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Analysis of Spatial Accessibility of Urban Climate Shelters

A Case study of Turin

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Abstract

Today, around half of the world's population resides in cities. This proportion is projected to increase significantly, with the urban population anticipated to more than double by 2050 – nearly 70% of the world's population is expected to be living in cities! Climate change significantly challenges the urban livability, with rising temperatures profoundly affecting thermal comfort for urban population. Urban areas experience pronounced impacts from climate change such as Urban Heat Island effect and frequent heat waves. These phenomena exacerbate the existing rising temperatures in cities, making living conditions increasingly severe. Urban populations, particularly the elderly are vulnerable to these extreme heat conditions, a situation expected to deteriorate further in the future. This critical concern underscores the urgent need for cities to enhance their climate adaptation strategies to protect their residents' health and well–being.

One innovative adaptation strategy is the implementation of Urban Climate Shelters (UCS), which provide refuge for the climate refugees during extreme heat events. Over the past few decades, Turin has been negatively impacted by UHI and intense heat waves; as a result, UCS intervention is necessary to protect the city's vulnerable population. With multiple nomenclature for this approach around the world, the efficiency of these shelters' centers on their level of accessibility to all the residents.

This master's thesis seeks to ensure that UCS in Turin efficiently serves to vulnerable populations, especially the elderly, by providing both spatial and temporal accessibility during extreme heat events. Moreover, the research study focuses on how public libraries can evolve as UCS after hours.

To achieve this, the research undertakes an extensive literature study on this adaptive tool, focusing on reference studies related to their accessibility. It also examines how UCS can be integrated into the popular urban planning concept – the 15 -minute city, enhancing overall accessibility and convenience. Further, a thorough study of Turin and its climate hazards, particularly the UHI effect and HWs emphasizing the impacts on vulnerable population, is carried out by analyzing the risk components. The research framework is based on an analytical overview of spatial and temporal accessibility with the help of parameter selection through various reference studies worldwide. Additionally, the study proposes converting 21 libraries in Turin into UCS and evaluates their spatial and temporal accessibility based on the walking speeds of the pedestrians in focus. Two methodologies are employed for this assessment: the Land Surface Temperature (LST) during the peak summer time and the hourly Solar Radiation method during the summer solstice. These methodologies aim to create comparative empirical scenarios to determine the most optimal accessibility routes for the elderly to the nearest UCS, minimizing sun exposure during extreme hot days. The study concludes with a strategic framework for prioritizing which should be immediately converted to UCS to effectively serve the vulnerable urban population.

This thesis underscores the importance of accessible urban climate shelters in enhancing urban adaptive capacity. The proposed interventions aim to create a resilient and more inclusive Turin, capable of withstanding the increasing threats posed by climate change.

Keywords: Urban Climate Shelters, Climate Adaptation, Spatial Accessibility, Climate Refugees, Pedestrian Behavior, Thermal Comfort, Urban Livability, Urban Resilience

Abstract (Italian)

Oggi, circa la metà della popolazione mondiale risiede nelle città. Questa proporzione è destinata a crescere significativamente, con la popolazione urbana prevista a più che raddoppiare entro il 2050 - quasi il 70% della popolazione mondiale vivrà nelle città! Il cambiamento climatico rappresenta una sfida significativa per la vivibilità urbana, con temperature in aumento che influenzano profondamente il comfort termico della popolazione urbana. Le aree urbane subiscono impatti pronunciati del cambiamento climatico come Urban Heat Island (UHI) e frequenti ondate di calore. Questi fenomeni esacerbano le già elevate temperature nelle città, rendendo le condizioni di vita sempre più severe. Le popolazioni urbane, in particolare gli anziani, sono vulnerabili a queste condizioni meteorologiche estreme, una situazione destinata a deteriorarsi ulteriormente in futuro. Questa preoccupazione critica sottolinea l'urgente necessità che le città potenzino le loro strategie di adattamento al clima per proteggere la salute e il benessere dei loro residenti.

Una strategia innovativa di adattamento è l'implementazione degli Urban Climate Shelters (UCS), che forniscono rifugio per i "climate refugees" durante eventi di calore estremo. Negli ultimi decenni, Torino è stata negativamente influenzata dall'UHI e dalle intense ondate di calore; di conseguenza, è necessaria un'intervento UCS per proteggere la popolazione vulnerabile della città. Con molteplici nomenclature per questo approccio in tutto il mondo, l'efficienza di questi centri rifugio dipende dal loro livello di accessibilità per tutti i residenti.

Questa tesi magistrale mira a garantire che gli UCS a Torino servano efficacemente le popolazioni vulnerabili, in particolare gli anziani, fornendo accessibilità sia spaziale che temporale durante eventi di calore estremo. Inoltre, lo studio di ricerca si concentra su come le biblioteche pubbliche possano evolversi come UCS dopo l'orario di chiusura.

Per raggiungere questo obiettivo, la ricerca svolge un'ampia revisione della letteratura su questo strumento adattativo, concentrandosi su studi di riferimento relativi alla loro accessibilità. Esamina anche come gli UCS possano essere integrati nel popolare concetto di pianificazione urbana - la città dei 15 minuti, migliorando l'accessibilità complessiva e la convenienza. Inoltre, viene condotto uno studio approfondito su Torino e sui suoi rischi climatici, in particolare sull'effetto UHI e sulle ondate di calore, enfatizzando gli impatti sulle popolazioni vulnerabili, analizzando i componenti di rischio. Il quadro di ricerca si basa su una panoramica analitica dell'accessibilità spaziale e temporale con l'aiuto della selezione dei parametri attraverso vari studi di riferimento a livello mondiale. Inoltre, lo studio propone di convertire 21 biblioteche a Torino in UCS e valuta la loro accessibilità spaziale e temporale in base alla velocità di cammino dei pedoni in esame. Per questa valutazione vengono impiegati due metodologie: Land Surface Temperature (LST) durante il periodo estivo di picco e il metodo dell'Irraggiamento Solare orario durante il solstizio d'estate. Queste metodologie mirano a creare scenari empirici comparativi per determinare i percorsi di accessibilità più ottimali per gli anziani fino al UCS più vicino, minimizzando l'esposizione al sole durante le giornate estremamente calde. Lo studio si conclude con un quadro strategico per prioritizzare quali biblioteche dovrebbero essere immediatamente convertite in UCS per servire efficacemente la popolazione urbana vulnerabile.

Questa tesi sottolinea l'importanza dei rifugi climatici urbani accessibili nel migliorare la capacità adattativa urbana. Le interventi proposti mirano a creare una Torino resiliente e più inclusiva, in grado di resistere alle crescenti minacce poste dagli impatti del cambiamento climatico.

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SECTION 1

Introduction

Chapter 1

1.1 Project Problem Statement and Background Study

Cities are the epicenter of the climate change crisis and are home to more than half of the world's population. Urban areas are under increased stress due to climate change. This includes more frequent and intense droughts, inland floods that compromise water supplies, and heat waves that threaten the health of the urban population. Coastal cities are also more vulnerable to storm surges and sea level rise, which can negatively impact residents and vital infrastructure, property, and ecosystems. However, considering the current demographic trends, cities account for at least 40% of the world's greenhouse gas emissions, a percentage that is expected to rise over time. These problems highlight that cities must reconsider how resources are allocated and people are protected, how to prioritize infrastructure spending, and how the climate will impact long-term growth and development strategies. As the physical effects of climate change worsen, many cities throughout the world are constructing or remodeling public areas to serve as climate refuges for their most vulnerable citizens, enabling them to prepare for catastrophic situations. These refuges consist of air-conditioned indoor spaces like cooling centers and disaster relief sites that provide temporary shelter during storm, flood, and wildfire episodes, in addition to green spaces. A prime example is Barcelona, which has a municipal network of "Climate Shelters" designed to provide thermal comfort to those who are particularly susceptible to high temperatures because of their age, health or socioeconomic status.

Thus, the term "urban climate shelter" refers to public areas or places like city parks, green spaces, squares, stadiums, schools, public libraries and other places that can offer urban residents' refuge, basic life security and rescue during extreme temperatures. Moreover, the further significant challenges to be addressed related to UCS are the accessibility and proximity to these climate shelters. The age, ethnicity, socioeconomic status and other underlying characteristics of the neighboring communities that raise the risk of heat-related health incidents should be taken into account when strategically placing these facilities.

Turin (Torino), the fourth most populous urban area in Italy, is the largest city in the northwest with a population of about 850,000. One of the main challenges faced by this city is the extreme temperature, such as heat waves and the occurrence of Urban Heat Island (UHI). Climate change exacerbates the existing weakness of the city such as the social – economic factors. Turin, with its rich cultural heritage and diverse urban fabric, presents a unique opportunity to explore the implementation of UCS within the city's existing infrastructure. The public libraries, with their presence in a neighborhood scale which is a contributing factor to the accessibility aspect, could serve as potential UCS, aligning with the 15 – minute city concept. This concept advocates for walkable neighborhoods where essential services are within a 15 minutes walking distance. Inclusion of UCS as an essential service is now required to respond to the worsening climatic conditions.

However, while the theoretical framework and various global reference studies provide valuable insights, there is a lack of empirical research regarding the accessibility of UCS, especially to Turin's context.

1.2 Research Question

"How can the conversion of libraries into Urban Climate Shelters in Turin, Italy, effectively provide spatial and temporal accessibility for vulnerable populations, particularly the elderly, during extreme heat events?"

This research question focuses on investigating the potential of repurposing libraries as Urban Climate Shelters to improve accessibility and resilience in Turin, addressing the needs of vulnerable populations in the context of climate change impacts.

1.3 Research Objectives

1. To understand the concept and impact of Urban Climate Shelters (UCS) as an emerging climate adaptation tool in the cities, that has become an essential service in this world of changing climate.
2. To examine the urban heat island (UHI) risk in Turin and explore how introducing Urban Climate Shelters (UCS) could improve urban livability.
3. To create comparative empirical scenarios to assess the spatial and temporal accessibility of proposed Urban Climate Shelters (UCS) during high temperatures.
4. To provide the framework for incorporating inclusive and accessible Urban Climate Shelters in the city of Turin for all urban population.

1.4 Research Aim

"To ensure that Urban Climate Shelters in Turin serve effectively to vulnerable populations, particularly the elderly, providing both spatial and temporal accessibility during extreme heat events."

1.5 Scope and Limitations of the research

This thesis investigates the potential and efficiency of adapting libraries in Turin, Italy, into Urban Climate Shelters. It focuses on enhancing the temporal and spatial accessibility of these spaces for vulnerable groups, especially the elderly population, during periods of excessive heat. The study will examine how the strategic repurposing of libraries—public spaces that are centrally located and accessible—can provide immediate and localized relief from high temperatures. The research attempts to illustrate how community-centric design and operating hours of libraries contribute to increased accessibility and resilience in the proposition chapters. Furthermore, the thesis will evaluate the broader impacts of incorporating measures for climate adaptation into urban design, with a focus

on urban health and social equality in relation to climate change. This research will offer insights into the benefits and practical implementation of Urban Climate Shelters and their accessibility through a combination of case studies from around the world - in addition to them being incorporated into popular urban planning concerts such as the 15-minute City. Ultimately this will help Turin to become a more resilient and inclusive urban environment.
This study encounters a few limitations that may impact the accuracy and applicability of its findings and propositions. Firstly, the study focuses solely on UHI and Heatwaves in terms of extreme weather conditions brought on by the climate change and their impact on the various urban domains. Secondly, the study exclusively considers public libraries as potential Urban Climate Shelters (UCS) for its accessibility assessment, which may overlook other viable public spaces that could also serve this purpose effectively. This narrow focus may limit the application of the results to other types of infrastructure. Thirdly, there are constraints related to the census data of the city that can potentially affect the accuracy of the spatial assessment with respect to the urban population. Furthermore, the research may encounter difficulties in acquiring comprehensive data on the operational capacities of libraries, including the availability of space during periods of high utilization. The efficacy of the libraries as UCS may be overestimated or underestimated as a result of these data restrictions. Finally, beyond what is investigated in this study, there are additional socioeconomic factors which might impact vulnerable groups' willingness and capacity to use these shelters, which are difficult to quantify and analyze comprehensively within the scope of this study.

1.6 Thesis Structure

This master thesis intends to explore the potential of converting public libraries into UCS in Turin to enhance the urban livability for the urban population, especially during extreme heat events. The integration of UCS within the existing infrastructure of the city’s urban fabric offers a unique opportunity to leverage their spatial and temporal accessibility. The multifaceted nature of this transformation necessitates an exploration of functional, institutional and social contexts. By adopting an interdisciplinary approach that draws from fields such as urban planning, climate resilience and public health, this thesis will evaluate how public libraries can be repurposed to serve as effective UCS. This investigation will provide insights into the accessibility planning of these shelters thereby contributing to the climate adaptation tool for urban heat island (UHI).

In addition to the introduction part, the thesis is structured into three main sections comprising seven chapters to systematically address the research objectives and question, ultimately assessing the accessibility and proposing viable framework for the effective and just implementation of UCS in the city of Turin.

Section 1 – Introduction

- Chapter 1:
  The introductory section of the research defines the problem statement on which this thesis is built along with the research objectives and boundary of the study. This chapter is further divided into – Research Question, Research Objective, Research Aim and finally the structure of this master’s thesis.

Section 2 – Literature Review

- Chapter 2:
  The theoretical framework explores the impacts of climate change focusing on the challenges posed to urban environments caused by urban heat island (UHI) and heatwaves. It delves into the European context and discuss about the urban resilience, sustainable development goals (SDGs) and how cities are responding through various climate adaptation tools. The frameworks introduce the concept of Urban Climate Shelters (UCS) as an innovative tool for adaptation, illustrated with a couple of examples. It also examines the accessibility of UCS in reference to research studies by Nayak et al., 2019 and Sehgal & Sehgal, 2023, further proposing their integration with the popular urban planning concept of 15 – minute city. This approach aims to address the significance of enhancing the availability and usability of UCS within urban contexts, thereby contributing to broader climate resilience efforts.

- Chapter 3:
  The chapter begins by outlining the methodological framework employed in developing this master's thesis, which includes structuring the study into three main sections: Preliminary Study, Assessment and Propositions. Further, the chapter details the various selected reference studies from around the world for the identification of behavioral parameters of pedestrians during high – temperature periods. This sub – section includes reference studies by Lin et al., 2013; Savvides, 2016; Nayak et al., 2019; Obuchi et al., 2021; and so on. Additionally, the study underscores the importance of addressing the research gap identified related to the accessibility of UCS and how Turin requires immediate recognition in terms of implementing this adaptive tool. Furthermore, it proposes an accessibility analysis based on parameters identified from these reference studies, focusing on different scenarios involving various pedestrian groups based on age category.

Section 3 – Urban Case Study of Turin

- Chapter 4:
  The chapter aims to establish the context of the study. The chapter is seen to be divided into two parts where the first part provides a general overview of the city of Turin, discussing its climatic challenges in the past years along with predictions for future conditions. Whereas, in the second part focuses on the impacts of UHI and HWs on Turin, further analyzing the study area's vulnerability to risk and exposure, using the city's UHI hazard data. The key references considered for this analysis include Turin's Climate Resilience Plan of 2020 and the study by (Ellena et al., 2023).

- Chapter 5:
  This chapter discusses the main adaptation strategies that have been implemented in the city over the past years, as outlined in the Climate Resilience Plan of 2020. It covers initiatives such as the Valdocco Liveable Projects, Green Infrastructure and their alignment with the Turin Action Plan, 2030 aimed at making the city more sustainable and resilient. The chapter also introduces the ideology of converting public libraries of Turin into UCSs in line with the resilience plan that established the idea of "Climate Refugee". The chapter further unfolds details of the identification of these libraries within the urban fabric and presents a spatial accessibility analysis conducted for various scenarios as mentioned in chapter 3. The spatial

and temporal accessibility analysis of the elderly and young adults during the summer season is developed with LST and RSR methodologies.

- Chapter 6:
  The chapter presents the inferences and findings from the assessment section, focusing on the spatial accessibility of the elderly population in different hazard zones. Two proposed frameworks are developed in order to prioritize the climatization of the public libraries in the city and identify areas that should implement the UCS tool. These propositions are further supported by design recommendations aimed at enhancing the thermal comfort of pedestrians on an urban street scale. Through these, the study aims to create a more resilient and livable urban environment for all its residents amidst the growing challenges posed by climate change.

- Chapter 7:
  The final chapter of this master's thesis summarizes the overall inferences and findings from various sections of the study, emphasizing the importance of integrating UCS into the city's resilience plan to enhance Turin's ability to protect its vulnerable populations such as the elderly during extreme heat events. Additionally, potential follow ups are also mentioned for further research opportunities on this topic. Finally, the study concludes by underscoring that the climate change phenomenon is a global challenge and highlights the urgent need for adaptation through by introducing innovative tools such as the UCS in urban areas around the world.

SECTION 2

Literature Review

Chapter 2

2.1. The Present Livability of an Urban Environment

Cities are representations of human achievement, civilizational advancement and the encouragement of comfort and ease. Throughout history, cities became a sanctuary for people to live, work and socialize. As the population and city grew, the initial equilibrium of urban environment [1] with the natural environment became unstable. Cities, where more than half of the world's population lives, are facing increasing challenges to their livability (Lian et al., 2021)). Climate change, the most widely debated and researched topic from the twentieth century, has certainly emerged as one of the crucial challenges (Musco, 2016). According to Intergovernmental Panel on Climate Change (IPCC) report 2023, human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850 – 1900 in 2011 – 2020. Forecasts from the IPCC indicate that climate variability-related phenomena will become more intense in the upcoming decades (IPCC, 2007) and that extreme climate events will become a greater risk to society and the environment (IPCC, 2012). Cities not only contribute to climate change, they are also particularly vulnerable to its impacts (Bulkeley et al., 2013).

2.1.1 Global Impacts of Climate Change – Heatwaves and Urban Heat Island

Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts on food and water security, human health and on economies and society and related losses and damages to nature and people. Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (IPCC Report, 2023).

The effects of climate change are already being experienced, and the outlook is dismal despite the global efforts to mitigate it. Many researchers discuss how the frequency and severity of extreme weather events—such as heatwaves[2] (HWs), storms, tropical cyclones, droughts, and floods—will increase. Consequently, heatwaves have emerged as a critical challenge for urban development as a result of a combination of the effects of climate change and urbanization processes (Eugenio Pappalardo et al., 2023). They are regarded as the meteorologically and climatically related natural disaster with the highest mortality rate (WMO, 2015). In the half of 2023, several regions of the world were affected by a series of heatwaves, mostly in southern Europe and north Africa (World Meteorological Organization, 2023). From the report released in the starting of 2024 by The Copernicus Climate Change Service (C3S), 2023 was the hottest year on record in at least 173 years, where the global temperatures came close to the limit 1.5°C and this is subjected only to increase in the following years. As expected, in the month of February 2024, another press release by C3S stated that, measured between 1850 and 1900, the average global temperature increased by 1.52°C over average temperatures at the beginning of the Industrial Revolution (Chart 1). According to IPCC, it's *virtually certain* (99 – 100% probability) that heatwaves will increase across most land regions in

[1] Urban environment is defined as ecosystem of an urban area in which the urban residents interact with biotic and abiotic factors. *Source - igi-global.com*

[2] Heatwave - a period during which the daily maximum temperature exceeds for more than five consecutive days the maximum normal temperature by 9°Fahrenheit (5°Celsius). Source – The World Meteorological Organization (WMO).

frequency, magnitude and duration and there is *high confidence* that they are driven by human activities (IPCC, 2021).

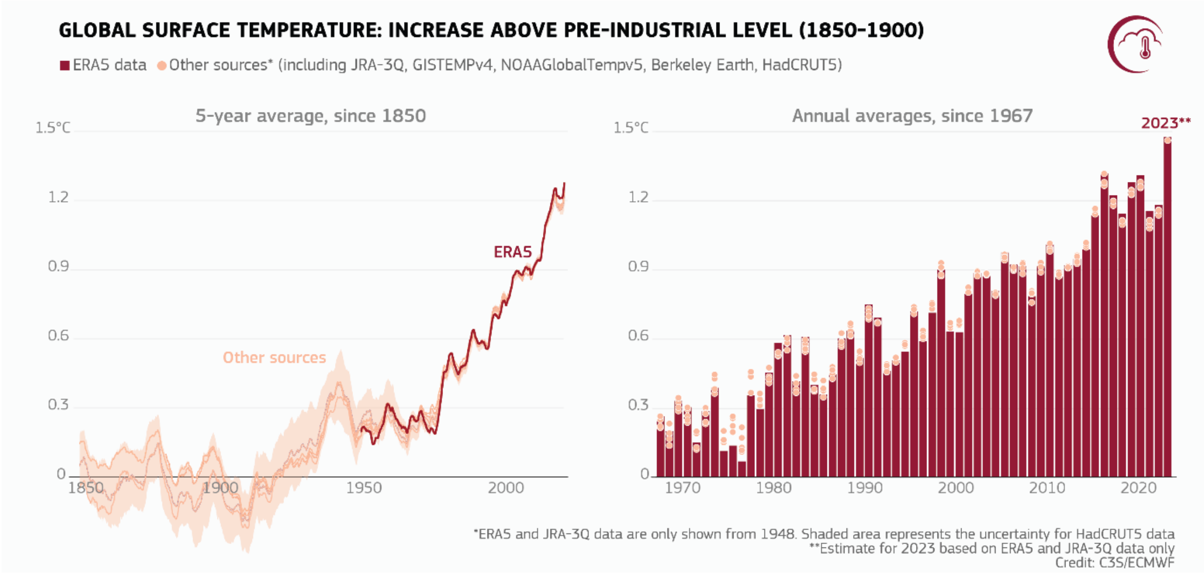

Chart 1: Graph depicting the rise of Global Temperature through centuries. Source: C3S (January, 2024)

Apart from these adverse meteorological extreme events, in the Global North, a widely and long-term researched concern caused by the urbanization process is the Urban Heat Island (UHI) effect (Oke, 1982, Taha, 1997). Luke Howard was the first scientist to provide evidence that air temperatures are often higher in a city than in its surrounding countryside (Howard, 1966). This phenomenon is caused by the presence of large impermeable surfaces (paved surfaces), an abundance of grey surfaces (asphalt and concrete, which have low albedo and high heat admittance rates), shortage of vegetation and green areas (trees and parks), and the additional heat released by human activities and its related energy impacts (transportation, building cooling and heating) (Oke, 1982).

Several studies have demonstrated a strong correlation between heat waves and UHI events, even though HWs and UHI are two separate meteorological phenomena. Their dynamic interaction will cause extreme heat events in urban areas. Heat events can have a wide range of environmental, energy-related, economic, and human health consequences, such as increased energy consumption or thermal discomfort (US Environmental Protection Agency, 2021).

Figure 1: Urban Heat Island (UHI). Source: Fuladlu et. al., 2018. It's noted that the temperature in city/urban area is 2° higher than its surrounding suburbs and rural areas.

HWs include seasonally extreme (summertime) events or seasonally anomalous warm spells (annual) (S.E.Perkins et al., 2012).

Heat Waves and Urban Heat Island – A European Overview

The deadliest extreme climate events in Europe are heatwaves...... - Copernicus, 2022

Over the last four decades, extreme weather events such as storms, HWs and flooding accounted for 85,000 to 145,000 human fatalities across Europe. Over 85% of those fatalities were caused due to HWs (European Environment Agency, 2024). According to Climate Change Service by Copernicus, the amalgamation of climate change, urbanization and rise in ageing population in this region creates and will further worsen, vulnerability to heat. Europe, the second densely populated continent after Asia, is characterized by wide urbanized areas, which house almost 75% of its total population (Eurostat, 2021). After the 2003 "deadly summer," which is estimated to have resulted in approximately 70,000 excess deaths (UNEP, 2004), Europe has seen a significant increase in extreme HWs. After 20 years, in the summer of 2023, Europe experienced record-breaking temperature rise especially over the southern half of the continent with temperatures above 45°C in parts of Greece, eastern Spain and southern Italy (ECMWF, 2023).

The influence that temperature, humidity, wind speed, and other environmental factors have on the human body is known as heat stress[3]. Entire southern Europe has already experienced up to 10 days of "very strong heat stress," according to data for the summer of 2023 that was collected (Copernicus, 2023). Across, Europe there is a rising trend for the number of summer days where the highest level of heat stress is classified as 'strong' and 'very strong' (Copernicus, 2023).
At the micro scale, the UHI is a thermal – related phenomenon. In a study conducted, it was observed that the UHI exhibits an aggravation during HW events in many of the European cities (Possega et al., 2022). The consequences of UHI are enhanced in European urban settings because of the heavily

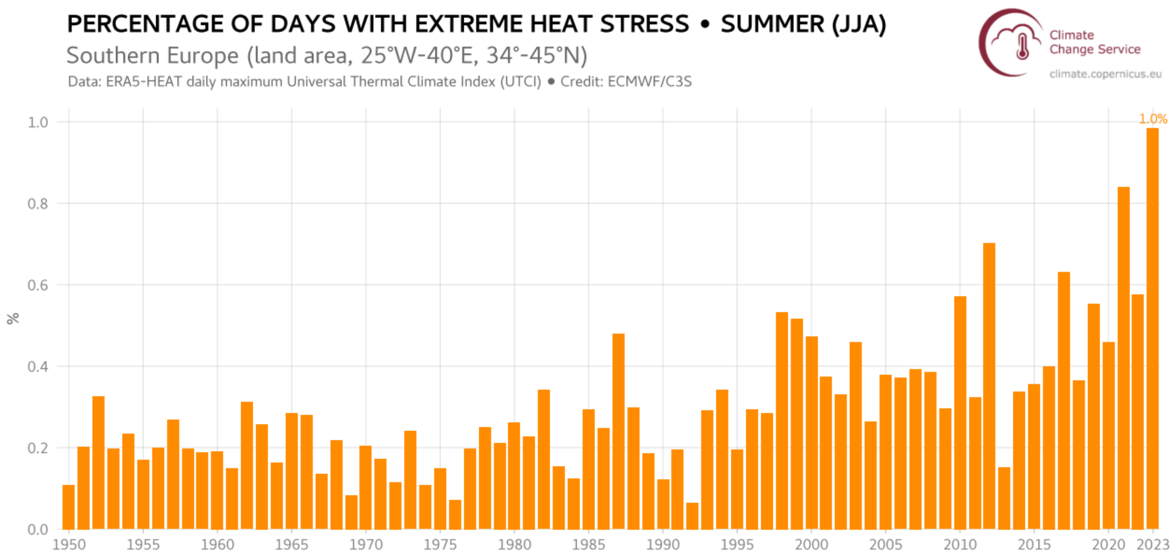

Chart 2: Percentage of days in summer (June to August) 2023 with extreme heat stress. Source: C3S (October, 2023)

[3] Heat Stress refers to a set of conditions in which the body is under stress due to overheating (deep core body temperature higher than 38°C, OSHA). This can lead to heat stroke, heat cramps, heat rash etc. Symptoms may include profuse sweating, dizziness, sweating cessation and collapse. Source – Environmental Health and Safety, Iowa State University

anthropogenic land cover, which is primarily comprised of impermeable surfaces with low albedo and a low ratio of build-up to vegetated land cover.

Europe is warming twice as fast as other continent – Copernicus, 2022

According to EEA, Europe is not prepared for rapidly growing climate risk even though it is the fastest warming continent in world. The European Climate Risk Assessment (EUCRA report, 2024) confirms that living conditions across the continent will deteriorate in the future, even in the most optimistic scenarios regarding global warming. According to the EEA's assessment, southern Europe and coastal regions will be the most affected regions by climate change (EUCRA, 2024).

2.1.2 Impacts of Heatwaves and Urban Heat Island on Urban Population

Population exposure to heat is increasing due to climate change. The urban heat island (UHI) effect poses a significant risk to human health during heat waves and other extreme heat events (World Health Organization, 2016). Exposure to heat causes severe symptoms, such as heat exhaustion and heat stroke (WHO, 2017). As documented widely, the most vulnerable population to heat stress are elderly (age > 65 years), children (age < 5 years), residents belonging to lower socio- economic background, migrants, women and other minority group (Mitchell & Chakraborty, 2018), potentially resulting in high mortality and morbidity rates along with social conflicts. In the summer of 2023, the data showed excess deaths among the elderly in Spain, Italy and France (ECMWF, 2023).

2.1.2a. *Not all citizens experience heatwaves in the same way* – The Socio – Economic impact of Climate Change

Cities in developed as well as developing countries must adapt to climate change; however, the starting points for these situations are very different and low-income economies will bear the greatest financial burden due to their comparatively higher exposure to the effects of climate change (Aggarwala et.al., 2011). As mentioned before, climate change, having different impacts on groups and individuals based on access to resources, is anticipated to worsen the already existing societal divisions (UN Habitat, 2011). Concerns in developed countries focus on the fact that climate change is anticipated to exacerbate pre – existing age, gender and literacy vulnerabilities (IFRC 2010). Recently, for the first time, the issue of climate justice was officially addressed by IPCC as an essential component of comprehending the ways in which climate change can affect a region in ways that are unequal, uneven, and differentiated in terms of space and society. Yet, due to the failure to address local social, economic and environmental conditions in policy and planning efforts, the inequitable impacts of climate change are recorded in various cities. Urban socio - economic approaches involve multiple stakeholders, working at the local level, comprehending the needs of each community and collaborating to develop adaptation strategies for climate change. The transition from policy to practice is one of the primary challenges in achieving urban resilience when adapting cities to climate change. Thus, encouraging the involvement of various stakeholders in the participatory design and collaboration process offers the efficiency of advancing from the development of policies to the achievement of outcomes (Diana Mitlin, 2008). Many countries across Europe, it is therefore considered to incorporate urban equality and spatial justice along with adaptation planning strategies (Eugenio Pappalardo et al., 2023). However, concerning spatial injustice and unequal effects of UHI and HWs on urban population, adaptation gaps and an uneven distribution of adaptation progress are noted (IPCC, 2022), especially in the local level. In the context of community collaboration research and the impacts of climate change, it is important to endorse an approach that calls for the active participation of local, regional, and national organisations in addition to community members. Researching specific communities is necessary to become familiar with local social and cultural conditions, the more general economic and political environments, and the knowledge and experiences of residents to assess the vulnerability and adaptation capacity of communities (Fazey et al., 2021; Pearce et al., 2009).

Heat also has significant indirect impacts on humans, resulting in mental health issues and aggressive behaviors. A major effect of UHIs is the increase of human discomfort which has been well documented by urban heat stress studies (Scherer et al., 2013).

Furthermore, urban heat poses a serious threat to many other dimensions of human society, including the failure of urban infrastructure and high energy consumption (Colelli et al., 2022). In addition, high-temperature wildfires and agricultural damage could result from HWs' effects on the urban ecosystems such as degradation of water quality which further affects aquatic species (US Environmental Protection Agency, 2008), which could lead to significant changes in carbon sequestration and, consequently, transform urban vegetation from carbon sinks to carbon sources (Eugenio Pappalardo et al., 2023).

2.2. Urban Resilience - Adapting cities for changing climate

Presently, since it's very evident that climate mitigation is no longer enough to shield humanity from the severe hazards posed by climate change, climate adaptation has emerged as a crucial component of climate policies around the world (Grafakos et al., 2020). According to IPCC Report 2023, all sectors and regions have seen advancements in the planning and execution of adaptation strategies, yielding numerous advantages. As a result of increased public and political awareness of the risks and impacts of climate change, at least 170 countries and numerous cities have included adaptation into their climate policies and planning procedures. Cities are being guided along a resilient path by effective measures like the Paris Agreement[4], the New Urban Agenda[5], and the Sendai Framework[6] (Making Cities Sustainable and Resilient Campaign). Adopted by the United Nations in 2015 within the framework of the 2030 Agenda for Sustainable Development, the 17 sustainable development goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that by 2030, all people enjoy peace and prosperity (United Nations).

[4] The Paris Agreement, a legally binding international treaty on climate change adopted at the UN Climate Change conference (COP21) in 2015, aims to *"hold the increase in the global average temperature to well below 2°C above pre – industrial levels" and "to limit the temperature increase to 1.5°C above pre – industrial levels."* Source – United Nations Climate Change (UNFCCC).

[5] The New Urban Agenda (NUA) adopted by the UN in 2016 represents a universal framework of actions on sustainable urban development for both developing and developed countries. Source – Habitat lll; UN Habitat.

[6] The Sendai Framework for Disaster Risk Reduction (2015 – 2030) adopted by UN in 2015 is an agreement of the post – 2015 development agenda with an objective of *"substantially reducing disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."* Source – United Nations Office for Disaster Risk Reduction (UNDRR)

The Sustainable Goals focused in this study are:

Figure 2: The Sustainable Development Goals of 2030 proposed by the UN. The highlighted are the key goals focused in this study. Source: United Nations Development Plan (UNDP)

Each goals have their own objectives and strategies. SDG 3 includes how to improve the health and well-being of millions of people, especially ageing populations such as those in European cities that are vulnerable to heat related risks, with more intense and frequent heatwaves and other climatic risks are predicted in the future. SDG 11 in particular offers a clear understanding of the climate risk in urban areas and SDG 13 aims to strengthen resilience and adaptive capacity to climate – related hazards by integrating climate change measures into national policies and planning (Sustainable Development Goals, United Nations[7]).

2.2.1. Climate Adaptation at Local/Urban Level – An overview of European cities

Through various adaptive strategies such as revitalization of brown fields, blue – green infrastructure, nature-based solutions (NBS) and so on, Europe aims to become a climatic – resilient union, fully adapted to the unavoidable impacts of climate change by 2050 (Climate – ADAPT, 2021). According to the argument proposed by Castan Broto (Castán Broto, 2017) in three key ways, cities are essential to transnational climate change governance: first, they facilitate learning and exchange between local governments and other subnational organizations. To carry out particular plans, they also acquire local expertise and resources. Thirdly, by elevating cities' status on global agendas, they attract the attention of business and political stakeholders.

Europe is among the world's most urbanized continents (74% of its population living in urban areas as of 2018 – UN, 2018). According to the study conducted by Euro LCP Initiative, a local plan for climate adaptation or mitigation exists in almost half of the large and medium-sized cities in Europe (48% of 885 cities) (Reckien et al., 2018). The following are the general overview of the types of plans found in European cities:

1. Climate Action Plans (CAPs):
    - Many cities gave developed comprehensive Climate Action Plans that outline strategies and actions to both mitigate greenhouse gas emissions and adapt to climate change impacts. These plans often include measures related to energy efficiency, renewable energy, transportation, water management and urban green infrastructure. For example, Copenhagen, Denmark demonstrates the successful incorporation of the CPH 2025 Climate Plan with its urban development plan that shows how feasible it is to combine growth, development and an enhanced quality of life (Urban Development, Technical and Environmental Administration, City of Copenhagen). Another example is the climate adaptation strategy for the city of Berlin. The Urban Development Plan for Climate Adaptation (StEP KONKRET) 2016, is a sectoral plan which offers a framework for the city's adaptation measures and enhances quality of life by encouraging the creation of water-sensitive urban development and heat-adapted cities (Interlace Hub, 2023).
2. Resilience Strategies:
    - Some cities have developed Resilience Strategies that focus specifically on building resilience to climate change and other shocks and stresses. These strategies may involve partnerships with various stakeholders, including local communities,

[7] Source: undp.org

businesses, and non-profit organizations. For example, The Resilient Rotterdam Strategy 2022 – 2027 aims to make the city prepared for the future threats including the climate, health and inequality crisis.

3. Urban Greening and Blue Infrastructure Plans:
    - Many cities prioritize urban greening and the development of blue infrastructure (e.g., waterways, wetlands) to enhance climate resilience, reduce urban heat island effects, and manage stormwater runoff. For example, Milan Green Strategy 2030 defines how the city is aiming to become a green city by reforesting 3 million trees, reducing the carbon emission by 45% by 2030 and so on (Comune di Milano, 2020).

Many European nations have established partnerships between weather services, civil protection agencies, and public health authorities at the national, subnational, or local level in the wake of dramatic heat wave events that occurred in Europe in the past, such as in 2003. When the forecast weather is expected to negatively affect population health in a nation, region, or city, these partnerships aim to protect citizens from the harmful effects of hot weather on their health by issuing advisories and putting mitigation measures in place. A heat-health action plan (HHAP) is the term used to describe the comprehensive response by national governments or regional authorities to the adverse health effects associated with extreme heat, while a heat-health warning system (HHWS) is the term used to describe the weather-based alert component of an HHAP (Climate – ADAPT). While specific plans may vary by city, they generally include measures to protect vulnerable populations, provide cooling resources, and raise public awareness.

2.2.2. Challenges and Gaps in Building Resilience: Limitations of Climate Adaptation Efforts

Climate action at the local level in Europe faces numerous challenges and gaps, which can hinder governments' ability to develop their adaptive capacity effectively such as a) ensuring climate adaptation strategies address social inequalities and prioritize the needs of vulnerable populations; b) the need to scale up the adoption of nature – based solutions (NBS), such as green infrastructure, urban forests, and wetland restoration, to enhance resilience and reduce climate risks; c) strengthening of cross – sectoral collaboration across multiple sectors and stakeholders, including government agencies, businesses, civil society organizations, and academia; d) the need to raise public awareness about climate risks and the importance of adaptation at the local level. Addressing these limitations and scope for improvement can help European cities enhance their resilience to climate change and better protect the well-being of their residents and ecosystems. By investing in adaptation measures, fostering collaboration, and prioritizing equity and inclusivity, cities can build more sustainable and resilient urban environments for the future (Aguiar et al., 2018).
Additionally, initiatives for adapting to climate change can include the measures taken to transform urban areas in order to make them more liveable, for instance through enhancing thermal comfort. Even in the most severe weather, adaptation strategies should permit people to walk from residential areas to urban activities via public open spaces and green corridors.

"…although all European cities are now dealing with soaring temperatures, EU leaders need to be more aware of the impact extreme heat is having on urban centers in the south."

-Mariano Fuentes, Urban Development Alderman, Madrid City.

2.3. Urban Climate Shelters – an innovative and effective *Climate Adaptation Strategy*

As mentioned previously, several cities around the world are creating or reshaping public spaces as a measure to adapt to the current and future effects of climate change especially as a refuge[8] for their most vulnerable population. The European Union’s Urban Innovative Actions Initiative implements various practices in different parts of Europe to adapt different areas determined at the urban scale to climate change. Climate shelters are one of the alternative solutions for climate change that the Urban Innovative Actions (UIA) encourage.

The concept of climate shelters, including those designed specifically for urban environments, has roots in the broader history of disaster preparedness and emergency management. Historically, shelters have been established during emergencies to provide temporary housing, food, and medical assistance to displaced individuals and communities. Over time, as the understanding of climate change and its impacts has grown, the concept of climate shelters has evolved to include facilities specifically designed to mitigate the effects of extreme heat, particularly in densely populated urban areas. One of the earliest formalized instances of climate shelters can be traced back to the establishment of cooling centers and heat emergency response plans in cities like Chicago, which experienced devastating heatwaves in the past. These initiatives aimed to provide relief to residents, particularly those without access to air conditioning, during periods of dangerously high temperatures. In Europe, the idea of climate shelter was initially established in the city of Barcelona in 2019, as an adaptive strategy for the changing climate and *to provide thermal comfort to its vulnerable population*. This initiative re-purposes existing public facilities to not only serve their actual function but also provide spaces for climate refugee[9] throughout the city (UIA, 2021).

Climate shelter is a relatively new approach to urban planning, with various names such as climate refuge, urban cooling island, cooling centers, cooling stations etc. (limiting to the extreme heat events). European cities like Madrid, Barcelona and Paris, each with its own nomenclature for the project, have created their own strategies to adapt to climate change. While Barcelona uses the term to refer to a cooling public space providing thermal comfort, Madrid uses terms like healthy school environments and caring for public spaces in schools. Paris' school Oasis project focuses on openness, adaptation, sensitization, innovation, and societies, aiming to create a cool island by adapting to climate change through school-based initiatives.

In addition, since the concept of a climate shelter originated in a natural setting, the term "urban climate shelter" will be used in this study to describe the phenomenon, incorporating the climate shelter's inherent principles but putting them into practice in an urban setting. An urban climate shelter (UCS) can be thus defined as an essential urban facility that offers strategies for climate change adaptation, provide thermal comfort to residents during extreme events. It achieves this through a multi-hazard strategy that combines sustainable infrastructures with local stakeholder partnerships.

[8] Refuge is a place that provides shelter or protection from danger or distress. Source: Merriam -Webster Dictionary

[9] Climate refugee is someone who was forced to leave their houses due to the environmental effects of climate change, typically related to drought, extreme events, sea level rising and so on. Source: ach.org.uk

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Over 200 climate shelters to beat the heat in the city

Climate emergency. Some 95% of local people will have a climate shelter within ten minutes of their home to protect them from the high temperatures.

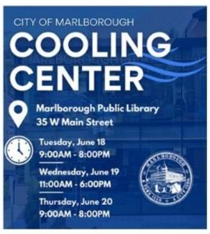
With the arrival of summer and the hot weather, the city's climate shelters have been activated around the ten districts, with an additional 30 of them bringing the overall number to 227. Shelters include various municipal facilities and public spaces, indoors and outdoors, open to the general public and offering a means of beating the heat and finding more comfortable temperatures.

Municipal facilities acting as climate shelters will be open until 15 September and include **libraries, local facilities in neighbourhoods and districts, municipal sports centres, parks and gardens, schools and museums**. While these places maintain their normal uses, they can also be used as spaces to get away from the high temperatures.

A temperature of around 27 degrees is recommended, particularly **for people vulnerable to heat**, such as babies, the over-75s, people with chronic illnesses or people with limited resources. These shelters have **good accessibility**, offer **water** and are safe places for people to relax in. However, they are not meant as an option for people requiring medical treatment. In this case, people should approach their local health centre.

Portland residents wait inside the Oregon Convention Center, which was repurposed as an emergency cooling center during a heat wave in June 2021. Hundreds of people died in the Pacific Northwest due to the heat wave.

PORTLAND, OR – JUNE 27: Portland residents fill a cooling center with a capacity of about 300 people at the Oregon Convention Center June 27, 2021 in Portland, Oregon. Record breaking temperatures lingered over the Northwest during a historic heatwave this weekend. (Photo by Nathan Howard/Getty Images)



ArchDaily › Architecture News › Barcelona Prepares Climate Shelters to Keep Residents Cool During the Summer Mo

Barcelona Prepares Climate Shelters to Keep Residents Cool During the Summer Months

Building of the Year 2022: You... Save

Written by Maria-Cristina Florian   Published on June 02, 2022

Cities across the Northern Hemisphere are preparing for the upcoming summer months, which are expected to be warmer and drier than average. The European Center for Medium-Range Weather Forecasts warns about temperatures rising above the norm in central and southern Europe this summer. Similarly, the forecast for the Unites States predicts hotter weather and below-average rainfall likely to fuel a megadrought. This poses threats for citizens, especially in larger cities, where heat-absorbing asphalt and waste heat generated by energy use create a "heat-island" effect. It translates to temperatures being up to 10°F (5.6°C) warmer in cities compared to the surrounding natural areas.

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Church in Action

Church offers 'cooling centers' to help poor beat heat as temperatures soared in India

Heatwave mortality in India has increased by more than 60 percent since 1980, according to the country's Ministry of Earth Sciences

Peerzada Ummer, India August 16, 2022

The Catholic Church's 'cooling centers' offer shelter to those most affected by the heatwave. (Photo by Peerzada Ummer)

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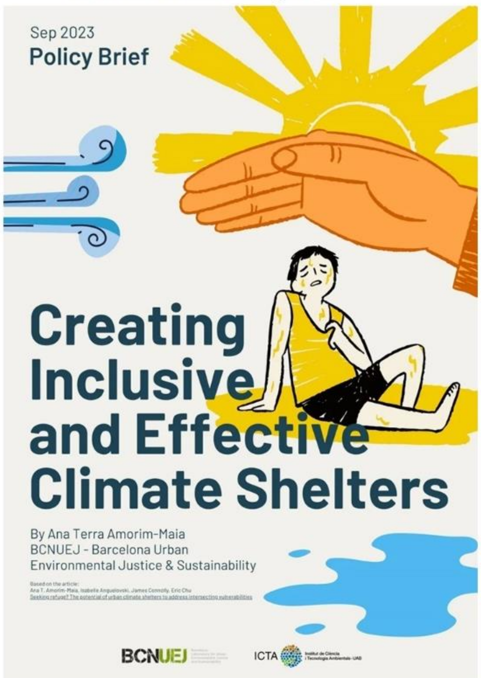
REFUGIS CLIMÀTICS

URBAN VISIONS | JUL 22 | 10 MINS

Cooling shelters: an urban response to the global crisis

Cities are engaged in the fight against climate change. Promoting public transport and renewable energies, urban transformation and reducing emissions from combustion vehicles are urgent measures, but adaptation and mitigation measures are also needed to guarantee people's health and well-being. The setting up of cooling shelters is one of the actions being rolled out in cities such as Barcelona, Brussels, Paris and Rotterdam to provide spaces offering shelter and thermal comfort at critical times such as during heatwaves.



2.3.1. Refugis Climatics – Barcelona, Spain

With over 200 identified climate refuges, Barcelona serves as an emblematic example regarding the new emerging urban infrastructure – climate shelter (Amorim-Maia et al., 2023). In Catalonia, around 20% elderly people die during a heat wave event. According to a study conducted by IS Global with data from 1983 to 2006, the duration of the heat wave is a more significant impact than its severity. In addition, the heat is a contributing factor in 1.6% of summer time deaths. Since the elderly are the most vulnerable demographic, rising temperatures cause a greater increase in mortality among them. In extremely hot weather, there is a 26% increase in deaths for people aged 80-90, while the rise is 15% for those in the 60 – 70 age group and 17% for those in the 70 – 80 age group (Barcelona Climate Plan 2018 – 2030, Ajuntament de Barcelona).

Project – Climate Shelter / Refugis Climatics, 2019 - 2021
GBG_AS2C – Blue, Green & Grey_Adapting Schools to Climate Change, Barcelona, Spain

Topic – Climate adaptation
For extreme heat events - UHI

Target – Transforming 11 schools into Climatic Shelters

3000 m2 of schoolyards will be transformed

4500 m2 of urban green areas will be added

Eur. 3,997,969.76 – Total ERDF budget

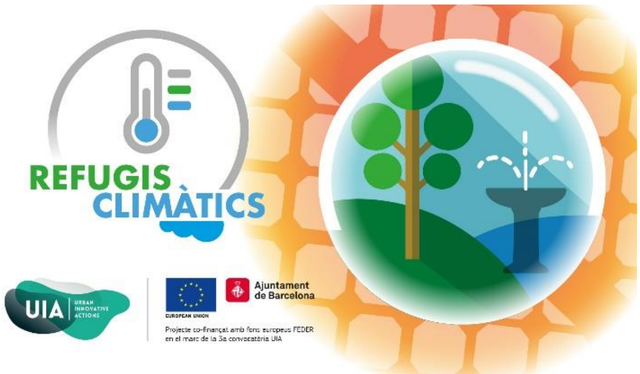


Figure 3: UIA project - Climate Shelter, Barcelona. Source: Ajuntament de Barcelona

Barcelona's adaptation proposal to the climate challenge, along with the support of Urban Innovation Actions, aims to change eleven schools that are now deemed heat-vulnerable into climate shelters that are accessible to all city residents. This will be accomplished by putting typical building heat-reduction strategies into practice and by changing playgrounds by adding greenery, shade areas, and water sources (UIA - The Climate Shelters project Journal, 2020).

The project, financed by Urban Innovative Actions[10] (UIA) of the European Commission, implements an innovative adaptation plan in order to reduce the risk of deaths in the city related to heat events and to prepare Barcelona to face the foreseen increasingly high temperatures during summer (Barcelona experiences extreme temperatures which can rise above 35°C (Barcelona_GBGAS2C_Journal. 2020). The overall idea is to provide a climate shelter in a 10 – minute walkable distance and is based on a participatory process involving both public and private stakeholders (Barcelona_GBGAS2C_Journal2. 2020). Notably, by 2030, Barcelona wants to make sure that every citizen lives five minutes' walk from a climate shelter (Amorim-Maia et al., 2023).

[10] Urban Innovative Actions (UIA) is an Initiative of the European Union that provides urban areas throughout Europe with resources to test new and unproven solutions to address urban challenges. Source: uia_initiative.eu

Similar to numerous other global cities, Barcelona has projected an increase in temperature over the next few decades, with an expected rise from 2.8 °C to 3.2 °C by 2050. Furthermore, a 20-day annual increase above 30 °C is anticipated, putting citizens at risk for serious health problems (Science in the City). Additionally, realizing that different parts of the same city have varying vulnerabilities to heat, Barcelona has created a neighborhood heat study.

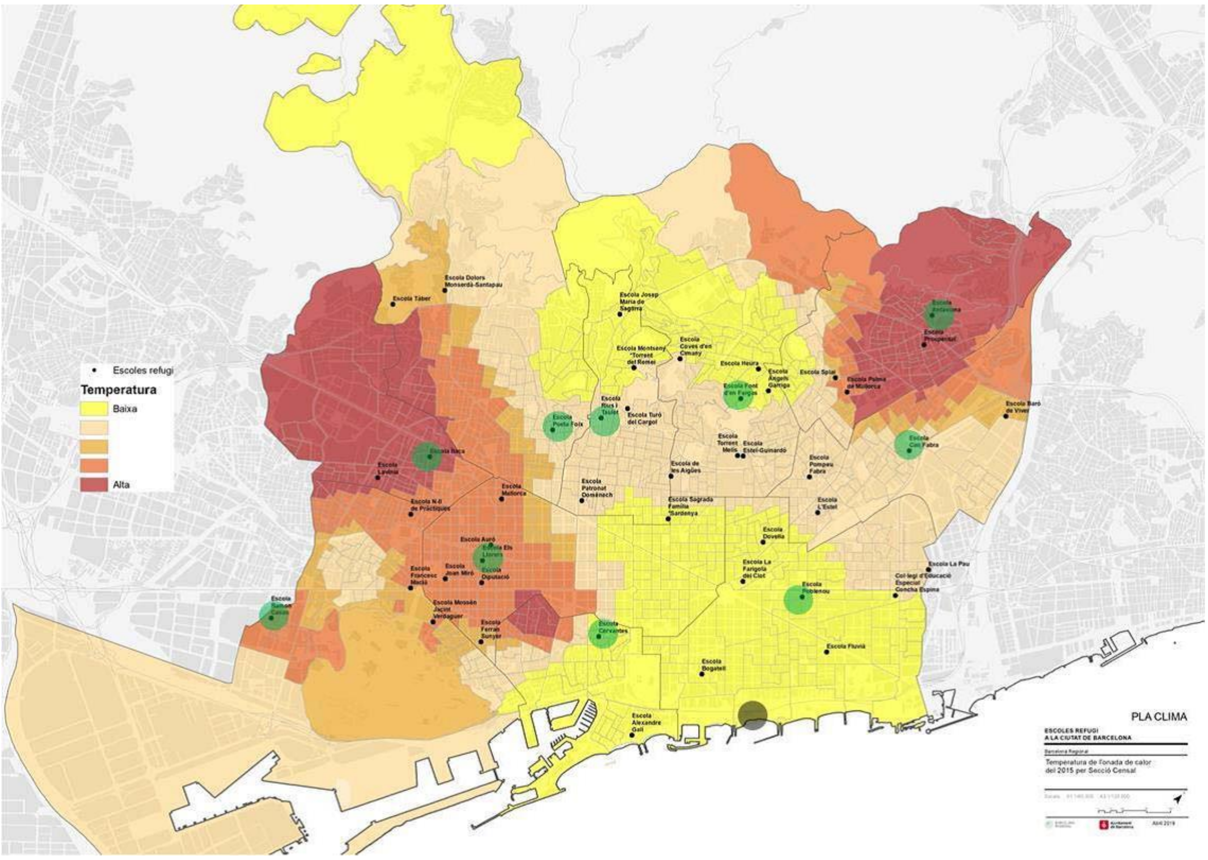


Figure 4: Air temperature differences from average for Barcelona. Source: UIA Initiative, 2020

The effects of climate change differ from city district to city district because they depend on various factors, including the condition of buildings and their thermal vulnerability, the amount, kind, and presence of vegetation, the percentage of impermeable surfaces, the density of the urban area, the distribution of heat sources, and the socioeconomic conditions that exist.

There are differences amongst Barcelona neighborhoods in terms of air temperature variance from the city average. Due to the sea's cooling influence, the places with the lowest daytime temperatures are those closest to the coast, with Les Corts, Eixample Esquerra, Nou Barris, and Ciutat Vella recording the highest daytime temperatures. On the other hand, at night the opposite occurs, with the coast recording the warmest temperatures.

"The city is not just looking for climate interventions addressing a singular environmental challenge, in this case heat; it is rather seeking resilience interventions with multiple benefits for the school community and the public in general. To this end, social and inclusion issues are also considered."

- Enric Cremades, coordinator from the city council of Barcelona in charge of the climate shelters project

2.3.2. Time2Adapt – Lille, France

Between 1955 and 2017, the temperature rise in the metropolitan area of Lille was 2°C, questioning the livability of urban areas especially in summer, causing discomfort and inequalities (European Urban Initiative, 2023). The city seeks to adapt to climate change by regenerating the public urban spaces to thermal shelters. The project was the winner of the 1st European Urban Initiative call for projects which focused on the theme of "new European Bauhaus" (MEL – Metropole Europeenne de Lille, 2023).

Project – Time2Adapt, 2023 - 2026
EUI – UIA project, New European Bauhaus theme, Lille, France

Topic – Climate adaptation
For extreme heat events - UHI

Targets –

- Making fresh spaces and buildings more accessible to the public by adapting their schedules (swimming pools, parks, gardens, etc.) or by opening places to other users (e.g. schoolyards)
- Transforming certain existing buildings to make them more accessible and allow the intensification of their uses
- Transforming certain spaces into islands of freshness
- Offering "refreshing" temporary installations

Eur. 6.2M – Total budget

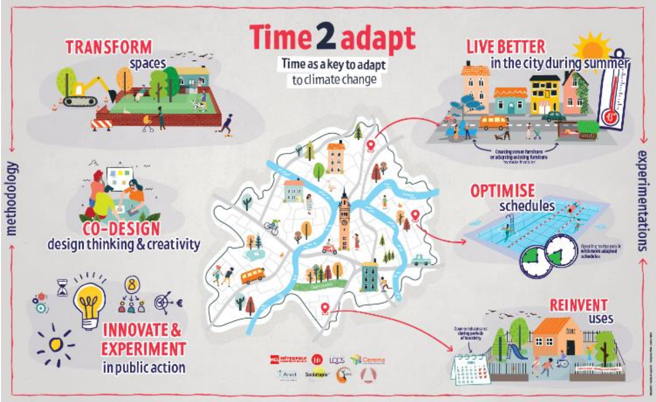


Figure 5: Time2Adapt project. Source: European Urban Initiative, 2023

Time2Adapt project aims to make the city more livable, more attractive in a *more egalitarian and socially just place, following New European Bauhaus principles*. Currently being in the initial stages of implementing the project, the concept is to test at a metropolitan scale, a time – based urbanism for better usage of public buildings and spaces, potentially to answer the challenge for more cool places during warm periods in cities. Another positive aspect of the project is to limit land artificialization and to intervene the project into the existing urban fabric.

To address the targets set forth by the project, innovative solutions include creating new usages and transforming public spaces to make them accessible to all and thermally comfortable with *refreshing artistic installations.*

Project phases:

Phase 1
September 2023 - March 2024
Initiation phase of the project which include organization and preparation of the project implementation in the cities of Lille and Loos.

Phase 2
March 2024 - September 2026
Metropolitan residents of Loos and Lille will be benifitted from the first actions from summer 2024.

Phase 3
September 2026 - September 2027
Further expansion of the project will be offered to other cities which will be able to complete by the summer of 2026

2.4. Urban Climate Shelter Accessibility and Spatial Proximity

Scholarly research highlights how crucial it is to improve accessibility in cities through sustainable methods to mitigate the social and environmental challenges (Bertolini et al., 2005, Banister, 2008, Willberg et al., 2023). The aforementioned examples of urban climate shelter demonstrate that one of the shared objectives of these projects is to make them spatially accessible to the local population, especially by means of walking in favour of all the vulnerable groups and social classes who are constantly denied the access to private or public means of transportation. By understanding the distribution of climate shelters and their accessibility to different population groups, urban planners, policymakers, and emergency responders can identify gaps, prioritize and improve the resilience of cities to climate-related risks.

2.4.1. Advancing Urban Accessibility: Evolution of the 15 – Minute City Concept

When it comes to the study of proximity and accessibility to everyday services, one of the popular concepts of urban planning – The 15-minute city concept is often discoursed upon. Even though the term "La Ville du Quart d'Heure" (The 15-minute city) was popularized by urban planner Carlos Moreno, the concept is derived from historical notions of proximity and walkability especially from Clarence Perry's neighbourhood unit during the 1920s. The 15-minute city concept builds upon Perry's ideas by emphasizing the importance of accessibility and connectivity within urban environments. It envisions cities where residents can access essential services, amenities, and activities within a 15-minute walk or bike ride from their homes, fostering sustainable, resilient, and liveable urban communities (Moreno et al., 2021). Moreno's vision of the 15-minute city gained prominence with the publication of the book "Réinventer Paris" ("Reinventing Paris") in 2015. The concept was embraced by then-Mayor of Paris, Anne Hidalgo, who integrated it into the city's urban planning agenda.

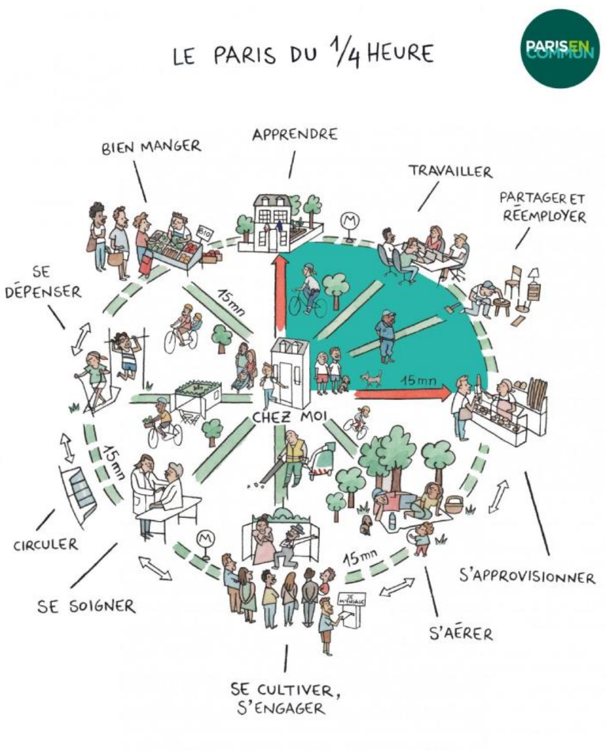


Figure 5: Paris as a 15 – minute city. Source: Micael – Resistire project

The concept of 'new urbanism', an approach to urban planning and design that advocates for walkable cities, surged in popularity in the United States during the 1980s. Over the past decade, similar iterations of 'urban cells' or neighbourhood's reachable within 30 or 20 minutes have also surfaced worldwide. Currently, many cities are characterized by operation-based neighbourhoods, where distinct zones are primarily designated for either commercial or recreational purposes. This fragmented urban planning often leads to urban sprawl, necessitating long commutes across the city. Conversely, the envisioned compact cities of the future prioritize a hyperlocal approach, focusing on urban infrastructure strategies aimed at integrating essential elements for living and working within local communities (15 – minute city, Deloitte).

In the study conducted (Khavarian-Garmsir et al., 2023), the basic parameters of 15 – minute city concept was thoroughly researched upon. The original framework of the 15-minute city concept is rooted in fundamental principles of proximity, diversity, and density. However, it has evolved beyond these core elements, incorporating additional aspects according to Moreno's perspective. For instance, Moreno emphasizes the importance of human-scale urban design and the multifunctionality of public and semi-public spaces within the strategy of Paris. In summary, the study identifies the following intrinsic features of the 15-minute city: proximity, connectivity, density, mixed use, diversity, adaptability, flexibility, modularity and human-scale design (Khavarian-Garmsir et al., 2023). The following table lists a comparison of 15 – minute city concept with various past neighbourhood planning movements based on these features.

Table 1: Comparison of neighborhood planning movements through history. Source: Khavarian-Garmsir et al., 2023*; modified by author*

Neighbourhood planning movements	Proximity	Connectivity	Density	Mixed use	Diversity	Adaptability	Flexibility	Modularity	Human scale design
Garden city	×	✓	×	×	✓	×	×	×	×
Neighbourhood unit	✓	×	×	×	×	×	×	×	✓
Modernism	×	×	×	×	×	×	×	×	×
Post – modernism	✓	✓	✓	✓	✓	×	×	×	✓
Eco - urbanism	✓	✓	✓	✓	✓	✓	×	×	✓
15 – minute city	✓	✓	✓	✓	✓	✓	✓	✓	✓

In the wake of the COVID-19 pandemic, the 15-minute city concept has taken on renewed significance in urban planning. The pandemic underscored the importance of resilient, self-sufficient neighbourhoods where residents can meet their daily needs without relying on long-distance travel or crowded public transportation. Lockdowns and social distancing measures highlighted the need for accessible green spaces, local businesses, healthcare facilities, and other essential services within walking or biking distance (Moreno et al., 2021). Cities like Bogota, Seattle, and Milan have responded to the pandemic by implementing temporary measures such as pedestrianized streets, expanded bike lanes and promote active transportation. These initiatives align with the principles of the 15-minute city concept, emphasizing the importance of prioritizing the well-being and convenience of residents within their immediate neighbourhoods.

This concept gained traction as a response to the challenges of urban sprawl, traffic congestion, and environmental degradation. By prioritizing local amenities, services, and facilities within walking or biking distance, cities can reduce carbon emissions, improve air quality, and enhance social cohesion.

Currently, many cities are characterized by function – based neighborhoods, where distinct zones are primarily designated for either commercial or recreational purposes. This fragmented urban planning often leads to urban sprawl, necessitating long commutes across the city. Conversely, the envisioned compact cities of the future prioritize a hyperlocal approach, focusing on urban infrastructure strategies aimed at integrating essential elements for living and working within local communities. Paris is not the sole city to adopt an x-minute city strategy; comparable endeavours have been undertaken across various regions. In Europe, initiatives such as Barcelona's superblocks and the United Kingdom's high streets have been implemented. Likewise, in Asia, examples include Shanghai's 20-minute Town and Singapore's 45-minute city. In Australia, Melbourne has introduced 20-minute neighbourhoods, while in the United States, cities like Portland have established 20-minute neighbourhoods, and Houston has developed walkable places (Pozoukidou G et al., 2021, Khavarian-Garmsir et al., 2023).

While the 15-minute city concept offers numerous benefits, it also faces several limitations and drawbacks. A study conducted, raises a concern regarding the recent critique based on social inequalities as marginalized groups are not considered, excluding them from the advantages of these initiatives (Willberg et al., 2023). While the critique has primarily focused on socio-economic disparities, individuals' physical attributes also play a significant role. The rapid aging of numerous populations has underscored the growing importance of older individuals in terms of accessibility, given that their physical abilities often lag behind those of younger adults. Accessibility plays a crucial role in facilitating the participation of older individuals and is closely linked to health and well-being outcomes (Liu et al., 2022, Willberg et al., 2023). Acknowledging these population group in initiatives such as the 15 – minute city is crucial for fostering greater inclusivity with urban areas (Willberg et al., 2023).

2.4.2. Accessing Urban Climate Shelters within the 15 – Minute City Framework

Ensuring access to essential services is a fundamental aspect of the 15-minute city concept. It is essential to adapt and evolve basic services in accordance with the evolving needs and lifestyles of the population. As the climate continues to change, urban climate shelters have emerged as indispensable services for safeguarding the well-being of residents. In the face of dynamic environmental conditions, these shelters provide vital refuge and support, underscoring their significance in the fabric of urban life. Thus, incorporating UCS into the framework of the 15-minute city is imperative for enhancing the resilience and quality of life of urban populations. Integrating UCS into this concept can also enhance the city’s ability to mitigate and adapt to extreme weather events.

Coincidentally, to study on the proximity range of UCS and walk duration, it was found that OSHA's (Occupational Safety and Health Administration) ‘light’ work category is equivalent to a casual walking pace of 2 miles an hour or 0.5 miles in the recommended 15 minutes. Several studies therefore analyzed the accessibility of UCS by setting the walkable distance to a range of 15 minutes. It was also mentioned in a study where the maximum acceptable walking time was set at 15 minutes based on the average speed of elderly (0.94 m/s) (Bohannon & Williams Andrews, 2011).

In a study conducted, the accessibility to cooling centers for heat – vulnerable populations in New York State (NYS) were assessed. This population category included elderly, elderly living alone, unemployed, differently abled, immigrant and other minorities with household income below poverty line (Nayak et al., 2019). The study was concluded by stating that in urban areas, many residents were not within the walking distance of a cooling center but nearly all were in the most heat vulnerable areas. In rural areas distances were longer and accessibility became a greater issue. Thus, a legitimate question surfaced:

Are urban climate shelters truly accessible for all?

Spatial accessibility in this study focuses on the barriers and difficulties posed by demographic differences in access to these urban climate shelters, in addition to discussing physical accessibility. The detrimental effects of heat on health can be mitigated by spending a few hours in a cooling centre. However, these facilities' limited availability or poor accessibility frequently act as an impediment to their use (Nayak et al., 2019).

In order to understand this particular notion, let's consider a study of cooling centers in the city of Boston, US. 72.6% of US households did not have either central air conditioning or room air conditioning in 2021. In Boston, central air conditioning is present in 44.0% of homes, while room air conditioning is not present in 5.5% of households (United States Census Bureau, American Housing Survey, 2021). Consequently, public cooling centers are a type of intervention that is becoming more and more popular to reduce heat stress (Widerynski et al., 2017). Boston has opened cooling centers at sixteen Boston Centers for Youth & Families community centers in response to the recent heat wave. The city also urged locals to look for Boston Public Library locations (City of Boston, 2022).

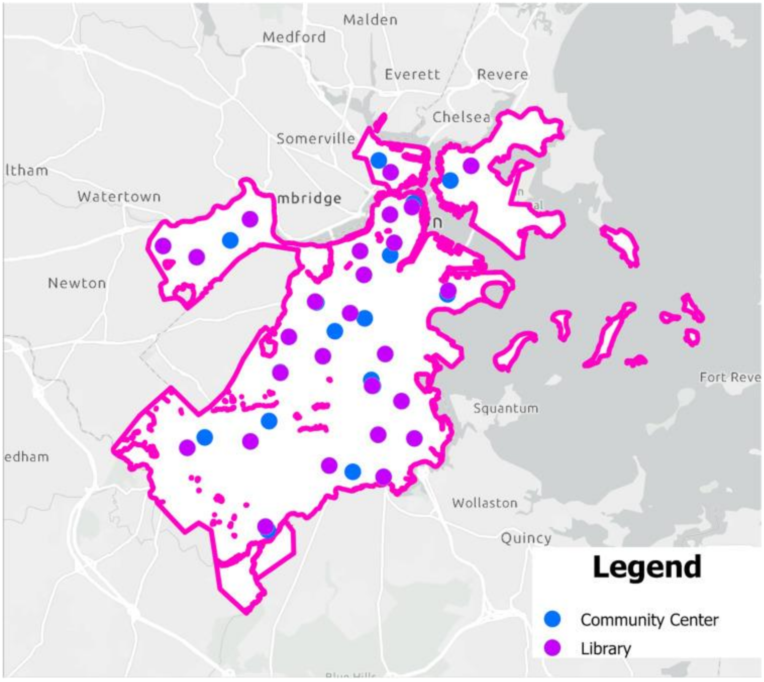


Figure 7: Location of current Cooling centers in Boston, USA. Source: Sehgal and Sehgal, 2023

In this 2023 study by Sehgal and Sehgal, which examined the spatial distribution of cooling centers in Boston's relation to the most vulnerable populations (racial/ethnic and socioeconomic), the variables of UHI, demographic census data, and walking time (maximum of 15 minutes) were analyzed. The results showed which neighborhoods and vulnerable groups were most exposed to urban heat. The 15-minute service areas cover 77.1% of the population of Boston (Figure 7); an estimate was presented indicating that the city would need to build at least 19 additional cooling centers to increase coverage from 77% to approximately 95% of the population. It was also found that existing cooling centers are located in areas with higher UHI.

On the other hand, it appears from recent news reports that Boston cooling centres were not fully occupied during the recent extreme heat events. For instance, it was reported that during a heatwave event in July 2022, there were no patrons at any of the two official cooling centres. The study also suggests that constrains such as inability to travel, poor public transport options, inaccessible by foot etc. might be the reasons for this (Sehgal & Sehgal, 2023).

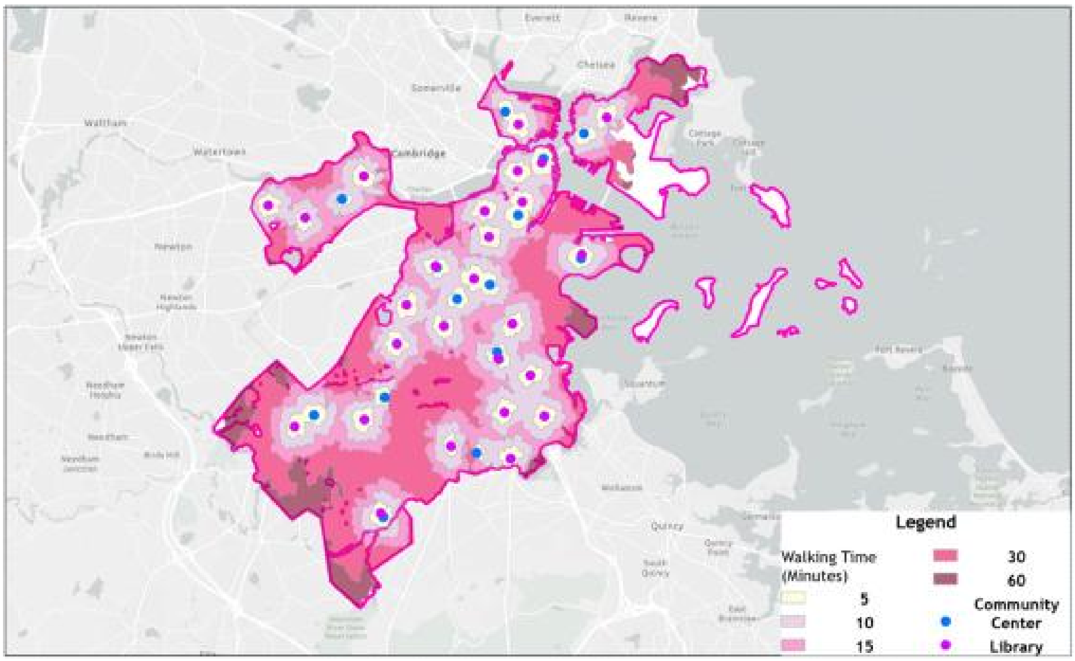


Figure 8: Walk time to cooling centers, Boston, USA. Source: Sehgal and Sehgal, 2023

Similarly, only 16.9% of Portland residents live within 15 minutes of a cooling center, according to recent research. Only one major city—Washington, DC—had more than 50% of its population living within a 15-minute walk of a cooling center, with an average coverage of 10.3%, according to a recent study that looked at 25 major cities (Sehgal & Sehgal, 2023). Another study conducted on the accessibility to cooling centers (K Lee and Y. Chae, 2021). The study was concluded by stating that only a small portion of the population could access the cooling centers.

Every study and research paper mentioned in this section focused on how accessible urban climate shelters are in terms of space, particularly focusing the populations that are more vulnerable to heatwaves. In the study conducted on the network analysis of public cooling centres in Los Angeles County, California and Maricopa County, Arizona found that the for all centres, the percent of visits within walking distance decreases on hot days in comparison with control days (Derakhshan et al., 2023). The study further reasons for this change in pattern of visit to these centres may have occurred due to individuals opting out of walking during extreme heat event and just walkability (spatial) is not an impetus for accessibility of cooling centres. This particular finding from the study brought out an interesting dimension to the accessibility study of urban climate shelter / cooling centers on which this study is further built upon. By incorporating the “thermal comfort” aspect of spatial accessibility, especially for the pedestrian mode of transportation, this study further ponders upon various factors relating to the true “walkability” like shade or protection from sun exposure and how it affects the pedestrian especially on their walk duration and speed and the route choices.

This study delves into the potential drawbacks and limitations associated with the concept of the 15-minute city, as highlighted by Willberg et al., 2022, and the present accessibility challenges encountered by urban climate shelters (UCS) or cooling centres, particularly noting that a significant portion of the urban population, predominantly the elderly, bears the burden of these challenges. Given the disproportionate impact on this demographic, it is imperative to address these limitations and hurdles effectively. Therefore, this research aims to identify strategies to mitigate the issues for the vulnerable population, especially the elderly population, thus enhancing the inclusivity and effectiveness of urban planning initiatives such as the 15-minute city and urban climate shelters.

Chapter 3

3.1. Methodology

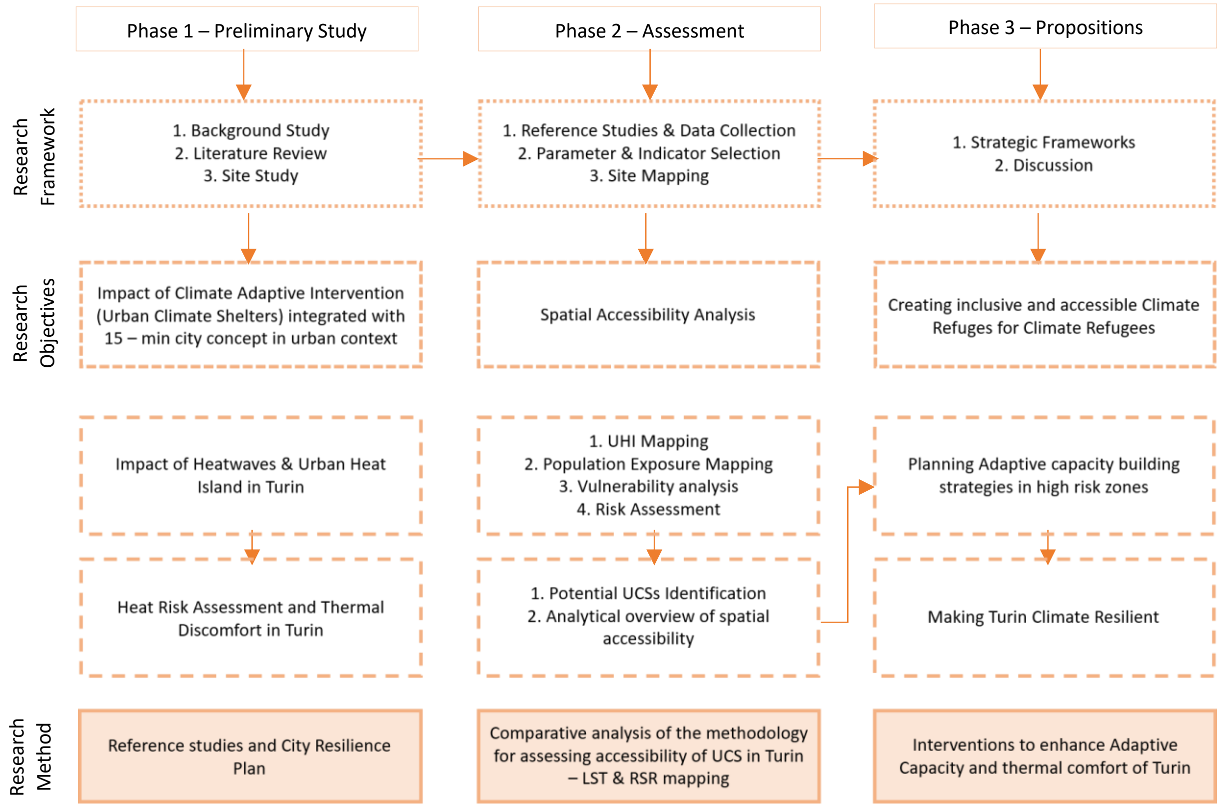


Figure 9: Methodology flowchart adapted for this research thesis. Source: Author

3.5. Thermal (dis)Comfort in Urban Settings: Impact on Pedestrian Behavior

In the beginning of the study, we discussed how the current livability of an urban environment is degrading due to the high rate of urbanization and global warming. When it comes to spatial-temporal context, as a vital part of life quality, the thermal comfort would impact individual outdoor activity levels and the utilization of urban space (Li & Ratti, 2019). ASHRAE defined thermal comfort as the condition of mind which expresses satisfaction with the surrounding thermal environment (ASHRAE 1966) (Talukdar et al., 2019). Environmental factors like radiation, air temperature, humidity and wind speed can affect how much heat is exchanged by the human body.
It is evident from various studies that climate change potentially affects people's travel behavior, especially pedestrians who are directly exposed to extreme weather conditions (Caprì et al., 2016).

How does rising temperature impact pedestrian behavior in an urban context?
Understanding how rising temperatures impact pedestrian behavior is crucial to create sustainable and resilient cities that prioritize the well-being of the population, especially in the face of climate change. Various studies conducted worldwide have recorded certain behavioral parameters in

response to rising temperatures, particularly in terms of thermal discomfort. A few such parameters are as follows:

- Route Selection: As temperatures rise, pedestrians may opt for routes with more shade or cooler microclimates to avoid direct exposure to the sun. This could lead to changes in typical pedestrian paths within the urban environment, favoring areas with more tree cover or buildings that provide shade.
- Walking Speed and Duration: High temperatures can lead to discomfort and fatigue, causing pedestrians to slow down their pace or shorten their walking distance. People may seek refuge indoors or opt for modes of transportation like cars or public transit to avoid prolonged exposure to the heat.
- Outdoor Activities: Rising temperatures can deter people from engaging in outdoor activities such as walking, jogging or cycling. In extreme heat, outdoor spaces like parks and plazas may see decreased foot traffic as people seek cooler indoor environments.
- Public Health Concerns: Pedestrians may be more cautious about spending time outdoors in extreme heat to avoid the health risks, impacting their willingness to walk or linger in urban areas.
- Social Interaction: Higher temperatures can affect social behavior, with people potentially seeking out cooler, shaded areas for socializing rather than open, sun-exposed spaces. This could influence the vibrancy and dynamics of public spaces within urban environments.

The below table lists the behavioral parameters with their respective reference studies.

Table 2: Reference studies used for identifying the behavioral parameters for the study. Source: Author

Sl. No.	Reference Study	Location	Research focus	Parameters	Values
1	Effects of solar radiation in the streets on pedestrian route choice in a city during the summer season. Azegami, Y., Imanishi, M., Fujiwara, K., Kusaka, H., 2023. Building and Environment 235, 110250. https://doi.org/10.1016/j.buildenv.2023.110250	Tokyo, Japan	The research aims to experimentally confirm the hypothesis regarding how solar radiation on streets influences pedestrians' route choice.	**Hourly based route selection**	-
2	Follow the shade: detection of optimally shaded pedestrian paths within the historic city center of Thessaloniki. Vartholomaios, A., 2023. IOP Conf. Ser.: Earth Environ. Sci. 1196, 012070. https://doi.org/10.1088/1755-1315/1196/1/012070	Thessaloniki, Greece	The research is based on the theory that pedestrians walking during a hot day will likely choose a comfortable route – shaded and easily traversable.	**Route selection** **Shade**	-

3	An examination of environmental design parameters affecting walkable route choices in Cyprus. Savvides, A., 2016. Presented at the SUSTAINABLE DEVELOPMENT AND PLANNING 2016, Penang, Malaysia, pp. 599–609. https://doi.org/10.2495/SDP160501	Cyprus, Greece	The research analyses user comfort and route choices along different urban streets throughout seasons.	**Hourly based route selection** **Thermal comfort**	-
4	Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types. Lin, T.-P., Tsai, K.-T., Liao, C.-C., Huang, Y.-C., 2013. Building and Environment 59, 599–611. https://doi.org/10.1016/j.buildenv.2012.10.005	Chiayi, Taiwan	The research assesses how thermal comfort and adaptation impact attendance across various levels of shading and types of activities.	**Thermal comfort** **Shade**	-
5	Walking is regulated by environmental temperature. Obuchi, S.P., Kawai, H., Garbalosa, J.C., Nishida, K., Murakawa, K., 2021. *Sci Rep*11, 12136 (2021). https://www.nature.com/articles/s41598-021-91633-1	Tokyo, Japan	The research determines the effects of environmental temperature on walking.	**Walking speed**	
6	Intra-day variation in daily outdoor walking speed among community-dwelling older adults. Kawai, H., Obuchi, S., Hirayama, R., Watanabe, Y., Hirano, H., Fujiwara, Y., Ihara, K., Kim, H., Kobayashi, Y., Mochimaru, M., Tsushima, E., Nakamura, K., 2021. BMC Geriatr 21, 417. https://doi.org/10.1186/s12877-021-02349-w	Tokyo, Japan	The research examines the walking speed of community – dwelling older adults between various interval of time on a day.	**Walking speed**	65 years > 1.26m/s - 1.33 m/s
7	Pedestrians' Normal Walking Speed and Speed When Crossing a Street. Montufar, J., Arango, J., Porter, M., Nakagawa, S., 2007. Pedestrians' Normal Walking Speed and Speed When Crossing a Street. Transportation Research Record 2002, 90–97. https://doi.org/10.3141/2002-12	Canada	The research examines the normal and crossing walking speed of adults (all age category)	**Walking speed**	65 years > 0.91 m/s
8	Accessibility of cooling centers to heat-vulnerable populations in New York State. Nayak, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Pantea, C.I., Ross, Z., Kinney, P.L., Zdeb, M., Hwang, S.-A.A., Lin, S., 2019. Journal of Transport & Health 14, 100563. https://doi.org/10.1016/j.jth.2019.05.002	New York, USA	The research assesses accessibility of CC to heat vulnerable population.	**Walking duration**	15 - Minutes

1. Azegami et al., 2023

The study discusses about the hypothesis proposed by the authors that "*on extreme hot days, pedestrians may choose paths/routes based on the presence of solar radiation*". To prove this hypothesis, an experiment was conducted in the city of Tokyo, Japan, where nineteen participants (20 – 69 years) walked without restrictions from a designated starting point on August 2, 2019 (a clear, sunny day in summer) from 11am to 2pm where the highest temperature was recorded to be 42.5°C. The following results were obtained from the study's conclusion, which looked at the connection between route choice based on a hot summer day walk in front of a large commercial facility near Tokyo station and solar radiation in urban streets:

- "Presence of shade" was the most common cause for the route choices among the participants for severe thermal environment.
- The particular reason provided for the above-mentioned selection was to protect their health from heat stroke and sun burn.

2. Vartholomaios, 2023

The study implements a novel approach to pedestrian pathfinding that considers walking distance, ability to navigate a slope and hourly shade. The study is conducted on August 15, 2023 in the city of Thessaloniki, Greece. With a climate classification of *CSa* (Koppen – Geiger), the city experiences high heat discomfort in the summer. The experiment is conducted for different hours of the day (9am, 12pm, 3pm, 6pm) for two different pair of routes (short distance with high slope and sun – exposed; long and complex street with shade) to examine the possible difference in route selection by the participants. The following results were obtained from the study's conclusion:

- For both routes, "optimal" paths exist for different hours of the day following the hourly shadow patterns which are as follows:

Table 3: The optimal paths selected by the participants based on hours. Source: Vartholomaios, 2023.

<table>
<tr><th>Time</th><th>Slope presence</th><th>Sun</th><th>Shaded</th><th>Short</th><th>Long</th></tr>
<tr><td>9:00</td><td>Present</td><td colspan="2">Sun</td><td colspan="2">Short</td></tr>
<tr><td>12:00</td><td>Absent</td><td colspan="2">Shaded</td><td colspan="2">Long</td></tr>
<tr><td>15:00</td><td>Absent</td><td colspan="2">Shaded</td><td colspan="2">Long</td></tr>
<tr><td>18:00</td><td>Present</td><td colspan="2">Sun</td><td colspan="2">Short</td></tr>
</table>

During the noon and afternoon hours, the optimal paths tend to be the longer and complex one as it puts less stress on the pedestrians.

3. Savvides, 2016

The study examines the microclimatic parameters along a busy and popular urban passage in Nicosia – Cyprus, Greece. Route choices are observed along this passage with the aim of "discerning correlation between urban morphology and microclimate with respect to preferred user route choices". The study also discusses the ways in which microclimate affects the thermal comfort and the behavior of pedestrians. The measurements for the experiment were taken at three different times of the day: 9am, 12pm and 3pm in all seasons without cloud cover. Percentage of participants were recorded that made the choice of walking in the shaded part of the passage. The average temperature recorded in area of study was 33.8°C. The following observations were recorded during the study:

- As the air temperature increased, the percentage of users on the site decreased in all seasons. However, the greatest drop in users occurred during the afternoon hours i.e., a 10°C increase in air temperature resulted in the loss of 28 users.
- The shaded paths recorded lower air temperature as expected.
- A strong positive correlation was recorded between air temperature and selection of shade throughout all the timeframes.

4. Lin et al., 2013

The study examines the influence of various shading levels to understand the relationship between thermal comfort and participants' attendance at a park in Chiayi, Taiwan using micrometeorological measurements during various seasons. The following conclusions were made based on the observations gathered from the experiment:

- When physiologically equivalent temperature (PET) was greater than 30°C, the proportion of the park users seeking shade increased significantly.
- When PET was greater than 34°C, 70% of all attendees were seeking shade.
- The ratio increased to 90% when PET was greater than 42°C.
- Therefore, it was noticed that when thermal discomfort increased, attendees moved to spaces where high levels of shadings were available, thus relieving the discomfort.

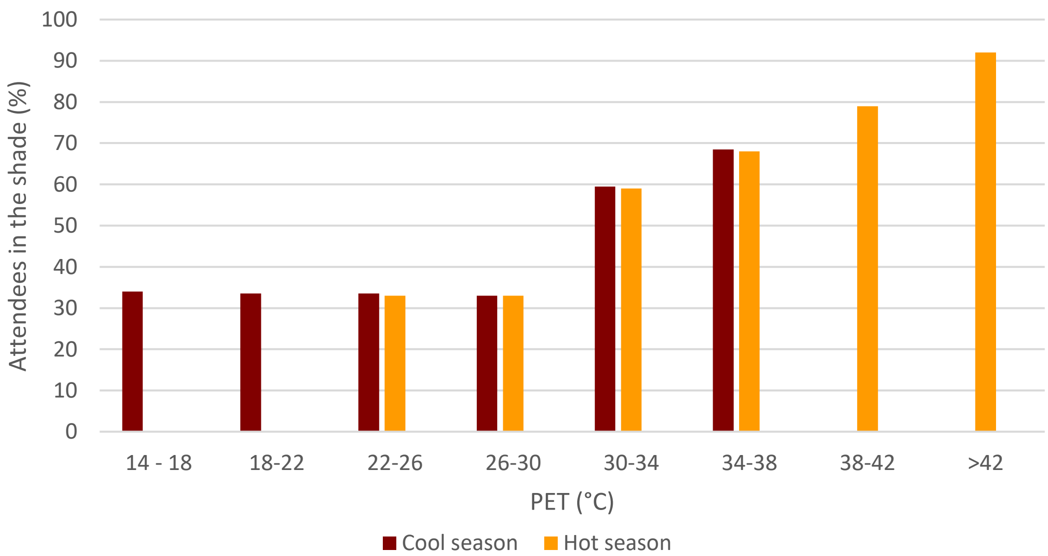


Chart 3: Percentage of people preferring shade during two seasons with respect to PET. Source: Lin et al., 2013

5. Obuchi et al., 2021

The study examines the hypothesis proposed by the authors that "… *walking is also involuntary and controlled by evolutionary aspects such as relationship between temperature and speed of* *movement"*. The study aims to determine the influence of temperature on walking speed, step length and cadence. The participants aged between 14 – 86 years were asked to walk unrestrained with a smartphone GPS application that recorded the walking parameters. The experiment was divided into the four seasons and three age groups – under 40 years, 40 – 64 years old and 65 years and above. The result of the experiment was recorded as follows:

- Mean walking speed and cadence were significantly higher in winter and lower in summer.
- Walking speed, stride length and cadence effect sizes were 0.27, 0.00, and 0.48 for men and 0.33, – 0.09, and 0.58 for women, respectively, between summer and winter.
- The results of a stratified analysis based on age indicated that the walking parameters' effect sizes in the summer and winter generally corresponded to the overall results.

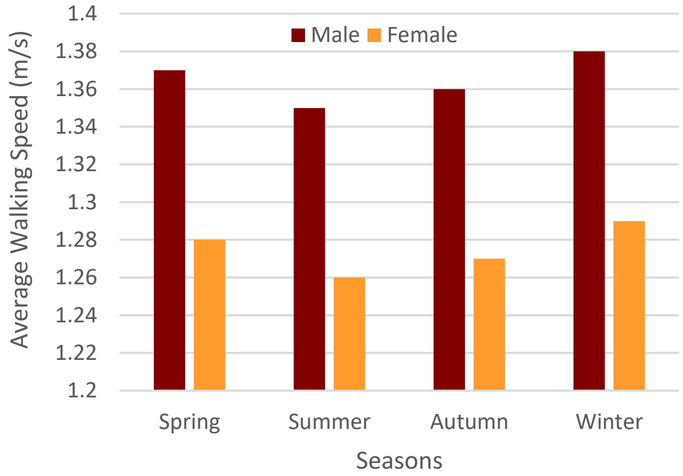


Chart 4: Seasonal changes in walking speed. Source: Obuchi et al., 2021

6. Kawai et al., 2021

The study examines the daily outdoor life walking speed of older adults throughout different time periods of a day. 92 participants, with an average of 71.9 years (±5.64), were observed using a GPS smartphone app for a month (October) in the city of Tokyo, Japan. The time was set to four different categories – early morning (4am – 7am), morning (8am – 11am), afternoon (12pm – 3pm), evening (4pm – 7pm) and night (8pm – 11pm). Walking speed, step length and cadence were recorded in each period of time using a linear model and Bonferroni post – hoc test and the participants were divided into two classes based on the walking speed variation by period: (1) fast walking speed with large variation and (2) slow walking speed with little variation. The following observations were made during the experiment:

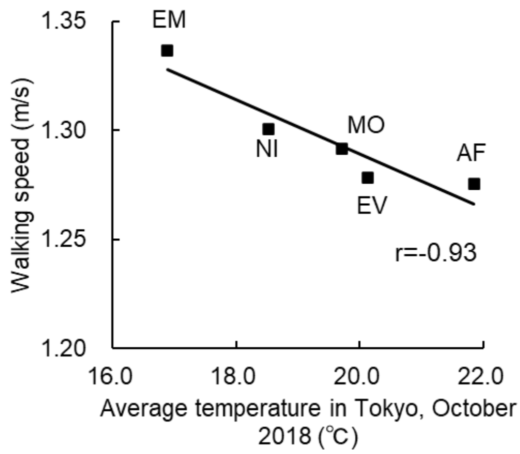


Chart 5: Average temperature with respect to the walking speed in each time period. Source: Kawai H et. al., 2021

- Class 1 – No significant differences for walking speed throughout the day (average walking speed was 1.18 m/s).
- Class 2 – Walking speed in early morning (1.41 m/s) was substantially faster than afternoon and evening walking speeds (1.34 m/s).

The study further discusses, based on the results, the three possible reasons for faster walking speed in the morning as compared to afternoon and evening. The third reason mentioned is related to air temperature. The highest average temperature of Tokyo in October was recorded to be 27°C.

7. Montufar et al., 2007

The paper reports on research done over eighteen months to ascertain the impact of seasonality on walking speed while accounting for age and gender and the differences between pedestrians' normal and crossing walking speeds at signalized intersections. In order to calculate the normal and crossing walking speeds, 1,792 pedestrians were timed at the chosen locations across a Canadian city. The following were the observations recorded during the course of experiment:

- According to the study, which compared the walking speeds of younger (20 years – 64 years) and older pedestrians (those 65 years of age and older), younger pedestrians walk faster than older pedestrians and males walk faster than females regardless of age or season. The following tables showcases the recorded results from the experiment with respect to seasons and gender for both the age categories.

Table 4: Walking speed of senior pedestrians. Source: Montufar J et al., 2007

Description	No. of Records	Total Percentage	Average Walking Speed (m/s)		15th Percentile Walking Speed (m/s)	
			Normal	Crossing	Normal	Crossing
Full data set						
All seniors	865	100	1.14	1.36	0.88	1.08
Female seniors	527	61	1.11	1.33	0.85	1.06
Male seniors	338	39	1.19	1.40	0.94	1.11
Summer						
All Seniors	541	100	1.18	1.35	0.94	1.08
Female seniors	324	60	1.15	1.33	0.90	1.08
Male seniors	217	40	1.23	1.39	0.97	1.09
Winter						
All Seniors	324	100	1.08	1.36	0.81	1.06
Female seniors	203	63	1.05	1.33	0.79	1.03
Male seniors	121	37	1.12	1.42	0.86	1.12

- Furthermore, the research observed that if the walking speed was set at 1.2 m/s, approximately two-thirds of older pedestrians would not be included in the design process due to their typical walking speed, and approximately 40% would not be included due to their crossing walking speed. If the walking speed was set at 0.91 m/s, this rate can be reduced approximately by 20% – 10%.

8. Nayak et al., 2019

The study examined how different forms of transportation could provide the heat-vulnerable population in New York, USA with access to cooling centers. The proximity of 377 cooling centers to heat – vulnerable population were calculated and determined their accessibility by walking, driving and public transportation. The study conducts the walking experiment corresponding to the OSHA's recommended distance i.e., 800m in 15 minutes. The following conclusions were curated with respect to the study's findings:

- Even though cooling centers are mostly found in urban areas, only roughly one-third of New Yorkers (apart from those living in Manhattan) lived close to a cooling center.
- Even though many residents live far from a cooling center, the majority (nearly 50%) — including all of those in the most heat-vulnerable areas—can walk to one via public transportation. Distances are longer and accessibility is a bigger problem in rural areas, where there might not be as much of a critical need for cooling centers because there are other options for cooling off.

The study suggests that the ideal distance to walk to a cooling center should not be more that 15 minutes i.e., 800m.

3.5. Relevance of this Study and addressing the research gap

Despite the increasing interest in the accessibility of urban climate shelters throughout Europe, a significant gap in research persists, particularly regarding the complex interplay among thermal comfort, pedestrian behavior, and proximity measures. While previous studies have highlighted the importance of spatial proximity in enabling access to urban climate shelters, the connection between thermal comfort and pedestrian behavior, particularly concerning vulnerable populations like the elderly, remains largely unexplored, to the best of my knowledge. This research gap is crucial, as it neglects the dynamic relationship between environmental factors, such as shade provision and sun exposure mitigation, and pedestrian preferences, including walking duration, speed, and route selection. Failing to incorporate these multifaceted factors into accessibility evaluations overlooks essential nuances that could greatly impact the effectiveness and inclusivity of urban climate shelter initiatives.

Addressing the said gap is vital for advancing our comprehension of urban climate shelter accessibility in Europe and for guiding evidence-based policies and interventions aimed at improving pedestrian experiences and ensuring fair access to essential urban resources, aligning with the principles of the 15-minute city framework.

3.5. The Italian Scenario

Average annual temperatures in Italy have risen by 1 degree Celsius in the last 100 years, according to the International Energy Agency, with an even faster increase in recent decades (Climate Reality Project, 2024). This warming has been especially prevalent in the spring and summer, at high altitudes, and has resulted in more and more heat waves baking the peninsula. Indeed, heat waves have become a major, pressing concern for Italy as the climate continues to change. Last summer, a heat wave the Italian Meteorological Society named "Cerberus" – the three-headed monster from Dante's "Inferno" – seared with temperatures soaring past 45°C (113° Fahrenheit) in some parts of the country. The long-lasting "heat dome" became so intense that Italy's health ministry "issued a red alert (meaning 'risk of death') in 27 cities" (CNN, 2023). In recent decades, the northern parts of the peninsula have shown a higher rate of heat related mortality than the southern regions (Ellena et al., 2023). In the summer of 2023, in northern Italy, Milan posted its highest average daily temperature in 260 years.

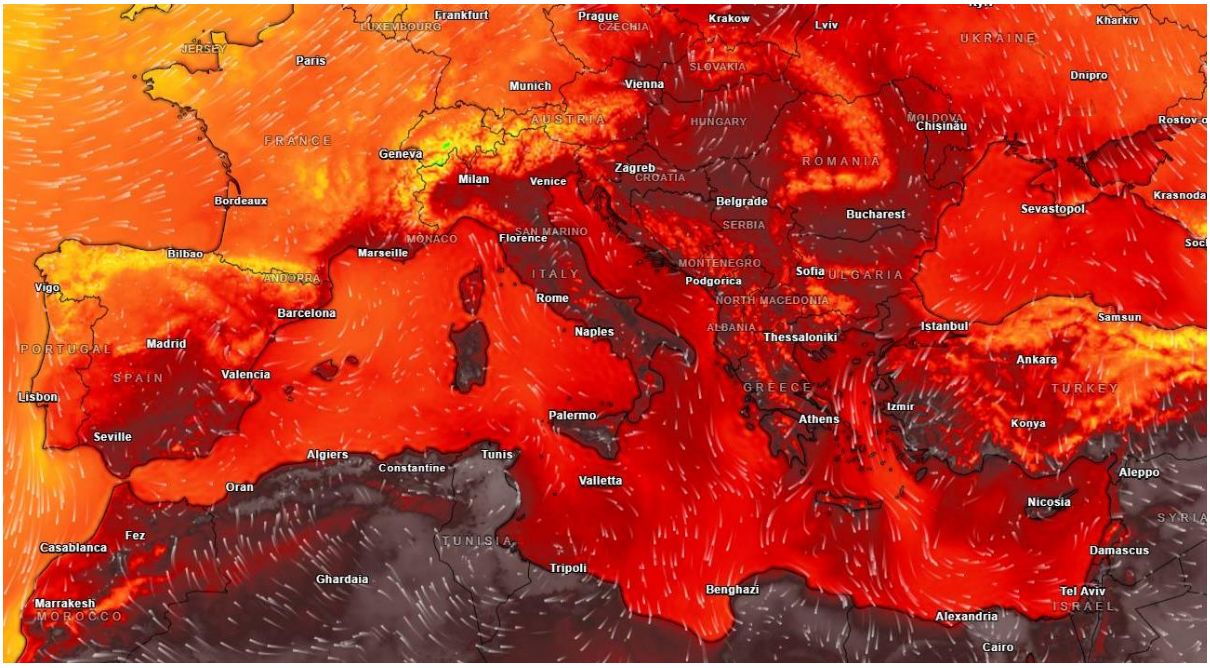


Figure 10: Heatwave "Cerberus" recorded throughout the southern Europe in 2023. Source: The Gaze, July 16, 2023

Although Italians are among the populations that are most affected by heat when compared to rest of European regions (Gasparrini et al., 2015), not much research has been done to determine the who, how and where are the most vulnerable to extreme temperature events (Ellena et al., 2023).

3.4.1. Why Torino?

As mentioned previously, the northern cities of Italy show higher mortality rate during the heat events. The city of Turin lies as a victim of rapid urbanization and unpredicted abandonment due to its economical downfall which resulted in great many of brownfields, 10 million sq.m. to be precise, along with densely urbanized fabric (Ellena et al., 2023). Being the largest city in northern western Italy, Turin, in recent years, has suffered from the impacts of climate change. The city and its economy suffer serious yearly consequences from extreme weather events that happen more frequently and intensely (Climate Resilience Plan, 2020). The city's death rate sharply increased in 2003, the year that saw the first heat wave-related emergency—a phenomenon that has been on the rise in recent years. Despite factors like an ageing population and deteriorating climate conditions, there is still a dearth of adequate research on vulnerable populations' and zones' proximity and accessibility to essential services during a heat event.

3.5. Inferences from Reference Studies

The following parameters along with its respective indicators and values obtained from the reference studies will be used to conduct the further analysis in this paper:

1. Walking Speed of Elderly during summer

Most scholarly articles and studies on pedestrian walking speeds have adopted an average pace of 1.2 m/s for senior citizens (Obuchi et al., 2021; Kawai et al., 2021). But in reality, about 66% of older pedestrians are excluded from design considerations when their average walking pace is assumed to be 1.2 m/s, and 40% is excluded from concerns related to street crossings. From the research conducted in Canada, it was concluded as a solution that if the walking speed was set at 0.91 m/s instead of 1.2 m/s, the percentage of older pedestrians that are able to be included in the design process based on their walking speed will be around 80% - 90% (Montufar et al., 2007).

Additionally, various other studies support the value for the average walking speed to be 0.9 m/s for elderly pedestrians.

- According to a study, 97.8% of older adults in Sao Paulo (60 years of age or older) walk more slowly than the required 1.2 m/s at pedestrian crossings (Duim et al., 2017). At a standard pedestrian walking speed of 1.1 m/s, this proportion stayed essentially unchanged at 95.7%. This ratio would drop to 69.7% if the reference speed was set at 0.9 m/s.
- A study that compared the walking speeds of the elderly population (65 years of age or older) in the UK for pedestrian crossings (standard speed = 1.2 m/s) found that the average walking speed for men and women was 0.9 m/s and 0.8 m/s, respectively (Asher et al., 2012).

2. Walking Speed of Young adults during summer

Most of the studies reported 1.4 m/s as the average normal walking speed associated with young adults (Bohannon & Williams Andrews, 2011; Montufar et al., 2007).

3. Walking duration during summer

According to the study from above, the ideal distance to walk to a cooling center should not be more that 15 minutes i.e., 800m (Nayak et al., 2019). Accordingly, as discussed in the section 2.4.2, the study also corresponds to the walking speed or walking duration mentioned in the Occupational Safety and Health Administration (OSHA) as 'light' work category is equivalent to a casual walking pace of 2 miles an hour or 0.5 miles in the recommended 15 minutes. Hence, in this study, 15 – minutes will be the cut – off time to analyze the proximity and accessibility to an UCS for an elderly person.

3.6. Proposed Scenarios based on Inferences from Reference Studies

Based on the research papers discussed in section 3.2 of this study, two scenarios are considered for evaluating the proximity and accessibility range in relation to walking speed of different population groups in Turin. These scenarios focus on the impact of heat distress on pedestrian behavior and how it affects access to UCS, using selected parameters and their indicators.

1. Scenario 1 – Walking speed of Young Adults (20 years – 64 years) based on reference studies:

Table 5: Young adult pedestrian walking speed and time collected from the reference studies and literature for further analysis. Source: Author

USER GROUP	PARAMETERS	INDICATORS	VALUES / FINDINGS	REFERENCE STUDY
Young Adults (younger pedestrian age group 20 – 64 years)	Walking speed	Normal walking speed	1.4 m/s	Montufar et al., 2007 When Crossing a Street. Transportation Research Record 2002, 90–97. https://doi.org/10.3141/2002-12
	Time Threshold (under clear sky in summer)		15 minutes	Occupational Safety and Health Administration (OSHA) Nayak, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Pantea, C.I., Ross, Z., Kinney, P.L., Zdeb, M., Hwang, S.-A.A., Lin, S., 2019. Accessibility of cooling centers to heat-vulnerable populations in New York State. Journal of Transport & Health 14, 100563. https://doi.org/10.1016/j.jth.2019.05.002

2. Scenario 2 – Pedestrian Behavior in Elderly (65≥ years) based on reference studies:

Table 6: Elderly pedestrian walking speed and time collected from the reference studies and literature. Source: Author

USER GROUP	PARAMETERS	INDICATORS	VALUES / FINDINGS	REFERENCE STUDY
Elderly (older pedestrian age group 65 ≥ years)	Walking speed	Normal walking speed	0.91 m/s	Montufar et al., 2007 When Crossing a Street. Transportation Research Record 2002, 90–97. https://doi.org/10.3141/2002-12
	Time Threshold (under clear sky in summer)		15 minutes	Occupational Safety and Health Administration (OSHA) Nayak, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Pantea, C.I., Ross, Z., Kinney, P.L., Zdeb, M., Hwang, S.-A.A., Lin, S., 2019. Accessibility of cooling centers to heat-vulnerable populations in New York State. Journal of Transport & Health 14, 100563. https://doi.org/10.1016/j.jth.2019.05.002

3. Scenario 3 – Pedestrian Behavior when exposed to the sun:

Scenario 3 is a comparison between the reduced speed on different age category of pedestrians when exposed to the sun in summer. According to a study conducted, reduction of 0.3 m/s in walking speed is observed during peak summer days

Table 7: Scenario – 3a: Young adult pedestrian behavior based on the parameters collected from the reference studies and literature during summer. Source: Author

USER GROUP	PARAMETERS	INDICATORS	VALUES / FINDINGS	REFERENCE STUDY
Young Adults (younger pedestrian age group 20 – 64 years)	Walking speed	Reduced walking speed due to sun exposure (peak summer)	1.1 m/s	Obuchi, S.P., Kawai, H., Garbalosa, J.C. et al. Walking is regulated by environmental temperature. Sci Rep **11**, 12136 (2021). https://www.nature.com/articles/s41598-021-91633-1 Kawai et al., 2021 Kawai, H., Obuchi, S., Hirayama, R., Watanabe, Y., Hirano, H., Fujiwara, Y., Ihara, K., Kim, H., Kobayashi, Y., Mochimaru, M., Tsushima, E., Nakamura, K., 2021. Intra-day variation in daily outdoor walking speed among community-dwelling older adults. BMC Geriatr 21, 417. https://doi.org/10.1186/s12877-021-02349-w
	Time Threshold (under clear sky in summer)		15 minutes	Occupational Safety and Health Administration (OSHA) Nayak, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Pantea, C.I., Ross, Z., Kinney, P.L., Zdeb, M., Hwang, S.-A.A., Lin, S., 2019. Accessibility of cooling centers to heat-vulnerable populations in New York State. Journal of Transport & Health 14, 100563. https://doi.org/10.1016/j.jth.2019.05.002
	Average Daylight Hours on June 21st, 2024 in Turin		15 hrs 38 mins.	https://www.calendariando.it/alba-e-tramonto/torino/
	Average Total Solar Radiation on June 21st, 2024		0.780326 kWh/m2	3D model – SDG 11 Lab, Politecnico di Torino

Table 8: Scenario – 3b: Elderly pedestrian behavior based on the parameters collected from the reference studies and literature during summer. Source: Author

USER GROUP	PARAMETERS	INDICATORS	VALUES / FINDINGS	REFERENCE STUDY
Elderly (older pedestrian age group 65 ≥ years)	Walking speed	Reduced walking speed due to sun exposure (peak summer)	0.61 m/s	Kawai et al., 2021 Kawai, H., Obuchi, S., Hirayama, R., Watanabe, Y., Hirano, H., Fujiwara, Y., Ihara, K., Kim, H., Kobayashi, Y., Mochimaru, M., Tsushima, E., Nakamura, K., 2021. Intra-day variation in daily outdoor walking speed among community-dwelling older adults. BMC Geriatr 21, 417. https://doi.org/10.1186/s12877-021-02349-w Obuchi, S.P., Kawai, H., Garbalosa, J.C. et al. Walking is regulated by environmental temperature. Sci Rep **11**, 12136 (2021). https://www.nature.com/articles/s41598-021-91633-1
	Time Threshold (under clear sky in summer)		15 minutes	Occupational Safety and Health Administration (OSHA) Nayak, S.G., Shrestha, S., Sheridan, S.C., Hsu, W.-H., Muscatiello, N.A., Pantea, C.I., Ross, Z., Kinney, P.L., Zdeb, M., Hwang, S.-A.A., Lin, S., 2019. Accessibility of cooling centers to heat-vulnerable populations in New York State. Journal of Transport & Health 14, 100563. https://doi.org/10.1016/j.jth.2019.05.002
	Average Daylight Hours (June 21st) in Turin		15 hrs 38 mins.	https://www.calendariando.it/alba-e-tramonto/torino/
	Average Total Solar Radiation (June 21st)		0.780326 kWh/m2	3D model – SDG 11 Lab, Politecnico di Torino

Additionally, walkability and pedestrian path choices during summer season are also taken into consideration:

Table 9: Pedestrian behavior based on parameters collected from the reference studies and literature. Source: Author

USER GROUP	PARAMETERS	INDICATORS	Findings	REFERENCE STUDY
Pedestrians	Walkability condition in Summer season	In Sun / In Shade	80% - 93% people in the shade when temp > 40°C	Lin, T.-P., Tsai, K.-T., Liao, C.-C., Huang, Y.-C., 2013. Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types. Building and Environment 59, 599–611. https://doi.org/10.1016/j.buildenv.2012.10.005

Similarly, Turin's Climate Resilience Plan[11] also discussed about the change in the behavioral pattern of the residents. It is mentioned that the residents are aware of the changing climate, especially HWs and recognizes them as a critical phenomenon as it impacts certain aspects of life. A survey methodology was carried out among residents aged 18 – 87 years where the respondents' key methods for responding to heat waves consisted of the following behavioral shifts:

1. Shifts in the number of hours spent away from home:
   People focus their movements primarily early in the morning or late at night, avoiding being outside during the hottest times of the day.
2. Shifts in routines or typical activities:
   People decide to limit their household chores to the essentials and skip the hardest ones; When it comes to mobility, people chose to walk than wait for long time in the sun to ride on buses without air conditioning.
3. Shifts in the leisure activities individuals opted:
   People try to avoid going outside as much as possible in favor of staying indoors with air conditioning and travelling to colder locations like mountains.

A thorough analysis of Turin and the consequences of climate change on the city is conducted in order to obtain a deeper understanding of this shift in behavioral patterns among the city's residents.

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[11] Source: Climate Resilience Plan, 2020 (p. 72)

SECTION 3

Case study of Turin

Figure 11: Map of Italy showing Turin. Source: Author

Chapter 4

4.1. Turin – Urban study at city scale

Turin, home to approximately 846,926 residents (ISTAT, 2024), is the fourth largest city in Italy, following Rome, Milan, and Naples. It serves as the capital of the Piedmont region in the northwest of the country. Located predominantly on the west bank of the Po River, the city is flanked by the Alps to the north and west. Spanning an area of 130.1 km^2, it has an average population density of 6,510 inhabitants per km^2 (Citta di Torino, 2024), making it the fourth most densely populated city in Italy. Turin was the industrial hub that fueled Italy’s economic recovery after World War II, particularly in the automotive and mechanical manufacturing sectors during the 1900s.

TURIN - Context	
Geography	45°04’45” N 07°40’34” E
	240m above sea level
Ecology	Rivers – Po River and its tributaries (Dora, Stura and Sangone) Green belt – Corona Verde
Administration Data	8 Circoscrizioni
Census Data (source – ISTAT, 2024)	846,926 Inhabitants (2024)
	130.1 km2 area
	6,510/km2 – Population Density (2024)
Metropolitan area (source – Comune di Torino, ISTAT, 2024)	2,203,353 Inhabitants (2024)
	6,827 km2 area
	322.7/km2 – Population Density (2024)
-0.11% Annual Population Change (2022 – 2024)	
Settlement Type (source – Salata et al., 2020; Sugoni et al., 2023)	Densely constructed - compact urban development
	7400 hectares – 57.55% (high degree of Impermeable areas)
	Central City with Baroque style (Mid 1500s – 1800s) Industries in city limits (1900s)
	Land use: Residential (80%), Industrial (8%), Commercial (5%), Service (5%)

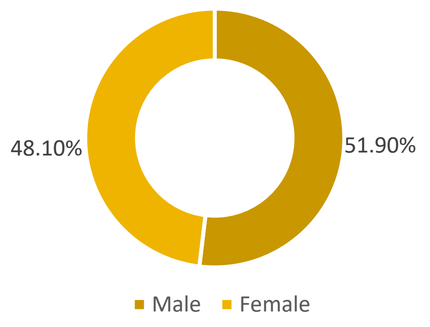
From the turn of the 20th century until the 1970s, Turin saw a new era of concentrated economic, population, and physical growth. The city grew rapidly in the course of a few decades, driven by the need to accommodate the growth of the industrial sector and a large-scale migration from southern Italy. Rapid urbanization resulted in an unprecedented depletion of greenfield while also causing significant social unrest as newcomers found it difficult to fit in with the community's sociocultural fabric. As this industrial boom swiftly ended, Turin experienced a population decline and abandonment from its fleeing industry (European Green Capital Report-EGCA – Turin, 2022).

The challenges aroused due to this economic and social changes were significant, including a 25% reduction in city’s population, a demographic shift toward ageing population and a legacy of 10 million square meters of brownfield (Ellena et al., 2023).

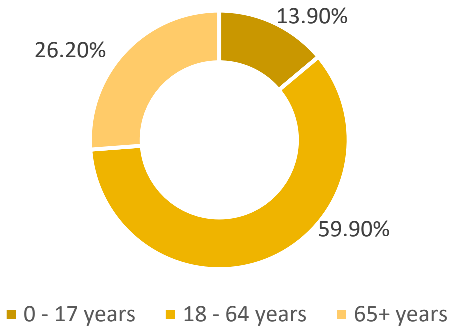
4.1.1. Demographic Structure

Turin is statistically partitioned to 3.843 census tracts with an average of 300 inhabitants residing in each tract (Ellena et al., 2023).

Population Statistics based on Gender - 2024



Population Statistics based on Age - 2024



Population Statistics based on Citizenship - 2024

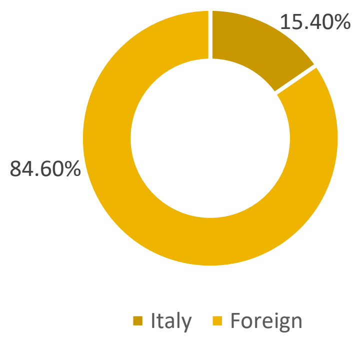


Chart 6: Demographic structure of Turin. Source: Citta di Torino, 2024

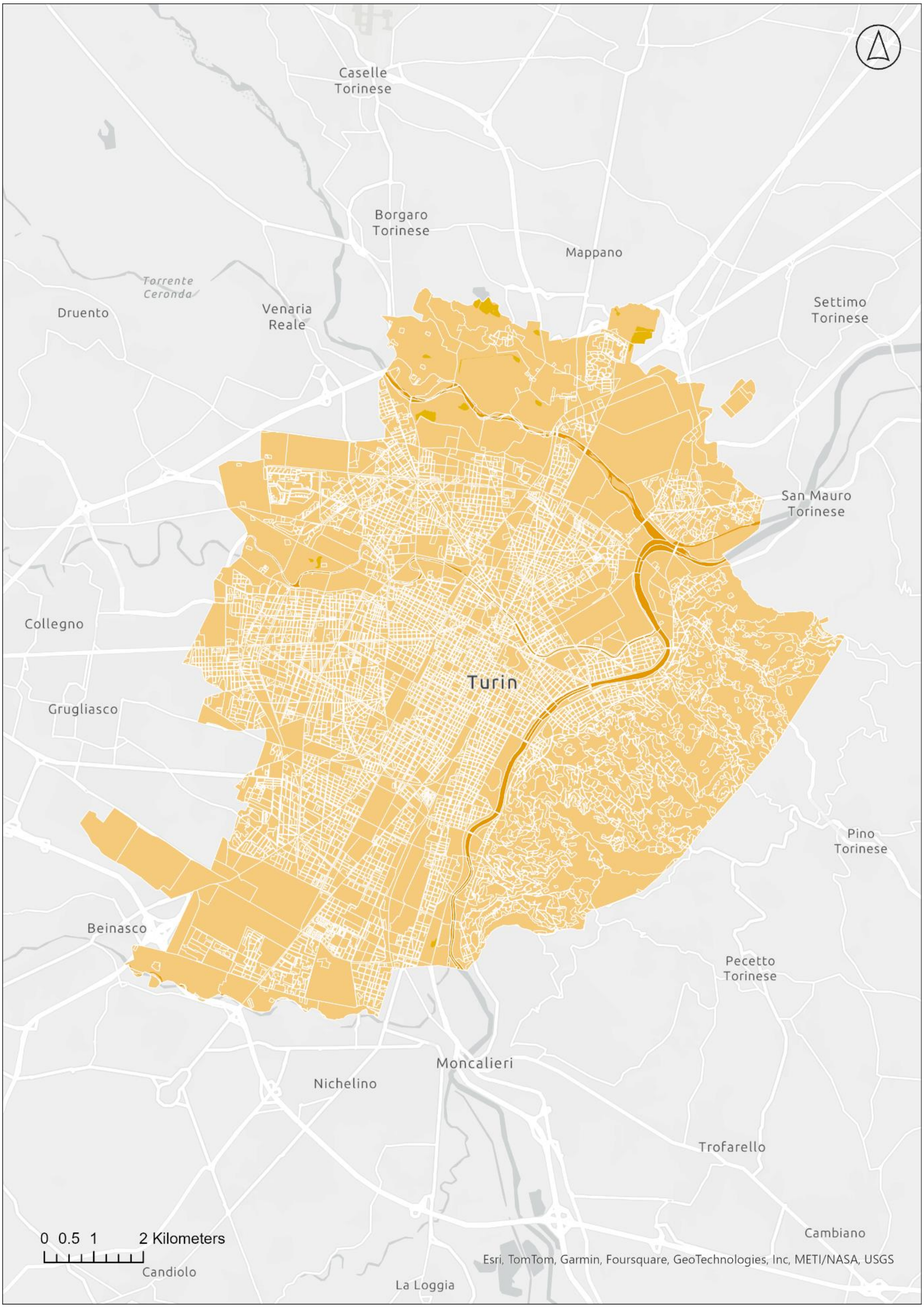


Figure 12: Map of Turin with census tract 2021. Source: Author

4.1.2. Turin and the Climate

Bordered by the Alpine Mountain chain on one side and the Superga hills on the other, Turin experiences limited circulation of foehn winds. This creates a diverse mosaic of microclimates in the city, resulting in dry summers and mild, wet winters, typical of the Mediterranean climate (Ellena et al., 2023), hence classified as *Cfb* by the Köppen – Geiger climate classification[12] (Citta di Torino, 2022). Turin, like many other cities, has to contend with shifting climate conditions, primarily brought on by greenhouse gas emissions generated by human activity. Each year there are severe weather phenomena that happen more frequently and intensely harm the city and its economy.

How the Temperature in the city is changing?

The maximum and average temperatures in Turin from 1951 to the present show a notable upward trend, while the minimum temperatures either stay relatively constant or slightly decline. Notably, according to the city's resilience plan, throughout all historical records dating back to 1951, the maximum temperatures exhibit a substantial trend of almost 0.6°C every decade. The last 30 years have been the most significant contributors to warming, with a trend of roughly 0.8°C per 10 years (Climate Resilience Plan, 2020). The first heat wave-related emergency was reported in the city in 2003, coinciding with a notable spike in mortality rate.
To comprehend the trend of the city over the previous thirty years, two climate indicators regarding rise in temperature were taken into consideration – a) Warm nights (number of nights with minimum temperature > 20°C) and b) Extremely hot days (number of days with maximum temperature > 25°C). These two indicators are crucial for analyzing how climate change affects human health and how much energy is used to cool buildings (Centro Euro – Mediterraneo sui Cambiamenti Climatici - CMCC – Turin, 2021). The graphs below (Chart 7 & Chart 8) show anomalies in the average temperature (°C) for the period 1989 – 2020 that have been consistently positive since 2014 and exhibit an evident upward trend over the previous 60 years, or roughly 2.2°C. The minimum temperatures exhibit a small downward trend that is not statistically significant, with many negative anomalies occurring recently (Climate Resilience Plan, 2020).

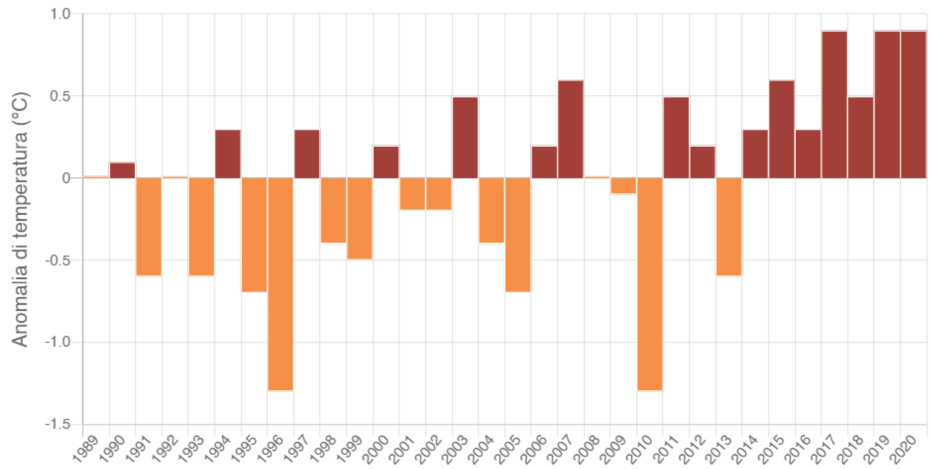


Chart 7: Average annual temperature anomaly trend over the period of 1989 – 2020. Source: CMCC – Torino, 2021

[12] The Köppen-Geiger climate classification is a widely used system for categorizing the world's climates based on average monthly temperature and precipitation patterns. This classification system divides climates into 5 main groups and 30 sub-groups based on criteria like temperature, which permits various vegetation growth. Source – Beck H.E. et al., 2018; National Geographic

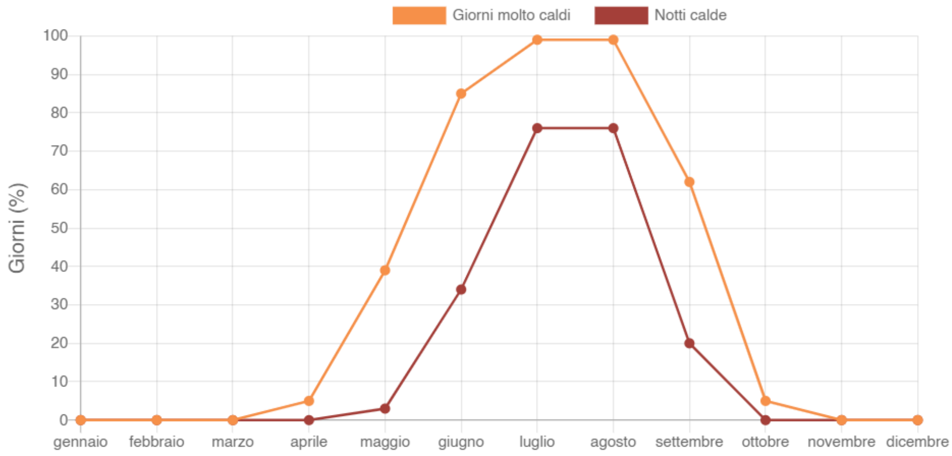


Chart 8: The yearly cycle (% of days per month) for the indicators, which are referred to in the text as warm nights (tropical nights, TR) and extremely hot days (summer days, SU). Source: CMCC – Torino, 2021

Towards warmer summers

The extremes in temperature, particularly during the summer, have also shifted. The records of over the past 30 years shows the highest daily summer temperatures have risen, with increases of about 1.7°C for the 95th percentile and roughly 1.8°C for the 99th percentile. Considering a macro scale, in 2023, Piedmont region experienced the second warmest year after 2022 in the historical timeline between 1958 – 2023 (L'Agenzia Regionale per la Protezione Ambientale del Piemonte – ARPA, 2024). In line with the overall temperature changes brought on by global warming, Turin's days of frost from 1951 to 2019 show a slight downward trend, while the tropical nights indicator shows no visible trend (Climate Resilience Plan, 2020).

Looking into the future, the analysis carried out for the Climate Resilience Plan in the mitigation scenario, the predicted trend of greenhouse gas emission remains the same as today – high. The climate scenario of 2100 will observe an overall increase of 3°C – 6.7°C in the annual temperature with an average rate of increase of 0.3°C – 0.63°C every decade respectively. Additionally, there has been a decline in the number of rainy days over the course of the century and except for the last thirty years, there has also been a slight decline in the average annual rainfall. The maximum annual length of dry periods is trending upward at the same time (Climate Resilience Plan, 2020).

4.2. Turin – Urban Analysis at city scale

Table 10: Turin in terms of rising temperature. Source: Climate Resilience Plan, 2020; modified by Author

TURIN – Rising Temperature	
Climate Classification	Cfb (Köppen – Geiger climate classification)
Maximum Temperature Recorded - 2019 (Source – ARPA Station 2019, Climate Resilience Plan, 2020)	39.40°C
Average Temperature (Source – Climate Resilience Plan, 2020)	14.62°C
Overall Temperature Trend 1951 – 2019 (Source – Climate Resilience Plan, 2020)	+2.3°C (summer)
Days when Avg. T is > 32°C (Source – Climate Resilience Plan, 2020)	1951 – 1988 = + 14 days 1989 – 2003 = 26.5 days 2004 – 2019 = 48.2 days
Main Climatic Hazards (Source – Climate Resilience Plan, 2020)	UHI & Heatwaves Flood Landslide
Intense Heatwave events recorded	2003, 2006, 2015 and 2017
Thermal Discomfort Index[13] - July 2023 (Source – ARPA, Piemonte)	33 (High Danger)

[13] Discomfort Index: proposed by Thom in 1959, "Discomfort Index" (DI) is considered one of the best indices for estimating the actual temperature. It is defined as "an arbitrary index" that combines, in a single value, the effect of temperature, humidity and air movement to human thermal comfort. The actual temperature accounts for both the dry and wet bulb temperatures in wind- and shade-protected areas. This index is appropriate for describing physiological discomfort caused by hot and humid temperatures, and it is sensitive within the temperature range of 21°C to 47°C. Outside of this range, even when relative humidity varies, the index always assigns the physiological condition to the extreme classes, namely "wellbeing" for temperatures below 21°C and "state of medical emergency" for temperatures above 47 °C. Source: arpa.piemonte.it, Author: Thom EC and Bosen JF

From the above table, it's evident that the most extreme summers in terms of temperature have happened in the new millennium and according to the data issued by Turin's Resilience Plan, there has consistently been at least one heat wave in recent summers (Climate Resilience Plan, 2020).

4.2.1. Impacts of Climate Change – UHI and Heatwaves

Climate scenarios indicate that temperatures will rise over the next several years, potentially increasing the likelihood of heat waves and the occurrence of urban heat islands. HWs are severe summertime weather events defined by high temperatures above average and can persist for several days or even weeks (Climate Resilience Plan, 2020).

The severity of the impact on the population is determined by three characteristics – the air's intensity, duration, and moisture content. In a city like Turin, heat waves that are known as "Moist Heatwaves"—humid ones—affect people's health because they are marked by high temperatures, humid weather both during the day and at night, the presence of clouds at night that prevent heat from accumulating during the day, and inadequate ventilation (WMO, 2015, Climate Resilience Plan, 2020). HWs can affect an entire region simultaneously and are known as Silent Killers because, unlike other extreme events, they do not leave a trail of destruction in their wake thus making them more dangerous (Luber & McGeehin, 2008) (Climate Resilience Plan, 2020).

Relating to HWs is the UHI phenomenon consisting of higher temperature in the urban environment compared to its peripheral rural areas. Turin experiences a temperature difference based on the data shown in the following figure (Figure 13). This phenomenon can be attributed to urban areas' increased ability to absorb solar radiation, store heat during the day, and release it at night. The primary cause is the thermal and radiative properties of the materials that make up urban surfaces, particularly concrete and asphalt, which absorb more solar radiation than they reflect (Climate Resilience Plan, 2020). The UHI is most evident at night when the urban areas are warmer than its surroundings. As a result, this phenomenon means that urban populations especially the vulnerable are at greater risk during heat waves (Climate Resilience Plan, 2020). Below table reviews the many impacts of HWs and UHI on Turin city that were identified by stakeholders in various sectors as explained in the Climate Resilience Plan.

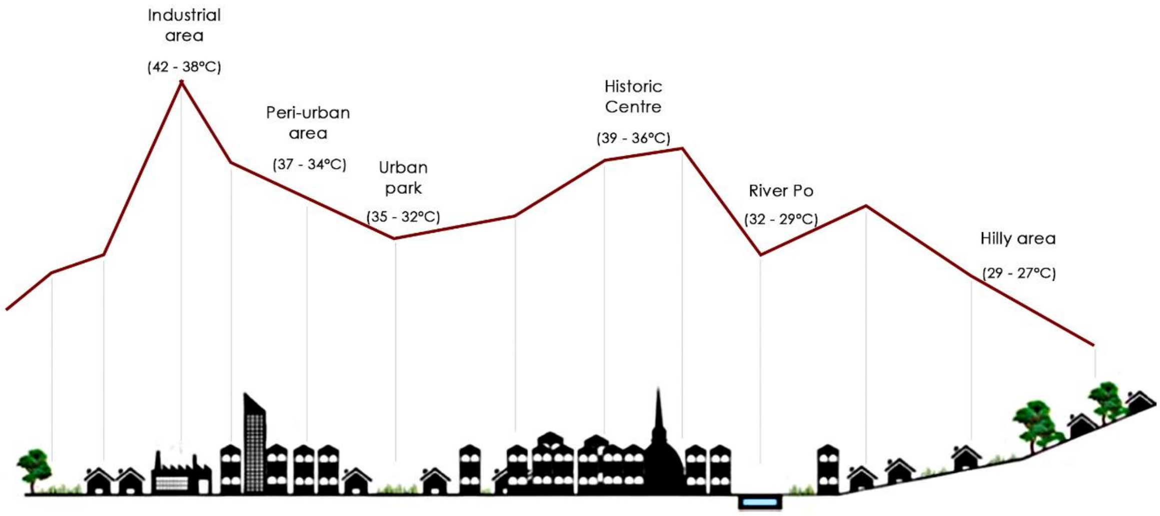


Figure 13: Temperature variation for different urban fabrics in Turin. Source: Climate Resilience Plan, 2020; LIFE DERRIS - Disaster Risk Reduction Insurance, 2018

The following table summarizes the impacts of UHI and HWs on various environmental and urban domains of the city.

Table 11: Impacts of HWs and UHI on various urban aspects of Turin. Source: Climate Resilience Plan, 2020. Modified by Author

Air	Potential increase in Ozone pollution
	Increased air temperature
	Combined health effects
Urban Green & Agriculture	Degradation
	Increased need for irrigation
	Greater management complexity
	Spread of invasive species and pesticides
Water	Scarcity
	Reduced flow rates (DMV) and spread of alien species
	Quality degradation along with industrial pollution
	Negative impacts on ecosystem
Land	Increase in surface temperature
	Decrease in moisture content
Energy	High consumption and demand rate (especially in summer)
	Increased chances of blackouts
Industry	Influence the process
	Increased need for system cooling
	Lower productivity
	Major catalyst of increasing temperature on other urban fabrics
Socio-Economic System	Decrease in productivity
	Negative effects on tourism
	Delayed service delivery
Health	Increased mortality rate (especially for vulnerable population)
	Increased morbidity
	Widespread conditions of thermal discomfort
	Unusual pollination period
	Vector diseases
Infrastructure	Effects transport infrastructure
	Effects public facilities
	Effects technological infrastructure
	Potential to interrupt health infrastructure
Quality of Life	Increased rate of thermal discomfort
	Decreased usage of public spaces
	Limitations on social life
	Limitations on urban mobility

UHI Hazard Map of Turin

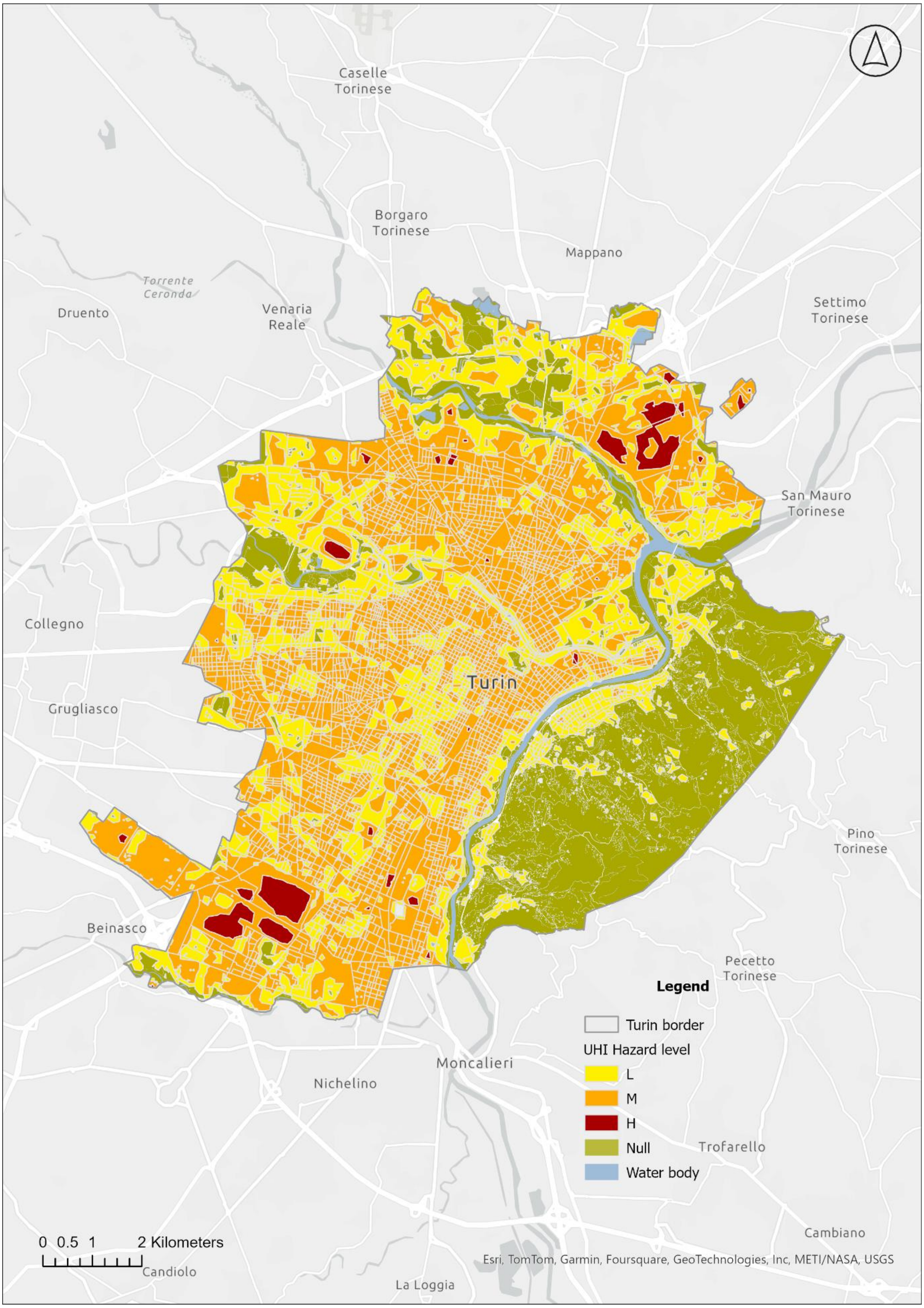


Figure 14: UHI map of Turin with hazard classes. Source: SDG 11 Lab, PoliTO; modified by Author

Heat Risk Analysis

The Life DERRIS Project[14] (DisastEr Risk Reduction InSurance) was the first to help prepare Turin's Climate Change Action Plan, 2019. The project studied the trend of extreme heat events in the city in the last five decades and observed the increasing intensity of HWs that was 33 times greater than in the past. The recent extreme historical HWs that occurred on August 11, 2003, July 21, 2006, and July 22, 2015, were also examined as part of this project.

A major rising trend in the city's average and maximum temperatures, particularly in the industrial zones, was revealed by ARPA Piemonte's 2018 climate assessment findings (Climate Resilience Plan, 2020). The analysis also revealed that while the majority of the city's urban fabric is found in medium-risk zones, the city's high-risk areas are concentrated, particularly around two huge industrial buildings: the IVECO complex in the northeast and the Fiat Complex in the southwest (Climate Resilience Plan, 2020). The study further analyzes the cause to comprehend how the presence of industrial zones affects the neighboring areas and the level of risk it creates. The average temperature during a chosen heat event was found to be 3°C higher than the city average within 50 meters of the industrial buildings, and to reach 1°C farther out at a distance of 50 to 100 meters (Climate Resilience Plan, 2020).

To summarize the data from resilience plan, the distribution of city's urban heat island percentage is as follows:

- 27% area is in low risk
- 44% area is in medium risk
- 2% area is in high risk

along with 27% area in no risk. (Climate Resilience Plan, 2020)

As previously mentioned, this risk further impacts the urban infrastructure and compromises on their adaptive capacity. The risks—which, in Turin's instance, extend beyond UHI—that affect the different public buildings and services are listed in the following table.

Table 12: Infrastructure exposed to risks of UHI, Flood and integration of the two risks. Source: EGCA Turin 2022

Infrastructure	Urban Heat Island	Flood	Multi – risk
Hospitals	24	6	5
Social – Welfare services	93	16	23
Administrative services	133	22	7
Schools	444	53	65
Trade	23,503	2,458	1,426

[14] The DERRIS Project (September 2015 – September 2018) was the first European project to bring various sector to colloborate on reducing the risks associated with extreme climate events. The project executed a specific analysis of Turin's industrial context which further resulted in the development of Integrated District Adaptation Plan (IDAP) – *a plan that relates to "Torino che protegge" pilot area.* Source: Climate Resilience Plan, 2020.

Thermal Discomfort in city and the Vulnerable Urban Population

With the number of days experiencing heat waves typically double or triple that of the preceding thirty years, the time around the middle of the century is extremely critical (Climate Resilience Plan, 2020). Analysis of different biometeorological indices[15] revealed a substantial spike in the number of days defined by discomfort over the last 20 years, which can be used to evaluate the effects of heat on human health and activities (Climate Resilience Plan, 2020). According to this plan, the future scenario of Turin involves an increase in the number and length of heatwaves, hence increasing the number of days of discomfort for the population.

Who are the most vulnerable in Turin during intense heat event?

The most important socioeconomic and demographic factors should be considered when analyzing the impacts of extreme temperatures on human health. These may pertain to the fundamental clinical fragility conditions, particularly in the elderly population (Ellena et al., 2023), aged 65 years and above. Different qualitative and quantitative research agrees on temperature – related mortality risk surges in the elderly population (Ellena et al., 2020). The living conditions, social isolation, and economic constraints of this population segment are additional factors to consider.

- Elderly individuals are more likely to live alone and may not have access to air conditioning or other cooling resources.
- Many elderly people live in older buildings that may not be well-insulated or equipped to handle extreme temperatures.
- Lack of social support can mean fewer people checking in on elderly individuals during heatwaves, leading to delays in recognizing and addressing heat stress symptoms.
- Limited income can restrict access to cooling devices like air conditioners and the ability to pay for higher electricity bills during heatwaves.

Hence, the climate refugees i.e. in this study, the exposed population is limited to the population group of 65 years and above for the analysis in this study.

4.2.2. Vulnerability Analysis and Vulnerable Zone Classification

According to the United Nations Office for Disaster Risk Reduction (UNDRR)[16], vulnerability is the state of being susceptible to or lacking in resistance to various risks, hazards, or unfavorable events. It is determined by physical, social, economic and environmental domains. It is thus important to determine the study area's vulnerability to understand the cause and impacts of a hazard, which in this case are the UHI and HWs.

Therefore, to understand the impact level of UHI and HWs in the city, we have to first define and define the vulnerability of Turin, especially concerning the social aspect. This can help in disaster preparedness which further contribute to the safety and well – being of all residents.

[15] Biometeorological Indices analysed in Turin's Climate Resilience Plan: HUMIDEX >30, Discomfort Index >27, Apparent max T° >32°C, Tropical days and Tropical nights. Source: Climate Resilience Plan, 2020.

[16] Source: undrr.org

The Spatial Unit of Assessment

The census tract, the most detailed data currently available in Italy, is the spatial unit under analysis in this study. There are 3.843 census tracts in Turin, and each tract has an average of 300 residents. The data was configured from the ISTAT population data of 2021 with the assistance from SDG 11 Lab, Politecnico di Torino.

The process of 2011 census tract refinement:

Data from the 2021 census that are linked to the 2011 census tract release (ISTAT 2011) were made available by ISTAT. These census tracts, especially the larger ones in the municipality of Turin, include land use classes aside from residential and urban, which can cause significant errors when estimating how accessible climate shelters are to residents. Figure 15 shows an example of this situation, where a census tract spanning around 90 hectares is a combination of industrial zones, agricultural land and urban green areas with the urban fabric serving a limited role. Overlapping the ISTAT 2011 census tract with isochrones (service areas) could lead to an overestimation of accessibility, whether by considering the total population of 557 residents or by calculating a ratio based on the overlapping area.

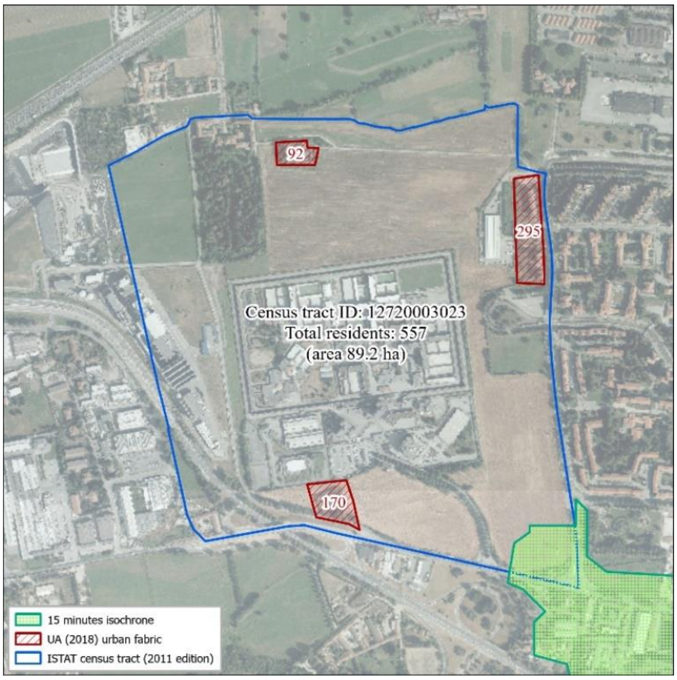


Figure 15: Example of ISTAT 2011 census tract reclassification. Source: Author

To address this issue, a method was opted to reclassify the ISTAT 2011 census tracts using the Urban Atlas Land Cover/Land Use 2018 [17](UA 2018) dataset. This dataset includes urban fabric classes, with a minimum mapping unit of 0.25 hectares and a minimum width of 10 meters, among other classifications.

In order to determine the locations of urban fabric areas within the first dataset, the UA 2018 urban fabric classes have been intersected with the ISTAT 2011 dataset. Next, the area of each urban fabric plot within each census tract were sub divided by the total urban fabric area and this ratio was used for further recalculation of all population census figures.

Hence, the 557 residents of the ISTAT census edition 2021 have been distributed across the three urban fabric plots (red labels in Figure 15), providing more accurate results when assessing accessibility.

[17] The Urban Atlas Land Cover/Land Use 2018 provides data on land cover and land use, integrated with population estimates of 788 functional urban areas in EEA38 countries and the UK. Source: land.copernicus.eu

Hazard

The UHI phenomenon compromises the health of urban population. Th UHI values are categorized 3 levels – high (H), medium (M) and low (L) (Figure 14). According to this map, the highest level of UHI relates to large industrial regions that lack vegetation and high percentage of impervious surface areas.

Exposure

The majority of recent research on European regions concurs that the elderly population is the one most affected in terms of health outcomes (i.e., mortality and morbidity) when it comes to the urban population's exposure to the extreme percentile of temperatures (i.e., 1st, 5th, 95th, and 99th) (Ellena et al., 2023, Martinez et al., 2022, Breil M et al., 2018). According to a recent study, this feature was especially prominent in Turin, analyzing heat-related relative risks (RR) and attributable fraction of mortality (AF) across various social and demographic categories (Ellena et al., 2023, Ellena et al., 2022). Thus, the number of those 65 and older in each census tract (updated to 2021 data) has been considered for the exposure assessment in this study (Figure 16).

Vulnerability

Introducing a certain level of vulnerability is required in order to comprehend the susceptibility of the exposed population in more detail. For this study, the vulnerability indicator chosen is women of age 65 years and above. The selection of this particular indicator is based on the thorough review of literature and reference studies that highlights the sensitivity of this particular potion of population. As per the census statistics from 2021, women make up approximately 58% of Turin's elderly population. The following figure (Figure 17) defines the distribution of vulnerable population – elderly women (65 years and above), in each census tract of the city ranging from very low to very high level of vulnerability.

Risk

The risk, analyzed on the city’s urban scale, is based on the interaction between the three key factors: Hazard[18], Exposure and Vulnerability, based on the data per census tract of 2021. The methodology used to compute the risk includes normalization of hazard, exposure and vulnerability based on the standardize field tool provided by the ArcGIS Pro, where the minimum – maximum method was carried out for each of the inputs. The minimum value was set to 0 and maximum to 1. Further, the risk related to each census tract was calculated by providing equal weightage to UHI hazard, exposure and vulnerability factors. The map (Figure 18), with the thresholds: 0.26 (low), 0.35 (medium) and 0.87 (high) are created with the natural breaks method, ensuring to identify the UHI risk in the city of Turin. The higher – risk zones are found to be in the localities where the population of elderly are more concentrated, especially in the areas of Barriera di Milano, Borgo Vittoria and Lucento in north and Mirafiori north in south. Majority of the city center area is in medium – low risk zone. From the UHI data of the city, it is seen that there is an absence of population in the high – level zone thus resulting in no risk areas around these zones.

[18] Source: Ellena et al., 2023

Exposure Map

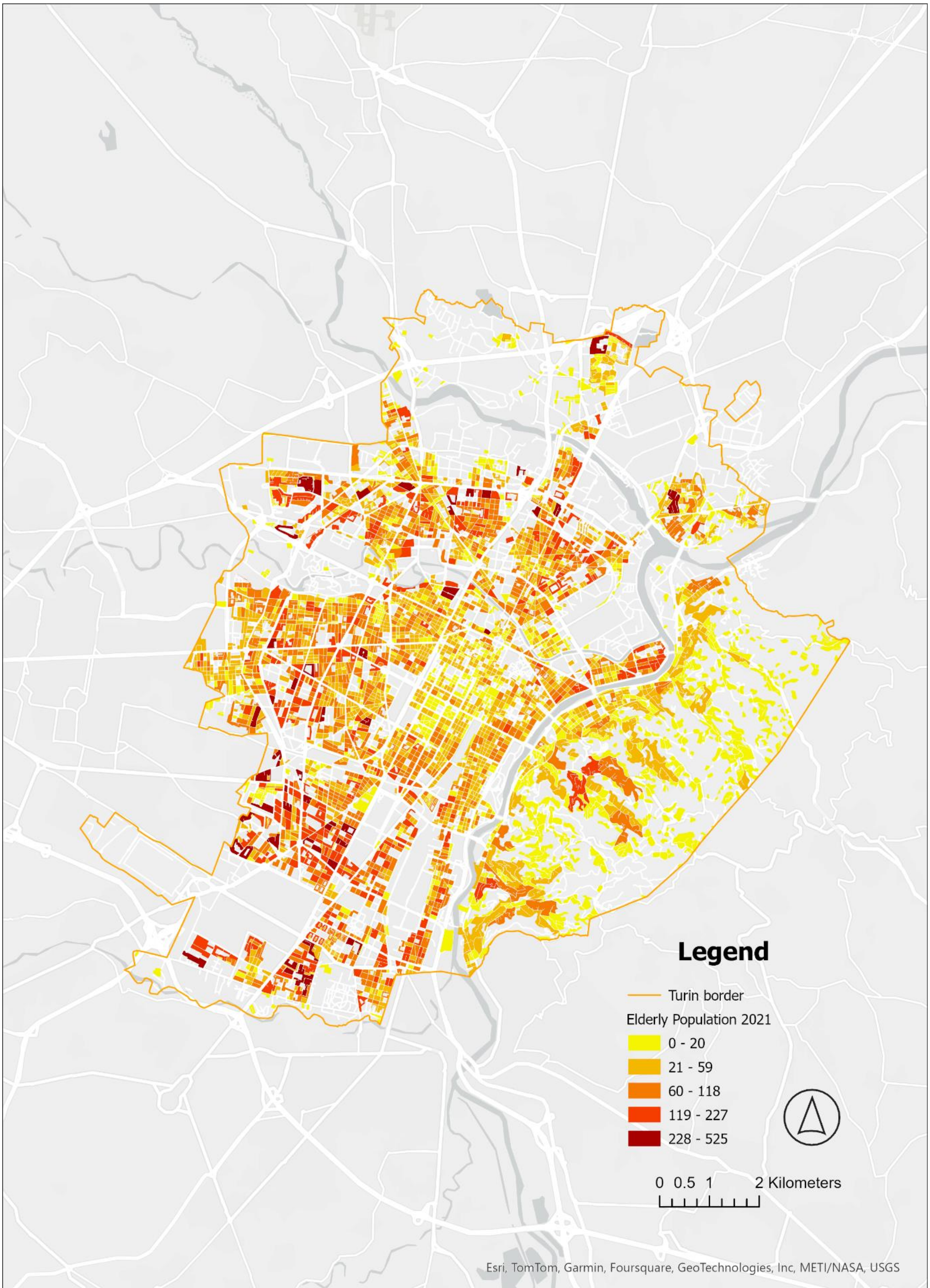


Figure 16: Census tract of Turin showing total elderly population (65 years and above), 2021. Source: Author

Vulnerability Map

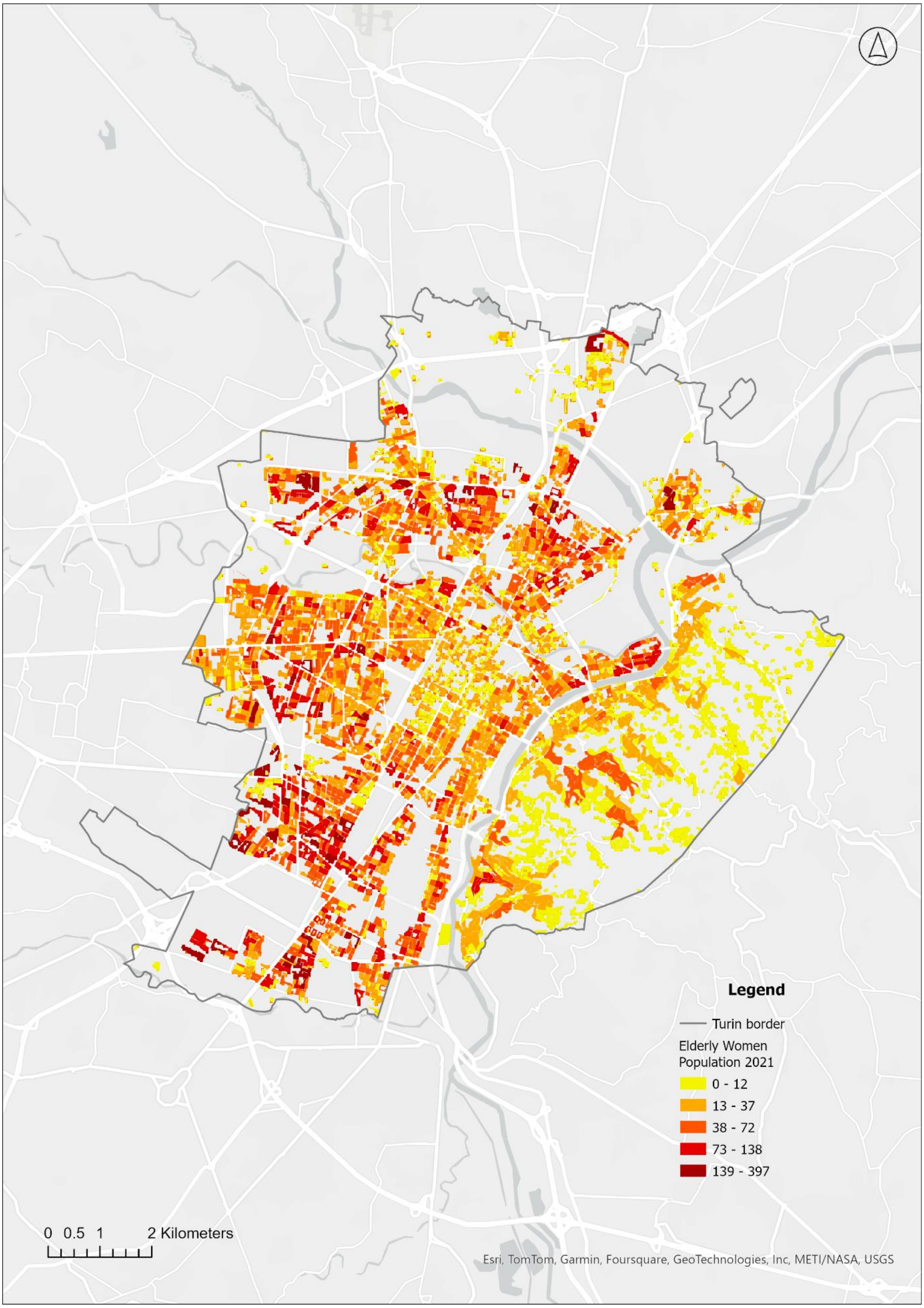


Figure 17: Census tract of Turin showing total elderly women population in Turin, 2021. Source: Author

UHI Risk Map of Turin

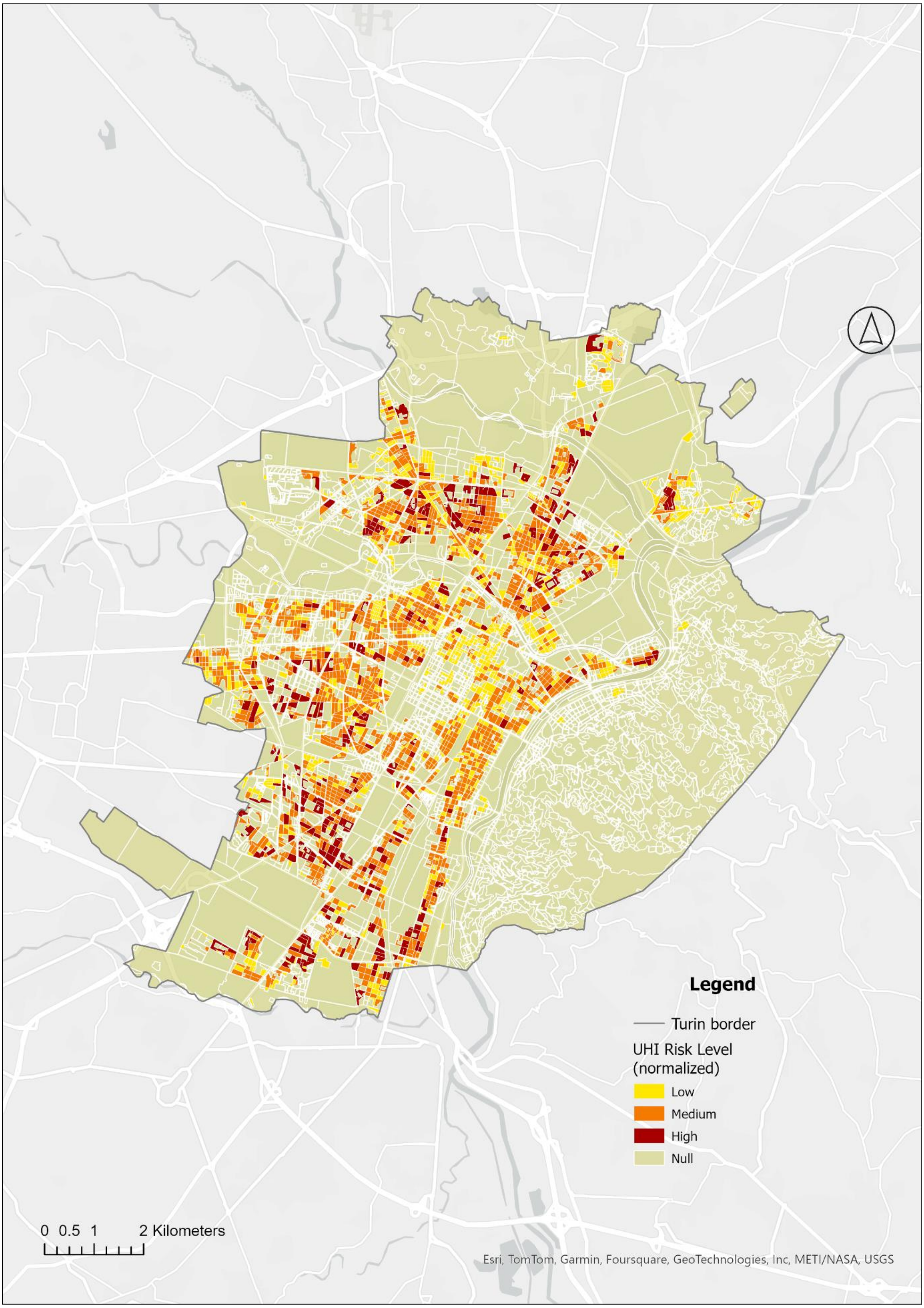


Figure 18: UHI Risk mapping of Turin. Source: Author

Chapter 5

5.1. Adapting the city of Turin to Changing Climate

Through the years, the city has implemented adaptation plans and initiatives in different fields.

Disaster Risk Project Reduction Insurance (DERRIS) [19]	
Year	2015 - 2018
Risk(s) identified	Extremes of **Temperature** and Precipitation
Objectives	1. Increase the resilience of small and medium sized enterprises (SMEs) towards UHI and flood 2. Promote greater risk culture 3. Research on innovative models for risk reduction

Turin – Climate Resilience Plan [20]	
Year	2020 (July)
Risk(s) identified	Extremes of **Temperature** and Precipitation
Objectives	1. Reduce the impacts of climate change on city and citizens 2. Try to reduce the frequency of extreme weather events 3. Adapt the urban environment and services to minimize the exposure and emergency management 4. Adapt buildings to enhance the quality of life and cover energy demand 5. Management of urban ecosystem and urban transformation 6. Develop a climate risk culture and public awareness

Valdocco Liveable Project [21]	
Year	Launched in 2020 (September)
Risk(s) identified	Extremes of **Temperature** and Precipitation
Objectives	1. Increase the green infrastructure and create environments to minimize the impacts of extreme weather events 2. Develop and experiment various methods against UHI and flood risk 3. Create a more livable urban environment 4. Create easily replicable intervention modules to adapt to new climatic scenarios

Green Infrastructure Strategic Plan [22]	
Year	2020 (December)
Risk(s) identified	Extremes of **Temperature** and Precipitation
Objectives	1. Increase quantity and quality of green areas in city 2. Develop green infrastructure in vulnerable areas to UHI and flood

[19] Source: derris.eu
[20] Source: Climate Resilience Plan 2020 (p. 47)
[21] Source: Citta di Torino, torinovivibile.it
[22] Source: Strategic Plan Infrastuttura Verde 2021 (p. 84)

These adaptation instruments all lines up into the Action Plan: Torino 2030[23], a plan that is launched on the basis of transitioning Turin towards a sustainable and resilient city (Citta di Torino).

Furthermore, the European Union-financed project “Interventions for a More Livable City” (January 2023 – October 2023) was launched with the goal to implement adaptation measures in place that minimize the impacts of climate change locally while adhering to the Climate Resilience Plan and the Green Infrastructure Plan (Citta di Torino). The goal of this project was to make Turin a more livable city by involving every district in the city.

According to the Climate Resilience Plan, the city of Turin is aimed at becoming:

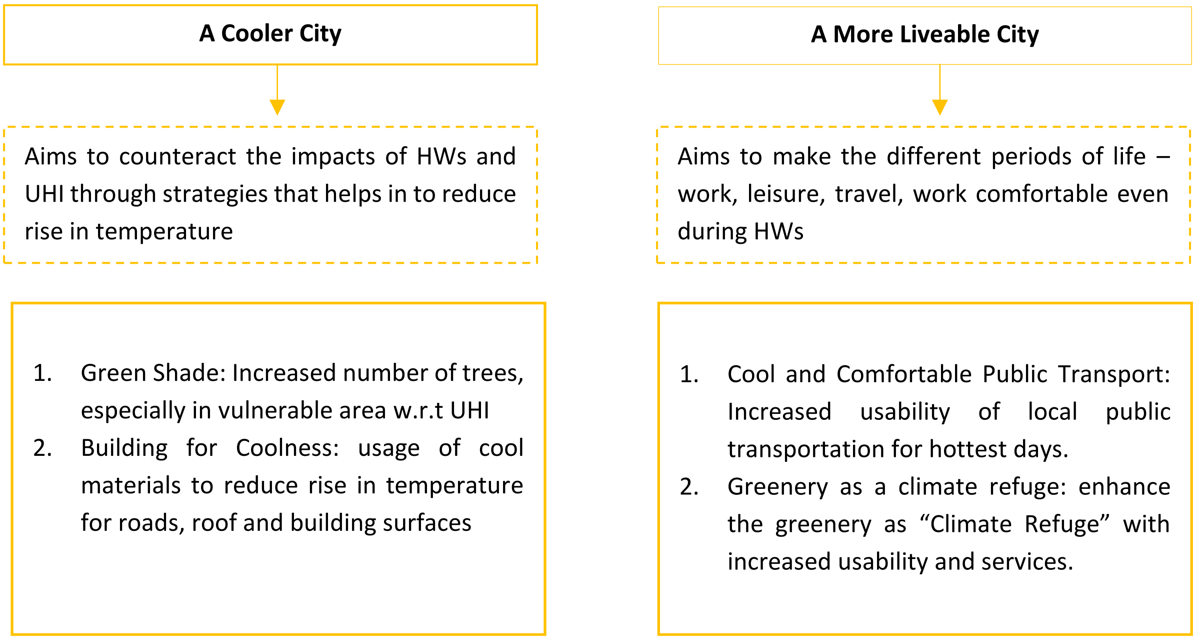


Figure 19: The concept for adaptation goals according to Climate Resilience Plan 202; Source: Climate Resilience Plan, 2020

Turin's Climate Resilience Plan, which is based on the city's climatic characteristics, outlines adaptation strategies for minimizing the impacts of extreme weather events and enhancing quality of life (Climate Resilience Plan, 2020). The plan mainly focused on two categories for the risks faced by Turin: a) Administrative Preparedness and b) City Adaptation (EGCA, 2022).

5.2. Climate Refuges for Climate Refugees: Introducing URBAN CLIMATE SHELTERS in Turin

According to the Climate Resilience Plan, several actions have been taken to respond the aforementioned impacts and enhance the quality of life for all individuals. “Assistance for living better” describes the implementation of a heat emergency plan that includes adopting interventions to lessen the susceptibility of vulnerable individuals during the summer and measures to minimize public discomfort, like offering air-conditioned public spaces to people on days with exceptionally high temperatures (Climate Resilience Plan, 2020). For several years, the municipal area has featured

[23] Source: commune.torino.it; themayor.eu

several air-conditioned locations (CICs, or air-conditioned meeting centers) open to the public to spend a few hours of the day in the company of others and the comfort of cool air.

Which public facility will make the most appropriate pilot case for UCS?

As one of the objectives of the study is to incorporate the 15 – minute city framework to the UCS concept, it is only rational to consider the original strategies of this framework. Hence, the UCS should be incorporated into one of the basic services that are generally taken into consideration in the 15 – minute city theory. From the literature, among the overall list of potential services for the x – minute city, the twenty services were chosen by a study conducted on the 5, 10, 15 – minute city concept of Turin, because they are offered at neighborhood scale. As services like hospitals and universities are delivered at the scale of the city rather than the neighborhood level, they are not included in the scope of this study (Staricco, 2022).

Further developing these ideologies proposed in the city's resilience plan, a strategy which involves the conversion of public libraries into urban climate shelters, thus creating a network of potential climate refuges for the climate refugees, is proposed.

Why Libraries?

Libraries are a rational choice for transformation into UCS due to their role as community hubs, capable of expanding their traditional function to meet the needs of a changing community. Turin's integrated action plans highlight the city's commitment to regenerating libraries, with a particular focus on serving elderly users. Over a seven – year old period, the city has undertaken a comprehensive evaluation process in an effort to enhance the services offered by all its libraries. The process aligns with the energy – efficient strategies outlined in the resilience plan, ensuring that libraries not only provide expanded services but also contribute to the city's climate adaptation and sustainability goals.
By transforming public libraries into urban climate shelters after hours, cities can create a resilient support system that not only provides immediate relief during climate emergencies but also fosters a sense of community and preparedness. This strategy leverages existing infrastructure, making it a cost-effective and practical solution for enhancing urban resilience and supporting vulnerable populations, including refugees.

Currently, twenty-one libraries are located in the city of Turin that can be extended into a network of potential UCS.

Libraries as UCS from around the Globe

Although the idea of using libraries as urban climate shelters is novel and innovative, there are several actual cases of libraries and other public facilities being utilized as cooling centers or climate shelters around the world. Cities that have already started this initiative to combat climate change and protect their most vulnerable citizens include Los Angeles, Phoenix, New York City, Portland, Toronto, Paris, Madrid, Barcelona and Melbourne among others.

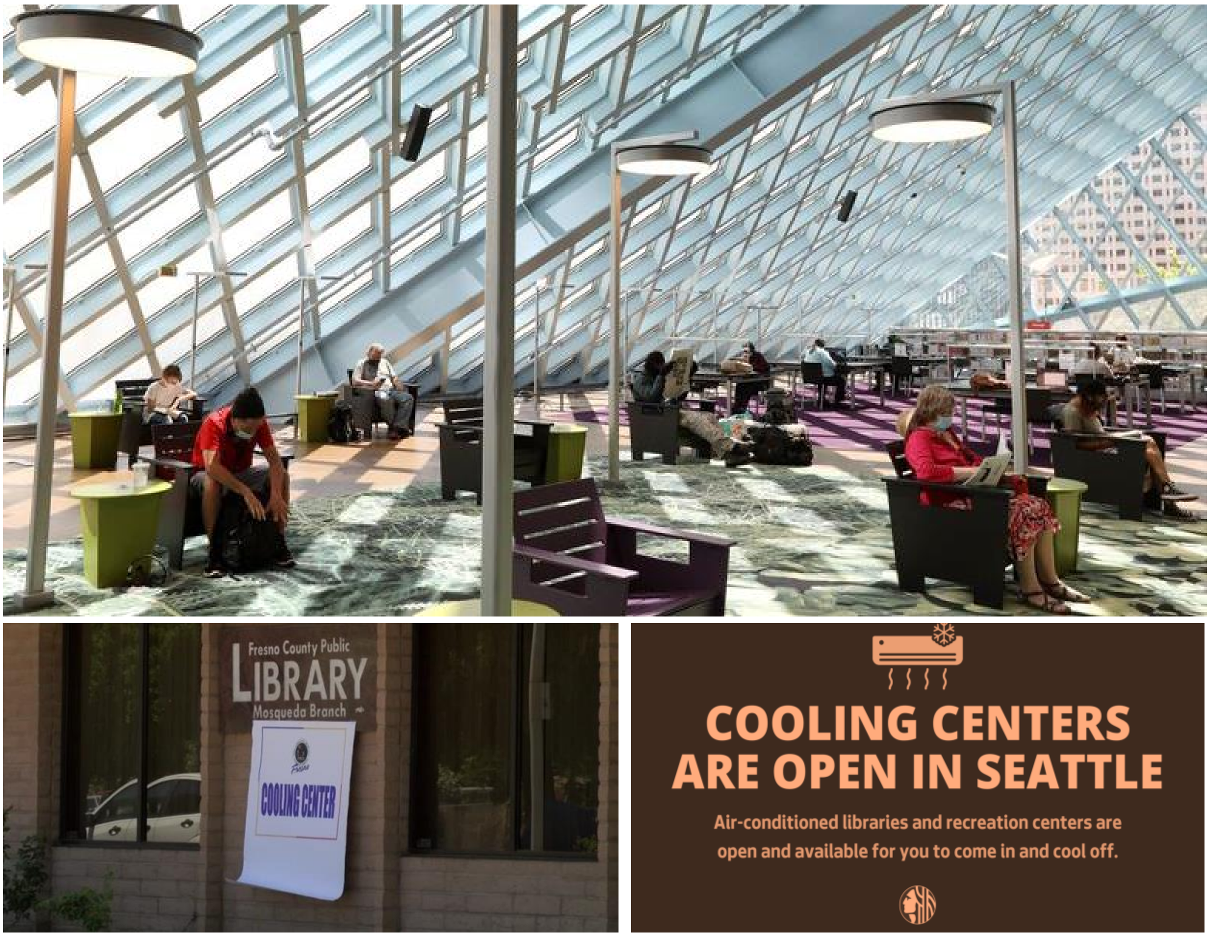


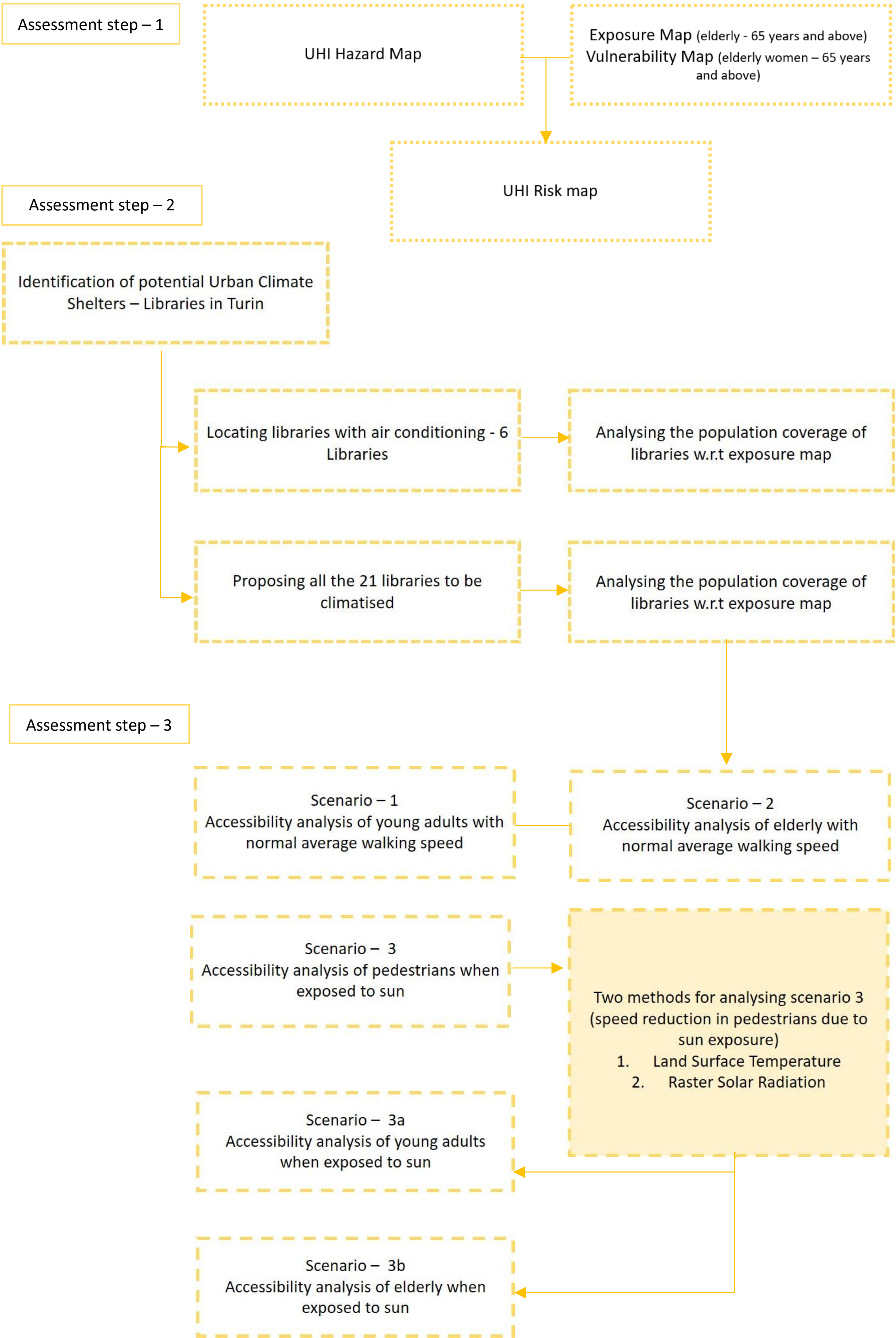
Figure 20: (above) People read in the "living room" on the third level of the Central Library in Seattle. Source: seattletimes.com; (below left) Library turned into cooling center at Fresco County amidst the 2023 heat wave. Source: yourcentervalley.com

5.3. Pedestrian Spatial Accessibility Analysis of proposed UCSs

Using libraries as Urban Climate Shelters (UCS) is an innovative approach that fits well with concepts in urban planning, such as the 15-minute city concept. This approach is particularly beneficial for elderly populations that need reliable and easily accessible shelters. To optimize libraries', reach and efficiency as UCS, strategic placement is a crucial factor in spatial accessibility. It is essential to make sure that UCS are easily available and close by, particularly for elderly people, who are more susceptible to severe heat. Since elderly people may experience mobility issues, UCS must be easily accessible within walking distance. From the literature section we have seen various studies referring to the accessibility of urban climate shelters to its residents and how according to parameters such as the walking distance of 15 – minutes (Sehgal and Sehgal, 2023; K Lee and Y. Chae, 2021; Bohannon R W et al., 2011).

Therefore, in accordance with the 15-minute time frame and parameters listed in tables (Table 5, Table 6, Table 7, Table 9 & Table 8), an accessibility analysis for the vulnerable population in Turin will be carried out further in this study. The following methodology has been adapted to carry out the accessibility analysis for the proposed UCS in Turin with regard to the vulnerable population.

Proposed Methodology for Pedestrian Accessibility Analysis for UCS



5.3.1. Assessment step – 2

Following the assessment step 1 in the previous chapter, step 2 considers libraries in the city – a) that currently have air conditioning facilities and b) has potential to repurpose as UCS by climatizing (Figure 21). Further, to calculate the elderly population served by these libraries during a heat event, the spatial accessibility to the libraries within the 15 – minute time frame is computed for pedestrians.

The accessibility analysis was carried out in ArcGIS Pro 3.2.2. developed by ESRI. Each location of libraries is georeferenced as a point with regard to the addresses retrieved from dataset available in Aperto[24]. As shown in the following figure (Figure 21), the libraries equipped with air conditioning at the moment are analyzed for the better understanding of the current situation of the city in terms of adaptive capacity, during an extreme heat event. As well, the situation where all libraries equipped with air conditioning and having the potential of repurposing into UCS is also analyzed further. According to the dataset provided for *biblioteche* in the Aperto[25] website, the city has a total of 21 libraries among which 6 are equipped with air conditioning. The following table showcases the libraries that are identified to create the UCS network in Turin.

Table 13: List of libraries in Turin to be proposed as UCS. Source: Author

Biblioteche No.	Name of the Library	Address	Circoscrizione	Air Conditioning
1	Biblioteca civica Don Lorenzo Milani	Via Dei Pioppi 43	6	Yes
2	Biblioteca civica Rita Atria	Strada S. Mauro 26/A	6	No
3	Biblioteca Centro Interculturale	Corso Taranto 160	6	No
4	Biblioteca civica Cascina Marchesa	Corso Vercelli 141 Int. 7	6	No
5	Biblioteca civica Primo Levi	Via Ruggero Leoncavallo 17	6	Yes
6	Biblioteca civica Italo Calvino	Lungo Dora Agrigento 94	7	Yes
7	Biblioteca civica Francesco Cognasso	Corso L. Quinzio Cincinnato 115	5	No
8	Punto prestito G. D'Annunzio	Via Gaspare Saccarelli 18	4	No
9	Biblioteca civica Torino Centro	Piazzetta Universita' Dei Mastri Minusieri 2	1	Yes
10	Biblioteca Nazionale Universitaria di Torino	Piazza Carlo Alberto 3	1	No

[24] Aperto is the open data website for the city of Turin. Source: aperto.comune.torino.it
[25] Source: aperto.comune.torino.it/dataset/biblioteche

11	Biblioteca civica Alberto Geisser	Parco Ignazio Michelotti 5	8	Yes
12	Biblioteca civica Natalia Ginzburg	Via Cesare Lombroso 16	8	No
13	Biblioteca civica I ragazzi di Utoya	Via Zumaglia 39	4	No
14	Biblioteca civica Musicale A. Della Corte	Corso Francia 186	4	No
15	Biblioteca civica Luigi Carluccio	Via Monte Ortigara 95	3	No
16	Biblioteca civica A. Passerin d'Entreves	Via Guido Reni 102	2	No
17	Biblioteca civica Villa Amoretti	Corso Orbassano 200	2	Yes
18	Biblioteca civica Dietrich Bonhoeffer	Corso Corsica 55	8	No
19	Biblioteca civica Cesare Pavese	Via Candiolo 79	2	No
20	Biblioteca civica Mirafiori	Corso Unione Sovietica 490	2	No
21	Mausoleo della Bela Rosin	Strada Castello di Mirafiori 148 Int. 7	2	No

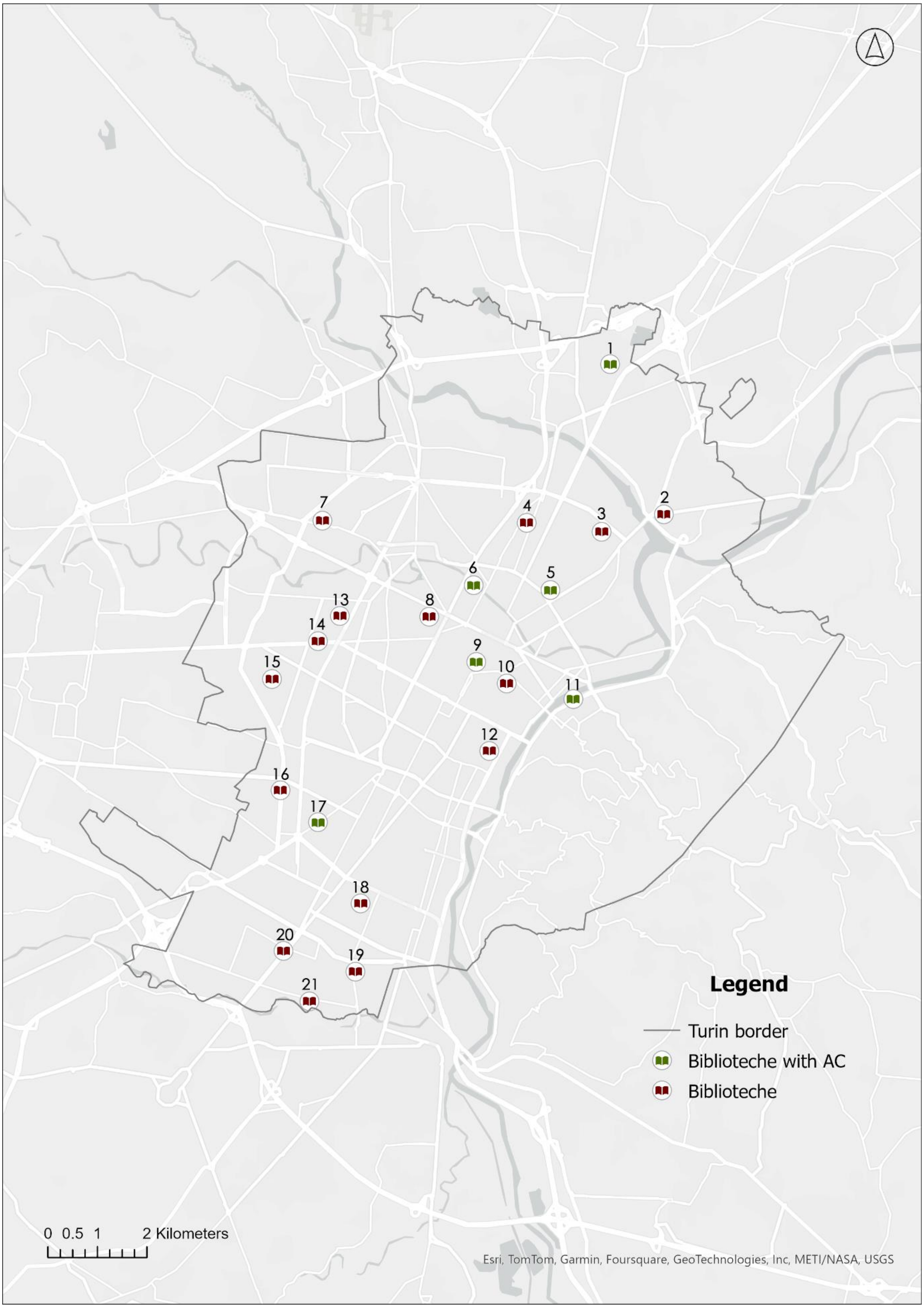


Figure 21: Location of all Libraries (potential UCS) in the city. Source: Author

Creating the 15-minute service areas or isochrones

As previously stated, calculating the proportion of elderly people serviced by these libraries relative to the total elderly population in the city is the first stage in the examination of spatial accessibility. The origin point is set to the service itself, in this case libraries of Turin, for the easy analyses of the coverage of population by the service area or isochrones within a 15 – minute walk (Figure 22 & Figure 23).

The service areas were created using the Network Analysis tool in ArcGIS Pro, which calculates the average walking speed of 0.91 m/s for the elderly pedestrians as mentioned in the reference studies. The travel cost was set up into the network dataset containing the streets that are also accessible to pedestrians, in the city of Turin. The dataset containing Turin's Street network was available in the BDTRE section from the GeoPortale Piemonte[26]. The result thus obtained after running the simulation show the spatial data of the population that are served by these libraries (Figure 22 & Figure 23).

[26] Source: geoportale.igr.piemonte.it

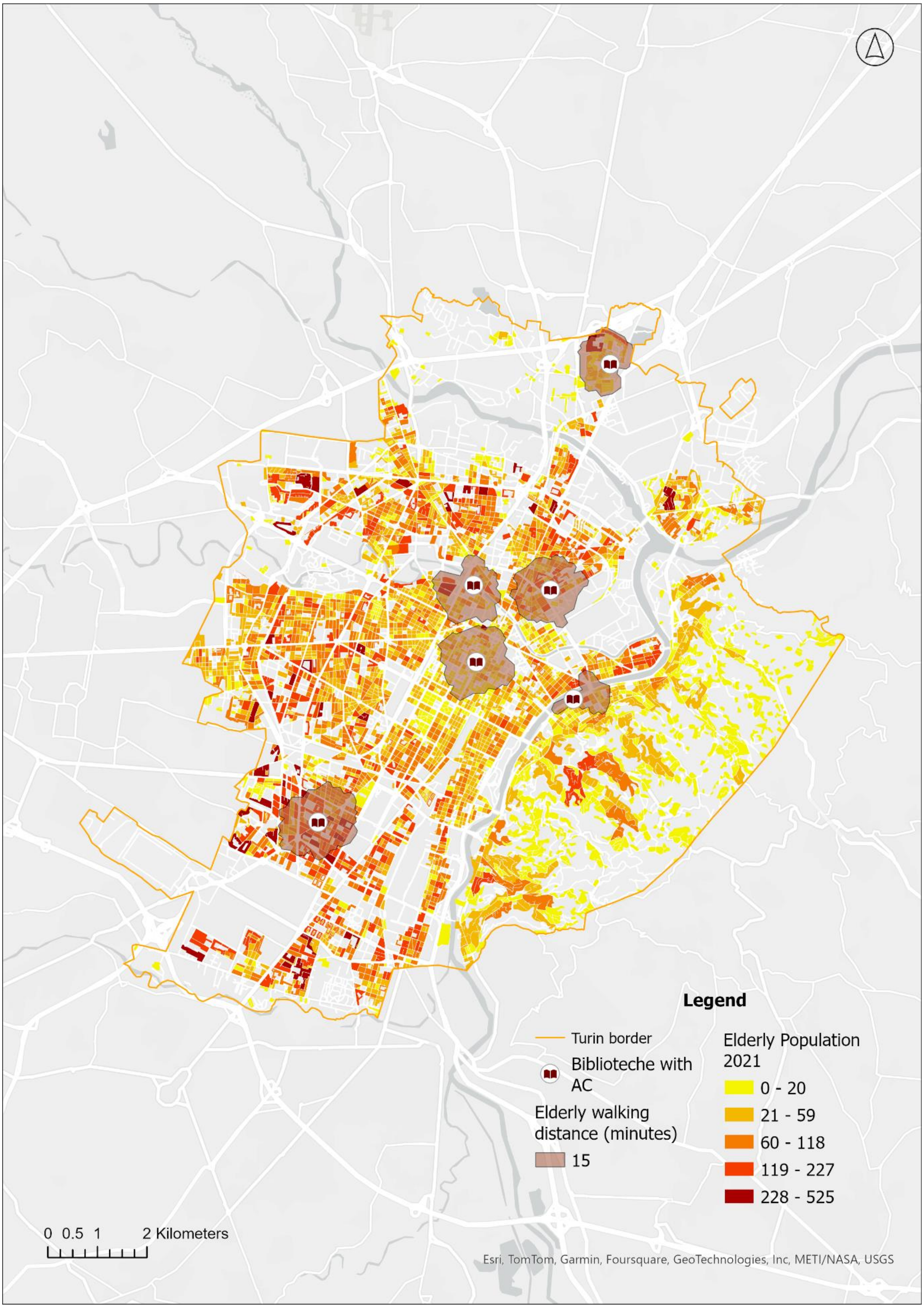


Figure 22: Elderly population (65 years and above) served by the current libraries (potential UCS) with air conditioning in the city within 15-, 10- and 5-minute walking distance. Source: Author

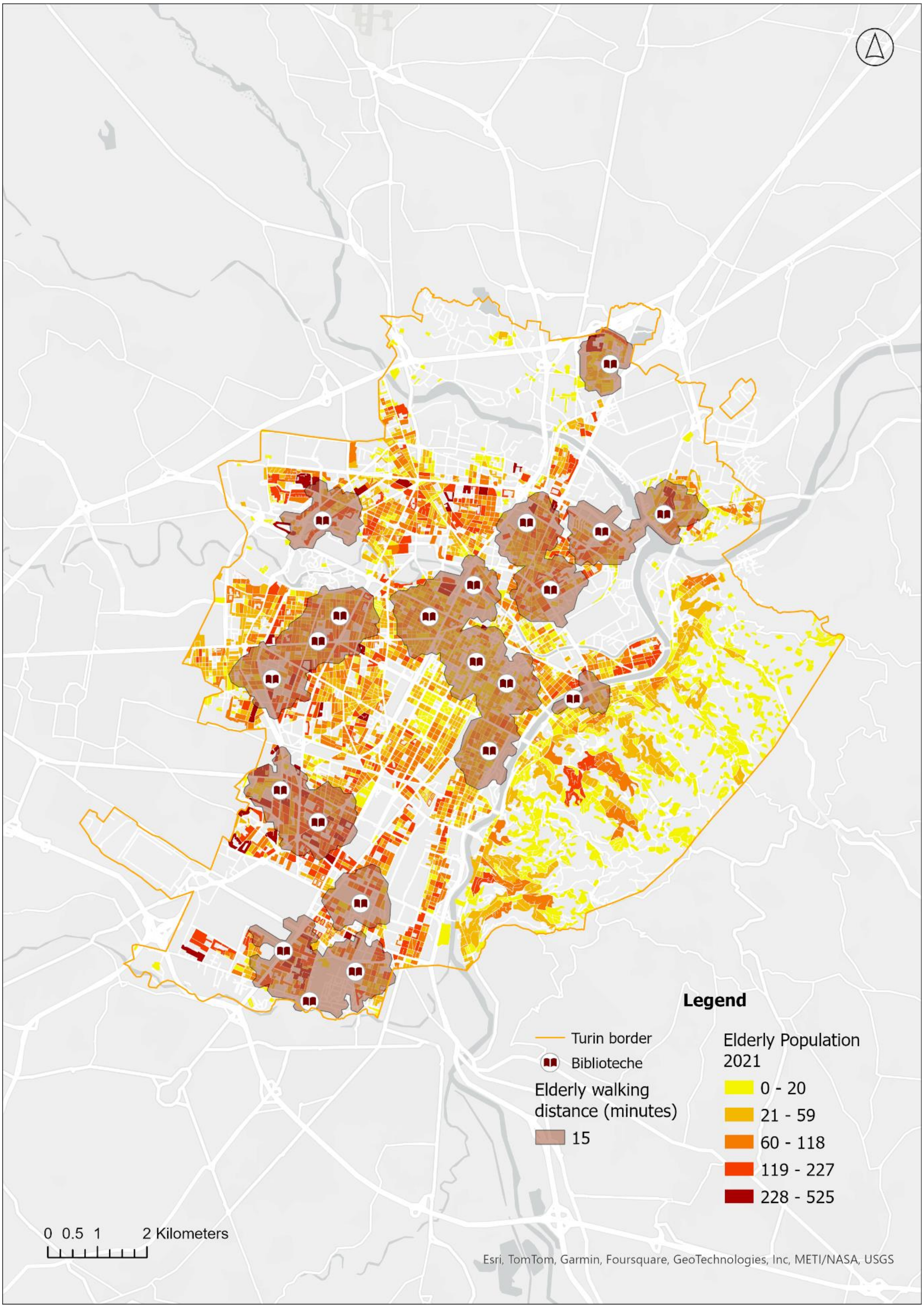
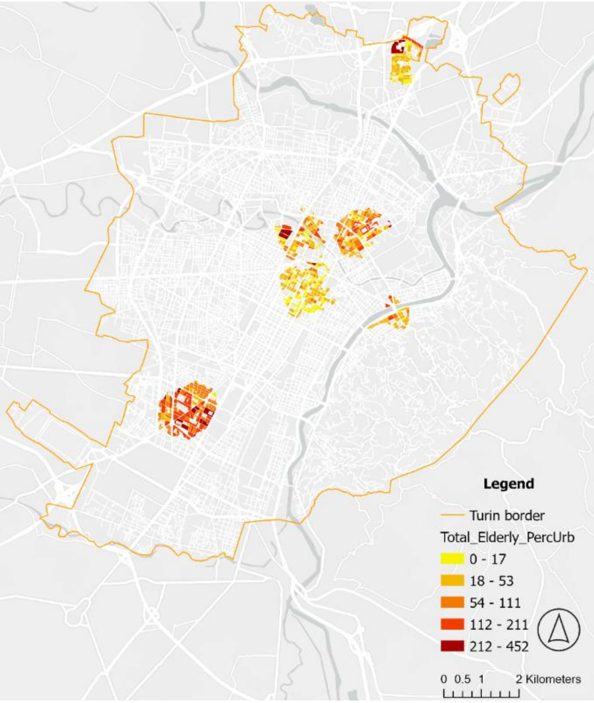


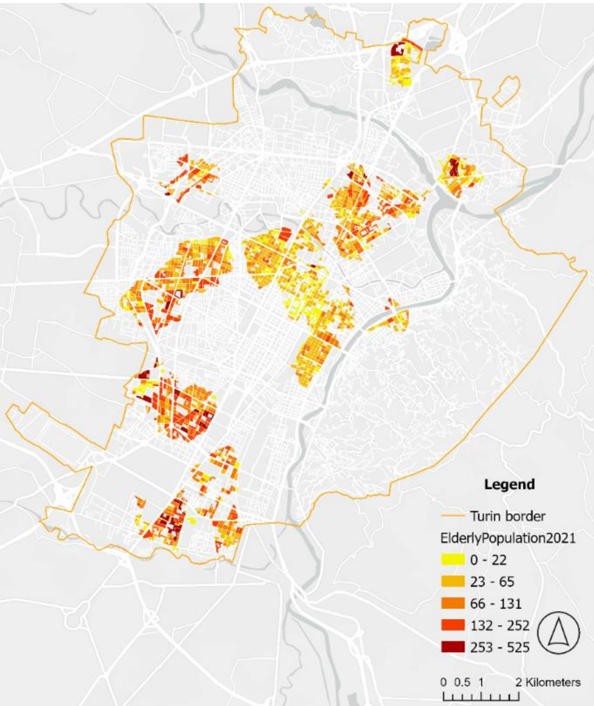
Figure 23: Elderly population (65 years and above) served by all the libraries (potential UCS) in the city within 15 – minute walking distance. Source: Author

Assessing the Spatial Accessibility of proposed UCS by elderly population

After the creation of service areas or isochrones, the percentage of population covered by each service areas are computed. It was shown that the libraries that are currently equipped with air conditioning covers only 14.8% of the total exposed population to UHI whereas, when all libraries are regenerated as UCS, the percentage increased to 48.78% (Figure 24). Yet, more than half of Turin's elderly population doesn't seem to be in preferred proximity to the libraries i.e. within the 15 – minute walking distance. Hence, it's evident that Turin requires effective and fast interventions for enhancing the libraries' adaptive capacity during a climate emergency scenario such as HWs.



Total elderly population served by 6 UCS = **14.8%**



Total elderly population served by 21 UCS = **48.78%**

Figure 24: Comparison between population coverage of libraries currently with A.C (above) and when all potential libraries in Turin are climatized (below). Source: Author

5.3.2. Assessment step – 3

Introducing pedestrian age group into the spatial accessibility analysis to understand the difference between the walking pace of young adults and elderly. This step is carried out to observe the libraries' service area coverage based on the walking speed of users.
From the sub – section 3.6., two scenarios based on pedestrian age group (young adults and elderly) along with the 15 – minute walking duration are mapped (Table 5 & Table 6).

1. Scenario 1: Young adults with average walking speed = 1.4 m/s
2. Scenario 2: Elderly with average walking speed = 0.91 m/s

Comparing the maps of these two scenarios, the difference in the service area is evident (Figure 25). The service area or isochrones of libraries for the younger adult age group are larger than for the elderly due to the differences in their average walking speeds. The average walking speed for young adults and elderly are considered to be 1.4 m/s and 0.91 m/s respectively (Table 5 & Table 6).

Table 14: Comparison between the 15 - minute service area of libraries for young adults and elderly. Source: Author

Scenarios	Total % of population with respect to Turin's Population 2021	Total % of population covered by service areas of 21 libraries
Scenario 1: Young adults (20 years – 64 years) with average walking speed = 1.4m/s	21.07%	67.88%
Scenario 2: Elderly adults (65≥ years) with average walking speed = 0.9m/s	9.48%	48.78%

Comparison of Scenario – 1 and Scenario 2

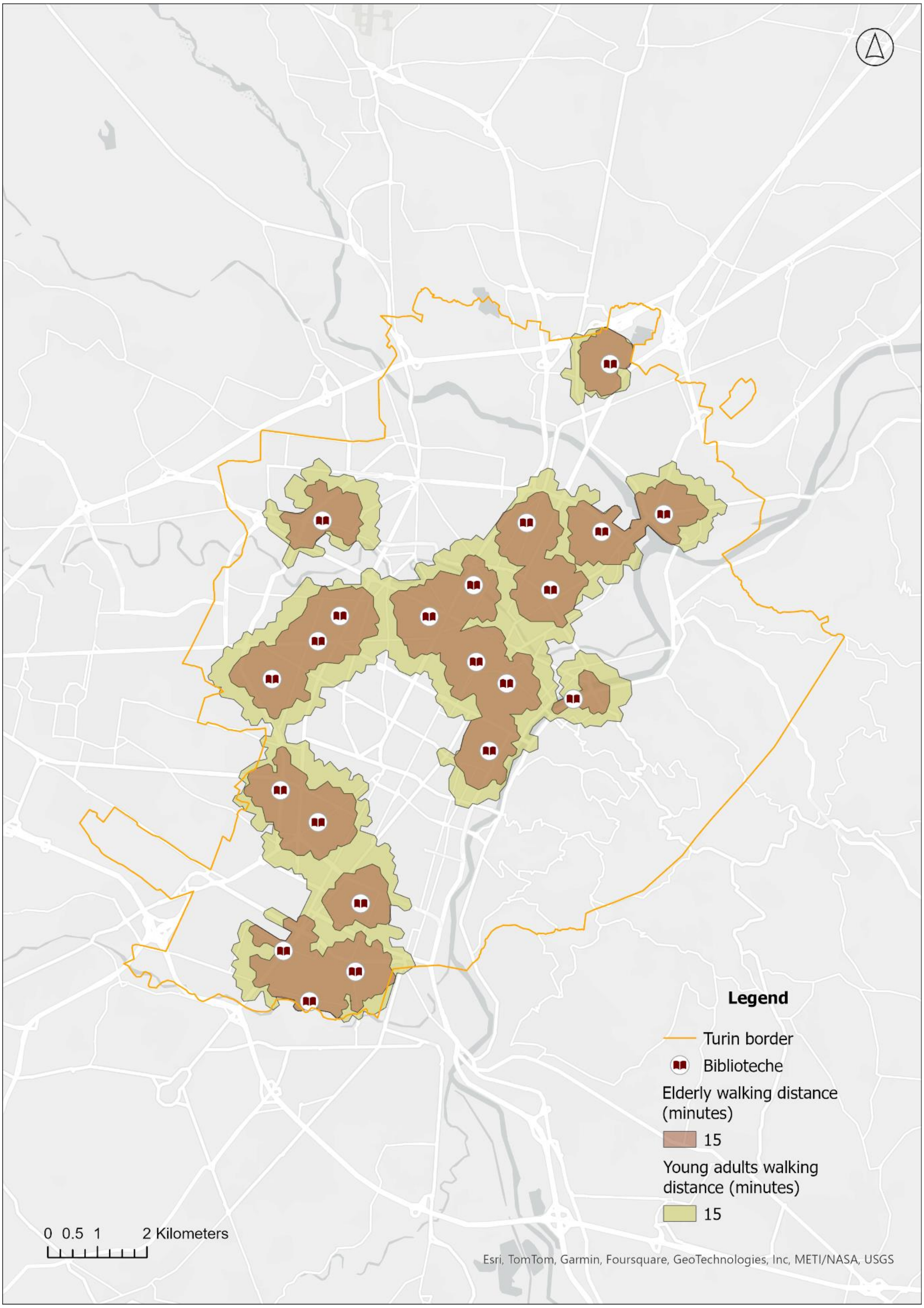


Figure 25: Map comparing the 15 - minute service areas of libraries for both young adults and elderly with respect to their walking speed. Source: Author

Introducing Temporal domain to Spatial Accessibility of proposed UCS by elderly population

In addition to the previous scenarios, a third scenario is proposed which considers the various parameters influencing the pedestrian behavior when exposed to the sun during peak summer time. These parameters are considered for both age groups (young and elderly) and analyses how these groups are impacted when exposed to the sun while accessing the urban climate shelters.

In order to carry out the spatial analyses based on the exposure to the sun based on scenarios 3a and 3b (Table 7 and Table 8), two methodologies are adopted for this study.

1. Accessibility analyses carried out with Land Surface Temperature (LST) in ArcGIS Pro 3.2.2;
2. Accessibility analyses carried out with Raster Solar Radiation tool of ArcGIS Pro 3.2.2

The two spatial analyst methodologies employed are compared in the below table, in order to understand the potential and limitations offered by both while identifying areas prone to HWs.

Table 15: Comparison between the two spatial analysis methodologies for accessing the temporal accessibility of UCS. Source: Author

	Methodologies	
	Land Surface Temperature (LST)	Raster Solar Radiation (RSR)
Definition	LST is the skin temperature of land i.e. temperature of Earth's surface. It is mostly the product of albedo, vegetation cover and soil moisture[27].	RSR tool is used to calculate the incoming solar radiation for every raster cell of a digital surface model (DSM) for Earth (or the Moon).
Unit of measurement	The LST temperature is in °C	RSR is in kWh/m2 as the amount of solar radiation energy per unit area during an amount of time is considered[28].
Applications	In ArcGIS, LST is derived from the satellite imagery like Landsat etc. The data offers insights to change in surface temperatures across various land covers that can be helpful for researches on climate change, UHI and environmental monitoring.	The tool provides detailed spatial analysis of solar energy that can be helpful in urban planning – especially for climate adaptation strategies, renewable energy planning etc.
Outputs	LST produces maps indicating how warm the surface is based on temperature.	RSR produces maps indicating solar radiation amount received on surface.
Pros	Direct measurement of Earth's surface conditions: Measures the Earth's temperature directly, providing information on UHI, impacts of climate change and so on.	Spatially explicit calculation of solar radiation: Provides spatially explicit measurements of solar radiation distribution across surfaces.

[27] Source: pro.arcgis.com; usgs.gov
[28] Source: pro.arcgis.com

	Provides multi – scale data: Allows to analyze surface temperature at different scales – local urban environments to regional and national scales.	Spatial resolution and Precise modeling: The tool works on a user – defined resolution w.r.t the spatial resolution of the input DSM. Thus, its capable of high – precision output considering shadowing effects on surfaces, slope etc.
	Temporal spatial data: Provides information on seasonal temperature variations that allows to study long – term climate trends.	Temporal spatial data: Unlike LST, the solar radiation can be calculated for different times of the day, seasons and year.
Cons	Spatial Resolution: Landsat thermal bands have a resolution of 30 meters and 100 meters (bands 4,5 and 10). Hence, micro – scale temperature variations are not captured.	Spatial data requirements: The tool relies on high resolution of DSM data. Low resolution data can lead to significant inaccuracies.
	Temporal data: Landsat satellites revisit the same location once in every 16 days, limiting the frequency of preferred LST data acquisition. Hence, data for different time periods won't be available.	Computational period: The duration of the simulation is further increased when employing high-resolution DSM, particularly for large spans of area.
	Atmospheric interferences: The sensors on satellites are sensitive to atmospheric components such as clouds, aerosols and water vapor.	Atmospheric interferences: The tool typically generalizes the atmospheric conditions like cloud coverage, which may not capture the actual conditions and can lead to inaccuracies, especially for area with high variations in atmospheric conditions.
	Surface cover influence: LST is influenced by surface types – roughness, vegetation cover and soil moisture. Landsat pixels often contain different surface types within a single pixel. This can cause errors in LST estimates.	Model sensitivity: The tool is sensitive to input data for parameters such as time, date and atmospheric conditions.
	Limitations on night time data: The data from satellite imagery during night time is limited. Thus, it creates a gap while assessing the temperature variations especially for UHI effects.	

1. **Accessibility Analysis by Land Surface Temperature method:**

For this method, the spatial data for the LST mapping is acquired from Landsat 8 with a spatial resolution of 30 meters. The map considers average surface temperature during summer months of June, July and August of 2023.

According to the LST map (Figure 26), the largest proportion of highest land surface temperature is seen in the northern side of Turin along with presence of hotspots in the south – west part and a few in the urban fabric. As a result, it aligns with the UHI distribution found in the heat risk analysis study. Additionally, as previously indicated, this map and the climate resilience plan show that the industrial zones have the highest temperatures. Over these three summer months, the highest recorded average temperature is 31.49 °C, while the lowest recorded average is 10.73 °C. The western part of the city, which includes Superga Hill, is among the areas that experience the lowest surface temperatures in the city due to the presence of high vegetation cover.

The major residential areas of the city are part of the central urban fabric, which has a surface temperature that ranges from moderate to high. The lower temperatures in the map corresponds to the presence of urban green pockets such as parks, gardens and other open green areas.

One of the major reasons for increased land surface temperature in Turin are:

- Surface materials: Urban surfaces like asphalts and concrete have lower albedo [29] compared to natural surfaces, thus leading to higher absorption of solar radiation and results in higher surface temperatures especially in industrial and high urbanized areas along with dense road/street networks.
- Reduced area for vegetation: Turin's industrial zones is devoid of green spaces and trees that eliminates the natural cooling effect provided by vegetation through shading and evapotranspiration[30].
- Air pollution: Turin's air pollution is among the worst in Europe, especially when it comes to NO2 and PM2.5 concentrations, which are mostly caused by vehicular emissions, accounting for 60% and 84% of the pollution, respectively (Staricco, 2022). This contributes to the increasing greenhouse effect.
- Geographical location of Turin: As mentioned earlier, the city is located in a valley and this impacts its climate and temperature patterns. The limited air circulation and temperature overturns results trapping of heat and pollutants close to the surface.

This data is further analyzed to understand the surface temperature's influence on the pedestrians walking speed. From literature it was understood that LST influences the ambient air temperature which further impacts the outdoor thermal comfort of residents (Obiefuna J N et al., 2021).

Therefore, from the above observations and from literature it can be stated that there is a positive correlation between the land surface temperature and thermal discomfort. According to WHO, with elevated thermal discomfort, heat stress and heat – related illnesses can occur in pedestrians – especially in those who are more vulnerable to this.

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[29] Lower albedo means a surfaces' ability to reflect sunlight will be low. Dark surfaces absorb the heat from the sun than light coloured surfaces. The heat is emitted at night causing the area to be warmer than its periphery. This is one of the principles of UHI effect. Source: Norwegian Polar Institute

[30] Evapotranspiration is the process by which water is transferred from the land into the atmosphere by transpiration from plants and trees as well as evaporation from the soil and other surfaces. Source: Oxford dictionary

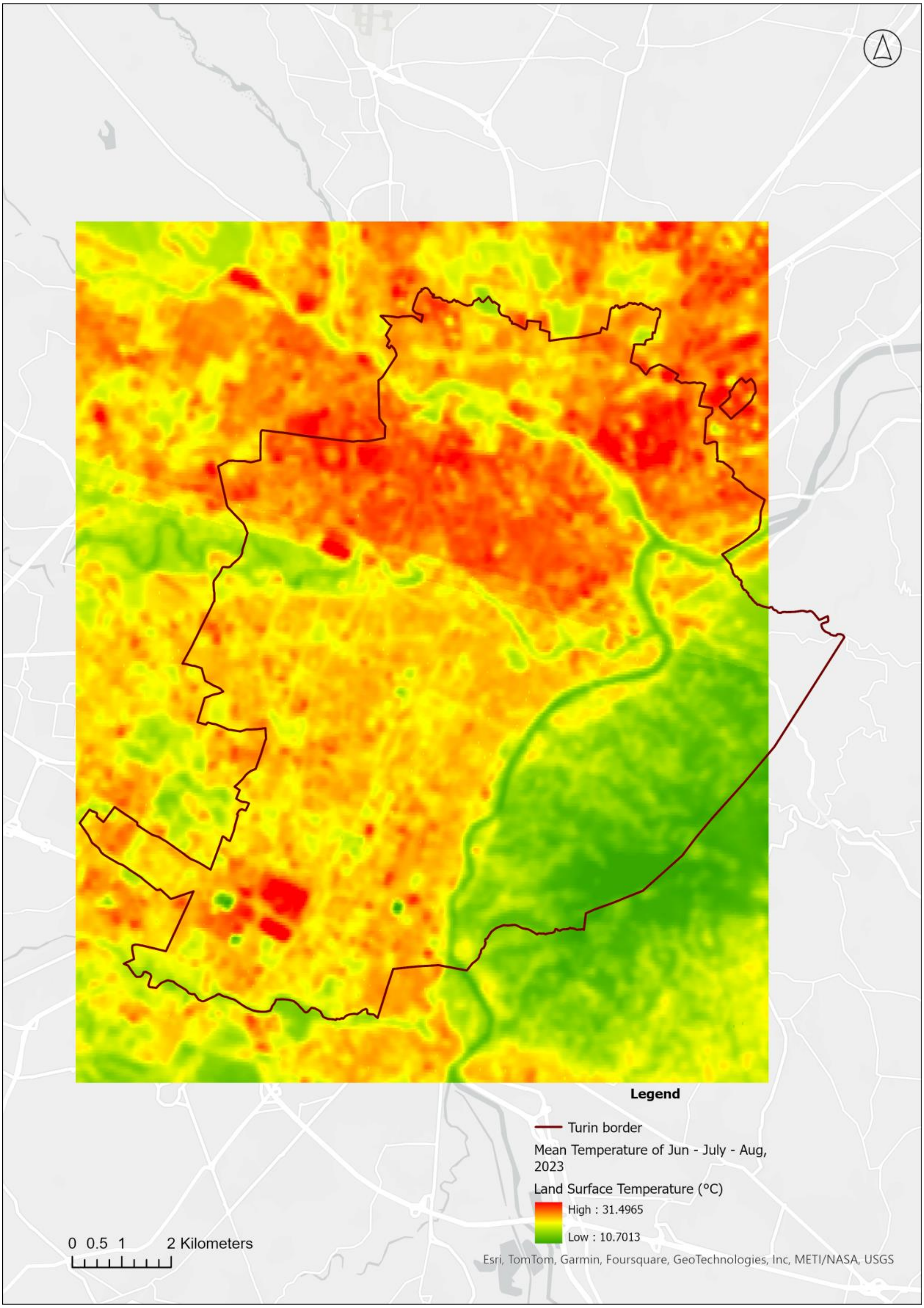


Figure 26: Average Land Surface Temperature of Turin for the months of June, July and August 2023. Source: SDG 11 Lab, Politecnico di Torino; Author

From the above map, mean LST value for each road segment is created for Turin's Road network (Chart 9). As mentioned earlier and in sub – section 3.6, a research study observed that within a year there is a maximum drop in walking speed of:

0.27 m/s for male (49 years +/- 14)

0.33 m/s for female (52 years +/- 12)

i.e. the walking speed decreases, especially in elderly population, during summer (Obuchi S P et al., 2021).

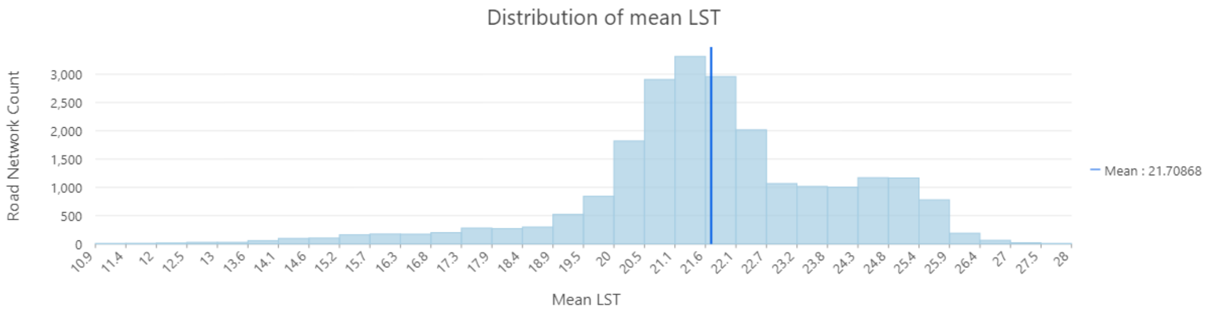


Chart 9: Mean LST distribution over Turin's Road Network. Source: Author

Hence, for this study, to compute the walking speed of pedestrians during peak summer time, a linear regression is calculated based on a 0.3 m/s speed drop when the mean land surface temperature of the road network hits maximum value of 28°C and minimum value of 11°C. Therefore, for computing the walking speed of elderly person the regression equation is as follows:

Elderly walking speed calculation at all hours (from 7 am to 9 pm):

P1 = (11.124024, 0.91)

P2 = (28.034419, 0.61)

$$y = -0.0177406x + 1.10735$$

where:

y = corrected speed

x = mean LST for a road segment

0.91 is the base speed for elderly as mentioned in the sub – section 3.6, table 6.

The equation defines a perfect negative correlation between mean LST of the road network and walking speed of elderly pedestrians. According to the inferences drawn from the references and the values derived from the aforementioned equation, an accurate definition of the true and precise spatial accessibility of libraries can be established for the elderly population that takes into consideration the thermal discomfort factor also.

Hence, through this methodology the surface temperature of each road segment is computed for the average summer temperature (Figure 27). Each road segment is related with its corresponding speed reduction factor and defines the path where the walking speed of elderly can vary from the base speed of 0.91 m/s to a maximum reduction up to 0.61 m/s.

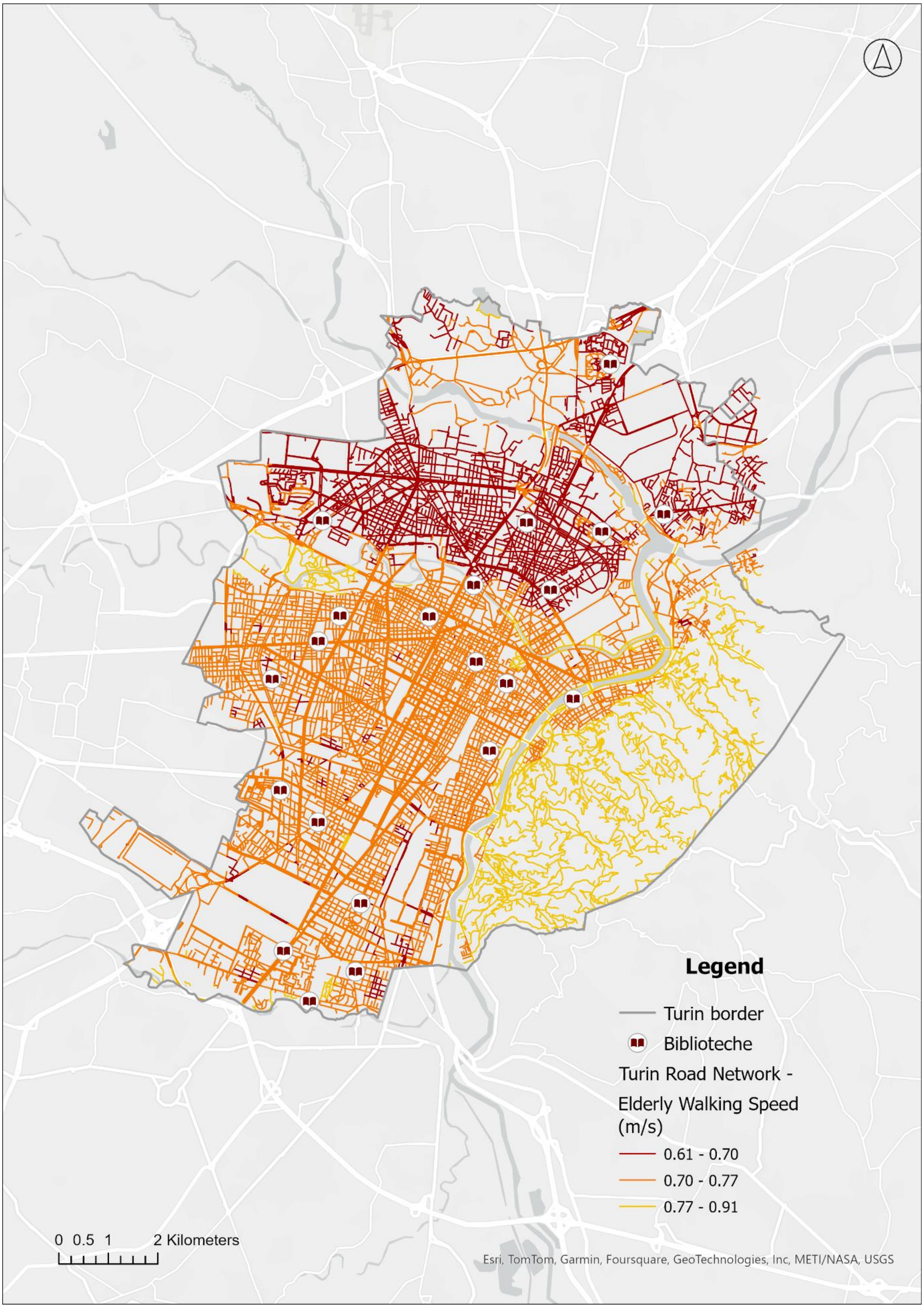


Figure 27: Walking speed of the elderly population based on the mean surface temperature on each road segments during summer. Source: Author

Accessibility Analysis by Raster Solar Radiation method:

In this method, the spatial raster data used for solar radiation mapping is a DSM file of Turin with a high spatial resolution of 5 meters. The data was acquired for the summer solstice of 2023, to generate a worst-case scenario.

The solar radiation map (Figure 28), acquired using the raster solar radiation tool in ArcGIS Pro, v3.2.2, describes the distribution of solar radiation level in the city at 10 a.m. (local time). The map shows lower solar radiation on the city's urban fabric compared to the industrial areas and other regions where shade projection is absent which indicates the presence of shadows within the dense urban fabric.

The principles regarding the high and low value for solar radiation is similar to the reasons said above for the LST methodology apart from the presence of shadows casted by the surface elements such as buildings, trees etc.

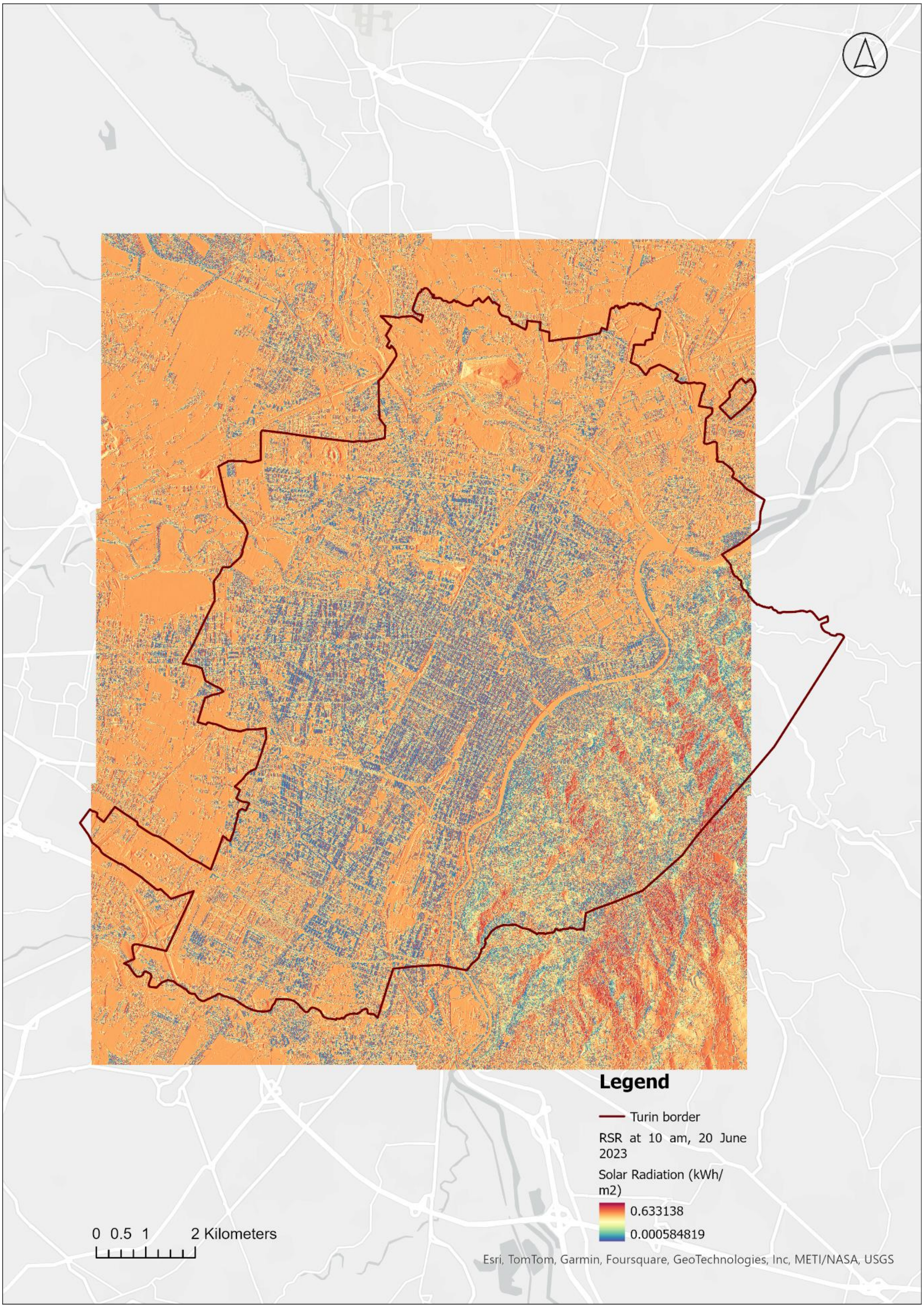


Figure 28: The solar radiation map for Turin at 10 am on June 21st 2023; Source: SDG 11 Lab, Politecnico di Torino; Author

Hourly Solar Radiation Analysis – 21st June 2023

Considering the same speed drop of 0.3 m/s, the following data are recorded. This finding correlates with the fact that solar radiation influences the thermal comfort which results in reduced walking speed, especially when exposed to the summer sun.

To better understand this further, the amount of solar radiation that Turin's road network receives from 7 a.m. to 9 p.m. is mapped, which may be used to comprehend pedestrian restrictions on each street based on the level of thermal discomfort that pedestrians experience from solar radiation. According to the recorded data, 21st June, 2023 has the longest daytime (summer solstice) i.e. the longest hours of sun light from the online calendar for Turin, 2023 (calendariando.it[31]).

Table 16: Daylight hours for June 20th, 2023. Source: calendariando.it

Date	Sun rise	Sun set	Total no of hours with sunlight
21/06/2023	5: 41 am	9:19 pm	15h 38 min

With the raster solar radiation tool, the calculation of solar radiation for the city's road network for every hour are carried out as shown in the following maps (Figure 30, Figure 31, Figure 32 & Figure 32). From these maps, it can be seen that morning and late evening hours are the best time to walk on the streets when concerned with thermal discomfort with respect to the sun's radiation. The shadow effect on the streets plays an important role in the overall thermal comfort of the pedestrians. This allows increase in pedestrian movement in certain streets, especially for elderly population during high temperature. Hence, we can clearly understand the advantage of the raster solar radiation methodology over the LST while comparing. Further, according to the solar radiation value computed using this tool on every BDTRE road segment of Tuin, the maximum solar radiation among all the road segments at all hours is noted to be 0.780326 kWh/m2 (Chart 10).

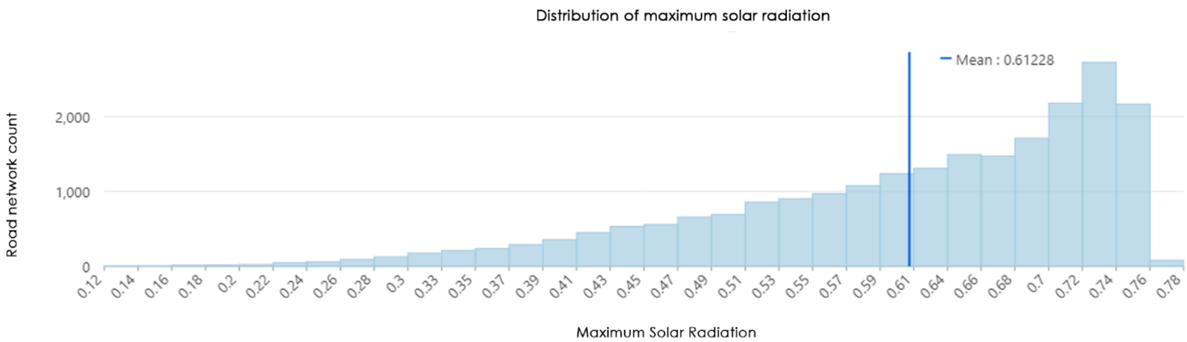


Chart 10: Distribution of maximum solar radiation on for each road segment in Turin's Road network. Source: Author

31 Source: calendariando.it

Hourly solar radiation level on Turin’s Road network – 7 am, 8 am, 9 am and 10 am:

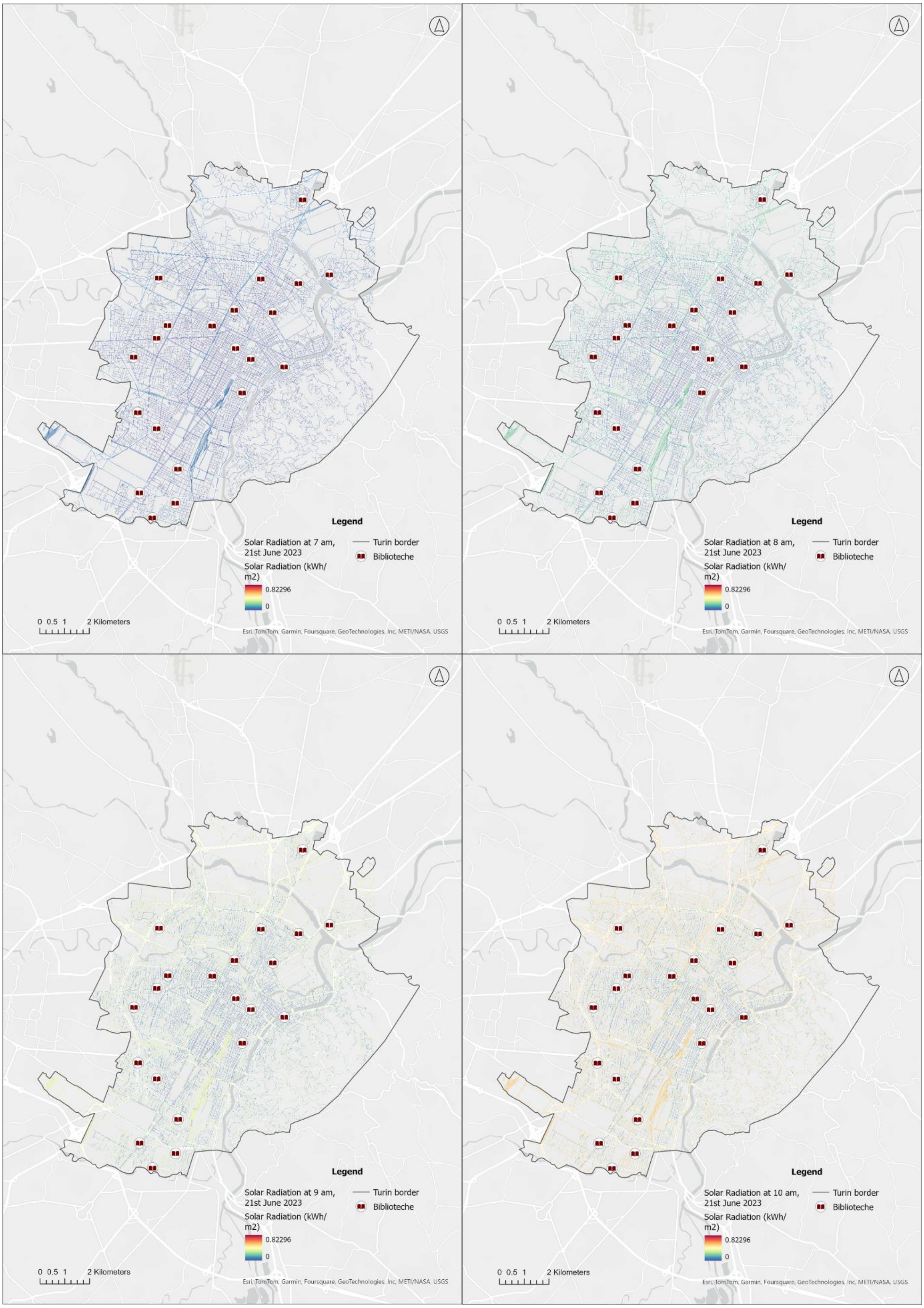


Figure 29: Hourly solar radiation on the road network calculated for the morning hours on 21st June 2023; Source: Author

Hourly solar radiation level on Turin's Road network – 11 am, 12 pm, 1 pm and 2 pm:

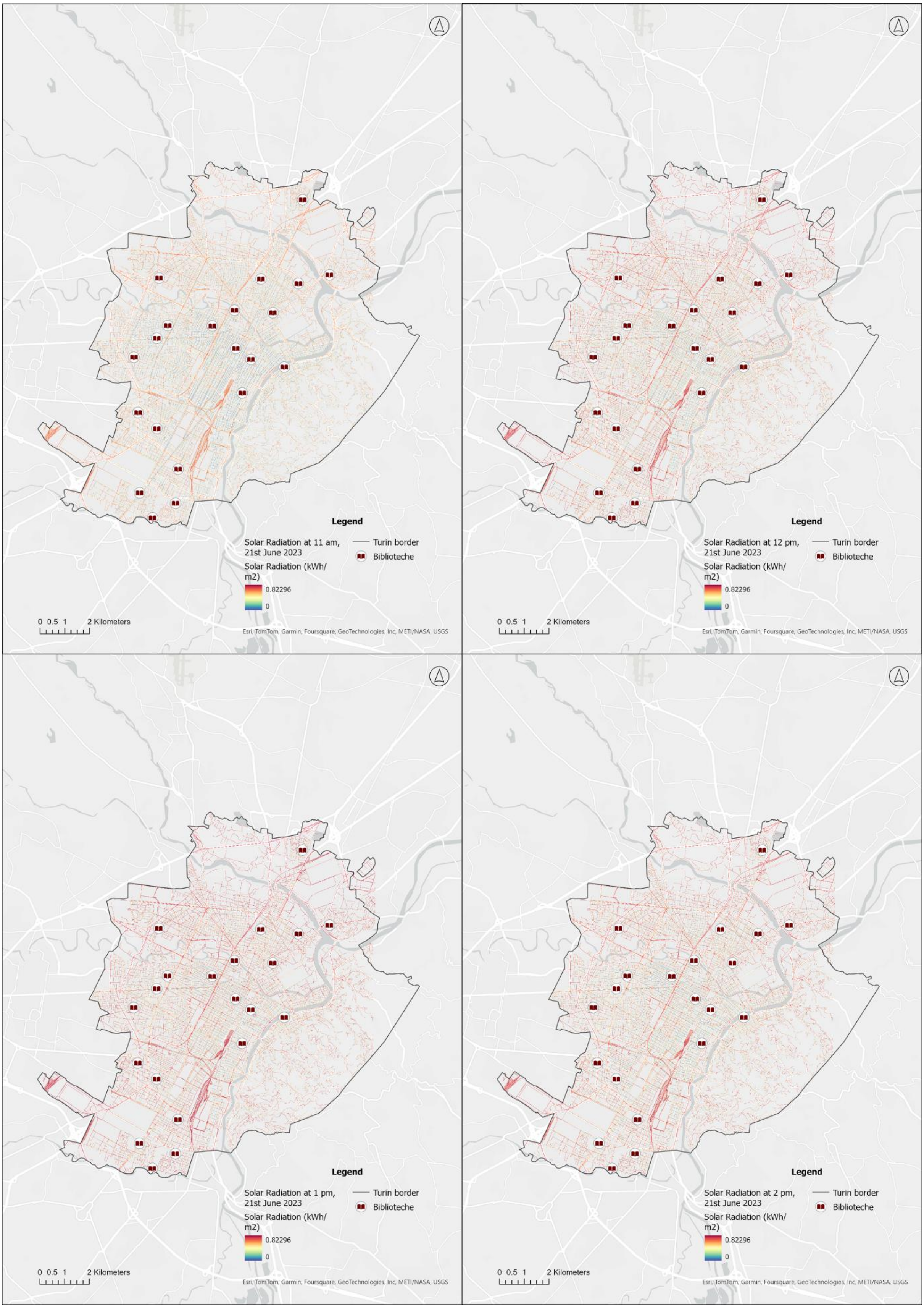


Figure 30: Hourly solar radiation on the road network calculated for the noon hours on 21st June 2023; Source: Author

Hourly solar radiation level on Turin's Road network – 3 pm, 4 pm, 5 pm and 6 pm:

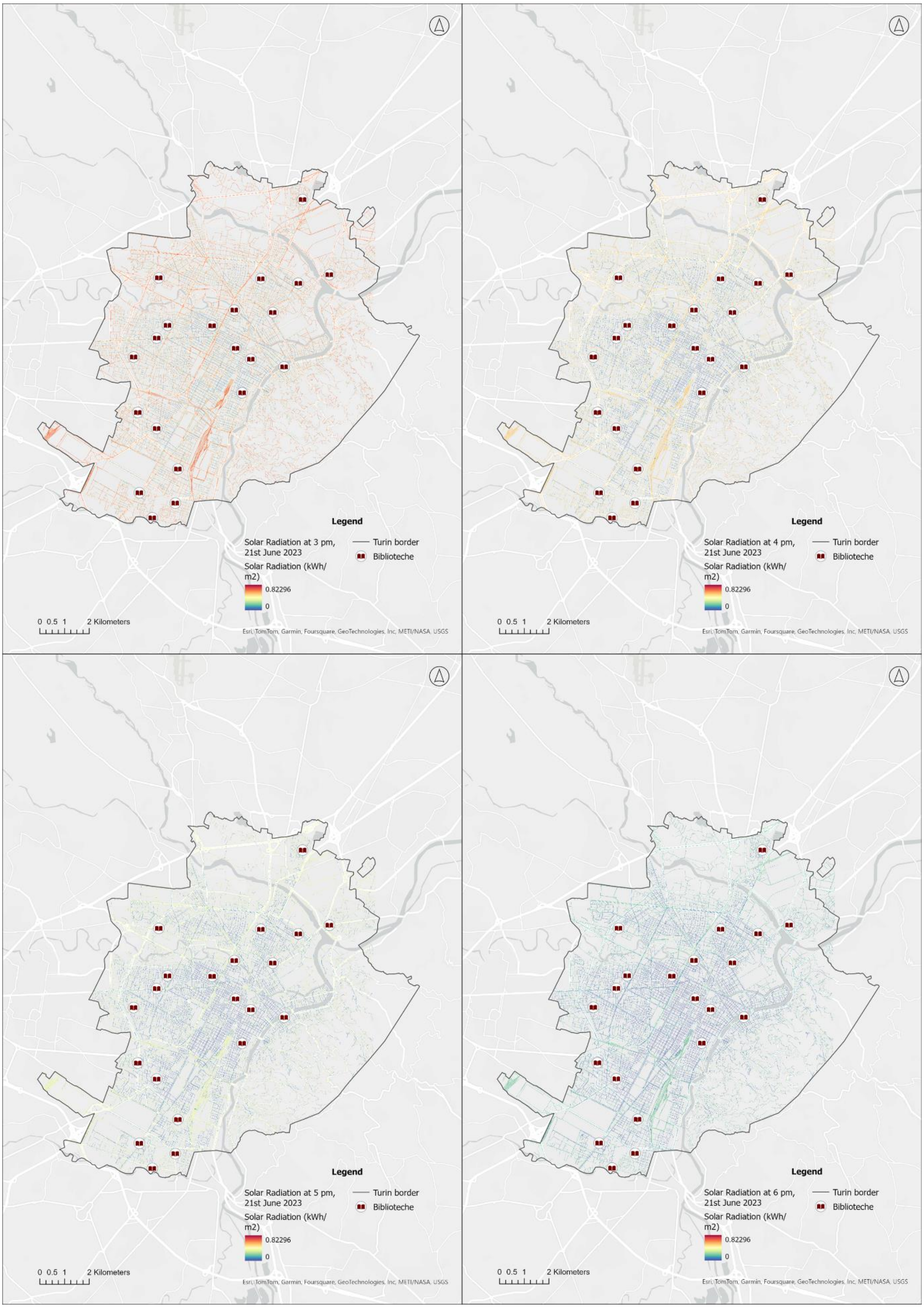
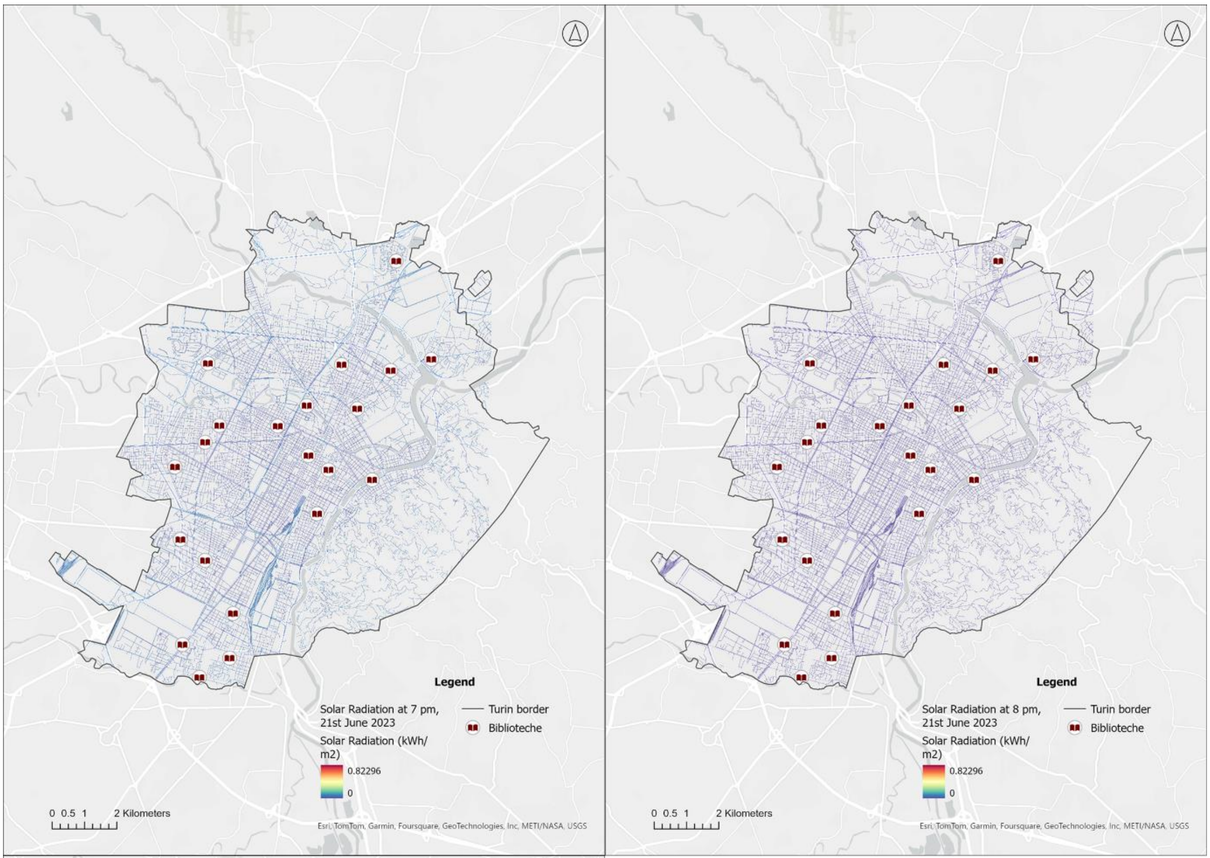


Figure 31: Hourly solar radiation on the road network calculated for the afternoon hours on 21st June 2023; Source: Author

Hourly solar radiation level on Turin's Road network – 7 pm, 8 pm and 9 pm:



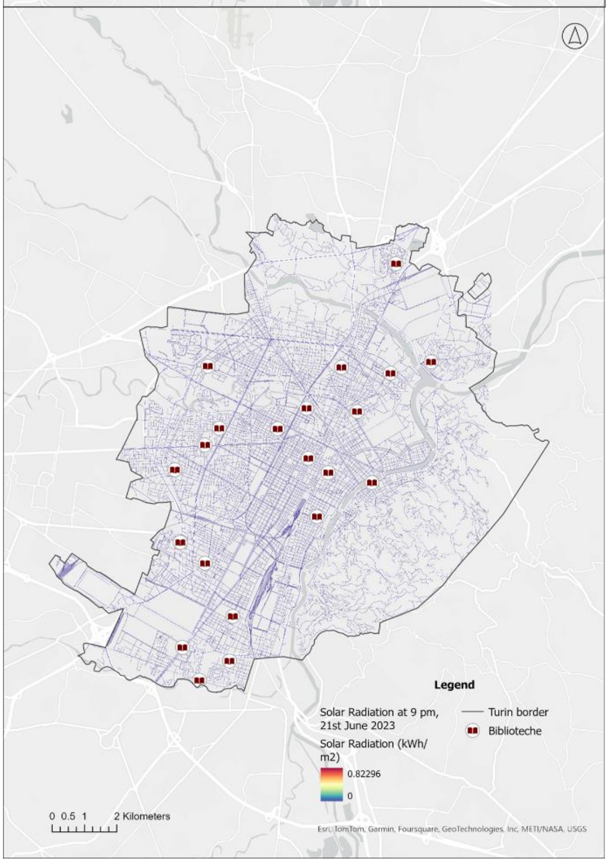


Figure 32: Hourly solar radiation on the road network calculated for the afternoon hours on 21st June 2023. Source: Author

Similar to the method of calculating walking speed of elderly during the mean summer temperature, for this study, to compute the walking speed of pedestrians for every hour of the day, a linear regression is calculated based on a 0.3 m/s speed drop when the solar radiation of the road network hits maximum value of 0.780326 kWh/m2. Therefore, for computing the walking speed of elderly person the regression equation is as follows:

Elderly walking speed calculation at all hours (from 7 am to 9 pm):

P1 = (0, 0.91)
P2 = (0.780326, 0.61)

$$y = -\ 0.384455x + 0.91$$

where:
y = corrected speed (m/s)
x = mean solar radiation for a road segment
0.91 m/s is the base speed for elderly as mentioned in the sub – section 3.6, table 6.

The equation defines a perfect negative correlation between the values of solar radiation of the road network and walking speed of elderly pedestrians.

According to the inferences drawn from the references and the values derived from the aforementioned equation, an accurate definition of the true and precise hourly spatial accessibility of libraries can be established for the elderly population. As a result, the map created (figure 30) specifies the road segments according to the elderly's walking speed with regard to the level of solar radiation received in each segment.

Similarly,
Young adults walking speed calculation at all hours (from 7 am to 9 pm):

P1 = (0, 1.40)
P2 = (0, 1.1)

$$y = -\ 0.384455x + 1.4$$

where:
1.40 m/s is the base speed for young adult as mentioned in the sub – section 3.6, table 5.

As an example, the following map (Figure 33) for 1 pm, a time characterized by peak solar radiation levels, illustrates road segments categorized by the walking speed of the elderly concerning the solar radiation received at that specific hour. This map provides a visual representation of how different road segments are impacted by solar radiation, thereby influencing the walking speed and accessibility for the elderly population.

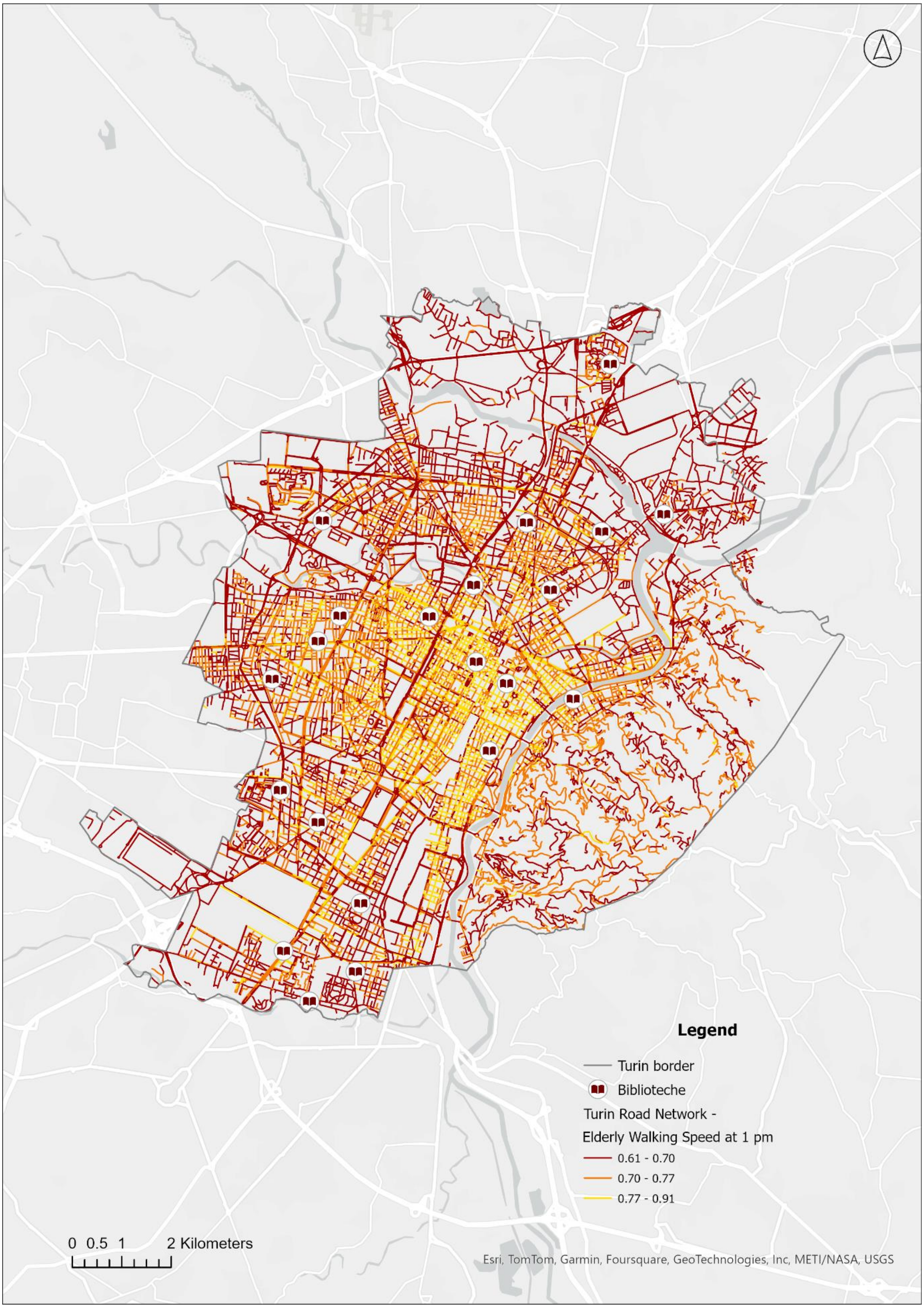


Figure 33: Walking speed of the elderly population based on the solar radiation at 1 pm on each road segments during summer solstice. Source: Author

5.4. Pedestrian Spatial and Temporal Accessibility of proposed UCS

With the data from previous sub – section, the pedestrian spatial accessibility mapping is carried out by incorporating both the methodologies – LST and RSR.

5.4.1. Spatial Accessibility during Mean Summer Time

As mentioned earlier, the mean maximum temperature from summer months of 2023 – June, July and August are taken for this methodology – the LST methodology. Upon further calculation of the drop in walking speed with respect to the increasing mean surface temperature, a comparative map (Figure 34 & Figure 35) is generated which clearly defines:

- The service area of each library reduces during the fifteen-minute travel time because of the high surface temperature, as this impacts pedestrian behavior and slows walking.
- During peak summer, the shrinkage of service area is evident when compared to the service area under comfortable environmental conditions, in terms of thermal comfort (Figure 34).

Table 17: % decrease in the 15 - minute service area of libraries for the elderly during mean summer temperature. Source: Author

Pedestrian Typology	Total % of population covered by service areas of 21 libraries within 15 - minutes in mean summer temperature	Total % of population served by the 21 libraries within 15 - minutes (Walking Speed = 0.91m/s)
Elderly adults (65≥ years)	30.43%	48.78%

Table 18: Table 18: % decrease in the 15 - minute service area of libraries for the young adults during mean summer temperature. Source: Author

Pedestrian Typology	Total % of population covered by service areas of 21 libraries within 15 – minutes in mean summer temperature	Total % of population served by the 21 libraries within 15 - minutes (average walking speed = 1.4m/s)
Young adults (20 years – 64 years)	58.50%	67.88%

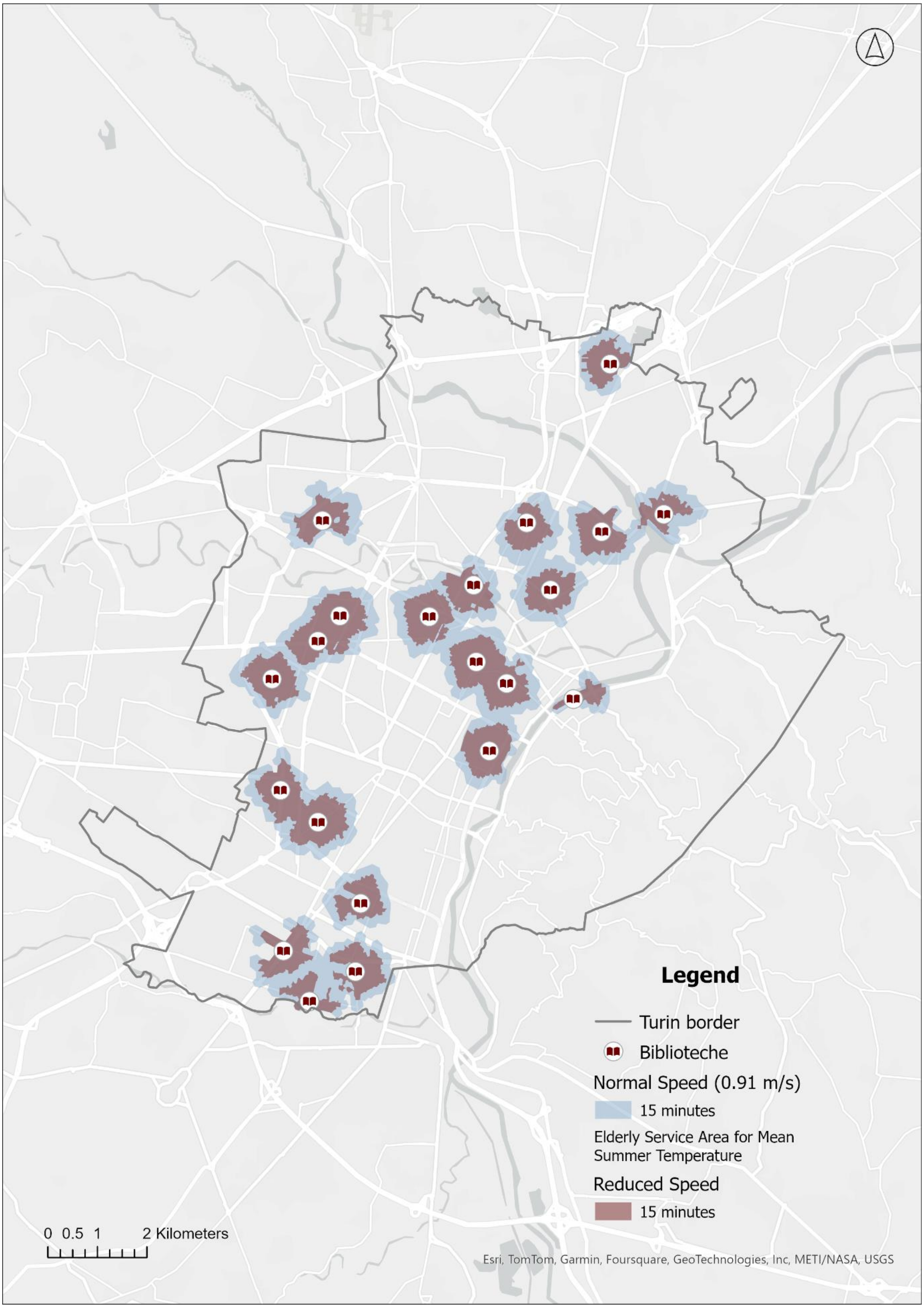


Figure 34: Change in service area of 15 - minutes for the elderly population during peak summer time when compared to an ideal thermal environment. Source: Author

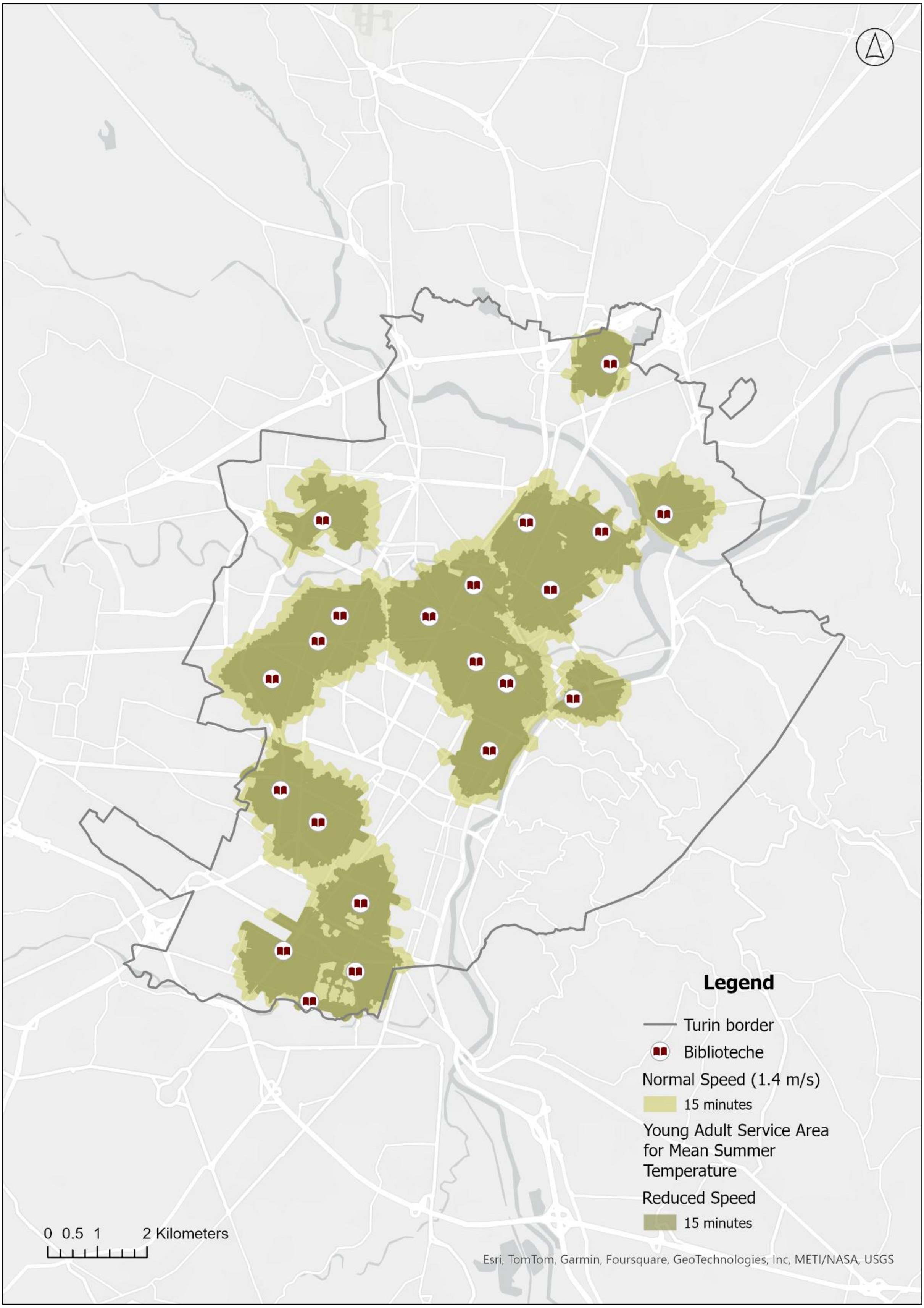


Figure 35: Change in service area of 15 - minutes for young adults during peak summer time when compared to an ideal thermal environment. Source: Author

5.4.2. Spatial Accessibility Variations during a Summer Day

As mentioned earlier, hourly solar radiation values are calculated for June 20th, 2023 from 7 am till 9pm. This intra – day observation of spatial accessibility is essential as it indicates the ideal time and route, based on the shade effect, that can be utilized by the elderly population. Additionally, considering that no route is ideal and can offer complete shade, this analysis can be utilized to reduce the negative impacts of HWs on pedestrians seeking shelter during severe weather.

Hence, upon further calculation of the drop in walking speed with respect to the increasing level of solar radiation on streets of Turin, an hourly comparative map (Figure 37) is generated which clearly defines:

- The service area of each library at different time during a day varies. The map shows the library service areas computed at 9 a.m., 1 p.m., 4 p.m., and 7 p.m. The shortest service areas are found at 1 p.m. and 4 p.m., with 1 p.m. being the smallest of the two (Figure 36).
- From this methodology, as stated previously, the shadow caused by buildings and trees creates a much more accurate and precise spatial accessibility analysis while considering thermal comfort.
- The shrinkage of service area is evident when compared to the service area under comfortable environmental conditions, in terms of thermal comfort (Figure 38). The time for comparison was taken as 1pm, as this hour experiences the maximum solar radiation in a day.

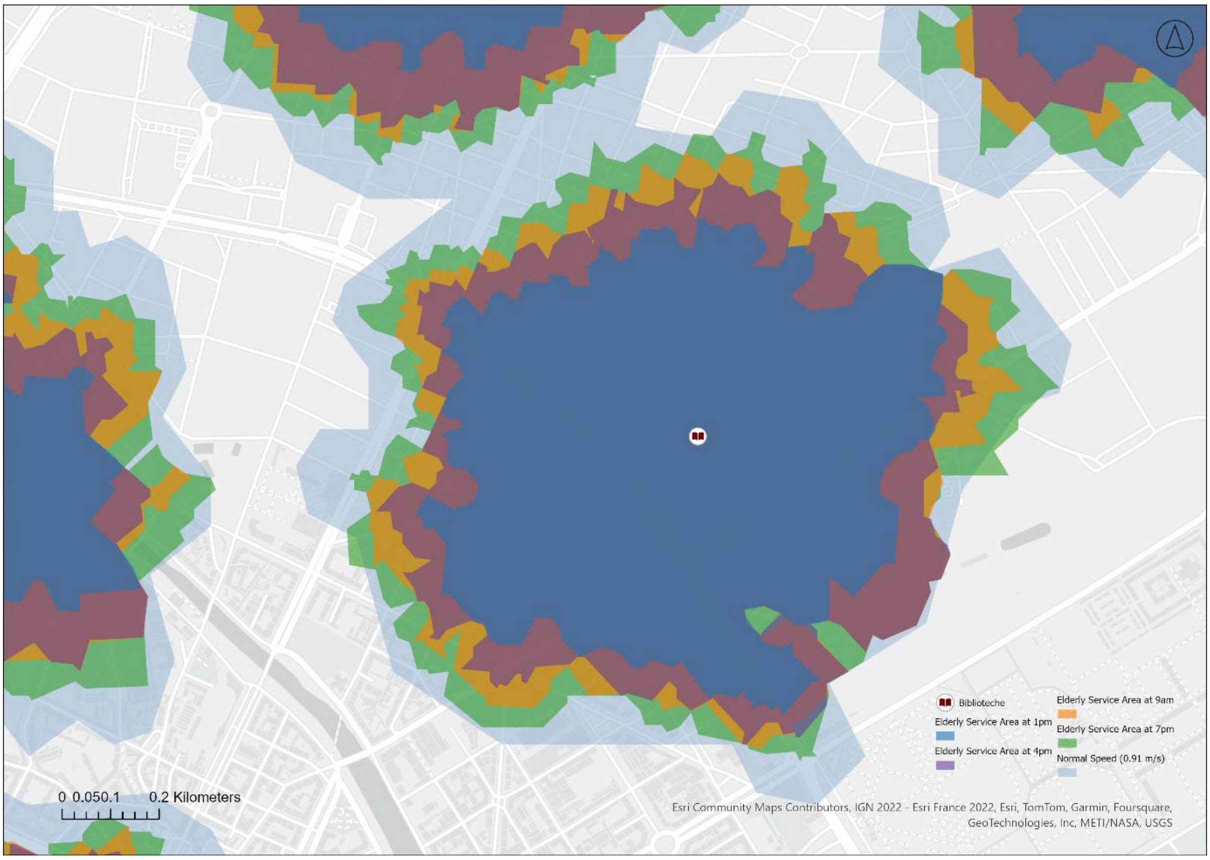


Figure 36: A detailed version of figure 35 and 36, showing the variation in each service area computed for different hours of the day for elderly population. Source: Author

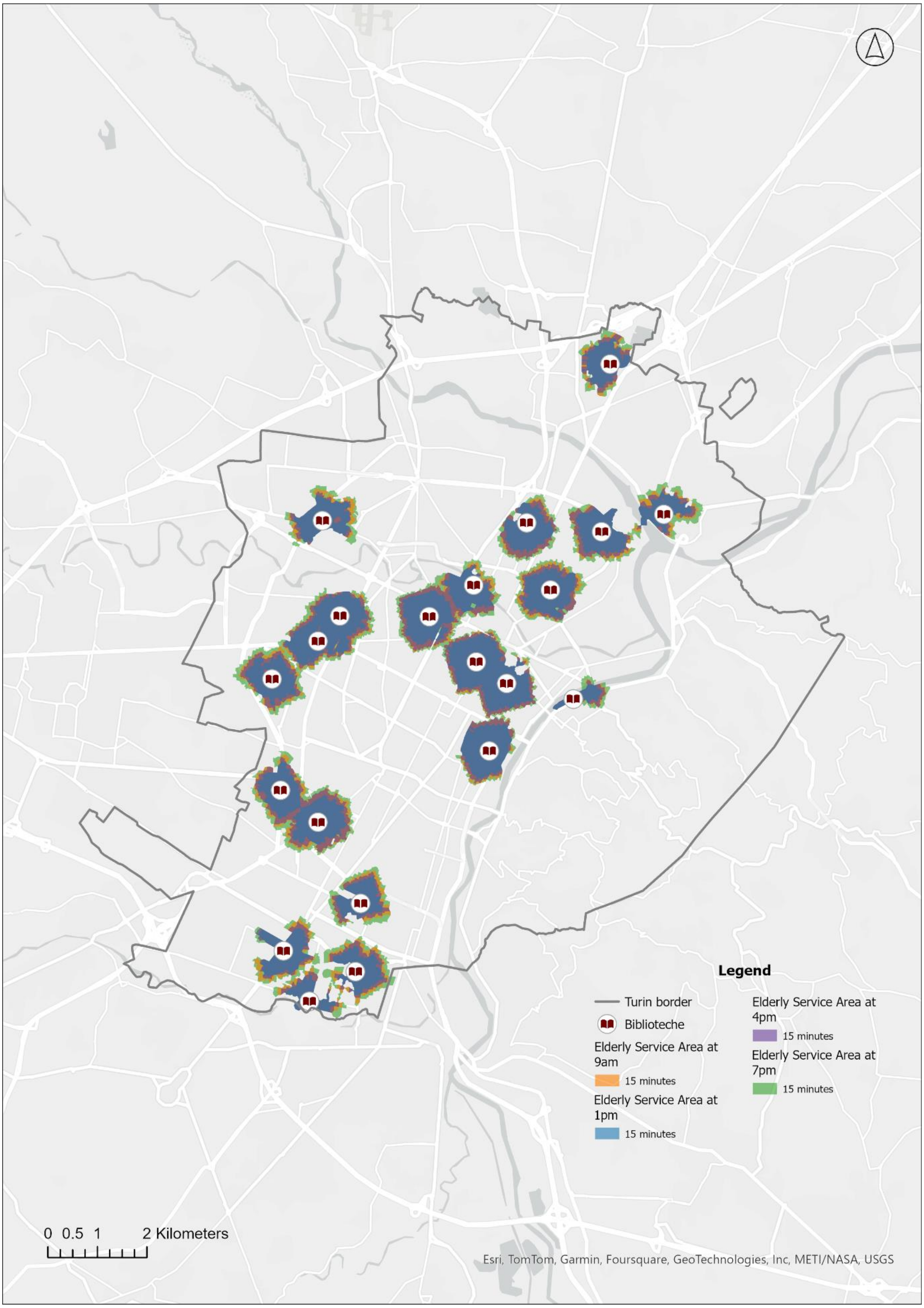


Figure 37: Variation in service area of 15 - minutes for the elderly population for different time periods in a day. Source: Author

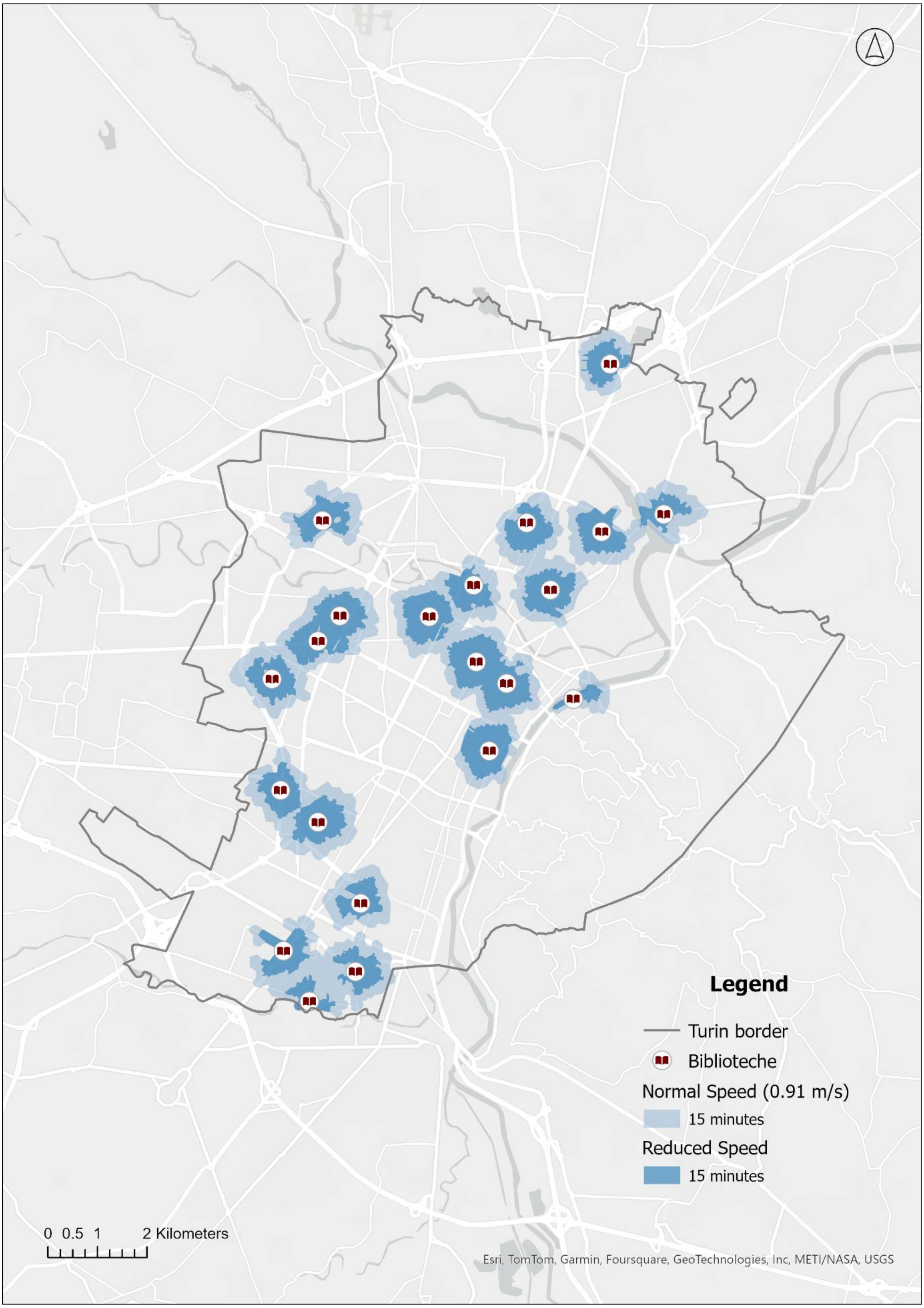


Figure 38: Change in service area of 15 - minutes for elderly population for the time 1pm when compared to an ideal thermal environment. Source: Author

5.5. Inferences from Assessment of Spatial and Temporal Accessibility of UCS

The two methodologies, LST and RSR, adopted in this study for analyzing the spatial and temporal accessibility demonstrate variation in the 15 – minute service areas with changes in surface temperature. To further comprehend the variations in the walking speed of the elderly, two pedestrian movement scenarios are compared as follows:

1. Elderly walking to the nearby library at the opening hour (9 am) and returning after four hours (1 pm)
2. Elderly walking to the nearby library in the afternoon hour (3pm) and returning at closing hour (7pm):

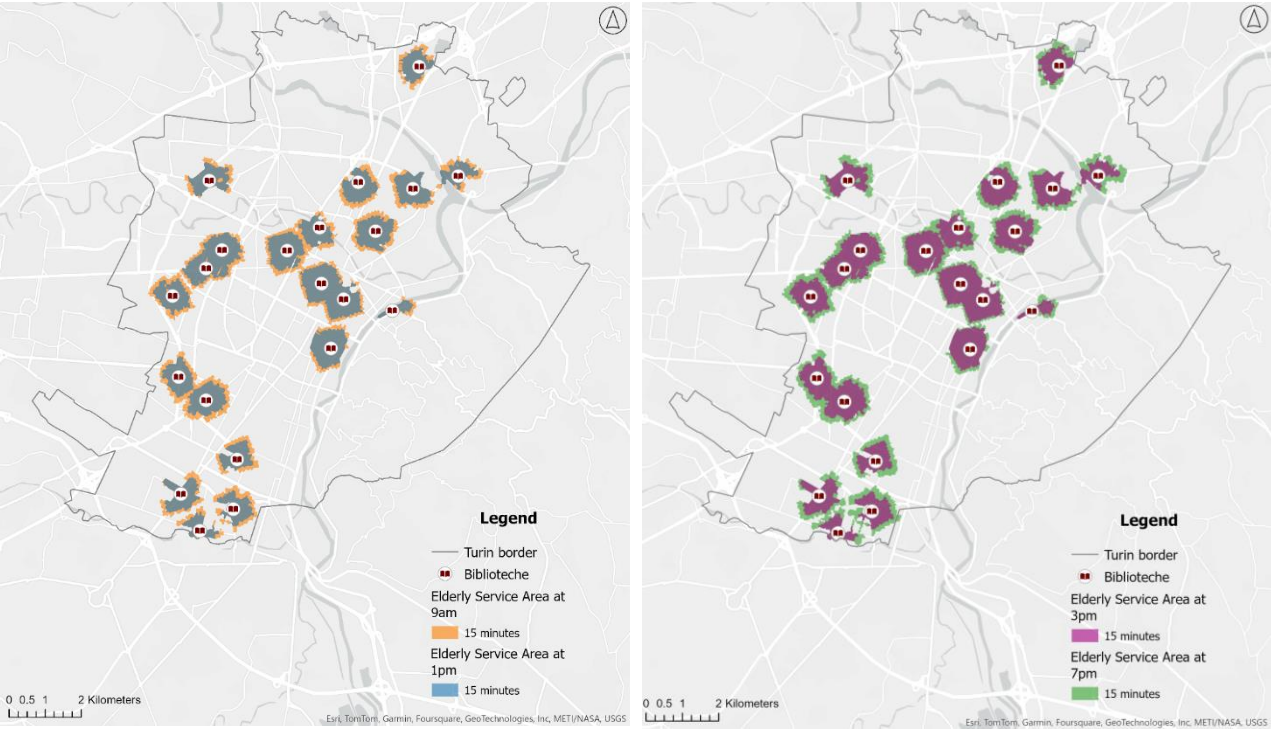


Figure 39: Comparing movement scenario of elderly pedestrians travelling to libraries at different hours of the day. Source: Author

In the first movement scenario, elderly pedestrians embark on their journey to the library early in the morning when temperatures are generally cooler. However, their return trip at 1 pm exposes them to the midday heat, which is typically intense and can significantly affect their walking speed and overall thermal comfort. Whereas, in the second scenario, the elderly walks to the library in the later afternoon when temperature start to decrease. Their return after the closing hours of the libraries i.e. after 7 pm, is during a more thermally comfortable hour. The estimated number of elderly who can access the libraries within a 15 – minute walk is calculated to be approximately 82,686 at 9 am, whereas at 3pm this figure decreases to 70,216.

Through this comparison of service areas, it becomes evident that the ideal times for travelling to and from libraries, especially during high temperate periods, are those that minimize exposure to intense solar reduction. Therefore, planning to access the libraries during thermally comfortable hours, especially in the morning before 10 am and after 3pm and should avoid walking during the peak high temperatures typically between 12 pm – 2 pm, promoting better health and well – being.

SECTION 4

Propositions & Recommendations

Chapter 6

6.1. Inferences and Findings from the case study of Turin

The impacts of climate change experienced on the various urban dimensions differ according to the level of risk during an extreme heat event. The UHI effect, coupled with intense heat waves, creates significant challenges to the urban livability in Turin. According to the city's resilience plan, as a response to these arising climatic challenges, the adaptation strategy of "A more livable city" comprises the implementation of interventions aimed to improve the thermal comfort of the buildings, making the indoor temperature more comfortable during the summer (Climate Resilience Plan, 2020). In addition to this, from the accessibility analysis, it was observed that the increasing thermal discomfort in the streets for pedestrians is a growing concern. Hence, vulnerable populations' proximity to climate refuges plays a crucial role.

Therefore, in order to support the resilience strategy and improve the city's capacity to adapt to extreme climatic conditions, this research study evaluates the proposal of UCS throughout the city as well as the temporal and spatial accessibility to these facilities. From the spatial analysis of this study, it was observed that through strategically locating the UCS within the framework of the 15-minute city concept, Turin can maximize the accessibility and effectiveness of these innovative adaptive tool. According to the spatial analysis carried out in the earlier sub - section, it is clear that at least 48% of the city's vulnerable population could have access to a climate refuge within a 15 – minute walk by converting the existing infrastructure, in this case, the libraries, into UCS. This particular fact describes about Turin's present condition in terms of adaptive capacity[32]. By implementing UCS in strategic locations, such as repurposing public libraries, the residents will have convenient access to cool places during periods of high heat, thus reducing heat – related mortality rates, which will promote a more livable, sustainable and equitable urban environment i.e. to increase the city's adaptive capacity.

In order to comprehend the implementation process of these UCS into Turin's urban fabric, it is necessary to evaluate the current UHI hazard levels with the location of these libraries.

6.1.1. Spatial Accessibility of the Elderly Population in different Hazard areas:

The literature related to the city's UHI effect describes the areas within Turin that are subjected to various levels of hazard. According to the hazard map (Figure 14), the residential zones represented varied hazard levels from low to medium while the industrial zones were in high hazard levels. The total elderly population residing in each level of UHI hazard is computed by intersecting the hazard data with the refined census tract data of 2021. According to this intersection, around 214,402 elderly residents are living in low – high hazard areas i.e. approximately 97.74% of the total elderly population of Turin where more than half is the elderly women population (57% of the total elderly population to be precise). The following are the population distribution with respect to different UHI hazard in the city of Turin:

- 26.59% in Low Hazard areas
- 73.40% in Medium Hazard areas
- Almost 0.01% in High Hazard areas

[32] Adaptive Capacity is the ability of a system or community to adapt to impacts of climate change. Enhancements of adaptive capacity reduces vulnerabilities and promotes sustainable development. Source: archive.ipcc.ch

To understand the population's spatial accessibility to these UCSs, the coverage of the elderly population by each library service area is calculated. These libraries are accessible to 49.31% of the total elderly population residing in various hazard areas throughout the city. Approximately 105,743 senior citizens live in different hazard areas covered by the UCS's service area, of which only 16.21% are served by the climatized libraries that are currently in place, meaning they have air conditioning. When the remaining 15 libraries are similarly climatized, this specific number is shown to increase significantly to 83.79% (Figure 40), indicating that the elderly, who are more susceptible to the effects of UHI, can benefit from the conversion of all libraries into UCS.

Thus, a spatial accessibility of all proposed UCSs, for the elderly population in relation to the UHI hazard levels is computed. To generate this map, first the map regarding the spatial distribution of elderly population within the 15 – minute service areas of all 21 public libraries are mapped (Figure 40). Followed by the mapping of different hazard zones within these service areas is also created as shown in the following figure (Figure 41). Further for better comprehension, population distribution for each hazard zones within the service areas are created separately for low and medium hazards (Figure 42) (the high hazard is not considered as the elderly population is absent in this hazard level).

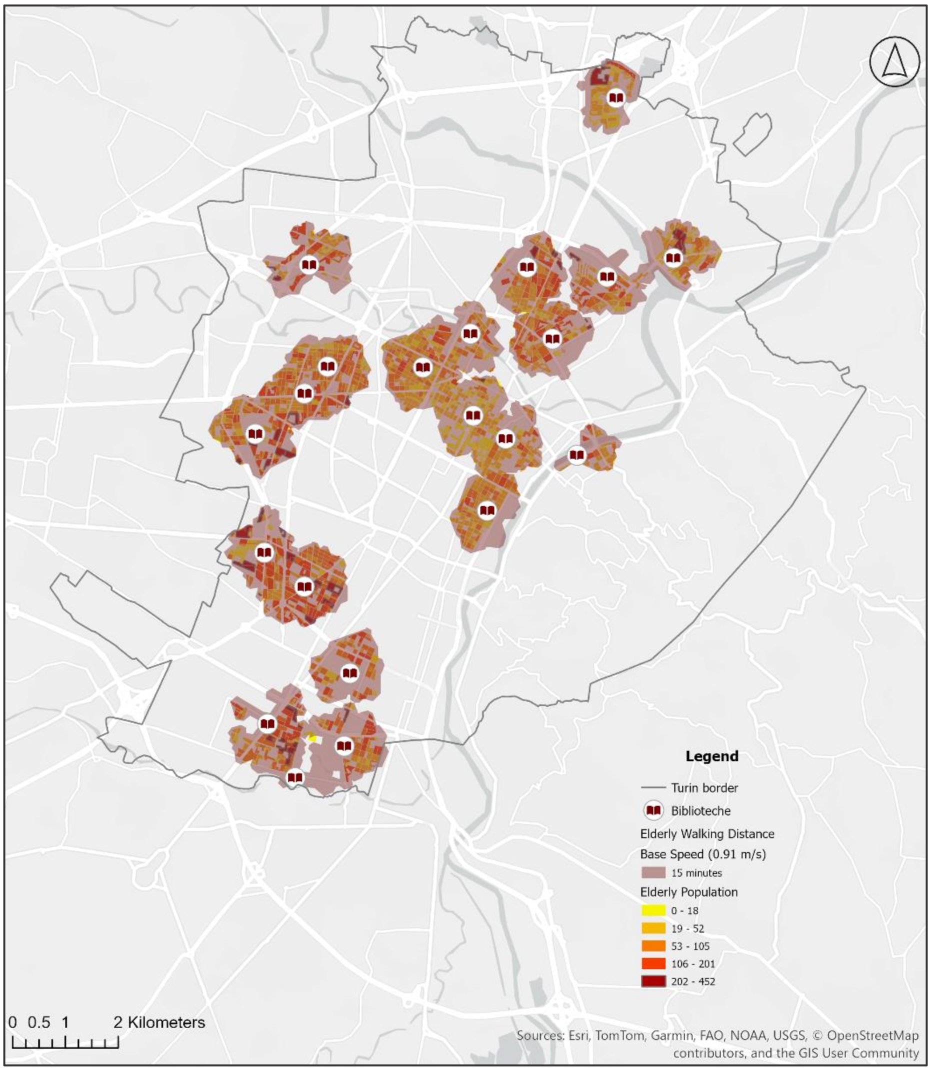


Figure 40: Elderly population residing in areas served by all 21 libraries. Source: Author

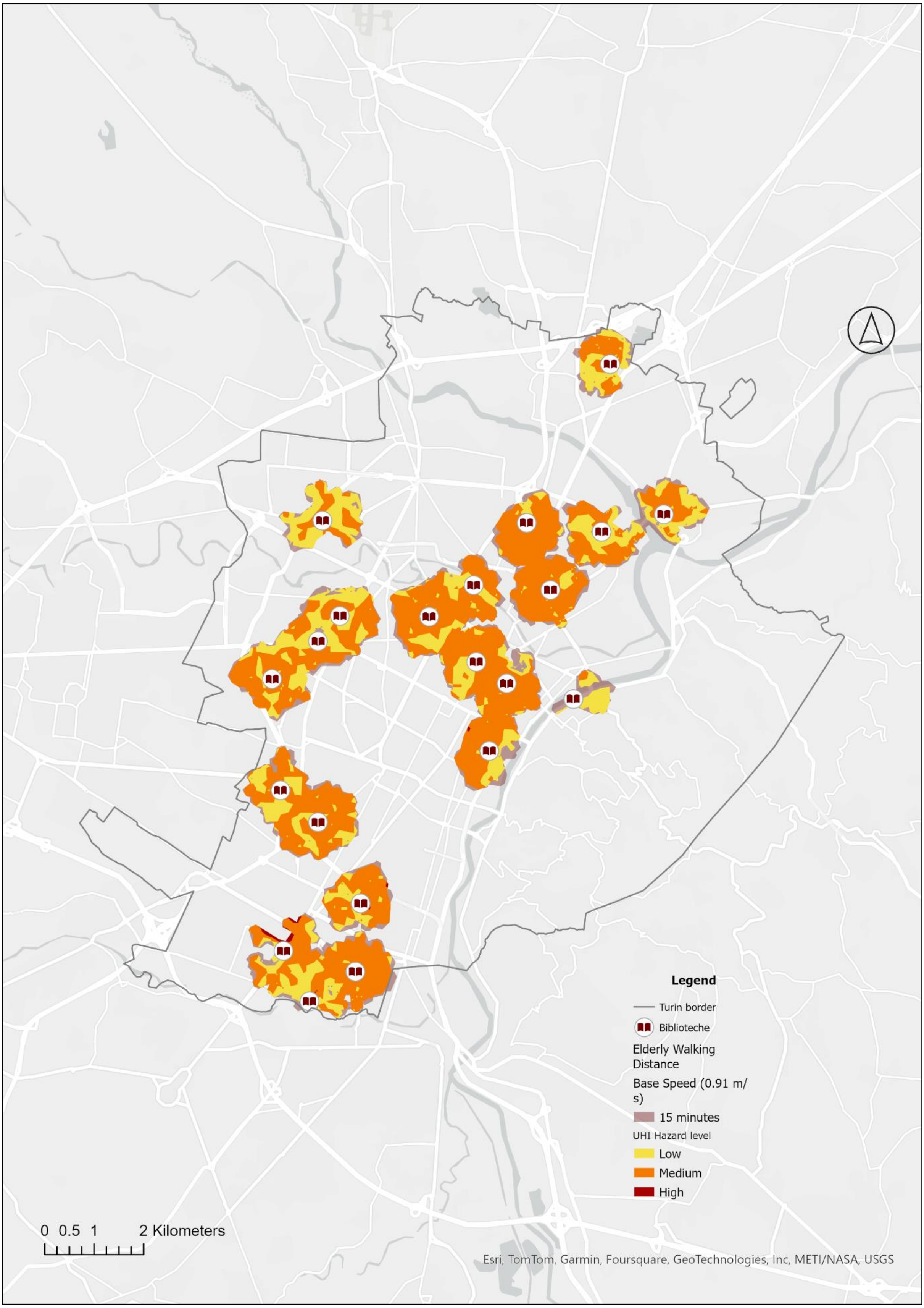
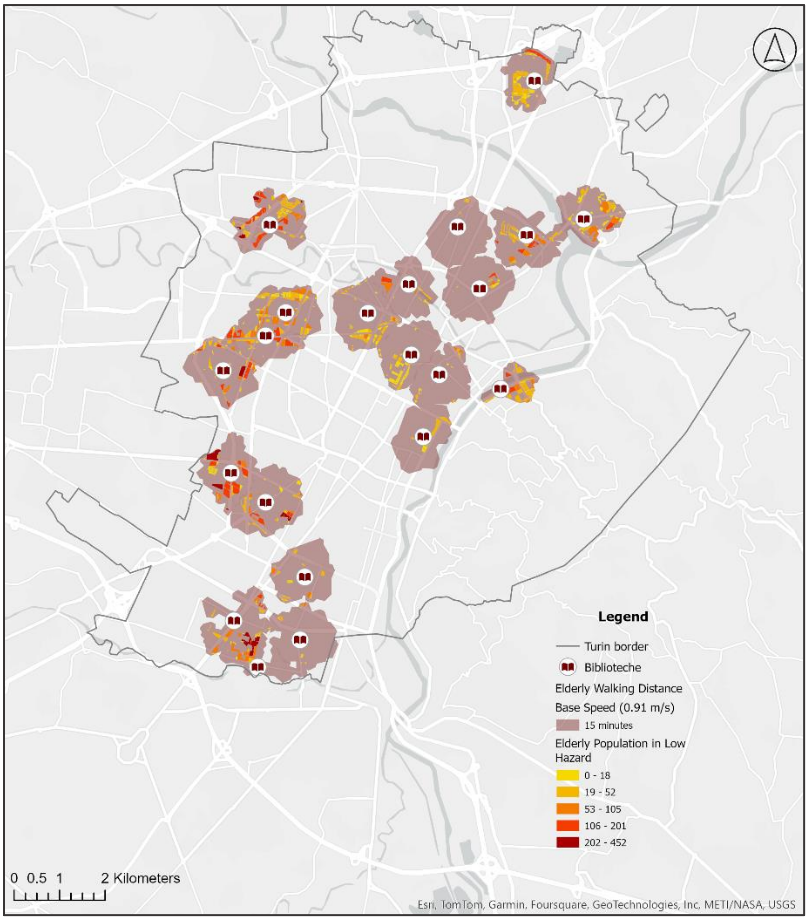


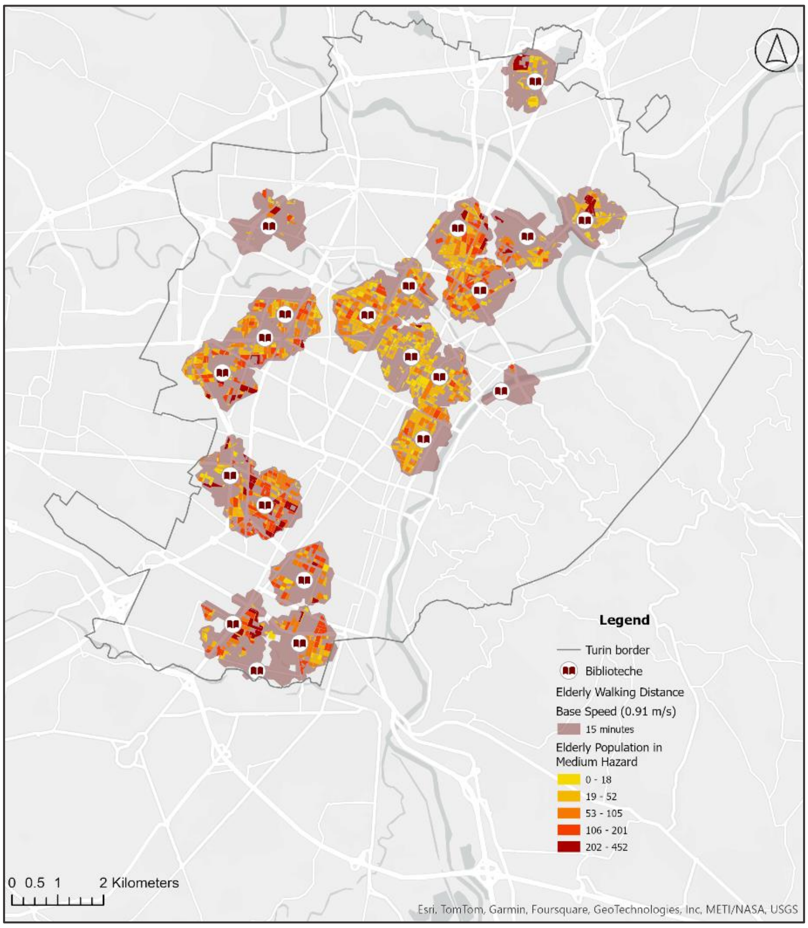
Figure 41: Spatial distribution of different UHI hazard zones within the services areas of libraries. Source: Author



The 15 – minutes service areas of libraries show the elderly population covered by base walking speed of 0.91 m/s.

The percentage coverage are as follows:

- Elderly population residing in Low Hazard areas that can access a library in 15 minutes = **26.31%**



- Elderly population residing in Medium Hazard areas that can access a library in 15 minutes = **73.68%**

Figure 42: (Top) Spatial distribution of elderly population in Low Hazard areas (top) and Medium Hazard areas (bottom) within the service areas. Source: Author

6.2. Proposition - 1

6.2.1. Prioritizing Climatization of Public Libraries based on the Elderly Population Served:

From the city's urban study and urban analysis, it is now well understood the challenges posed by extreme heat events on vulnerable populations. A city's public library is one of those institutions that serves as a vital hub for the community, an essential component of urban life, and a provider of essential services and a safe environment during an emergency for all of its residents.
However, many of these libraries in Turin lack adequate air conditioning facility, compromising their ability to serve as refuges during heatwaves. Hence, through the following proposition, this master thesis aims to establish a prioritization framework for the climatization – through implementation of air conditioning facilities, of public libraries within the UCS system in Turin. This framework is based on the spatial analysis of the elderly population served by each library, ensuring that resources are allocated to maximize the comfort and livability of the residents.

Identifying Vulnerable Population to the UHI risk

Vulnerable population is identified (sub - section 4.2.2) with the demographic information from the census data of Turin – ISTAT 2021. Elderly population of age 65 years and above is selected for this step and is mapped.

Urban Study

Identifying Potential UCS (Public Libraries)

Locating public libraries in the neighborhood level of the city is conducted that resulted in a total 21 libraries. These facilities' neighborhood-scale location plays a part in their potential conversion to UCS.

Quantifying the Elderly Population Served by each library

Spatial and temporal accessibility analysis are computed to map the distribution of the elderly population in Turin and their proximity to public libraries. Here, the 15 – minute city concept is also incorporated to understand the accessibility and proximity of the UCS by the elderly population.

Analyzing the existing condition of libraries

Out of the 21 libraries that were located earlier, only 6 were identified to have a cooling facility such as air conditioning. According to computation based on spatial analysis, just 14.8% of Turin's elderly population is served by these six libraries.

Proposal of climatizing all the existing libraries

This further led to proposal of climatizing all the existing libraries in order to increase Turin's adaptive capacity. Thus, the 14.8% is increased to 48.78%.

Urban Analysis

Priority mapping of the libraries to be climatized based on the elderly population served by each

To determine which libraries, require rapid climatizing adaptations to house the vulnerable population, a priority mapping approach is done where libraries are classified according to the priority level ranging from very low – high priority as per the number of elderly served within 15 – minute time frame.

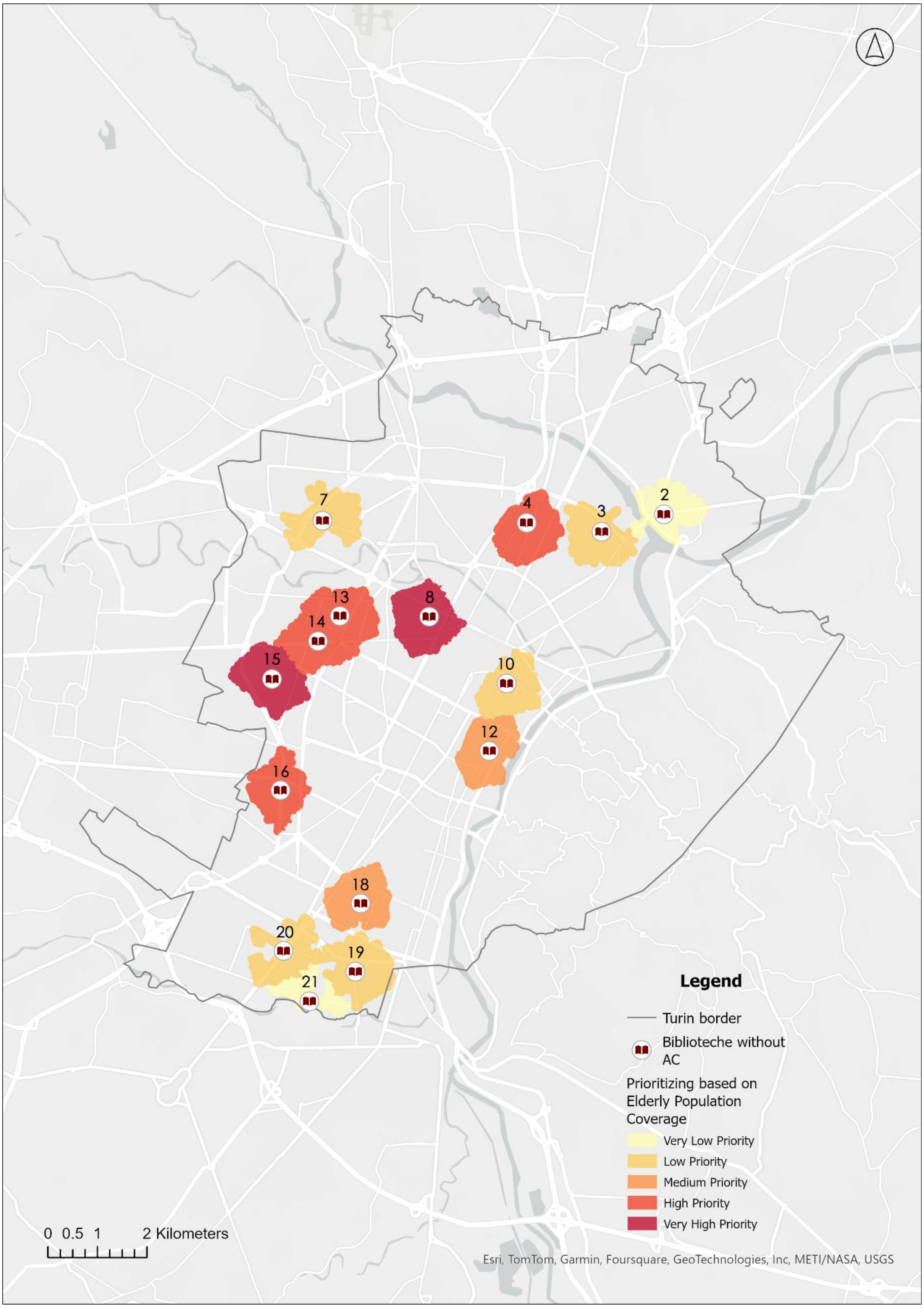


Figure 43: Prioritizing libraries to be air conditioned based on the number of elderly served by each in 15 minutes. Source: Author

Table 19: Priority list of existing libraries (without air conditioning facility) in Turin for climatizing. Source: Author

Biblioteche No.	Name of the Library	Address	No. of Elderly people served	Priority Level
15	Biblioteca civica Luigi Carluccio	Via Monte Ortigara 95	8840	Very High Priority
8	Punto prestito G. D'Annunzio	Via Gaspare Saccarelli 18	8571	Very High Priority
4	Biblioteca civica Cascina Marchesa	Corso Vercelli 141 Int. 7	7246	High Priority
14	Biblioteca civica Musicale A. Della Corte	Corso Francia 186	6762	High Priority
13	Biblioteca civica I ragazzi di Utoya	Via Zumaglia 39	6648	High Priority
16	Biblioteca civica A. Passerin d'Entreves	Via Guido Reni 102	6480	High Priority
18	Biblioteca civica Dietrich Bonhoeffer	Corso Corsica 55	5655	Medium Priority
12	Biblioteca civica Natalia Ginzburg	Via Cesare Lombroso 16	5384	Medium Priority
20	Biblioteca civica Mirafiori	Corso Unione Sovietica 490	4917	Low Priority
19	Biblioteca civica Cesare Pavese	Via Candiolo 79	4845	Low Priority
3	Biblioteca Centro Interculturale	Corso Taranto 160	4839	Low Priority
7	Biblioteca civica Francesco Cognasso	Corso L. Quinzio Cincinnato 115	4806	Low Priority
10	Biblioteca Nazionale Universitaria di Torino	Piazza Carlo Alberto 3	3454	Low Priority
2	Biblioteca civica Rita Atria	Strada S. Mauro 26/A	2088	Very Low Priority
21	Mausoleo della Bela Rosin	Strada Castello di Mirafiori 148 Int. 7	1028	Very Low Priority

Very High Priority · High Priority · Medium Priority · Low Priority · Very Low Priority

From the above table, a priority ranking for each library is set into action in regard to the number of elderly served by each, thus enhancing the city's adaptive capacity. The libraries with high priority are found in circoscrizioni 3 and 4. Therefore, through this analytical process to facilitate the priority ranking can be used in order to determine the libraries that require immediate interventions, which need not limit to air conditioning, to serve the elderly population. By ensuring that public libraries in Turin are sufficiently equipped with air conditioning, this proposal aims to enhance the well – being of elderly population, promote health equity and ensure that libraries remain accessible community areas.

6.2.2. Prioritizing Climatization of Public Libraries based on the Elderly Population served with regard to UHI Hazard:

In addition to the above priority ranking for climatizing the libraries, the UHI hazard factor is also taken into consideration along with the elderly population data. The spatial distribution of the elderly population from the sub – section 6.1.1. is further analyzed to determine this particular ranking, the total elderly population covered by the service area of each potential UCS is multiplied by a UHI hazard factor.

For this analysis, the following steps are taken into consideration to achieve the final priority ranking list which includes the 15 libraries:

- The spatial distribution map (Figure 40) of the elderly population residing in areas served by the libraries that are yet to be climatized is considered. The population is normalized from a scale of 0 – 1 through the minimum – maximum method offered by the standardize field tool.
- The following step involves the normalization of the UHI hazard level map for each service area into:
  - 0.33 – Low Hazard
  - 0.66 – Medium Hazard
  - 1 – High Hazard
- Further, the maps obtained as a result of both the previous steps are multiplied i.e. the population is multiplied by the above UHI hazard factor for each respective hazard class. The resulting map (Figure 44) is normalized further using the minimum – maximum method to achieve a hazard – population index to illustrate the priority ranking of each service area of the libraries.

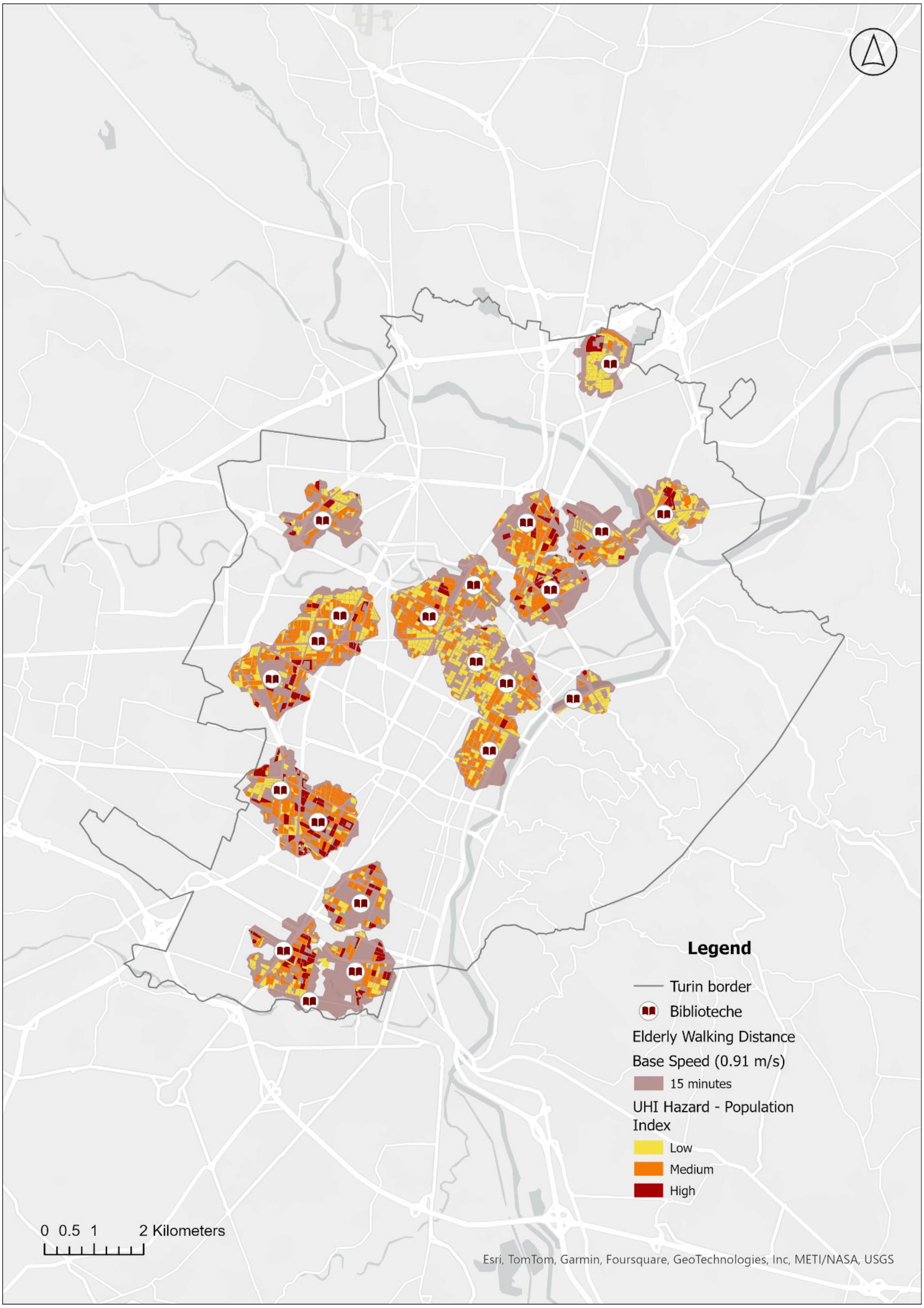


Figure 44: Spatial distribution of a Hazard - Population index within each service areas. Source: Author

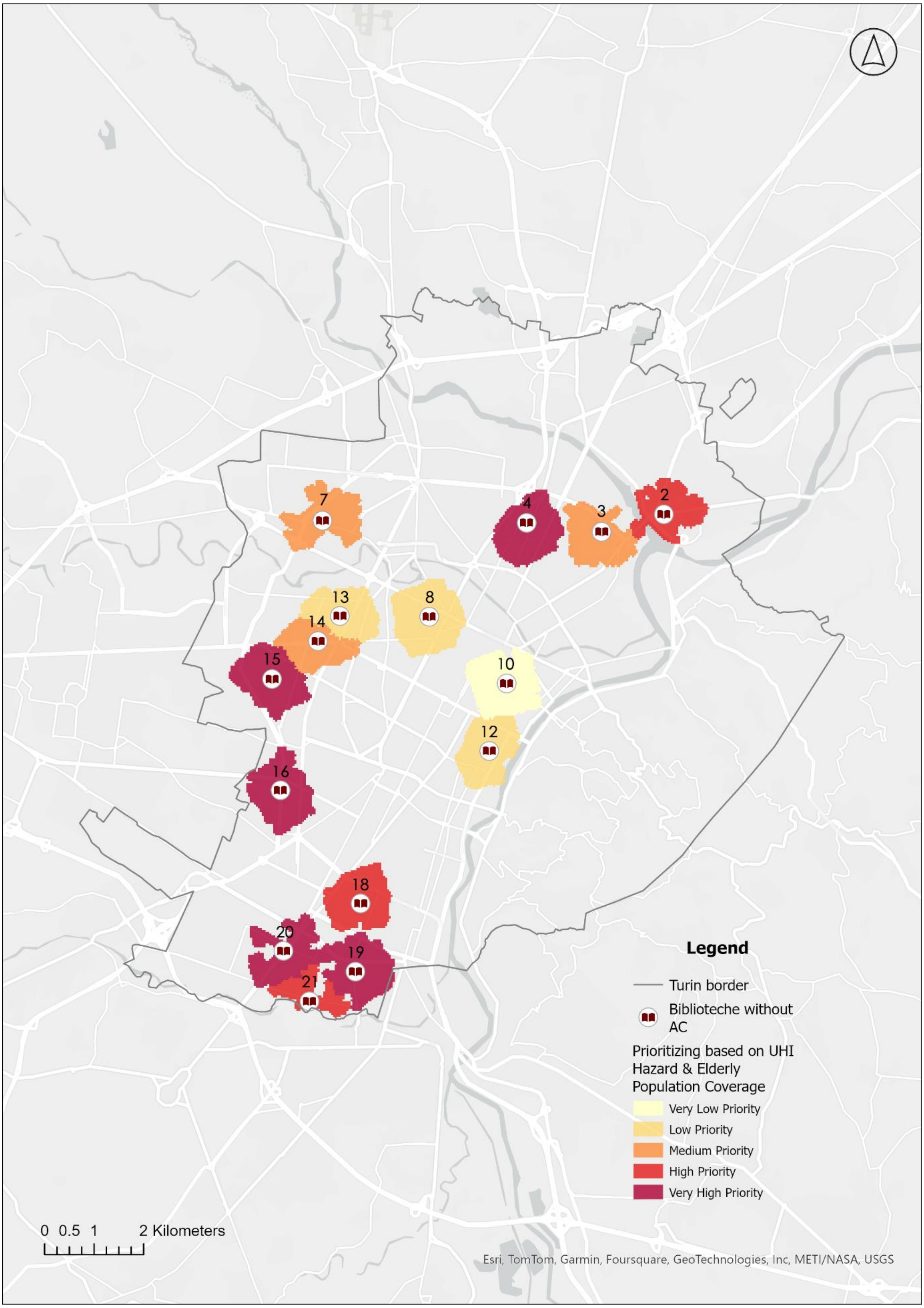


Figure 45: Prioritizing libraries to be air conditioned based on UHI Hazard and number of elderly served by each in 15 minutes. Source: Author

Table 20: Priority list of existing libraries (without air conditioning facility) in Turin for climatizing. Source: Author

Biblioteche No.	**Name of the Library**	**Address**	**Circoscrizione**	**Priority Level**
15	Biblioteca civica Luigi Carluccio	Via Monte Ortigara 95	3	
4	Biblioteca civica Cascina Marchesa	Corso Vercelli 141 Int. 7	6	
16	Biblioteca civica A. Passerin d'Entreves	Via Guido Reni 102	2	
20	Biblioteca civica Mirafiori	Corso Unione Sovietica 490	2	
19	Biblioteca civica Cesare Pavese	Via Candiolo 79	2	
18	Biblioteca civica Dietrich Bonhoeffer	Corso Corsica 55	8	
2	Biblioteca civica Rita Atria	Strada S. Mauro 26/A	6	
21	Mausoleo della Bela Rosin	Strada Castello di Mirafiori 148 Int. 7	2	
14	Biblioteca civica Musicale A. Della Corte	Corso Francia 186	4	
3	Biblioteca Centro Interculturale	Corso Taranto 160	6	
7	Biblioteca civica Francesco Cognasso	Corso L. Quinzio Cincinnato 115	5	
8	Punto prestito G. D'Annunzio	Via Gaspare Saccarelli 18	4	
13	Biblioteca civica I ragazzi di Utoya	Via Zumaglia 39	4	
12	Biblioteca civica Natalia Ginzburg	Via Cesare Lombroso 16	8	
10	Biblioteca Nazionale Universitaria di Torino	Piazza Carlo Alberto 3	1	

Very High Priority   High Priority   Medium Priority   Low Priority   Very Low Priority

Thus, as shown in the above table, a priority ranking for each library is set into action in regard to the number of elderly served by each service area based on the UHI hazard across the city. This strategy aims to enhance the city's adaptive capacity by focusing on the effective and fair allocation of resources. The libraries allocated with very high priority are located in circoscrizioni 2, 3, 4 and 6.

By implementing the priority ranking as illustrated in the section 6.2.1 and 6.2.2, the city can strategically allocate resources to climatize the 15 libraries, thereby improving the accessibility and effectiveness of these proposed UCSs. This targeted approach of the alignment of the priority ranking with the UHI hazard map underscores the importance of maximizing the impact of adaptive measures to improve resilience during extreme heat events.

6.3. Proposition - 2

Beyond Libraries:

According to the climate resilience plan of Turin, unless appropriate mitigation and adaptation strategies are put into place, the city's future climate conditions are not expected to improve. The literature and accessibility assessment of this study highlights the effectiveness of public facilities as UCS, especially when integrated into a broader urban resilience strategy. As mentioned earlier, Turin's adaptive strategy – "A more livable city", discusses a set of actions that include green areas as a climate refuge and introducing cool and comfortable schools and public amenities (Climate Resilience Plan, 2020). These actions include emphasizing access routes to climate refuges, improving indoor thermal environment and provision of required services to optimize the functionality of these public facilities, especially during summer. Through the following proposition a framework for introducing UCS in high – priority areas of Turin are set. These UCS include not only public libraries but also green spaces and other public infrastructure. The risk assessment completed in Turin's urban study subsection will serve as the basis for this prioritization. As seen from the prior subsections, only 48.78% of the senior population is served by the libraries, despite the fact that every library is climatized. This significant gap highlights a vital area for improvement. The intent of this proposal is to raise this proportion, which will increase the number of elderly populations who have spatial access to the nearby UCS. By strategically expanding and optimizing the UCS network, this proposal ensure that more elderly have access to nearby climatized facilities. This is essential to protect their health and well – being, especially during extreme heat conditions. As a result, the city can be one step closer towards building a more resilient, inclusive and moreover a livable urban environment that serves to the needs of its most vulnerable. Identifying areas or neighborhood that require immediate provision of an UCS is based on the elderly population living in high-risk area and is not served by any of the proposed UCSs i.e. the public libraries.

UHI Risk assessment with respect to the vulnerable population of Turin

Analyzing the distribution of risk level in the city to further understand the areas that needed to be prioritized for establishment of UCS.

Performing Spatial Accessibility Analysis

To determine the proportion of the population that lacks physical accessibility to these libraries, service zones for the elderly have been developed within a 15-minute time frame concerning libraries.

Identifying High Risk areas, not served by any Libraries

From the UHI risk assessment combined with the service areas of proposed UCS reveal that several neighborhoods in Turin aren't spatially accessible to these UCS. Hence, recognizing these areas is required in order to provide accessibility to UCS for all exposed population, particularly those residing in high - risk areas of the city.

From the below figure, the visual identification of priority areas for enhancement of UCS intervention in the urban fabric of Turin is carried out.

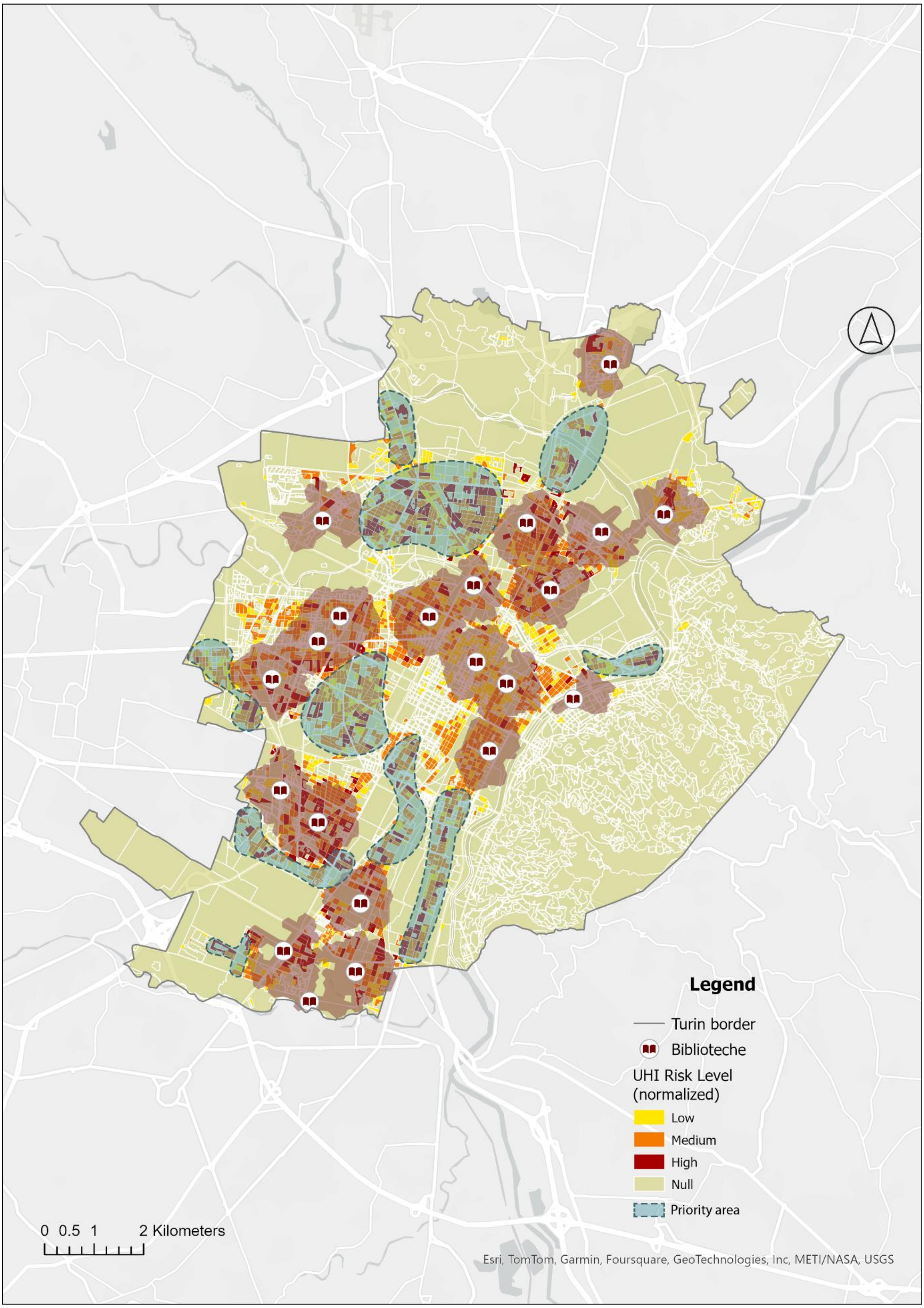


Figure 46: Identification of priority area based on the assessments of UHI risk and UCS accessibility with respect to the elderly population. Source: Author

The supportive tasks for this particular proposal include selection of potential infrastructure from the public facilities inventory including community centers, green areas and other recreational areas, assessing their ability for UCS adaptation.
Through this particular interdisciplinary approach i.e. by combining risk assessment, spatial accessibility analysis and community engagement, Turin's adaptive capacity can be improved.

6.4. Recommendations

While spatial accessibility to UCS is important, assessing pedestrian walkability during high summer temperatures requires a comprehensive evaluation of the urban environment. As mentioned in the literature, thermal comfort is defined as the condition of mental contentment with the thermal environment and is also a key determinant of walkability, especially for the elderly who are more vulnerable to heat stress and heat – related health issues. High temperatures can deter the elderly from walking thus contributing to social isolation and restricting their access to essential services like UCS. Through the reference studies and the city's resilience plan, it can be confirmed that exposure to high temperatures can alter the behavioral patterns of pedestrians. As explained in chapter 3, certain behavioral parameters in response to thermal discomfort are observed in pedestrians such as route selection to avoid direct exposure to the sun, walking speed reduction and alteration in social activities of urban areas. Residents opt to interact during the morning or late evening hours to avoid any discomfort caused by the high temperatures in the urban areas (Climate Resilience Plan, 2020). The change in behavior to avoid intense heat has an impact on public space usage and social dynamics, with noticeable reductions in outdoor activities around midday.

Solar access or the exposure to solar radiation is one among the most influential elements on the outdoor thermal comfort at the pedestrian level (Shashua-Bar et al., 2011). Through the hourly solar radiation analysis carried out for each road segments of Turin, it was observed that the during the day, especially in the noon time, most of the streets experience high solar radiation which can impact the thermal comfort of pedestrians who use these streets in order to reach the nearby UCS. Unlike air temperature, solar exposure can be regulated by incorporating certain street level shading interventions.

Therefore, mitigation and adaptation strategies in response to UHI and HWs should also focus on micro – scale such as the urban street scale. This focus is important for enhancing pedestrian comfort, safety and walkability. These micro interventions are essential as they directly impact the daily experiences of pedestrians and can improve the thermal environment of the dense urban fabric.

"It's one thing to know that there's a library with A/C downtown, but it's another thing to get there. If you don't have a car, you either have to walk or wait at a bus stop in sweltering heat, which might be more dangerous than staying where you are."

- Jake Bittle (writer at Grist.org) on Seattle HW 2021

6.4.1. Pedestrian – Centric Approach: Creating Cooler and Comfortable Streets

Through a pedestrian – centric approach, the focus can be on creating cooler and comfortable streets to enhance the walkability and overall quality of life for all its citizens. This approach prioritizes the needs and comfort of pedestrians by integrating various cooling and shading strategies into the urban fabric. The following design strategies were proposed for the university campus of Malaga, Spain [33] to improve the thermal comfort of users during extreme weather conditions:

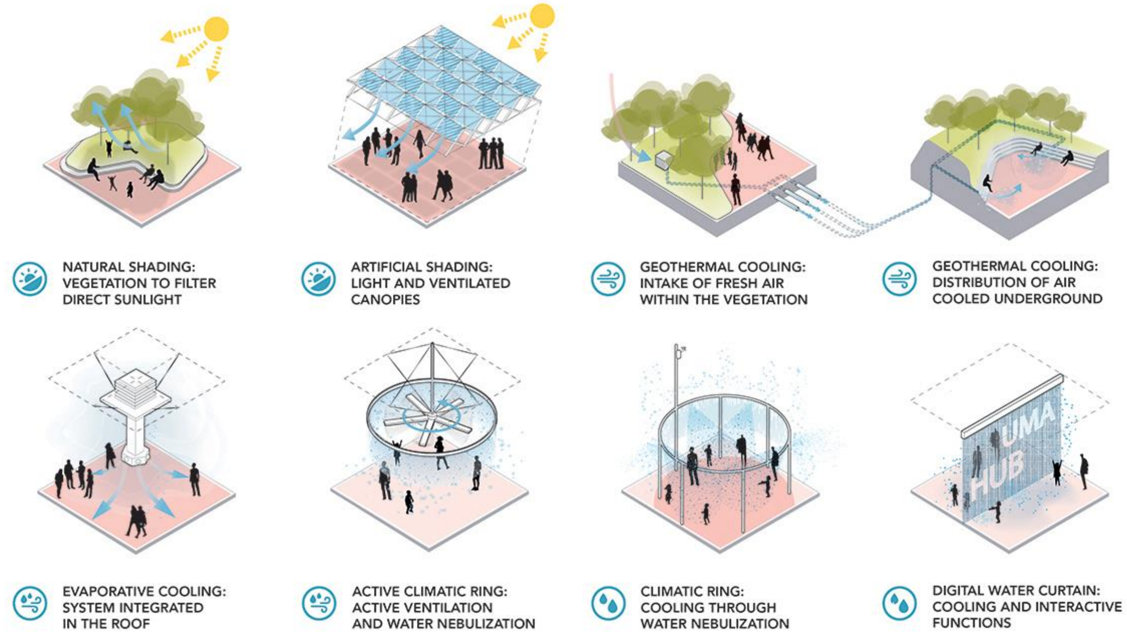


Figure 47: Design strategies to enhance the thermal environment in the Campus of Teatinos of the University of Malaga, Spain; Source: Ecosistema Urbano, Malaga Campus.

These street scale design strategies can be implemented on the streets of Turin to reduce thermal discomfort for pedestrians during their trip to libraries on high temperature days. The urban heat island effect can be significantly mitigated by using cool, reflective materials for building surfaces and pavements in addition to green infrastructure. Immediate relief from sun exposure can be obtained by installing shading structures over sidewalks and public spaces, such as pergolas, canopies and awnings. By using evaporative cooling, adding water elements like fountains and misting systems improves thermal comfort even further. The location of UCS and shaded rest areas, in conjunction with smart urban planning and design that promotes natural circulation, ensures that streets are accessible and comfortable throughout the day.

By focusing on these pedestrian-centric strategies, cities can create more resilient, livable, and sustainable urban environments that cater to the needs of all residents, regardless of age or mobility.

[33] Source: ecosistemaurbano.com

Chapter 7

7.1. Conclusion

The study presented in this master’s thesis explores the potential of converting public libraries into Urban Climate Shelters (UCS) in the city of Turin to enhance spatial and temporal accessibility for vulnerable population, especially the elderly, during extreme heat events. The findings underscore the critical need for adaptive measures in urban planning to make the city more resilient to the adverse effects of climate change, particularly the Urban Heat Island (UHI) effect and Heat waves, which exacerbates heat stress in urban environments, thus compromising the livability of the city.

The study reveals that climate change impacts differ across various urban dimensions. The study shows that Turin’s existing resilience plan, which includes the "A More Livable City" strategy, aims to enhance the thermal comfort of the city by introducing the concept of climate refuge. However, the increasing thermal discomfort for pedestrians highlights the necessity of *accessible* – in terms of spatially and temporally, climate refuges. The spatial analysis indicates that by strategically locating UCS within the framework of the 15-minute city concept, approximately 48% of Turin’s vulnerable population can access a climate refuge within a 15-minute walk, significantly improving the city's adaptive capacity. This particular ideology can be considered as a response to the research gap found in the accessibility study of climate shelters or cooling centers.

Addressing the research question, *“How can the conversion of libraries into Urban Climate Shelters in Turin, Italy, effectively provide spatial and temporal accessibility for vulnerable populations, particularly the elderly, during extreme heat events?”,* the study provides a data – driven strategy. When normal walking speed is taken into consideration, the spatial accessibility analysis of libraries shows that 73.68% of the elderly population in medium-hazard areas and 26.31% in low – hazard areas, can access the libraries within 15 – minute. In order to exploit the advantages of UCS, this study emphasizes the necessity of focused initiatives in particular to urban areas.

Repurposing public libraries to implement UCS addresses multiple facets of urban resilience. First of all, it offers immediate relief amid heatwaves, reducing elderly heat-related mortality and morbidity rates. Second, by making use of already-existing infrastructure and fostering resource efficiency, it meets broader goals concerning urban sustainability. Moreover, the prioritized framework for climatizing libraries guarantees resource allocation where it is most required, enhancing the city's overall ability to adapt. The study emphasizes how strategically significant it is to incorporate green areas and other public amenities within the UCS network. This broader approach encourages a more welcoming and livable urban environment in addition to increasing the availability of accessible climate refuge. As mentioned above, the significant gap in UCS coverage with only 48.78% of the elderly served by Turin’s public libraries, indicates the potential for considerable improvement through the inclusion of different public spaces. The ultimate goal should be to increase this 48.78% to 100%, ensuring that no one is left behind.

Moreover, broadening the scope to encompass additional public areas and facilities as potential UCS will provide a more all-encompassing strategy for urban resilience. Using qualitative data to influence feasibility studies can help create and deploy a more effective UCS network. This coordinated strategy will boost community resilience, promote climate adaptation, and improve the health and well-being of urban residents.

In addition to Proposition 1, which gives priority to ranking current libraries for conversion into Urban Climate Shelters (UCS), evaluating the social and health benefits of climatized libraries for the elderly population is a crucial step that requires more research. The quantitative results of this master's thesis can be complemented by further qualitative analysis, which focuses on the added advantages that the elderly actually and perceivably receive. Surveys and interviews shall be done with elderly residents and library users in order to collect essential qualitative data. The first-hand reports of the supposed benefits of air-conditioned areas, like increased comfort, better social interaction and improved health during heatwaves, will be provided by these approaches. A thorough grasp of the impact of climatized libraries will be possible with such an integrated approach, supporting the quantitative data with insightful, rich qualitative insights. When combined, these studies can provide policymakers and library administrators in Turin with practical recommendations that will guarantee that the initiatives are both user-centered and data-driven. Further, this can determine particular features and services that should be incorporated into UCS by recognizing the needs and preferences of the elderly. In order to make sure that the UCS network is both usable and appealing to its intended users, this qualitative analysis will also address any challenges or limitations that might prevent the elderly population from utilizing these areas, making the UCS network both accessible as well as appealing to its target audience.

Furthermore, Proposition 2, which identifies the neighborhoods that are not served by any UCS, for immediate interventions, also advocates for conducting a qualitative analysis based on these surveys and interviews. Creating a feasibility study from this data can contribute significantly to structure a more efficient UCS network in the city of Turin. This approach will improve the health of the urban population, climate adaptation, and the role of public infrastructure in building community resilience in addition to improving the design and application of UCS. The results of these qualitative analyses will play a crucial role in developing public infrastructure that is resilient to climate change and in giving decision-makers useful, fact-based advice to assist the city's adaptation plans.

In conclusion, Turin's transformation of public libraries into Urban Climate Shelters offers a viable and effective way to enhance the temporal and spatial accessibility of vulnerable groups during periods of excessive heat. Turin can greatly increase its capacity for adaptation and promote a more resilient, inclusive and livable urban environment by giving priority to the climatization of libraries and broadening the UCS network to encompass a variety of public areas. Policymakers and urban planners can use the knowledge gathered from this research to create focused initiatives that address the immediate concerns brought on by climate change, thereby improving the health and well-being of the city's most vulnerable residents.

7.2. Final Consideration

During the course of writing this thesis, my hometown, Kochi in India faced one of the warmest summers this year following the record-breaking summer of 2016 when temperature reached 41.9°C.

The unprecedented summer of 2024 brought the unfamiliar HW condition back to this coastal state of Kerala raising the temperature to be 41.8°C as recorded by the Indian Meteorological Department (IMD). The 2024 HW saw over 300 morbidity cases related to heat and 10 mortalities in Kerala alone. As the state has tropical monsoon climate (Am by Köppen – Geiger climate classification), the intermittent summer rains added to the woes of increasing humidity. On the other hand, north India experienced HWs due to low humidity. According to the IMD, one of the main reasons for the drastic change of climate across the country is change in the land use and land cover driven by the urbanization process.

The El Nino phenomenon increased the global temperature resulting in extreme heat conditions in many parts of the world. Majority of the countries in the world are experiencing the adverse impact of changing climate and global warming. The devastating wildfires of Australia 2019, the severe flooding of 2020 in Bangladesh and many more are only a few examples that underscores the urgent need for global action to mitigate and adapt to the climate change.

Innovative tools such as UCSs are important, however, a single such shelter won’t be able to provide relief at the city scale. Therefore, it’s important to upscale these actions in order to enhance the urban resilience, thus promoting the concept of “Shelter Cities”.

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