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Investigating the Impact of Heat Stress and Green Space Accessibility for At-Risk Communities

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Investigating the Impact of Heat Stress and Green Space Accessibility for At-Risk Communities

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Abstract. This work addresses the urban heat island issue and its impact on vulnerable populations in cities. Urban heat islands refer to the phenomenon where temperatures in built-up areas exceed those of surrounding rural regions due to the absorption and retention of heat by built-up surfaces and the lack of vegetation. The study focuses on Milan and uses data from Daytime Near-Surface Air Temperature estimates and the Normalized Difference Vegetation Index to assess accessibility to green spaces during an extreme heat event. The goal is to establish a practical approach for assessing urban areas that are particularly vulnerable to extreme heat and have low accessibility to possible 'urban cool islands' to inform climate-proof urban planning, design, and policies and promote equitable access to green spaces. The methodology involves constructing a 3x3 table containing nine classes based on matrix logic, representing different degrees of thermal perception-based accessibility to green. The results of this study could be used to prioritize interventions to increase thermal comfort and achieve a more sustainable urban environment.

1. Introduction

Over the past few decades, the effects of climate change have become increasingly evident, with rising temperatures, changing weather patterns, and more frequent extreme events. One of the most pressing challenges climate change poses is the impact on urban areas, particularly vulnerable to global warming effects. In addition to being significant contributors to greenhouse gas emissions, cities also exhibit a phenomenon known as the urban heat island [1], whereby temperatures in built-up areas can exceed those of surrounding rural regions by several degrees. The Urban Heat Island (UHI) effect is caused by a combination of factors, including the absorption and retention of heat by built-up surfaces such as roads and buildings, the lack of vegetation, and the concentration of human activities. The UHI effect can have serious consequences for public health. Studies show that long-period exposure to extreme heat is strongly related to an increased risk of heat stroke, dehydration, and cardiovascular and respiratory diseases, especially for vulnerable groups [2], such as the elderly, children, and low-income communities, resulting in increased mortality [3]. The vulnerability here describes the state where certain groups have limited coping mechanisms to survive heat waves. That can be due to several reasons, namely, physiological factors, social isolation, or existing health conditions.

Moreover, heat waves, which are often exacerbated by the urban heat island effect, have been shown to significantly impact outdoor thermal comfort and pedestrian behaviour, with individuals more likely to opt for air-conditioned cars over active modes of transportation such as walking or cycling in response to extreme temperatures [4], [5]. Actually, the use of sustainable and healthier modes of transport is strictly related to several factors, including vegetation, urban materials, the presence of water, and natural ventilation, which can influence the psycho-physiological conditions of people and create a sense of comfort in outdoor spaces [6]. For instance, access to green spaces can have a significant impact on resilience to heat stress during hot spells. However, although studies have explored various factors that influence pedestrian patterns [7]–[9], few studies have tried to correlate thermal perception-based issues with different travel modes [10], or the relationship between heat waves and pedestrian accessibility.

This study is a first attempt to establish an effective approach for assessing urban areas that are particularly vulnerable to extreme heat and have low accessibility to possible 'urban cool islands'. Special emphasis is placed on at-risk populations. The analysis considers an extreme event, and as a case study, we have considered the city of Milan, Italy. Expected output could be used to inform climate-proof urban planning, design, and policies to prioritize interventions for more comfortable thermal perception and achieving a more sustainable urban environment. Ultimately, the goal is to promote equitable access to green spaces, and to enhance heat stress resilience and well-being of the most vulnerable members of the community.

2. Materials and methods

2.1. Data

This analysis focuses on the city of Milan, situated in the northwestern Italian region of Lombardy. The area, classified as 'Cfa' under the Köppen climate classification scheme, is characterized by a humid subtropical climate with moderate temperatures and hot summers [11], [12]. To assess the accessibility to green spaces during extreme heat events, we first identify heat-stress areas using the Daytime Near-Surface Air Temperature (NSAT) estimates. Accessibility is calculated using a street centreline network and residential buildings, with vulnerable populations, as points of origin, while the potential green areas in the city served as destination points. The population data were extracted from the census tracts provided by the Italian National Institute of Statistics (ISTAT). To identify the potential green areas, we used the Normalized Difference Vegetation Index (NDVI) obtained from Planet-Scope satellite imagery at a spatial resolution of 3 meters per pixel. To account for high greenery density, a NDVI threshold of 0.4 was used to select green areas. Based on the Land Use Land Cover (LULC) system in the Lombardy region, only green areas within the urban settlement have been considered, while rural areas were excluded.

2.2. Methodology

The methodological approach aims at assessing thermal perception-based accessibility to green spaces on a city scale, specifically targeting vulnerable populations selected based on their vulnerability to extreme heat. This assessment considers groups such as the elderly, children, and individuals with no income, who are particularly susceptible to the adverse effects of high temperatures. The method entails a few steps as follows: (i) After calculating the data, we passed the average values of accessibility to green spaces and daytime NSAT to Census Tracts; (ii) secondly, we classified the values of both, accessibility to green spaces and daytime NSAT into three categories (H-high, M-medium, L-low) using Equal Count (Quantile) mode; (iii) lastly, we constructed the matrix table that contains the nine classes built based on a matrix logic as follows: on the X axis we reported the three classes of accessibility to green spaces (H, M, L), and on the Y axis we have the three classes of thermal comfort perception (H, M, L). The combination of the axes results in a nine-classes of thermal perception-based accessibility to green, as shown in Figure 1. Each class represents a different degree of thermal perception-based accessibility, starting from the H class, where both values are high in a positive matter (i.e., high accessibility to green spaces and better thermal perception), to the L class, which shows the critical places in the city during extreme heat events (i.e., low accessibility to green spaces and low thermal perception).

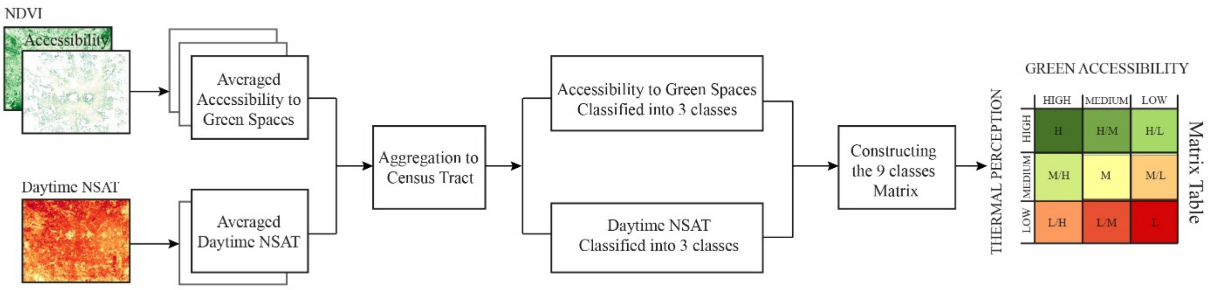
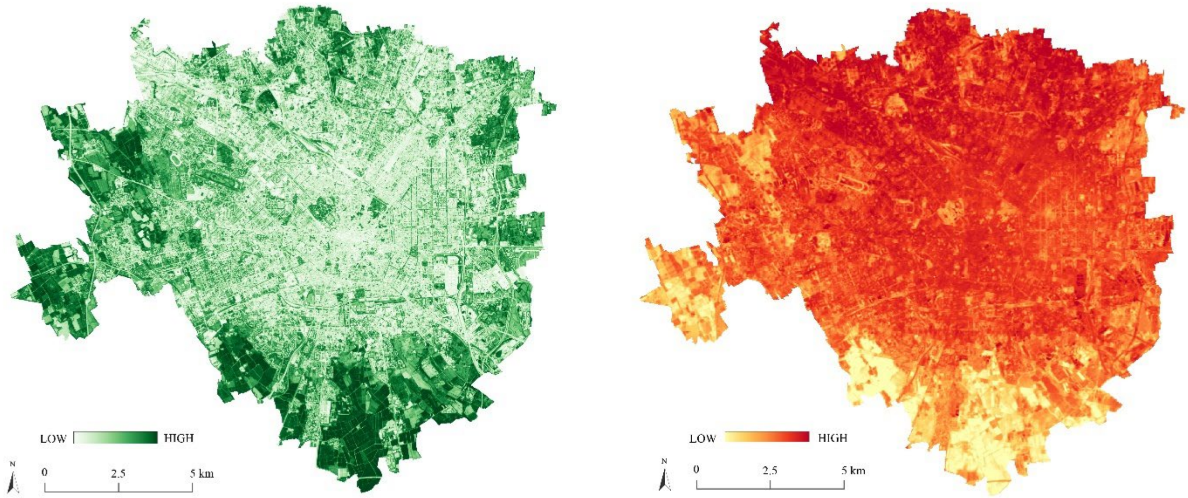


Figure 1. Workflow of the methodology

2.3. Constructing the Daytime NSAT and NDVI Map

To estimate NSAT we combined thermal data from the MODIS sensor (onboard the Terra satellite) that provides Land Surface Temperature with air temperature measured by weather stations provided by the Regional Environmental Protection Agency (ARPA). Through a geo-statistical *model,* we get air temperature (raster format), at a resolution of 1 km per pixel, for a critical event (warmest day) that in 2017 was the 4th of August. Optical data-derived albedo, from Landsat satellites, was used to downscale NSAT at 30 meters spatial resolution per pixel (Figure 2b). Hence, NSAT is used as a proxy for thermal comfort.

On the other hand, urban green areas were considered as destination points where at-risk urban populations will feel better thermal perception during heat waves. Indeed, vegetation is widely recognized to have a high negative spatial correlation to temperature [13]–[15], which means the higher vegetation the lower the temperatures. For assessing the destination points of green spaces we used the NDVI (Figure 2,a), which has been broadly explored for UHI studies [15], [16].



(a) (b)

Figure 2. (a) The NDVI at 3m spatial resolution; (b) The Daytime NSAT at 30m spatial resolution

2.4. Constructing the Accessibility to Green Spaces Map

The necessity to measure and analyse accessibility in cities has brought many innovative techniques and toolboxes into urban studies. For this study, to estimate pedestrian accessibility, we used the Urban Network Analysis (UNA) toolbox [17] in Rhino. Based on the UNA toolbox, and the search radius approach, we can currently calculate the accessibility of different transportation perspectives such as walking, biking, and driving [9]. In particular, we focused on the gravity metric, as one of the suitable accessibility metrics, providing a strong measure that takes into account the number of the ‘attractiveness destinations’ and the reaching cost [9]. According to Sevtsuk [9], both the gravity and reach metric explain the convenience of reaching each location from its surrounding environs. For this study, an 800m radius distance is used as a threshold, which represents an area within a 10-minute walk, typically the maximum distance that many individuals are willing to walk by foot. Residential buildings with at-risk populations were used as origins. Figure 3 shows the spatial distribution of the percentage of at-risk populations, which includes children under 9, elderly over 65, and no-income populations, over the total population per census tract.

As destination points, we have used a fishnet approach to derive several equally distributed points within each green area, at a distance of 30 meters, according to a hexagonal grid. Further, we assumed that the at-risk population would be less willing to walk longer distances and modelled this behaviour through a stronger distance penalty. Finally, the average of both datasets, accessibility to green spaces and daytime NSAT are assigned upon the census tracts of the city of Milan, as it is shown in Figure 4,a and 4,b, respectively.

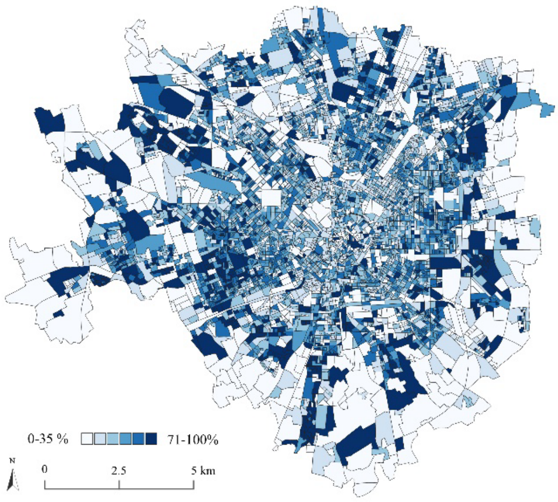
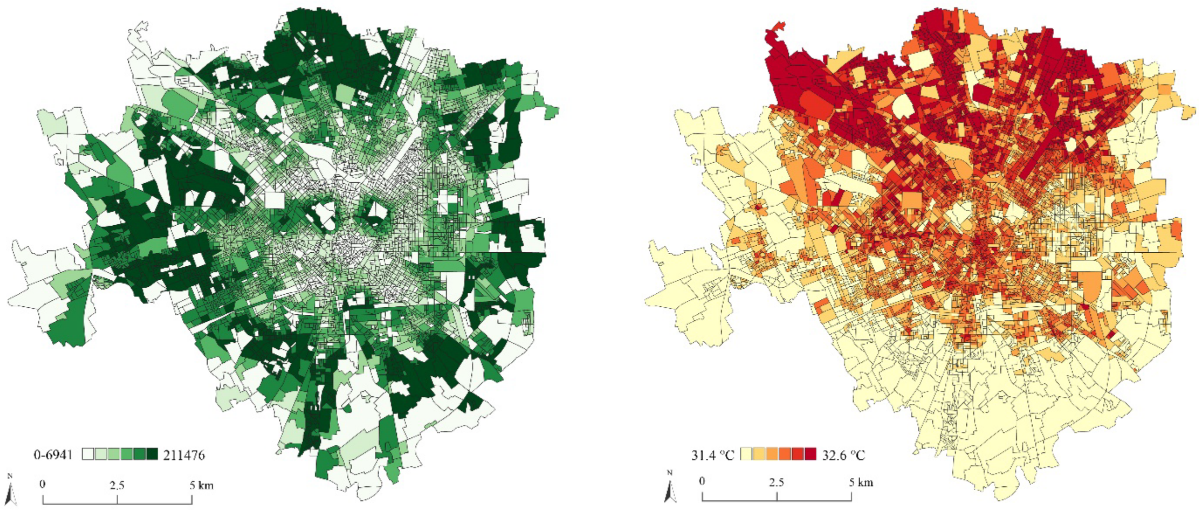


Figure 3. Spatial distribution of the percentage at-risk population by census tract



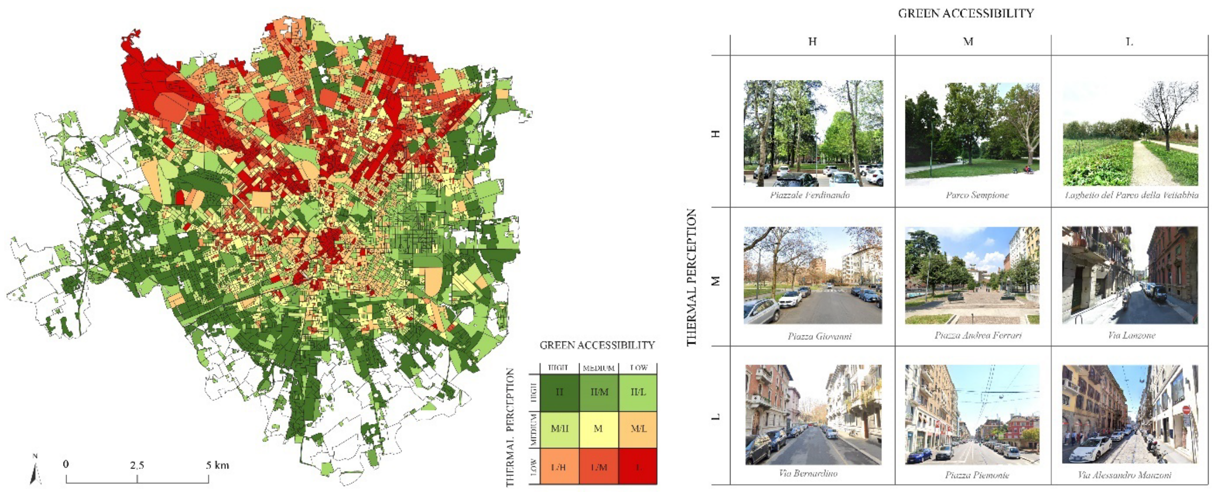
(b) (b)

Figure 4. (a) The averaged accessibility to green spaces; (b) The averaged daytime NSAT

3. Results

The result is a map that shows the spatial distribution of the possible thermal perception-based accessibility to green spaces (Figure 5,a), within a 10-minute walking radius (800m), with a special focus on at-risk populations during hot spells. The 3x3 matrix table is also illustrated with Google Street View photos (Figure 5,b) to give a sense of the different levels concerning some in situ samples of each category. For instance, the H class shows the highest accessibility to green spaces along with the best thermal perception conditions, based on the NSAT map as a proxy, i.e., low urban temperatures describe better thermal perception and vice versa. Hence, the H category indicates the most comfortable thermal perception places in the city due to nearby vegetated areas. Whereas the L category shows places that do not have accessible green spaces within 10 minutes, and high temperatures. This condition can affect people's health and well-being. Nonetheless, we must highlight that in the M or M/L class, although we have low accessibility to green spaces, we can have medium thermal perception during the day due to lower temperatures from shadow casting generated by tall buildings and the dense urban form.

Based on the map, we emphasize that the most affected areas are the major exit routes from the city (viale Monza, via Padova, viale Fulvio Testi, viale Certosa), Chinatown area (in particular around via Paolo Sarpi), the area above Garibaldi Station and the very core of the city centre, confirming the condition of greater suffering in the areas north of the city, due to the greater urban density and imperviousness of the soils. Therefore, if we exclude the city centre, the large radial urban arteries also intercept vulnerable areas from a socio-economic point of view, exacerbating population fragility. Hence, this mapping can be of great support to the local government in identifying hotspots in emergency management during extreme events, and in identifying places of attention when allocating economic resources for urban regeneration.



(a) (b)

Figure 5. (a) Thermal Perception-based Accessibility; (b) Representation of the matrix table with site location photos, using Google Street View

4. Conclusions and further research

This study employs data-driven analysis, utilizing GIS and remote sensing techniques, to assess thermal perception-based accessibility to green spaces for at-risk populations. The framework presented aims to support climate-proof planning and design, specifically tailored for vulnerable groups, in outdoor urban retrofitting. The results identify areas characterized by low accessibility and high temperatures, underscoring their potential impact on population health and well-being. The findings emphasize the importance of climate-proof urban planning and targeted interventions to improve heat stress resilience and ensure equitable access to green spaces for vulnerable populations.

However, this research has some limitations that may affect the results of the maps and requires further examination in future research. Firstly, we used the daytime NSAT as a proxy for thermal perception. Nonetheless, other comfort-oriented indicators, such as the Universal Thermal Climate Index (UTCI) and Mean Radiant Temperature (MRT), should be considered. Also, the analysis should consider different hours of the day and test different grid aggregations for representing higher resolution data rather than just relying on Census tracks as the aggregation unit. Secondly, even though the gravity metric has proven to be suitable to address accessibility to destination points (in our case, green spaces), further investigations should at least explore and compare different accessibility metrics, different models, and, mostly, different ranges of walking radius tailored for different population targets. Lastly, there might be some ambiguity using only the NDVI. Even though we assigned a high threshold for the NDVI to capture densely vegetated areas, this can also be considered as a proxy of the green areas that, instead, should be derived considering the urban land use land cover. Further research will address different contexts and indicators for heat-stress resilience and urban health in cities, i.e., mapping thermal perception-based accessibility during heat waves of children to kindergartens, employees to work or elderly to comfortable (cooler) places. Also, not only the accessibility to green areas but rather the exposure to green spaces should be considered as a heat stress resilience measure.

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