Climate Risk Analysis Related to Urban Heat Islands in Metropolitan Areas for Urban Health: The Case Study of the Florence Plain

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Urban heat islands (UHI) have become a widespread phenomenon in metropolitan areas worldwide, manifesting as an increase in the average ground surface temperature in urban environments compared to suburban areas. Climate change and intensified urbanization exacerbate this process, making it a key challenge of our time. In this context, urban planning plays a crucial role in developing UHI mitigation plans and adaptation strategies aimed at enhancing urban livability and climate resilience. This research

1. Introduction

In recent years, the climate emergency has impacted various environments across the globe, manifesting through extreme temperatures and severe natural hazards, and leading to an increase in hot days and tropical nights. The World Health Organization highlights that heatwaves are among the deadliest natural hazards, with older adults, infants, and socially disadvantaged groups being most at risk. Elevated temperatures contribute to an increase in human mortality, a phenomenon that is further exacerbated during heatwaves, resulting in a spike in deaths (Tomlinson et al., 2011). Densely *carries out a model for assessing and tackling climate risk associated with UHI in the Piana Fiorentina area, focusing on areas where thermal stress and population sensitivity are especially high, making heat-reduction interventions a priority. The study also proposes targeted responses and simulates the effectiveness of various design solutions for mitigating UHI effects and implementing adaptation strategies, highlighting the potential to adapt this method to other metropolitan areas.*

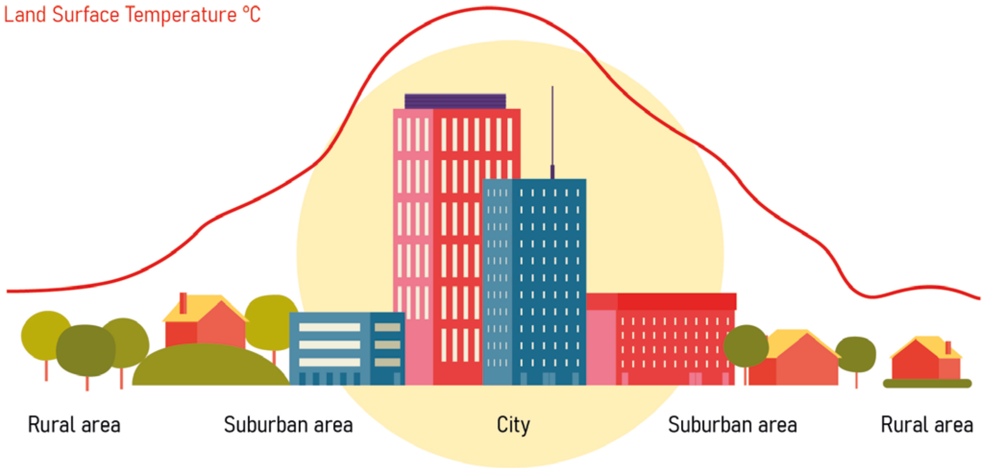
populated areas are particularly affected, as they tend to heat up more than surrounding regions (fig. 1), creating what are known as 'Urban Heat Islands'.

This creates significant discomfort for people who live in cities, which currently account for more than half of the global population, with projections indicating that by 2050, approximately 88% of people will reside in metropolitan areas (Guerri et al., 2021). As population grows, so does the amount of urbanized land, leading to more impervious surfaces such as roads and buildings. The degree of impervious surface coverage, along with the amount of vegetation present, are among the most influential indicators in moderating surface temperature levels in urban environments (Mancuso, 2023).

That's why more and more cities around the world are looking for ways to tackle urban overheating in order to preserve a high quality of life and actively safeguard the health of their inhabitants. This is where technical planning for heat adaptation becomes essential. It identifies the most critical sectors for temperature reduction and develops concrete strategies to address the issue in urban contexts, based on two primary objectives: preventing overheating of the entire urban area and specifically alleviating conditions in vulnerable urban zones. By learning from strategies already implemented in other cities, it is possible to identify the most compatible solutions for the city under consideration.

This study aims to develop a model for analyzing the urban heat island phenomenon in the area known as the Piana Fiorentina, a region that includes 20 municipalities across the provinces of Prato, Pistoia and the Metropolitan City of Florence. The approach combines satellite-based remote sensing data on urban heat with social segmentation data, using a spatial risk assessment methodology to pinpoint areas where heat-related risks may be especially high.

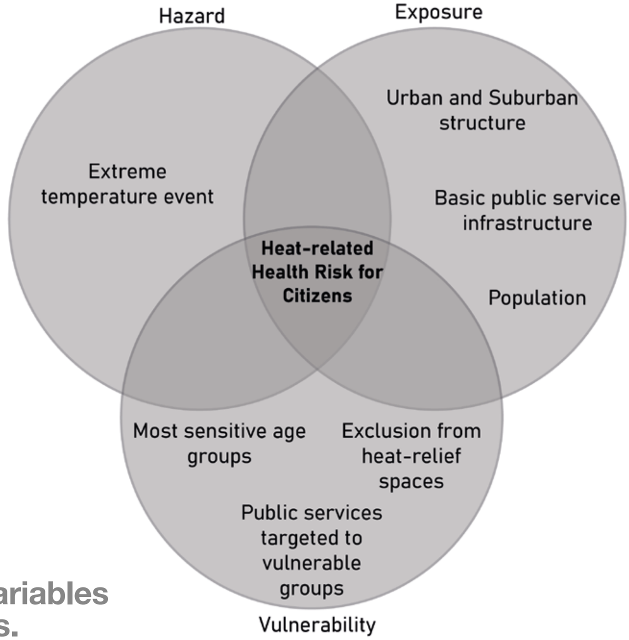
Taking inspiration from Zurich's 'Heat Mitigation Plan' and building on earlier research carried out in this region, the study conducts a climate risk analysis for the Piana area and puts forward adaptation strategies aimed at guiding territorial interventions.



Conceptual diagram of Urban Heat Island Effect.
Fig. 1

2. Materials and Methods

Risk is determined by the interaction of three key factors: Hazard, Exposure, and Vulnerability, as defined in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014). In the context of heatwaves, the hazard refers to the rise in temperatures. Exposure relates to the presence of people or assets in areas affected by such extreme events, typically measured using census data that show how population is distributed across impacted zones. Vulnerability, on the other hand, reflects the limited ability of individuals or communities to cope with or adapt to extreme heat. This can be influenced by personal factors, such as age or health conditions, as well as urban characteristics, like the availability of adequate infrastructure. By combining these three components, it's possible to create a comprehensive risk map, integrating a hazard index with indicators of exposure and vulnerability. Tools like the Land Surface Temperature (LST) index (Morabito et al., 2015), which captures ground-level thermal variations and serves as a key indicator for assessing the intensity of urban heat, are crucial for informing urban planning interventions aimed at reducing the environmental and public health impacts of extreme heat. Certain demographic groups, including the elderly, young children, individuals with chronic illnesses, or those experiencing social isolation, are particularly sensitive to extreme heat. The physical structure of the city also plays a crucial role: a lack of green spaces and high building density can worsen thermal discomfort and reduce a city's ability to adapt (Buscail et al., 2012). Vulnerability is not a static condition: it can be reduced through targeted and inclusive adaptation strategies. Increasing a system's adaptive capacity directly enhances its resilience to extreme weather events, by reducing both immediate risks and long-term exposure. Climate change adaptation, therefore, involves



Synthesis chart of risk variables and associated elements.
Fig. 2

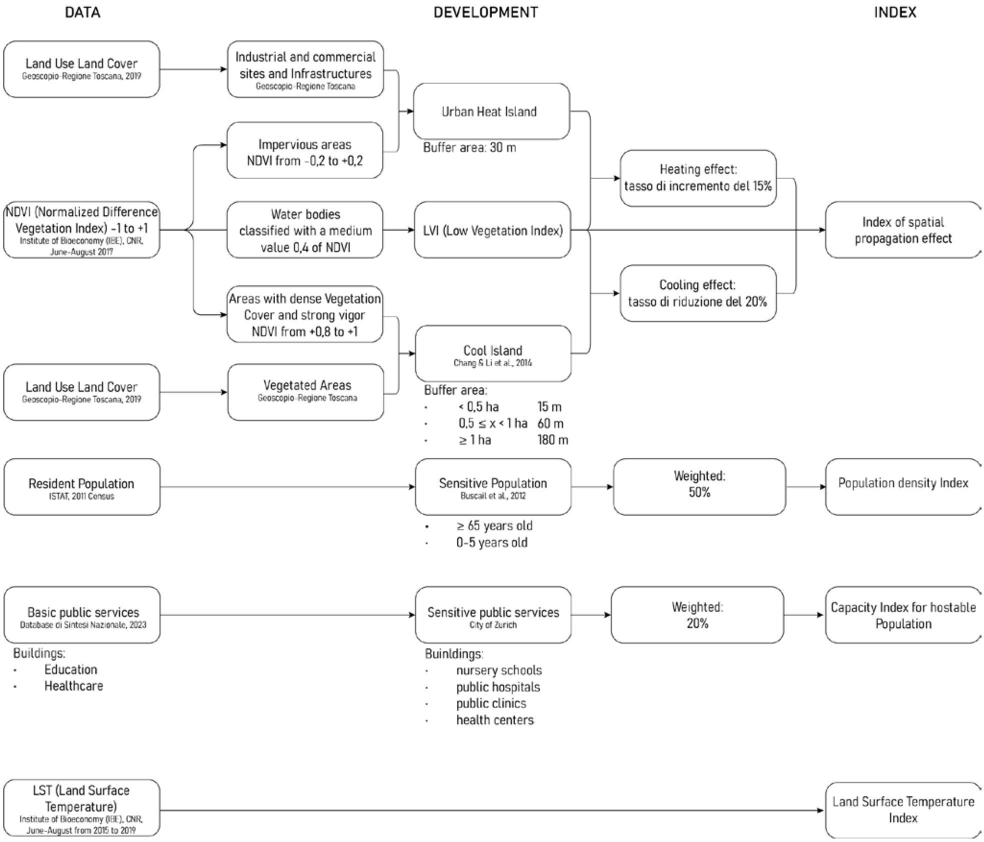
the implementation of measures that address existing vulnerabilities to minimize future impacts. In urban contexts, this often means rethinking and redesigning public and private spaces to improve their capacity to withstand and moderate the effects of global warming (D'Ambrosio, 2016; Losasso, 2021).

Analyzing climate risk associated with urban heat islands requires a structured investigation of the underlying dynamics driving the phenomenon, along with a detailed assessment of its impacts on the population. This study focuses on identifying the most vulnerable urban areas, those characterized by critical levels of heat stress, where high concentrations of at-risk populations coexist with a lack of green spaces capable of providing thermal relief. The percentage of vegetation cover in the area is derived using the Normalized Difference Vegetation Index (NDVI) and hierarchically classified based on its definition (Morabito et al., 2015).

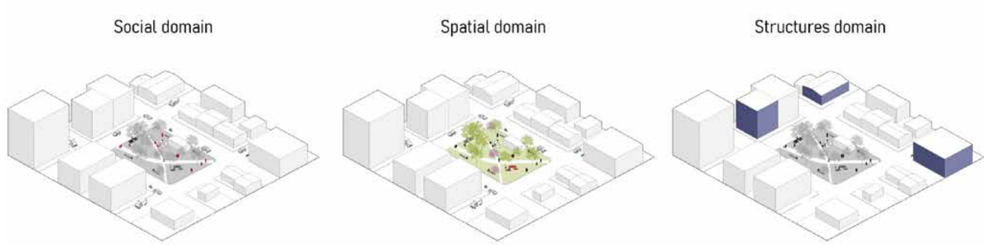
The vulnerability component adds further depth to the analysis, with particular attention to the most fragile population groups, such as the elderly and young children, who require priority protection measures against high temperatures. Facilities frequented by these groups – including hospitals, schools, and childcare centers – are also considered, as they represent critical points of exposure (fig. 2).

By combining these layers of information, the analysis pinpoints the urban areas within the Piana Fiorentina where climate risk is highest, highlighting priority zones for implementing heat reduction strategies and protecting the population from thermal stress. Among the proposed solutions, the expansion of green infrastructure stands out as an essential strategy, offering tangible and lasting benefits by creating cooler and more livable microclimates within the urban fabric (Morabito et al., 2021).

To support the planning of heat adaptation measures, the urban area was analyzed based



Flowchart of the risk assessment model adopted.
Fig. 3



Geographic Framework and definition of the study area based on administrative boundaries and the 200-meter elevation threshold.
Fig. 4

on Land Use and Land Cover (LULC) categories. These categories provide a fundamental reference for assessing thermal load and vulnerability, while also serving as a basis for developing city-wide analyses and proposals. They help identify potential pilot areas for testing various operational approaches and developing targeted intervention plans. In this study, raw data for each of the three key variables – hazard, exposure, and vulnerability – were processed and scaled using linear normalization, making the analyses more locally accessible and interpretable (fig. 3). This approach produced synthetic indicators of hazard, vulnerability, and overall risk, all expressed on a standardized scale from zero to one. Such normalization facilitates planning efforts and supports decision-making processes (Buscail et al., 2012). The results of this analysis can also be applied to other areas with similar urban characteristics and environmental conditions, enabling more targeted and effective planning across comparable contexts.
The analysis is structured into three domains (fig. 4), based on Land Use and Land Cover:
a. Social domain
b. Spatial domain
c. Structures domain
Each of these includes relevant exposure factors, from which vulnerability components are derived. This reasoning led to the development of a risk assessment formula in which the indicators of Exposure and Vulnerability are broken down into the three domains: social, spatial and structural. Among these, the social dimension serves as the essential foundation for evaluating the others, since the aim of this research is to identify areas where the population suffers particularly from high temperatures.
This relationship is represented in the following formula:

$$R = H \times E_a \times V_a \times [(E_b \times V_b) + (E_c \times V_c)]$$

R: Risk
H: Hazard
E: Exposure
V: Vulnerability
a: Social domain
b: Spatial domain
c: Structures domain

2.1. Study area

This research considers the territory of the Piana Fiorentina as the study area for the phenomenon of urban heat islands. The area includes 20 municipalities (tab. 1), located within the provinces of Prato, Pistoia, and the Metropolitan City of Florence, from which only the portions of territory located below 200 meters above sea level are selected. This choice was made to reduce elevation variance, as the subject matter requires the analysis to be limited to a geographically and morphologically homogeneous area and focused solely on the most densely populated

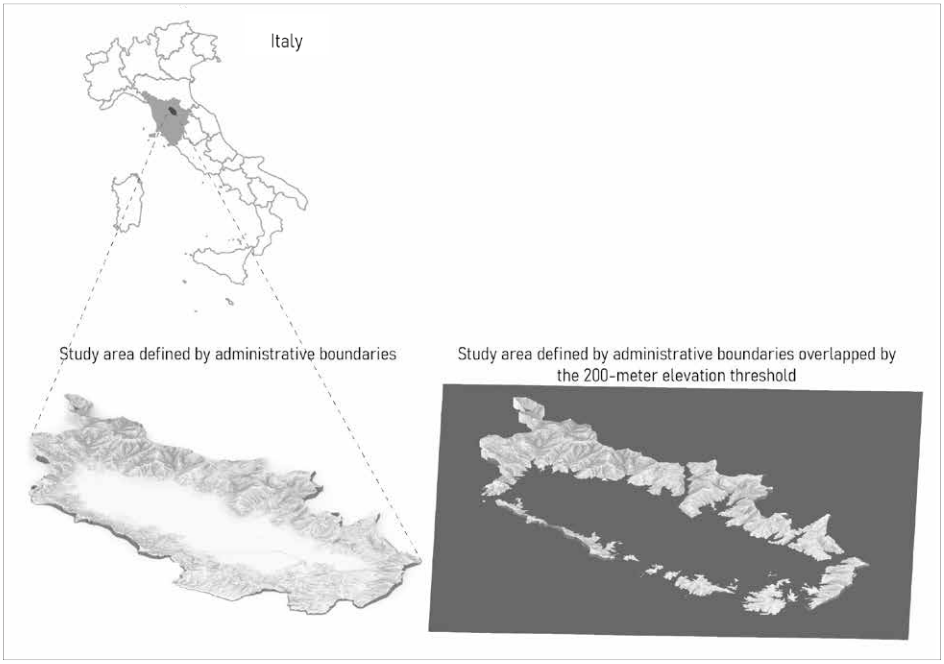
Province	Municipality
Pistoia	Pistoia
	Agliana
	Montale
	Serravalle Pistoiese
	Quarrata
Prato	Montemurlo
	Vaiano
	Prato
	Poggio a Caiano
	Carmignano
Metropolitan City of Florence	Signa
	Campi Bisenzio
	Calenzano
	Sesto Fiorentino
	Fiesole
	Firenze
	Lastra a Signa
	Impruneta
	Bagno a Ripoli
	Scandicci

Municipalities located within the provinces of Prato, Pistoia, and the Metropolitan City of Florence.
Tab. 1

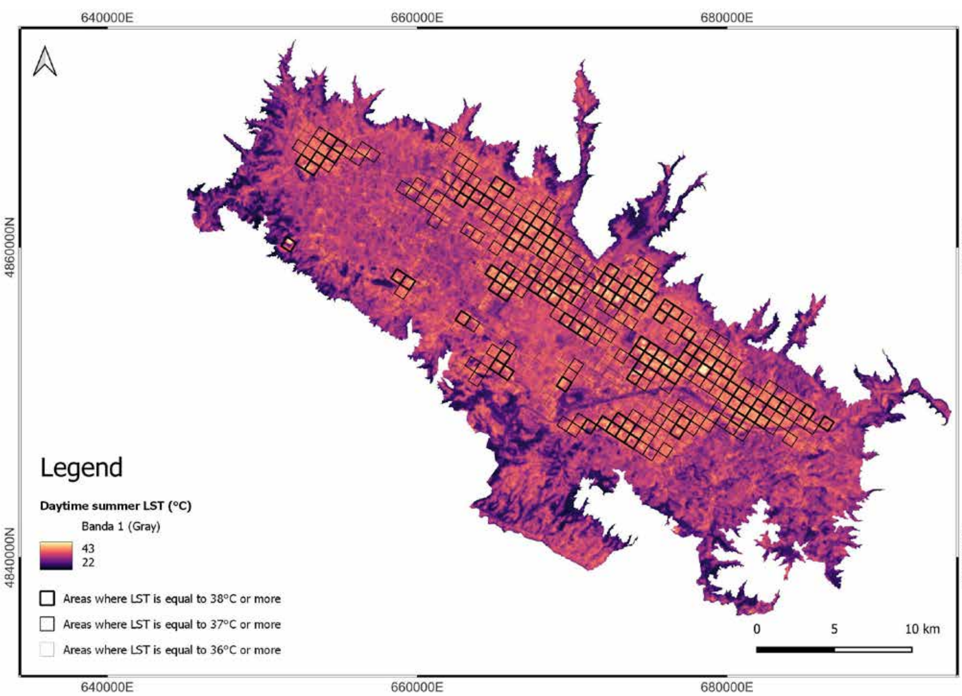
portion. The boundary of the study area was defined by combining administrative limits and the 200-meter contour line (fig. 5), resulting in a total surface of approximately 675 km^2. As an additional spatial reference, the reconstruction of the Roman centuriation system was adopted, based on Schmiedt's model (1989), providing a regular extended grid that subdivides the study area and supports both analysis and design. The Roman centuriation offers a coherent, historically grounded spatial framework. In fact, it was a central element of Roman territorial expansion, enabling structured land planning and resource distribution. Its traces remain visible today, integrated into the current landscape and road network.

2.2. Hazard Index

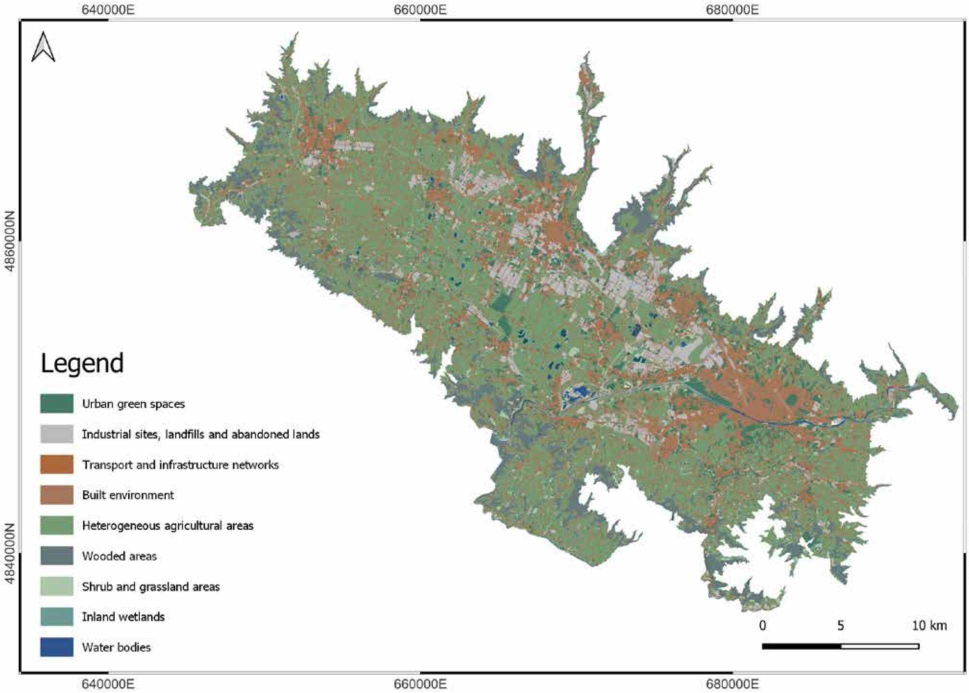
The hazard is represented through thermal stress mapping (fig. 6) with LST data derived from Guerri et al. (2021). Research has shown that 37°C is the threshold temperature for human heat tolerance (Harlan et al., 2014); beyond this point, mortality rates increase. Centuriation sectors were used to highlight temperature ranges around this threshold –



Conceptual axonometric diagram for representing the three domains of analysis.
Fig. 5



Thermal stress map – LST.
Fig. 6



Exposure map.
Fig. 7

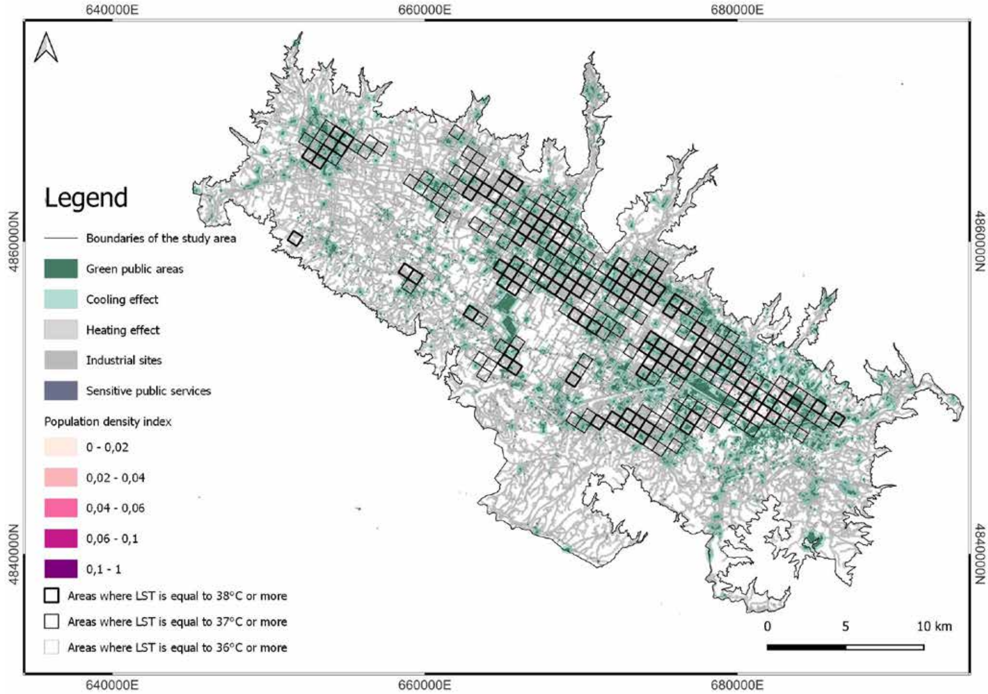
36°C, 37°C, and above 38°C – each representing a level of severity to be considered in adaptation plans. Land Surface Temperature data for this study was derived from Landsat 8 satellite imagery, analyzing three summer months (June to August) each year from 2015 to 2019. The 37°C threshold helped identify hotspots correlated with highly urbanized zones, although other factors also contribute. For the spatial analysis, the coordinate reference system used was WGS 84 / UTM zone 32N. This projection was selected due to its suitability for the study area, which falls within the central European region. The use of UTM zone 32N ensures accurate distance and area calculations, which are essential for reliable geospatial assessments and for the precise localization of interventions within the urban fabric.

2.3. Exposure Index

Exposure includes all territory elements potentially affected by excessive heat events, such as built surfaces, natural land, and resident populations (fig. 7). A special focus was given to land type, distinguishing between impervious (paved) and pervious (natural) soil. Impervious surfaces, lacking evapotranspiration capacity, contribute significantly to local heat increases.

2.4. Vulnerability Index

Vulnerability to heatwaves results from a combination of risk factors, with socio-demographic variables playing a decisive role. Age extremes, such as children under the age of five and seniors over sixty-five, are particularly sensitive, due to their reduced physiological re-



Vulnerability map.
Fig. 8

silience to extreme heat (Morabito et al., 2015). Elderly individuals face increased difficulty coping with thermal extremes, often exacerbated by limited mobility or pre-existing medical conditions. Numerous studies highlight this population segment as among the most affected during heatwave events. Similarly, very young children are also vulnerable. Research from countries such as Australia, the United States, and the UK confirms the high risk for this age group, which is often overlooked in adaptation strategies (Tomlinson et al., 2011). This study includes population segments particularly sensitive to extreme heat: children up to 5 years old and individuals aged 65 and over. The value of this population group is weighted by 50% more than the general population to emphasize its significance in the vulnerability index. In the present study, the youngest age group is novelly considered on equal terms with the elderly population, who are typically prioritized in assessments of vulnerability to urban heat island impacts (Morabito et al., 2015; Tomlinson et al., 2011). Population groups with disabilities, respiratory or cardiovascular diseases, or precarious socio-economic conditions are not included due to the lack of publicly available spatialized data. In the spatial domain, all open surface elements in the Piana are considered exposed. Vulnerable areas are those not within urban park cooling zones or located within or adjacent to industrial sites, where heat-accumulating effects are expected. In the infrastructure domain, public service facilities such as schools and healthcare centers are considered exposed. Among

Intervention methodology for the study area based on the cited criteria. Site 1: a predominantly residential area within the municipality of Prato, extending from Mezzana to the Macrolotto industrial site. Site 2: a predominantly industrial area, also located within the municipality of Prato. Site 3: a predominantly industrial area within the municipality of Florence, corresponding to the area of Calenzano.
Fig. 9

these, facilities primarily serving vulnerable populations, such as kindergartens, hospitals, local health units, and clinics, are categorized as vulnerable.

In summary, the following levels are considered vulnerable (fig. 8):

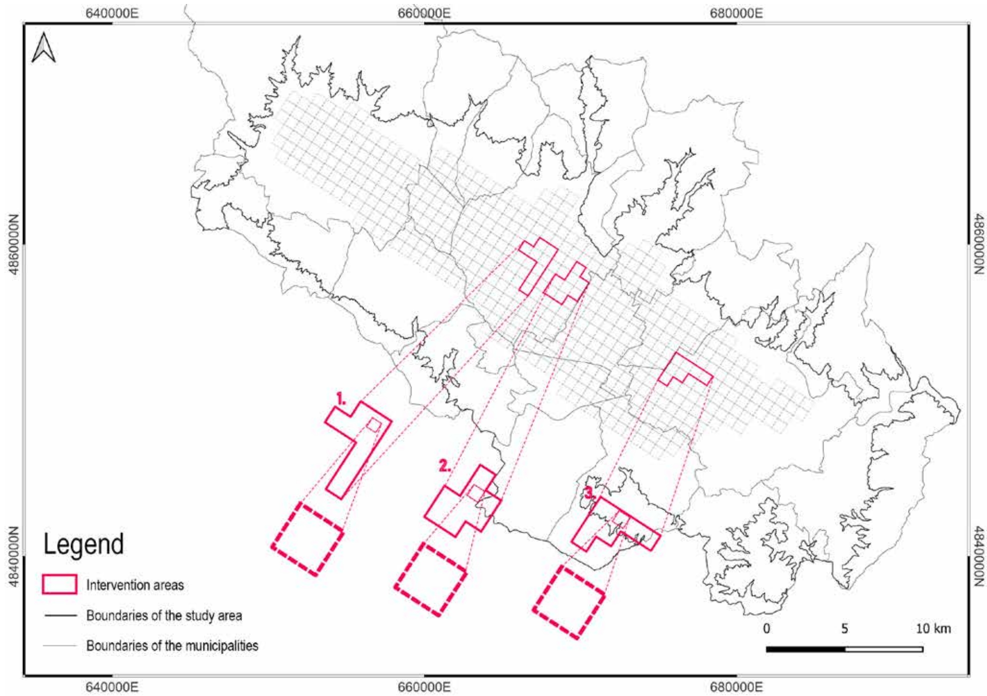
4. Population density: weighted toward sensitive demographics (ages 0-5 and 65+ years), as they are most affected by thermal stress.
5. Sensitive facilities: kindergartens, clinics, and hospitals are prioritized as areas requiring heat-mitigation strategies.
6. Heat-influenced zones: vegetation has a proven cooling effect in urban settings, based on plant vitality and park size. Air temperature in areas surrounding urban parks is affected by the movement of cool or warm air masses above the vegetation and water vapor release from plant transpiration. These processes create a cooling effect that extends beyond park boundaries, acting as a counterbalance to the urban heat island (Chang & Li, 2014). For this reason, differentiated buffer zones were applied based on park size. Only urban parks with the highest NDVI were considered - with NDVI data derived from Guerri et al. (2021) - representing optimal vegetation health and cooling capacity. In contrast, industrial areas, lacking vegetation, exacerbate urban heating. While there is no definitive study on the extent of their heat influence, a fixed minimum buffer was applied around industrial sites to model a worst-case scenario. These areas are thus characterized by a lack of cooling relief and proximity within 30 meters to heat-generating sources.

2.5. Intervention Methodology

The identification of the areas with the greatest need for intervention is not solely derived from the results of the risk assessment; it is also informed by a strategic reasoning process that considers the potential for urban transformation. Areas with a high degree of immutability are excluded, while those with a greater adaptive capacity are prioritized. This approach allows for a more realistic assessment of the feasibility of implementing proposed interventions in the actual urban context.

As such, areas that, despite exhibiting a high level of risk, are located within or in close proximity to historic city centers are excluded. These zones are often associated with heritage conservation constraints and possess limited adaptive potential. Conversely, peri-urban areas, typically subject to fewer planning restrictions, represent more plausible contexts for the implementation of climate adaptation strategies.

Similarly, urban areas located near significant sources of air cooling, such as large urban parks, are evaluated based on their spatial relationship to these features and are thus



potentially considered mitigated by the beneficial effects of their surroundings.

As a result, the areas identified for transformation interventions tend to be those situated towards the inner part of the Piana Fiorentina, distant from forests and large green parks. These are zones characterized by a high percentage of sealed surfaces and located outside the historical city centers.

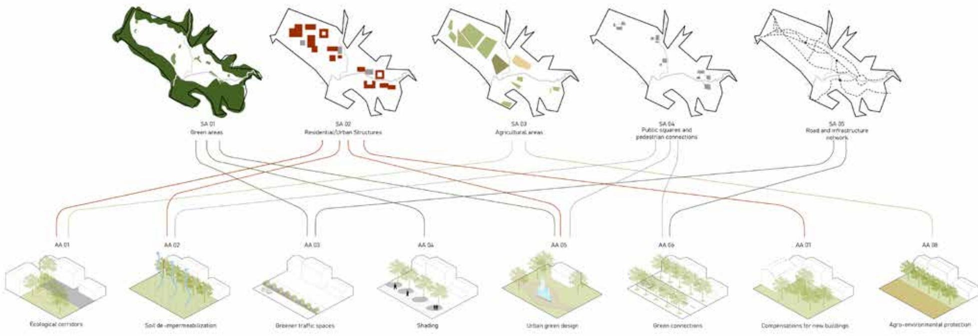
An additional parameter considered in the selection process is the identification of which component of the risk analysis had the greatest influence on the results. This allows for a more precise selection of the most appropriate strategies to be applied, depending on whether the greatest vulnerability is found in relation to the resident population, the open spaces, or the public service infrastructures.

Three areas were ultimately selected (fig. 9): the first is where risk is primarily driven by the density of population, weighted by the proportion of sensitive individuals; the second is characterized by a high percentage of impermeable surface; the third features a combination of different urban fabrics, residential and industrial, as well as the presence of certain sensitive public service facilities. This typological differentiation enables a more tailored intervention strategy.

Selected areas:

- A predominantly residential area within the municipality of Prato, extending from Mezzana to the Macrolotto industrial site.
- A predominantly industrial area, also located within the municipality of Prato.
- A predominantly industrial area within the municipality of Florence, corresponding to the area of Calenzano.

The proposed methodology draws upon the Zurich Heat Mitigation Plan (2023) and Prato's urban Forestry Action Plan (2019), and is based on the implementation of specific ap-



Schematic representation of adaptation strategies associated with primary Land Use/Land Cover classes.
Fig. 10

proaches within five Action Spheres (fig. 10), each representing a distinct planning layer of the urbanized territory. These spheres guide strategic implementation and help clarify the urban structures involved in each intervention. Serving as the foundational framework for territorial planning, they address urban challenges related to thermal stress mitigation, by focusing on key urban priorities, such as green spaces, connectivity between open and green areas, streets and squares, as well as sources of heat emissions. Moreover, they provide a reference for interpreting and guiding potential future urban development. Each sphere may be linked to one or more actionable approaches, which can be applied at the local scale.
Spheres of Action (SA):

- SA 01 – Green Areas
- SA 02 – Residential/Urban Structures
- SA 03 – Agricultural Areas
- SA 04 – Public Squares and Pedestrian Connections
- SA 05 – Road and Infrastructure Network

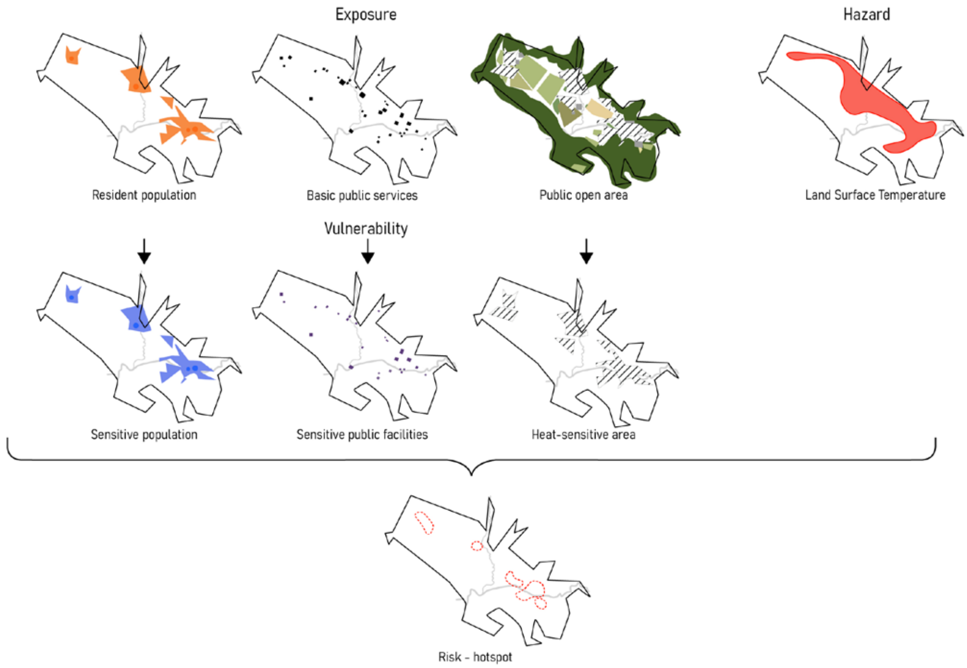
Action Approaches (AA) define the applicable intervention type for each vulnerable area:

- AA 01 – Ecological corridors
- Integration of green and interstitial agricultural zones via biodiversity-oriented ecological corridors.
- AA 02 – Soil de-impermeabilization
- The de-impermeabilization of soil surfaces contributes to a significant reduction of the urban heat island effect. Vegetated areas can lead to decreases in temperature of 1 to 4°C in their immediate surroundings.

- AA 03 – Greener traffic spaces
- De-sealing and greening surfaces mitigate heat by enhancing evaporation and transpiration, with temperature reductions reaching up to 6°C (Zurich Heat Mitigation Plan, 2023), particularly when asphalt is replaced by grass. These interventions also promote improved air quality, biodiversity and the overall quality of public spaces.
- AA 04 – Shading
- Shading in urban public spaces, such as rest areas, pedestrian pathways, and streets, contributes to improved quality of life and reduces thermal load. Trees and artificial structures are key instruments for achieving these objectives. Beyond providing shape, trees offer further climate-related benefits through evapotranspiration and air purification.
- AA 05 – Urban green design
- Effective planning of urban green spaces is essential to balance competing land-use demands while enhancing climate resilience. As climate change intensifies, prioritizing diverse, multifunctional green infrastructure becomes vital for sustainable and livable cities.
- AA 06 – Green connections
- Linear afforestation zones established along major roadways and within densely built-up urban areas function as key strategies for environmental mitigation and air pollution reduction. These green corridors also help improve urban livability through the integration of public spaces and vegetated areas, thereby enhancing the overall quality of the urban environment.
- AA 07 – Compensation for new buildings
- New urban developments incorporate land compensation mechanism by offsetting sealed surfaces with the creation of green spaces, aiming to maintain ecological balance and mitigate the environmental impact of increased soil impermeability.
- AA 08 – Agro-environmental protection
- The establishment of an agro-environmental buffer zone at the urban-rural interface serves to protect the boundaries of agricultural land from expanding urban areas. Afforestation along agricultural edges, through rows of trees and hedgerows, can contribute mitigating the urban heat island effect while maintaining, or even improving, crop productivity.

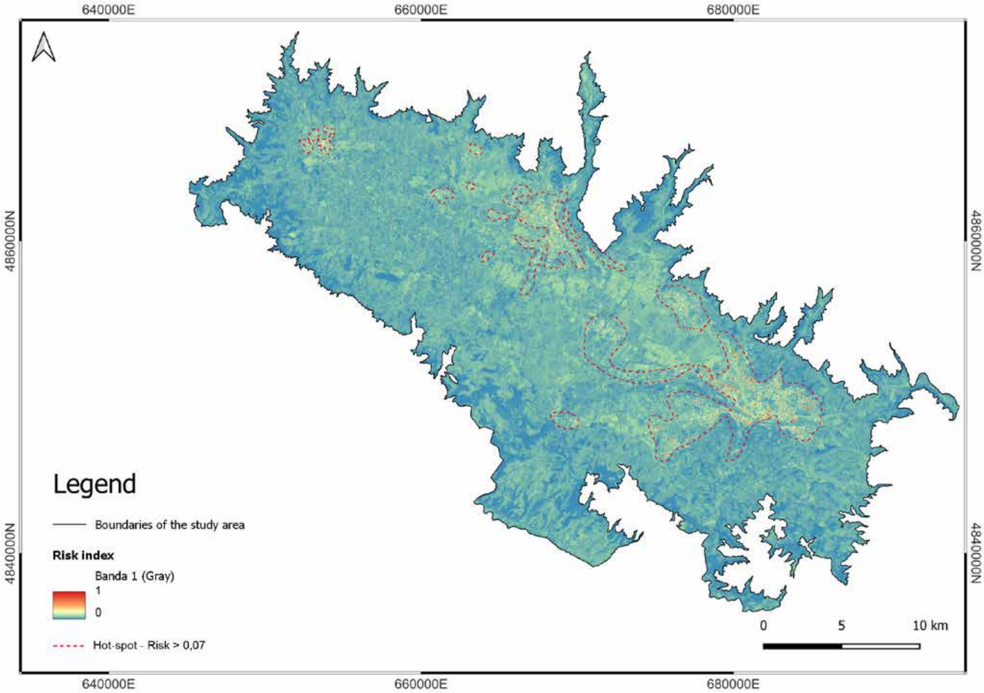
3. Results

The final analysis, combining the layers of social, structural, and spatial vulnerability, yielded a total vulnerability map showing populations at risk due to urban heat islands in the Piana Fiorentina. The risk map was created by mathematically multiplying the vulnerability, exposure, and hazard layers. This produced hotspot areas where urgent mitigation interventions are necessary. Figure 11 illustrates the spatial risk

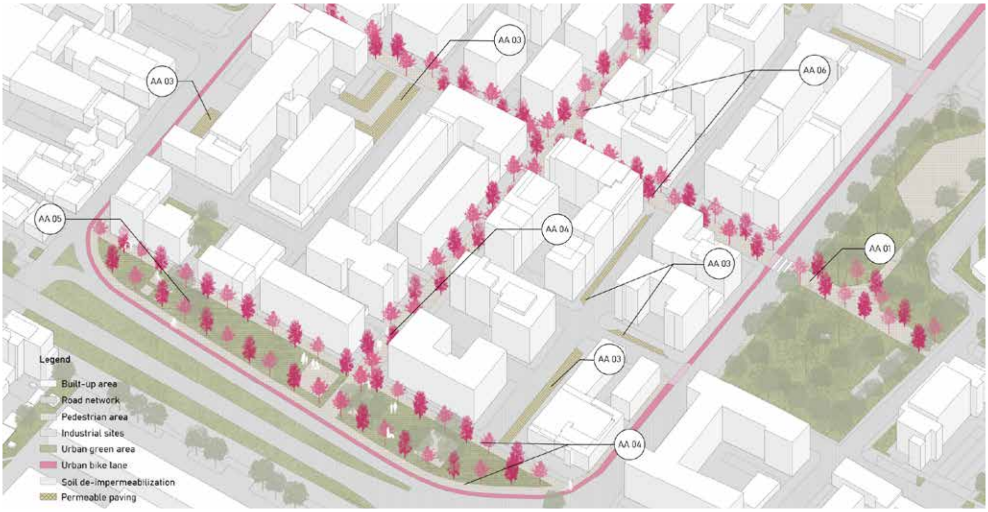


Conceptual flowchart according to the three components of risk.
Fig. 11

model as a conceptual flowchart showing how exposure, hazard, and vulnerability converge to produce risk and define hotspot zones. Risk is highest in urban centers such as Florence, Prato, and Pistoia, especially in city cores and densely built neighborhoods like Rifredi and Novoli, as well as smaller urban centers like Sesto, Scandicci, and Campi Bisenzio. Some areas exhibit moderate risk, driven primarily by land type: for instance, industrial zones with low population density, where risk remains significant due to the proportion of impervious surfaces and industrial land use (fig. 12).
The proposed interventions outlined in the previous section are applied within the identified areas, with the aim of mitigating the analyzed levels of risk.
The first project intervention (fig. 13) targets a predominantly residential urban area characterized by high weighted population density. The selection of the intervention site was informed by a risk analysis, prioritizing areas with elevated demographic concentration in order to maximize the impact of mitigation strategies.
The intervention focuses on restructuring internal mobility by restricting vehicular access exclusively to residents. This approach supports the gradual transformation of the area into a pedestrian-oriented environment. Two perpendicular pedestrian axes are introduced as key connective elements linking existing green infrastructures: one axis extends from the Karl Marx Park, a central green node, while the other originates from a green space situated at the edge of the site along Viale Leonar-



Map of heat-related health risk in the study area.
Fig. 12



Axonometric view of the project area and implementation of Action Approaches for adaptation.
Fig. 13

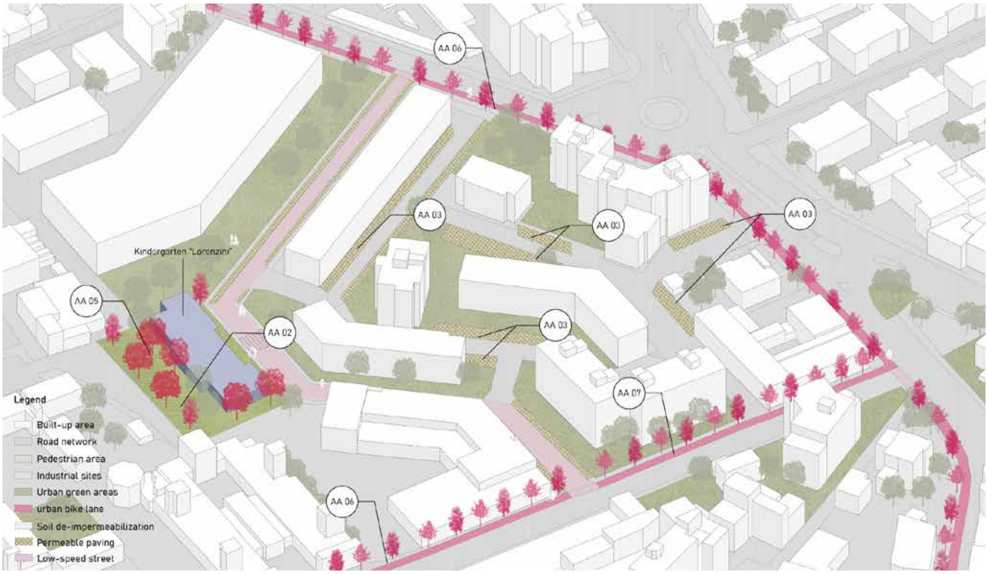
Axonometric view of the project area and implementation of Action Approaches for adaptation.
Fig. 14

do da Vinci, which is also subject to ecological restoration and demineralization. Open space design emphasizes ecological enhancement through new tree plantings, particularly along the main pedestrian routes, with the goal of improving environmental and microclimatic quality. Perimeter mobility is reconfigured to accommodate a new bicycle lane, promoting sustainable transportation and ensuring effective integration with the surrounding urban fabric.

The second intervention (fig. 14) addresses an area characterized by a high degree of soil impermeability and a predominantly industrial land use, with minimal residential presence and scarce public green spaces. In response to these conditions, the project adopts a set of strategies aimed at ecological restoration and environmental mitigation, including the establishment of ecological corridors, compensation measures for new developments, agro-environmental protection, soil de-impermeabilization, green connectivity, and the integration of vegetation within transportation infrastructure.

The proposed design focuses on the creation of multifunctional tree-lined boulevards. These green corridors serve multiple roles: providing shade, integrating vegetation into traffic routes, and acting as buffers between urbanized and agricultural areas. Particular emphasis is placed on the demineralization of non-essential paved surfaces to restore soil permeability and support natural drainage processes.

The third design intervention (fig. 15) is located within the Municipality of Florence, in an area characterized by predominantly residential land use, interspersed with some industrial sites and a limited supply of public green spaces. The adopted strategies include the creation of new green areas, soil de-impermeabiliza-



Axonometric view of the project area and implementation of Action Approaches for adaptation.
Fig. 15

tion, compensation measures for new buildings, the implementation of tree-lined boulevards, and the integration of vegetation into traffic-related infrastructure. The site includes a kindergarten, identified during the analysis phase as a sensitive urban function. The project proposes to enhance the safety and quality of the school's immediate surroundings by converting into a pedestrian zone the street segment directly in front of the facility, thereby limiting vehicular traffic and promoting pedestrian and bicycle mobility. Vehicular circulation is redirected along peripheral streets, where a dedicated bike lane is also introduced. Additional measures involve the demineralization of parking surfaces to increase soil permeability and mitigate urban heat island effects. New tree plantings are planned along pedestrian paths to provide shading, improve public space usability, and enhance the microclimatic resilience of the area.

4. Discussion

This study contributes to the growing body of research on urban heat islands and heat-related health risks by advancing an integrated and context-specific approach. While much of the existing literature tends to focus either on the physical dimension of UHI dynamics or on epidemiological correlations between heat and health outcomes, the present work combines remote sensing indicators of surface temperature with socio-demographic measures of exposure and vulnerability. This integration makes it possible to generate a spatialized representation of heat risk that captures not only where extreme thermal conditions occur, but also who is most affected by them. This orientation is consistent with the findings of the IPCC Sixth Assessment Report, which highlights that urbanization processes interact with climate hazards to amplify vulnerability and exposure, particularly for low-income

groups, children and the elderly (IPCC, 2022).
The proposed formula is derived from the risk equation commonly found in literature, but has been here adapted to better align with the specific objectives of this research. The modification emphasizes the estimation of population health risk as a function of both environmental and contextual determinants. In this framework, factors such as the availability of supportive facilities and the cooling or heating effect produced by the surrounding urban environment contribute to shaping the overall level of exposure and vulnerability. Drawing on the review of several comparable methodologies, this study introduces a revised version of the equation that preserves its conceptual framework while incorporating these local dynamics essential to a territorial understanding of heat-related risk. This formulation provides a conceptual basis for further testing and validation in future applications.

A distinctive aspect of this work is the strategic assessment of urban transformability. Rather than focusing solely on risk identification, the study evaluates the feasibility of interventions according to the adaptive potential of different areas, prioritizing peri-urban zones while excluding highly immutable contexts such as historic centers. The application of the proposed strategies to the selected areas provides a robust validation of the model, establishing a foundation for a realistic visualization of potential urban heat mitigation scenarios. In this way, the research advances a perspective that not only diagnoses urban climate risks but also outlines operational strategies, thereby bridging analytical results with planning practice. Such an approach aligns with recommendations from the WHO, which stress that the adverse health impacts of heat are largely preventable when supported by urban planning, preparedness of health and social systems, and timely public communication (WHO, 2020). By linking environmental and social data with local planning constraints, the research moves beyond descriptive mapping to provide a framework that is both diagnostic and operational. This dual orientation distinguishes it from previous approaches and offers a practical reference for aligning climate adaptation strategies with the socio-spatial realities of contemporary urban systems. In line with recent calls from both IPCC and WHO, which emphasize the need for timely, context-sensitive, and multi-level responses to extreme heat (IPCC, 2022; WHO, 2022), the proposed methodology demonstrates how research can support actionable, locally grounded adaptation strategies that enhance both environmental resilience and social well-being.

5. Conclusions

Given the complexity of the urban heat island phenomenon, the numerous ongoing studies, and the intricate urban ecosystems affected by it, a comprehensive consideration of all contributing variables to the risk analysis remains a considerable challenge. The following is a list of the limitations of this research, detailing all those elements that were excluded, due to gaps in the literature, lack of accessible data, or the impossibility of data collection, leaving room for potential future integration:

- Pre-existing health conditions can increase susceptibility to heat-related illnesses and mortality.
- Air conditioning is a strong protective factor against heat-related deaths but is not recorded in census databases.
- Public transport services.
- Public nursing homes and residential care facilities for the elderly.
- The effects of water bodies (lakes and rivers) on temperature and urban heat island intensity.
- Elements of urban settlement structure, which further contribute to temperature increases.
- The impact of heat islands on the conservation status of buildings and infrastructure.
- The impact of heat islands on protected natural ecosystems in the territory.

As noted in the limitations above, water bodies, although not considered in the present work, could be integrated into the analytical framework as cooling elements, similar to urban parks, whose actual contribution would warrant further investigation.

The research could be further refined by differentiating the subject of the analysis affected by urban heat island according to gender, economic status, level of education, marital status, and health-related information such as past or existing physical conditions. From an urban perspective, further variables may include the state of building conservation, considered in terms of their performance under high-temperature stress, as well as building density.

The analysis conducted in this research highlights that urban heat islands represent a growing threat to public health and well-being, especially in the context of climate change, where extreme temperatures are expected to become more frequent and intense. Through the assessment of climate risk in the Piana Fiorentina, it was possible to identify the most vulnerable areas and propose targeted adaptation strategies capable of mitigating the impacts of urban overheating and improving the quality of life in cities. The resulting maps are derived from numerical datasets, which, due to space constraints, are not fully reported within this article. Once the post-implementation scenario of the proposed strategies is calculated, it will be possible to quantitatively evaluate their effectiveness, thereby offering a concrete method to assess and optimize urban planning measures aimed at reducing heat-related vulnerabilities.

The challenges posed by urban overheating require timely responses and strategies that are both effective and sustainable over time, strategies that combine environmental resilience with social well-being. This study has provided a useful framework to guide planning and design decisions in the Piana Fiorentina, emphasizing the importance of placing climate and livability at the core of future urban transformation processes.

Author Contributions

Conceptualization: C.P., S.C., E.G., B.D.D.; Methodology: C.P., S.C., E.G., B.D.D.; Formal analysis: B.D.D.; Investigation: S.C., E.G., B.D.D.; Resources: E.G.; Data curation: B.D.D.; Writing - Original Draft: B.D.D.; Writing - Review & Editing: C.P., S.C., E.G., B.D.D.; Visualization: B.D.D.; Fund acquisition: S.C., C.P.; Supervision: S.C., C.P.

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Data Availability Statement

The datasets generated and analyzed during the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.17414886

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