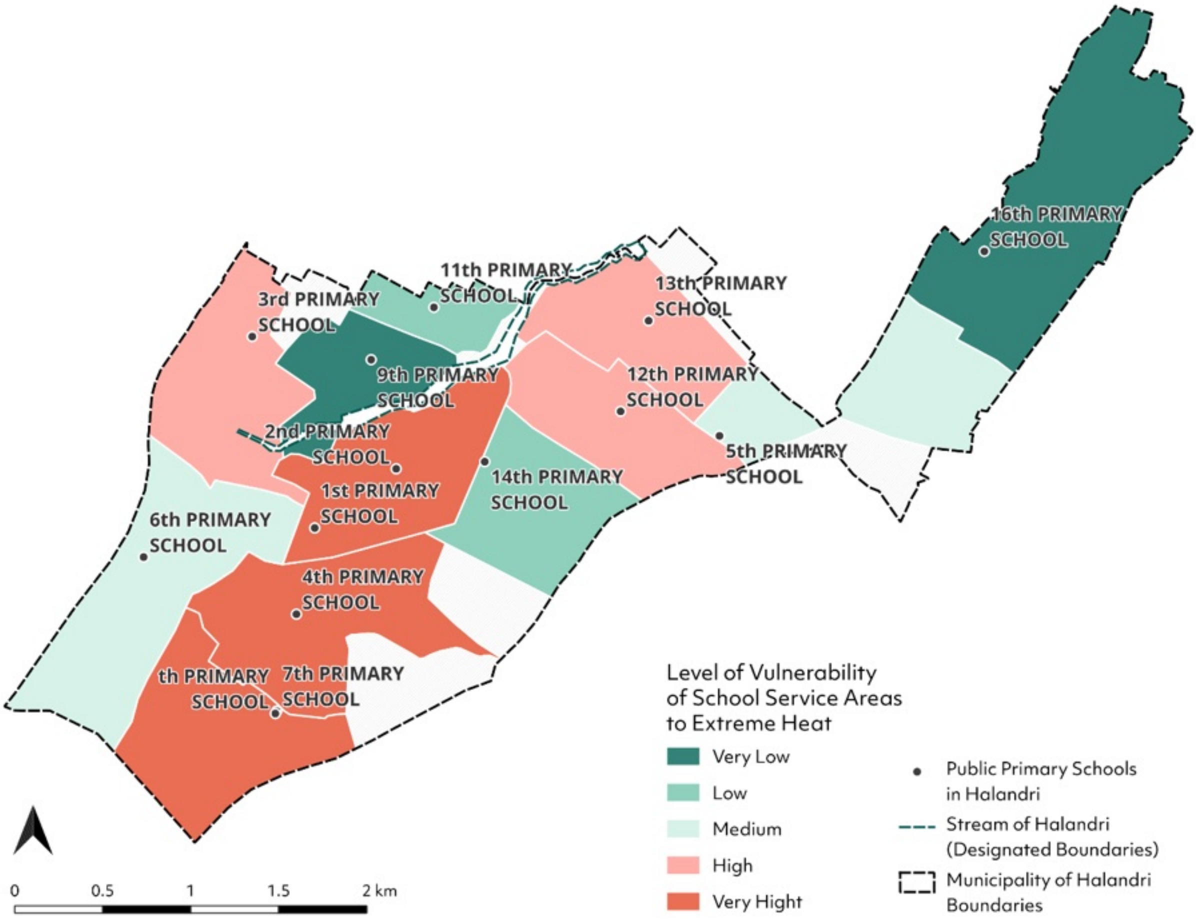


Figure 25 | Comprehensive vulnerability map of the school service areas in Halandri (Source: Authors elaboration. Data source: ELSTAT - Greek Census 2021, Copernicus, Halandri Geospatial Portal)

In Figure 24 are presented the maps with the spatial distribution of vulnerability levels, stemming from the socio-economic and urban environment climatic measures independently. The focus areas with the highest vulnerability in terms of population's socio-economic status are around the 4th, 7th – 10th and 3rd primary schools. In terms of physical elements and environmental conditions the most disadvantaged areas are the districts around the 1st – 2nd, 12th and 5th primary school.

Regarding the distribution of the overall urban heat vulnerability across the school areas (Figure 25), **the highest levels of comprehensive vulnerability are clustered around commercial core of Halandri and the eastern part of Kato Halandri,** namely around the 1st - 2nd, 4th, and 7th - 10th primary schools (very high category). Relatively high vulnerability is detected also in Synoikismos neighborhood (3rd primary school) and partly in the district of Toufa (12th and 13th primary schools). By contrast, the northern-eastern edges of the municipality (around the 16th primary school in Patima), and the districts east from the Stream (around 9th and 11th primary school) exhibit lower levels of vulnerability.

Summarizing, the primary schools located in the areas with the highest vulnerability rates are the **1st, 2nd, 4th, 7th and 10th primary schools (very high level), followed by the 3rd, 12th, and 13th primary schools (high level).**

Schools' vulnerability to climate hazards in Halandri

The location of the primary schools in areas with high vulnerability to heat is an essential, but not the only factor in the school selection for UCS implementation. Further criteria that should be taken into account are the structural and environmental features of the schoolyards, such as the size, vegetation, materials, or further sustainability conditions, and accessibility by the local community. At the same time, equally important is the willingness and engagement of school administrations and the broader school community to actively participate in the UCS co-design process.

In Halandri the data on the characteristics of Halandri's public schools derive from multiple sources, including desktop research, municipal databases, and consultations with key informants from the Municipality. Beyond desktop research, particular emphasis was placed on engaging the school community in the data collection process. Thus, additional insights were obtained through participatory processes involving the school community, namely through an online survey[18] addressed to the families of Halandri's primary schools, as well as through a collective mapping exercise held during the MAINCODE kick-off event in June 2025.[19]

The information collected about Halandri's primary schools that stems from municipal databases refers to several key aspects of their schoolyards and facilities. First, concerning the **vegetation in schoolyards,** the presence and type of trees has been systematically recorded and mapped [20] (Figure 26). This data provides an indication of the natural shading and cooling potential of each site. In parallel, the **size of the schoolyards** is noted, as yard surface area determines both the scope for adaptation measures and the capacity of the schools to host climate-resilient interventions. Furthermore, information on the **ongoing and planned energy efficiency interventions at the school buildings** is also collected and considered to ensure alignment with the further existing climate adaptation initiatives, that are undertaken by the Municipality in the schools.

Beyond these measurable elements, the analysis incorporates **qualitative characteristics.**

Complementing these datasets, **the collective mapping exercise with parents and educators** generated a wealth of qualitative information that helped to situate the schools within their everyday social and environmental context. Participants shared their perspectives on how schoolyards are structured, used, and maintained, while emphasis was also placed on practices such as the **opening of schools during the summer period.**

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[18] The online survey sought to explore issues of social vulnerability and exposure to climate hazards, with the aim of capturing household-level risks associated with climate change, especially rising temperatures. The highly uneven distribution of responses across schools with some of them overrepresented and some not represented, limited the potential for robust interpretations and comparisons. Nevertheless, the survey provided valuable insights into local perceptions of climate hazards, particularly in Halandri's central district where most responses were concentrated. Heatwaves emerged as the most frequently cited hazard in recent years, followed by heavy rainfall and flooding, and then wildfires. When asked about the frequency of such events, almost 80% of respondents reported experiencing them annually or even more often.

[19] For more details on the process and the findings of the collective mapping and the MAINCODE kick-off event see the MAINCODE Comprehensive Stakeholder Mapping Report (D2.1).

[20] In the context of a previous collaboration, the Municipality of Halandri together with COMONSPACE members conducted recently the monitoring and assessment of all trees in the public areas of Halandri, incl. public school areas.

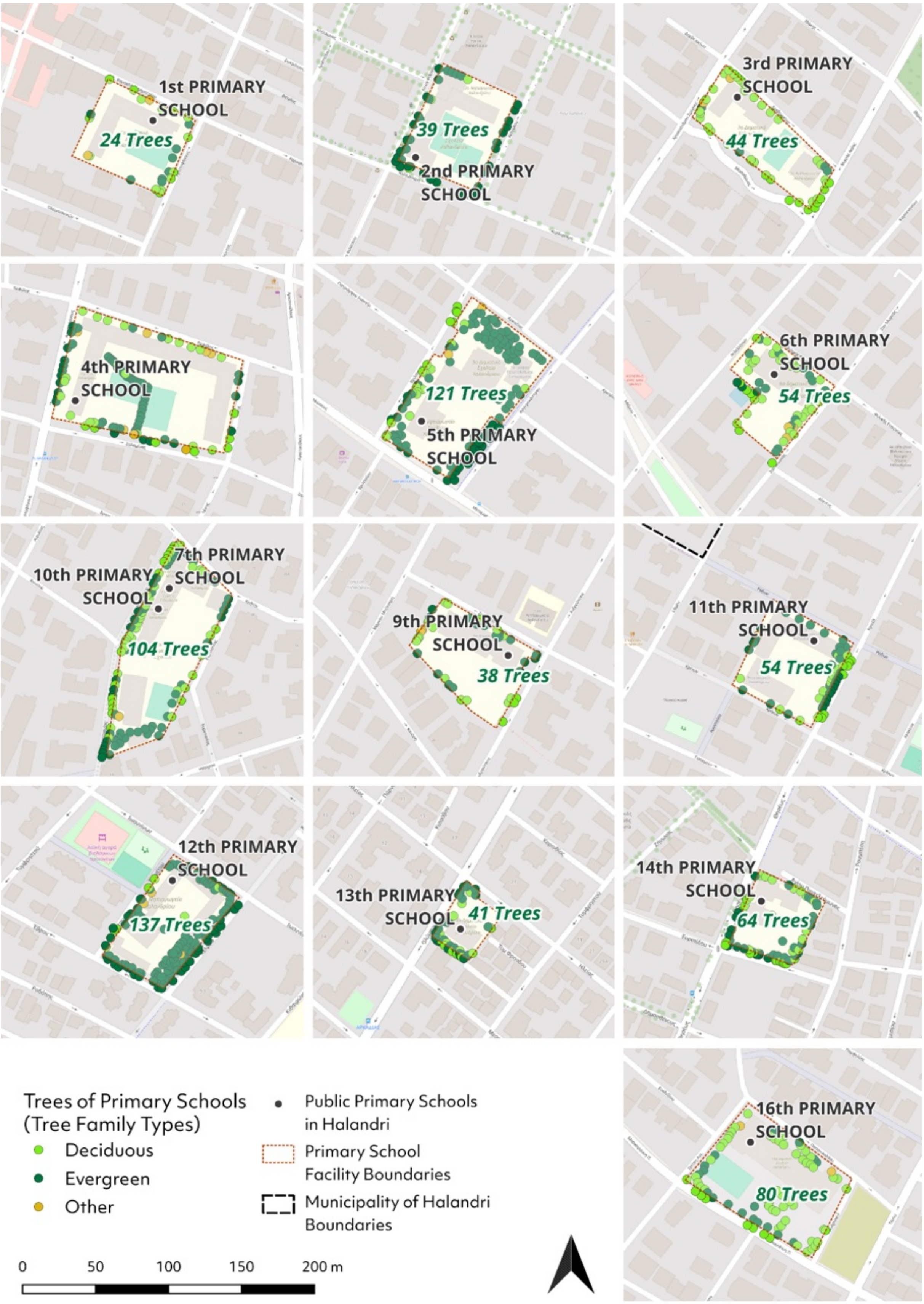

Figure 26 | Mapping of trees in Halandri's primary schoolyards (Source: Authors elaboration)

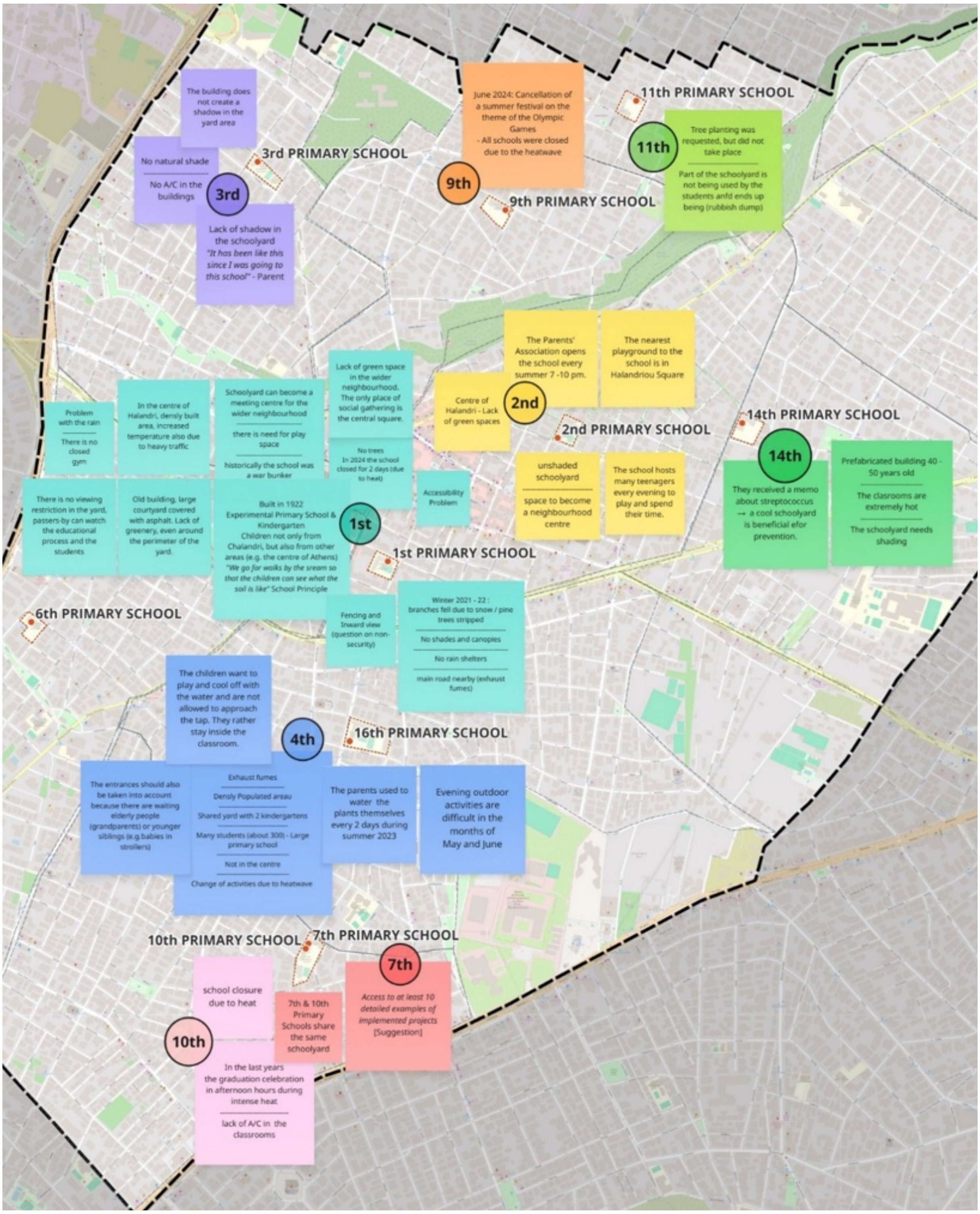

Figure 27 | Key characteristics of public primary schools in Halandri in terms of schoolyard function, challenges and opportunities to address heatwaves (Data source: Collective mapping activity during the local kick-off event in Halandri, 02.06.2025)

At the same time, during the collective mapping process, participants recounted their **direct experiences with extreme heat events and how they affect the school environment, voiced** concerns about existing conditions, and proposed ideas for improvement. A recurring theme across the groups was the limited presence of vegetation in many schoolyards and the urgent need for more effective shading and cooling solutions. These contributions, captured in Figure 27, highlight the decisive role of community knowledge in identifying vulnerabilities and shaping adaptation priorities. By combining measurable datasets with participatory insights, the aim is to gain a holistic and context-sensitive understanding of the conditions and needs of primary schools in Halandri.

The various relevant measurable data collected about the public primary schools in Halandri are outlined in the following Table 10, along with estimated level of vulnerability.

Primary School	Level of Vulnerability	Energy efficiency interventions	Schoolyard Features	
			Vegetation (Number of Trees)	Size of the Yard
1st	**VERY HIGH**	**YES** (Hlektra Program[21])	24 trees	Small
2nd	**VERY HIGH**	**YES** (Hlektra Program)	39 trees	Small
3rd	**HIGH**	YES (Hlektra Program)	44 trees	Medium
4th	**VERY HIGH**	**NO**	93 trees	Big
5th	**MEDIUM**	**YES** (PV / Net metering)	121 trees	Medium
6th	**MEDIUM**	**YES** (Hlektra Program)	54 trees	Medium
7th	**VERY HIGH**	YES (Hlektra Program)	104 trees	Big (shared with 10th)
9th	**VERY LOW**	**YES** (Hlektra Program)	38 trees	Medium
10th	**VERY HIGH**	**YES** (Hlektra Program)	104 trees	Big (shared with 7th)
11th	**LOW**	YES (Hlektra Program)	54 trees	Medium
12th	**HIGH**	**YES** (PV / Net metering)	137 trees	Medium
13th	**HIGH**	**YES** (Hlektra Program)	41 trees	Small
14th	**LOW**	**YES** (Hlektra Program)	64 trees	Small
16th	**VERY LOW**	**YES** (PV / Net metering)	80 trees	Big

Table 10 | Collected data on primary school facilities and schoolyard features in Halandri

[21] The interventions included in Hlektra energy modernization program are thermal insulation, replacement of frames, installation of heat pump, installation of mechanical ventilation, installation of LED lighting, PV installation.

Shortlist of schools in Halandri

According to the vulnerability mapping, the following **5 primary schools are the shortlisted candidates for UCS implementation in Halandri,** as they are identified within areas with very high degree of vulnerability:

- **1st primary school**
- **2nd primary school**
- **4th primary school**
- **7th and 10th primary schools (shared yard)**

The next **3 schools with high vulnerability level emerge as possible candidates for participation in additional practices and participatory processes** that will support the co-design of UCS:

- **3rd primary school**
- **12th primary school**
- **13th primary school**

Following, in Table 11 are outlined some key features of the shortlisted schools as well as preliminary expression of interest in MAINCODE participation

Primary School	Level of Vulnerability	Key Features (Source: Collective mapping event in June 2025)
1st	VERY HIGH	Old building (built in 2022 and historically used as refuge during war) Limited greenery and no shade, and no rain shelters. Easy access and visibility to the yard. Affected by extreme heat the last month before summer closure ***Expressed Interest***
2nd	VERY HIGH	Central location with no amenities for children in the surroundings It opens in summer period 7-10 pm and has a lot of teens in evenings Unshaded and frequently affected by heatwaves ***Expressed Interest***
4th	VERY HIGH	Large school (around 300 students) Schoolyard shared with 2 kindergartens, Unshaded entrances Parents' association take care of watering during summer Affected by heatwaves in May and June (rescheduling of activities) ***Expressed Interest***
7th & 10th (shared yard)	VERY HIGH	Big shared schoolyard Lack of cooling equipment in the classrooms (A/C) Increased challenges due to heat (school closure during very hot days) ***Expressed Interest***
3rd	HIGH	Lack of natural shade Lack of cooling equipment in the classrooms (A/C) Affected by heatwaves annually ***Expressed Interest***
12th	HIGH	***Non - Expressed Interest to date***
13th	HIGH	***Non - Expressed Interest to date***

Table 11 | The shortlist of schools in Halandri

The final selection of schools for UCS co-design and pilot implementation will be informed by the above-described school characteristics, and will take place during the coming stages of MAINCODE project, after thorough examination of the interest of the school administrations and broader school community to take part in the process.

5. Conclusions

In the present report (D3.1), vulnerability mapping has been carried out for Turin and Halandri to guide the selection of pilot schoolyards for the implementation of Urban Climate Shelters (UCS). A comprehensive vulnerability map for each city has been developed through the integration of multiple layers of social, spatial, environmental and climate-related data, combining a range of metrics that capture both the sensitivity and adaptive capacity of the population to heat (socio-economic vulnerability), but also the structural and environmental features of the urban landscape that influence how much residents are exposed to extreme heat and how effectively the built environment can reduce it (urban environment climatic vulnerability). Overlaying these diverse datasets within a geospatial framework resulted in a detailed spatial visualization that highlighted the zones where extreme heat risk intersects with social vulnerability, thereby identifying priority areas and possible primary schools for UCS implementation in the two cities.

Concerning the key findings of the vulnerability mapping in Turin and Halandri, the comparison of the two cases highlights how **differences in urban scale, data availability, and spatial context influenced both the analytical methodological choices, and the results of the mapping.** While both cities followed a common methodology, slight adjustments in metrics and indicators were introduced to reflect context-specific data availability and diverse urban characteristics. Moreover, in Turin, the larger city context made it appropriate to adopt administrative districts as spatial units of analysis, with the mapping process ultimately identifying *Circoscrizione 6* as the most vulnerable focus area, an area roughly equal in size to the entire Municipality of Halandri. In contrast, Halandri's smaller scale required a more localized approach, with school service areas chosen as the spatial framework to capture local-level vulnerability hotspots.

The mapping results also revealed notable differences in the spatial distribution of vulnerability. In Turin, vulnerability was found to be more clearly concentrated, forming clusters of high-risk areas, while in Halandri, patterns were more dispersed and variable, reflecting a mosaic-like pattern across the municipality and shaping micro-scale vulnerability outcomes. By combining these findings with further data on the schools' structural and environmental characteristics, the shortlists of schools were identified in both cities. The additional analysis of schools' suitability incorporated various factors and types of information, which differed between the two cities due to variations in data collection methods and the availability of school-related datasets. **The overall analysis led to the identification of 6 shortlisted schools in Turin and 8 shortlisted schools in Halandri.**

Looking ahead, the findings of D3.1 contribute to the understanding of climate vulnerabilities and risks in the two cities, and could support ongoing collaboration with municipal authorities on developing strategies and practices to address them. **In the MAINCODE context, the insights gathered in D3.1 establish a strong foundation for the coming project stages of UCS co-design and implementation in Turin and Halandri.**

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- **City Water Circles (CWC) Project:** https://www.torinoeuprojects.it/cwc-city-water-circles
- **Torino Cambia Platform:** https://www.torinocambia.it/
- **National Operational Program for Metropolitan Cities (PON Metro):** https://risorse.comune.torino.it/ponmetro/pon-metro-torino-presentazione
- **National Recovery and Resilience Plan (PNRR) - Projects for Turin:** http://www.cittametropolitana.torino.it/cms/pnrr

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