ICLEI Local Governments for Sustainability

UCCI Unión de Ciudades Capitales Iberoamericanas
União das Cidades Capitais Ibero-americanas

IberAtlas

Ibero-American Urban Climate Atlas

Supported by:

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Credits

This document was prepared based on consultancy work conducted by ICLEI within the scope of the UCCI Technical Cooperation Project: "IberAtlas: Ibero-American Urban Climate Atlas," funded by UCCI, Madrid City Council and ICLEI South America.

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UCCI

In a world in crisis and transformation, the growing urbanization is a global phenomenon that strongly manifests itself in cities. Approximately 70% of Greenhouse Gas (GHG) emissions come from urban areas, which together account for more than 80% of the global Gross Domestic Product (GDP) (UN-Habitat). As such, the effects of climate change, such as extreme weather events, heatwaves, rising sea levels, and food and water insecurity, are being addressed on the ground, within communities.

Cities, therefore, are key in leading the progress toward sustainable, resilient, and inclusive development, undertaking urgent and trans-formative actions across multiple actors and levels to address climate change mitigation and adaptation.

In the framework of the Decade of Action and the five-year period leading up to the implementation of the Sustainable Development Goals (2025-2030), it is also crucial to recognize the role of Ibero-American local governments as political entities and agents of change, as well as the power of strengthened cooperation and strategic partnerships to achieve these goals.

Without contextualized and reliable data that provide clarity and dependability regarding the challenges and opportunities faced by cities, it will be more difficult to define action priorities and implement effective public policies that address comprehensive solutions to achieve climate goals and sustainable development.

With this in mind, the Union of Ibero-American Capital Cities (UCCI) and ICLEI – Local Governments for Sustainability, together with 11 member cities with dual membership, are driving the Urban Climate Atlas of Ibero-America: IberAtlas. This tool aims to raise awareness, strengthen the position, and influence our region regarding the issue of urban heat islands as a priority problem, serving as a roadmap toward COP 30 in Belém do Pará 2025.

Committed to bringing the voice of Ibero-American local governments to the center of global decision-making and emphasizing the importance of partnerships, as reflected in the First Meeting of Ibero-American Cities (October 31, 2024, Madrid), UCCI and ICLEI present this IberAtlas as a pioneering knowledge management tool and a concrete contribution to accelerating climate commitments.

Furthermore, accompanying this initiative is a call to action for local governments as protagonists, eleva-ting our region's vision on climate action, sustainable financing, and the conservation of biodiversity and natural and cultural heritage, to ensure a better quality of life for the people living in our cities and for future generations. A community of more than 76 million people united on both sides of the Atlantic, representing a significant demographic force with decisive influence on global governance for a prosperous, humane, and sustainable development.

Luciana Binaghi Getar,

General Director

ICLEI SOUTH AMERICA

The complexity of the contemporary world demands coordinated actions among different levels of government to seek the best solutions for global challenges, such as the climate crisis. City networks play an important role in this regard, enabling the collective impact of local governments within the international system, horizontal exchange of experiences, and the identification and systematization of best practices throughout the implementation process.

The Ibero-American region holds significant potential for collaboration, making the alliance between influential networks like UCCI and ICLEI strategically essential. The signing of an Institutional Cooperation Agreement for the creation of the “IberAtlas: Ibero-American Urban Climate Atlas” for COP 30 in Belém do Pará, Brazil (2025), exemplifies the potential impact of this alliance. The agreement aims to strengthen climate action policies in Ibero-American cities and to enhance their joint influence in strategic spaces.

Heat waves and the frequency of extreme temperatures, both day and night, are expected to increase as a result of climate change, as indicated by the Intergovernmental Panel on Climate Change (IPCC). These phenomena are intensified by population density and urbanization patterns — including verticalization, extensive paving, and insufficient preservation and distribution of green areas — which contribute to heightened thermal discomfort, declining air quality, and an increase in respiratory diseases. Urban heat islands and heat waves cause serious health issues and affect the population’s well-being, especially among low-income individuals, the elderly, and children.

In this context, the Institutional Cooperation Agreement is crucial for driving transformative actions grounded in effective technical cooperation. It enables analysis of both the specific local conditions of each city and the broader regional level concerning global climate change risks, with particular emphasis on the impacts of urban heat islands. Thus, the objective of this study is to assess changes in temperature regimes and their territorial effects in cities.

ICLEI is proud to have contributed to another important project involving cities that play a significant role in the global climate landscape. Including Barcelona, Belém do Pará, Bogotá, Buenos Aires, Lisbon, Madrid, Montevideo, Quito, Rio de Janeiro, San Salvador, and São Paulo. We hope this document inspires action. This document serves as a support tool designed to strengthen strategic recommendations for the Ibero-American context, intended for presentation to high-level multilateral organizations.

Have a nice reading!

Rodrigo Perpétuo,

Secretario Ejecutivo

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Presentation

The “IberAtlas project: Ibero-American Urban Climate Atlas,” developed within the framework of the UCCI 2024 Technical Cooperation Project Call and led by the Union of Ibero-American Capital Cities (UCCI) and ICLEI – Local Governments for Sustainability, focuses on creating an Ibero-American urban temperature atlas, built on a technical-scientific foundation. This project includes 11 partner cities with dual membership: Barcelona, Bogotá, Buenos Aires, Lisboa, Madrid (UCCI member), Montevideo, Quito, Rio de Janeiro, San Salvador, São Paulo e Belém do Pará (ICLEI member).

The research aims to analyze the local context of each city as well as at the Ibero-American regional level, regarding the risks of global climate change. With a focus on the impact of heat islands, the objective is to assess changes in temperature patterns and their territorial effects within cities. Additionally, it considers how the onset of heat waves could further strain these territories.

On the other hand, the advocacy component of the project consisted of the construction and presentation of a Position Paper/Call to Action, launched within the framework of COP 29 in Baku, Azerbaijan, in the presence of political representatives, experts, municipal authorities and city networks. The document was anchored in the exchange of experiences on sustainable public policies in response to the impacts of climate change generated by urban heat islands, and served as a strategic tool for the political positioning of Ibero-American local governments in the face of the global challenges of the climate agenda.

As part of the project’s activities, two virtual awareness-raising workshops were held, designed as virtual dialogues to facilitate the exchange of experiences and examples of adaptive actions from partner cities in response to rising temperatures. They serve as an information-gathering process for the IberAtlas tool.

Throughout these sessions, the IberAtlas methodology and preliminary results were discussed, and discussion groups were organized with guiding questions to collaboratively draft the *Positioning Document/Call to Action* on strategic recommendations for the Ibero-American region, to be presented to high-level multilateral organizations.

Next, an introduction is provided on the urban context, focusing on cities, heat islands, and heat waves, followed by the IberAtlas methodological approach and technical profiles for each city, with reliable and up-to-date data.

1. Introduction

Cities offer a wide range of essential services, such as education, health care, and leisure, along with enhanced cultural, social, and employment opportunities. In 1960, about 34% of the world's populatio — approximately 1.02 billion people — lived in urban centers. Today, that figure has grown to around 57% — or 4.52 billion people. This number is expected is projected to reach 68% by 2050 (UN-Habitat, 2022; Our World in Data, 2022).

Meanwhile, due to the ways in which urban spaces are developed and utilized, climate change — a process accelerated by greenhouse gas emissions — disproportionately impacts urbanized areas. Consequently, the quality of life in cities is expected to worsen in the coming decades, as more frequent and severe extreme events pose significant risks to public health, human life, and biodiversity (Jabbar *et al*., 2023; Marinaccio Urban *et al*., 2019).

Among the climate threats associated with urbanization patterns, this study will examine heat islands and how these areas may become increasingly vulnerable to the effects of heat waves, which are anticipated to grow more frequent due to climate change.

1.1 Heat Waves

Heat waves are a natural environmental effect associated with variations in atmospheric patterns and climatic fluctuations. These phenomena can influence global climate patterns, leading to periods of higher temperatures in certain regions. Heat waves occur when a region experiences a prolonged period of exceptionally high temperatures, usually lasting several days or weeks. Although there is no exact definition for the duration that constitutes a heat wave, the World Health Organization (WHO) and the World Meteorological Organization (WMO) define an extreme weather event as a heat wave after 2 or 3 consecutive days of air temperatures significantly higher than the average daily maximum temperatures for the reference period (World Meteorological Organization, WMO).

However, although heat waves are natural phenomena, their frequency, intensity, and duration have increased in recent decades due to climate change caused by human activities. Global warming is raising global average temperatures, making heat waves more common and severe. In other words, while discussions about climate change often focus on global average temperatures, what people truly endure from climate change are extreme temperatures. This means that higher temperatures, which were once rare, will become increasingly common.

It is important to highlight that "heat waves" are caused exclusively by climatic phenomena and can occur in rural areas, where there is potential for droughts and fires, whereas "heat islands" are an exclusively urban phenomenon.

Furthermore, it is essential to recognize that the planet's climate is not uniform; heat waves are intensified in specific regions and are influenced by how we use space and structure our societies. In this context, urbanization is among the factors that increase the impacts of heat waves, particularly due to its overlap with the effects of the urban heat island phenomenon.

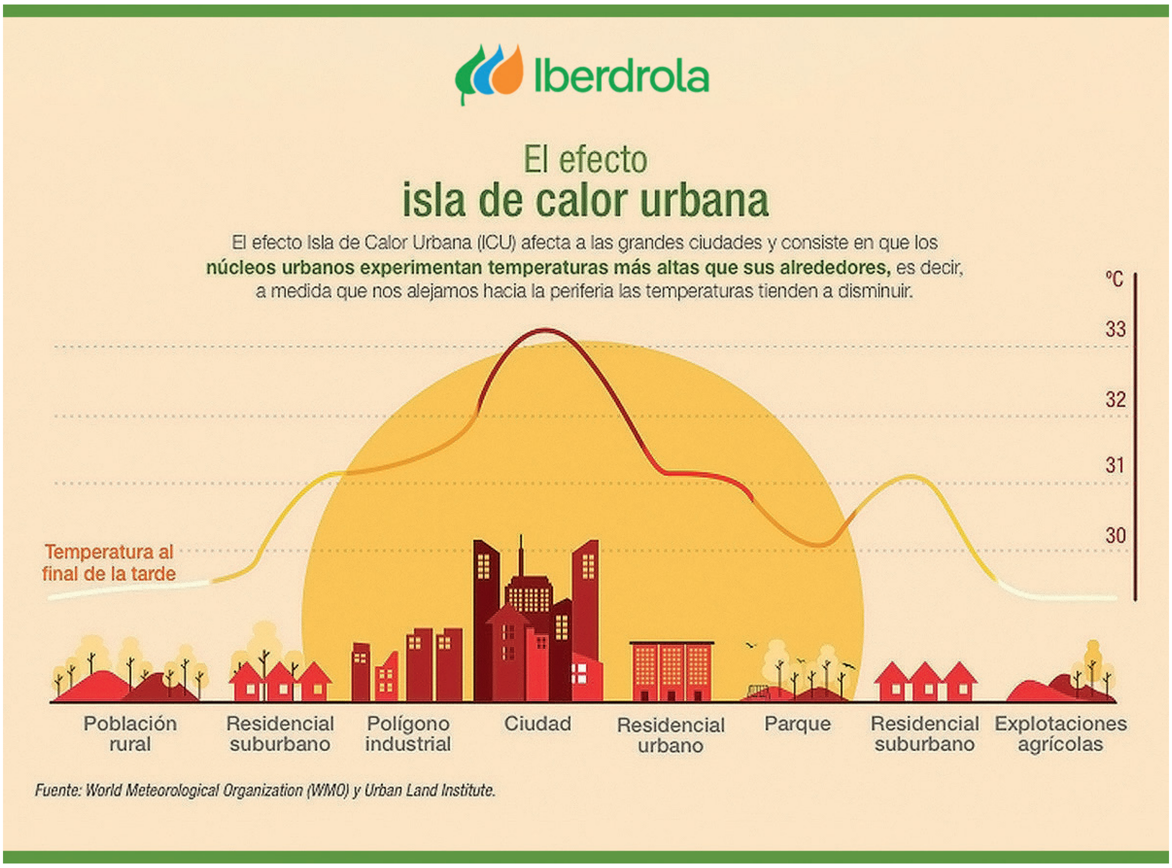
1.2 Heat Islands

Unlike heat waves, which are extreme weather events related to air temperature and large-scale processes, heat islands are inherently urban dynamics. A heat island refers to an urbanized area that, compared to a non-urban or rural area, appears warmer based on its morphological, environmental, and functional characteristics (Oke *et al*., 2017).

In this sense, neighborhoods, districts, or regions with less vegetation, more impermeable surfaces, more compact and dense buildings, and construction materials with greater thermal conductivity (e.g., glass, metals, asphalt) present more intense heat islands than areas with opposite characteristics.

In general, as one moves away from urban centers, temperatures decrease (Figure 1).

Figure 1: Conceptual Diagram of the Urban Heat Island Effect



Source: World Meteorological Organization (WMO) and Urban Land Institute.

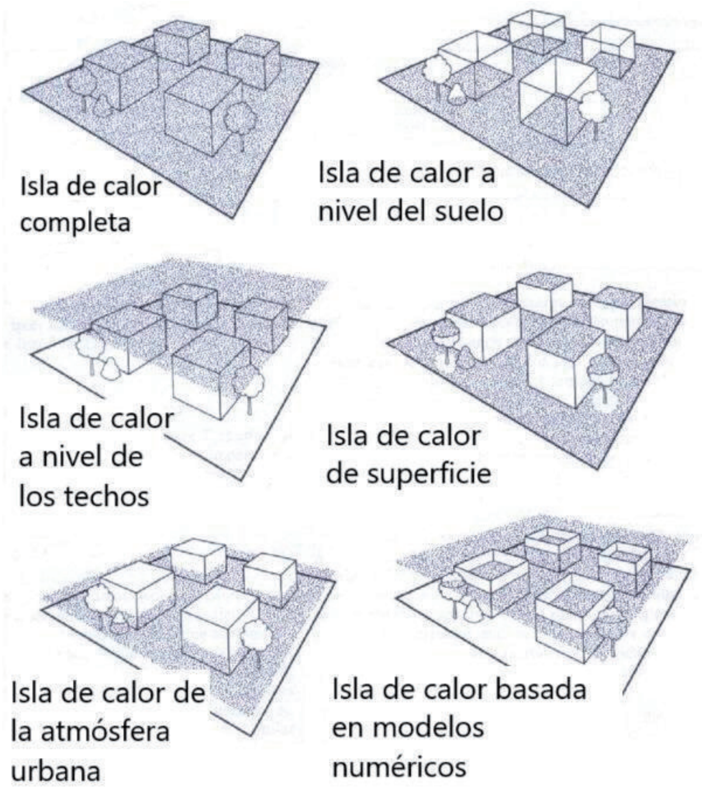
This study is focused on Urban Heat Islands, given the fact that cities are the object of this Atlas and where the greatest part of the world's human population lives. The following section details how the concept was implemented in the utilized methodology.

2. Methodology

The methodological framework of IberAtlas builds on the Urban Heat Island Assessment in Local Climate Zones[1] (Rech *et al.*, 2024), employing satellite imagery alongside a classification of landscape typologies as a foundation for the statistical analysis of heat islands. The study takes into account factors like vegetation, urban morphology, soil permeability, and construction materials, assessing how each influences the presence and intensity of this urban phenomenon. The following sections present the results outlined in the technical profiles of the prioritized UCCI/ICLEI cities, providing detailed information specific to each city.

2.1 Urban Heat Islands Retrieval

Figure 2: Possible reference layers for data collection and subsequent heat island assessment



Source: Fialho, 2012. Translation by Rodrigo Nehara, Biodiversity Assistant, ICLEI South America.

1 Adapted Translation.

Heat islands can be assessed using different methods and reference layers (Figure 2). The human-sensitive layer is known as the urban canopy layer, which is simply the air temperature between ground surfaces and the rooftops of buildings in these spaces.

To comprehensively evaluate the presence and intensity of heat islands, temperature measurements must be taken at multiple locations throughout an urban area. Direct in situ measurements using meteorological stations, for instance, can periodically record air temperatures close to the surface. However, these devices are often very isolated, potentially costly, and in many regions — including Latin America and the Caribbean — are not widely accessible.

Consequently, thermal remote sensing data are extensively used to study temperature dynamics in urban spaces, particularly because of their broad spatial coverage and accessibility. In this case, because Land Surface Temperature (LST) from satellite imagery is used instead of actual air temperature, the phenomenon is referred to as Surface Urban Heat Islands[2] (SUHI) (Gallo *et al*., 1995; Rao, 1972; Zhou *et al*., 2019). Landsat image collections are the primary data source for high-resolution spatial SUHI analyses (Abdullah *et al*., 2020; Reiners *et al*., 2023) and were therefore chosen as the data source for this research. A reference satellite image was used and processed according to thermal range to capture temperature variations within the study area, representing urban heat characteristics at that specific moment.

2.2 Urbanization, Morphology, and Urban Heat Islands

Urbanization varies globally in form, typology, and territorial proportion, making it a heterogeneous phenomenon. As a result, urban-related phenomena are not restricted to cities' political-administrative boundaries. However, urban planning policies often remain confined within these boundaries, which may overlook the full extent of phenomena like heat islands, since they can also impact areas beyond these limits (Marandola Jr., 2013).

This choice of boundaries, which fails to fully encompass the phenomena under study, may hinder the practical implementation of effective strategies. It may also lead to common misconceptions in urban planning for large, conurbated cities. Thus, using an urban expansion perimeter as a reference for heat island studies provides a more comprehensive understanding of their behavior. This additional area, known as the peri-urban perimeter, allows for the consideration of thermal interactions beyond the strict city limits.

2 Air temperature and land surface temperature cannot be directly correlated, as they are influenced by various factors beyond one another—such as wind, surface conductivity, and emissivity, all of which impact both air and surface temperatures.

This perimeter around the city is essential for capturing the full extent of the heat island effect, as temperature variations can extend beyond densely built-up urban areas and affect adjacent regions. To define this peri-urban perimeter, we used the following calculations (equations 1, 2, and 3) (Sobrino *et al*., 2020):

Equation 1: Calculation of the urban adjacency perimeter.

$$WUa = 0{,}25AUM^{1/2}$$

Equation 2: Calculation of the future urban adjacency perimeter.

$$WUa = 0{,}25AWU^{1/2}$$

Equation 3: Calculation of the final peri-urban perimeter (expanded boundary).

$$WPUa = 1{,}5UM^{1/2} - WFUa - WUa$$

Where:

A: total area of the city

WUa: urban adjacency perimeter

$WFUa$: future urban adjacency perimeter

$WPUa$: final peri-urban perimeter (expanded boundary)

Additionally, to capture urban heterogeneity and more accurately assess this phenomenon, the Local Climate Zones (LCZ) methodological framework can be applied (Figure 3). The landscape classification methodology developed by Stewart and Oke (2012) provides a standardized system for categorizing typologies based on surface structure, function, land cover, urban metabolism, and related characteristics.

The LCZ classification enhances understanding of urban composition and offers insights into its effects on local climate dynamics (Borges *et al*., 2022; Kaloustian and Bechtel, 2016; Xia *et al*., 2022). A global LCZ classification map is freely available (Demuzere *et al*., 2022), facilitating the study of SUHI on a global scale. This classification served as the foundation for all IberAtlas case studies.

Figure 3: Local Climate Zones

Source: Picone, 2019.

Following the aforementioned methodological guidelines, for each city associated with the project, the following were produced: *(i)* a map of Local Climate Zones (LCZ) to understand the local landscape structure[3]; *(ii)* charts related to their distribution within the city's territory to account for the percentage and predominance of each LCZ; *(iii)* a Surface Temperature map, which provides information on thermal range — cooler and warmer zones; and *(iv)* statistical graphs showing the density and intensity of Surface Urban Heat Islands (SUHI), using an adapted version[4] of the Urban Thermal Field Variance Index (UTFVI) by urban LCZ to estimate the effect of each typology on the local climate. Additionally, surveys were distributed to collect data on governance, risk management, and urban-environmental planning for the cities evaluated in this document.

For this study, the local governments of the following cities were considered:

- Barcelona, Spain;
- Belém do Pará, Brazil;
- Bogotá, Colombia;
- Buenos Aires, Argentina;
- Lisbon, Portugal;
- Madrid, Spain;
- Montevideo, Uruguay;
- Quito, Ecuador;
- Rio de Janeiro, Brazil;
- San Salvador, El Salvador;
- São Paulo, Brazil.

3 It's important to note that LCZ maps are based on datasets with a spatial resolution of 100 meters, with each pixel representing the predominant feature in that area. However, studies like those in this Atlas focus less on micro- or intra-neighborhood climates, aiming instead to abstract city-level climate dynamics. This level of detail allows for broader insights, though more granular studies could later be conducted with similar methods but using higher-resolution data.

4 The UTFVI is based on calculating temperature variations across thermal images from an averaged data perspective. In this research, the proposal is to approach this by averaging the temperatures of tree cover in UCCI-ICLEI cities (LCZ*A* and LCZ*B*), as these areas conceptually have the capacity for urban cooling.

3. UCCI-ICLEI Cities

This section presents the technical profiles for each city involved in the project, featuring: a Local Climate Zones (LCZ) map, a heat island map based on the Urban Thermal Field Variance Index (UTFVI), and statistical graphs, alongside a data analysis that provides localized context for each city.

To enrich the data available, in-depth surveys were conducted to gather detailed information from the cities on governance, risk management, and urban-environmental planning topics. Furthermore, specialized governmental departments with relevant thematic expertise contributed additional strategic documents on climate action, as well as local climate norms — including air temperature, relative humidity, and precipitation data — along with graphs illustrating monthly electricity consumption.

It is important to note that the UCCI-ICLEI cities analyzed here exhibit significant variation in urban-vegetation ratios and overall area sizes (see Table 1). This heterogeneity is a crucial factor to consider throughout the analysis.

Table 1: Proportion of Areas in IberAtlas Cities

Ciudad	Área Total ~ km²	Área del Paisaje Urbano (LCZ 1-10)		Área de Cobertura Vegetal (LCZ A-B)	
		%	~ km²	%	~ km²
Barcelona	102 km²	84,88	86	14,16	14
Belém do Pará	1.059 km²	39,36	417	56,05	594
Bogotá	1.636 km²	24,44	400	57,23	936
Buenos Aires	200 km²	93,39	187	3,85	8
Lisboa	100 km²	87,25	87	9,26	9
Madrid	604 km²	45,56	281	17,59	106
Montevideo	530 km²	59,55	315	31,67	168
Quito	420 km²	62,61	263	30,3	127
Rio de Janeiro	1.200 km²	55,12	662	38,12	457
San Salvador	1.412 km²	72,1	1018	27,88	394
São Paulo	1.521 km²	62,16	945	33,97	515

Source: Data provided by local governments and LCZ mapping (WUDAPT, 2020).

3.1 Barcelona, Spain

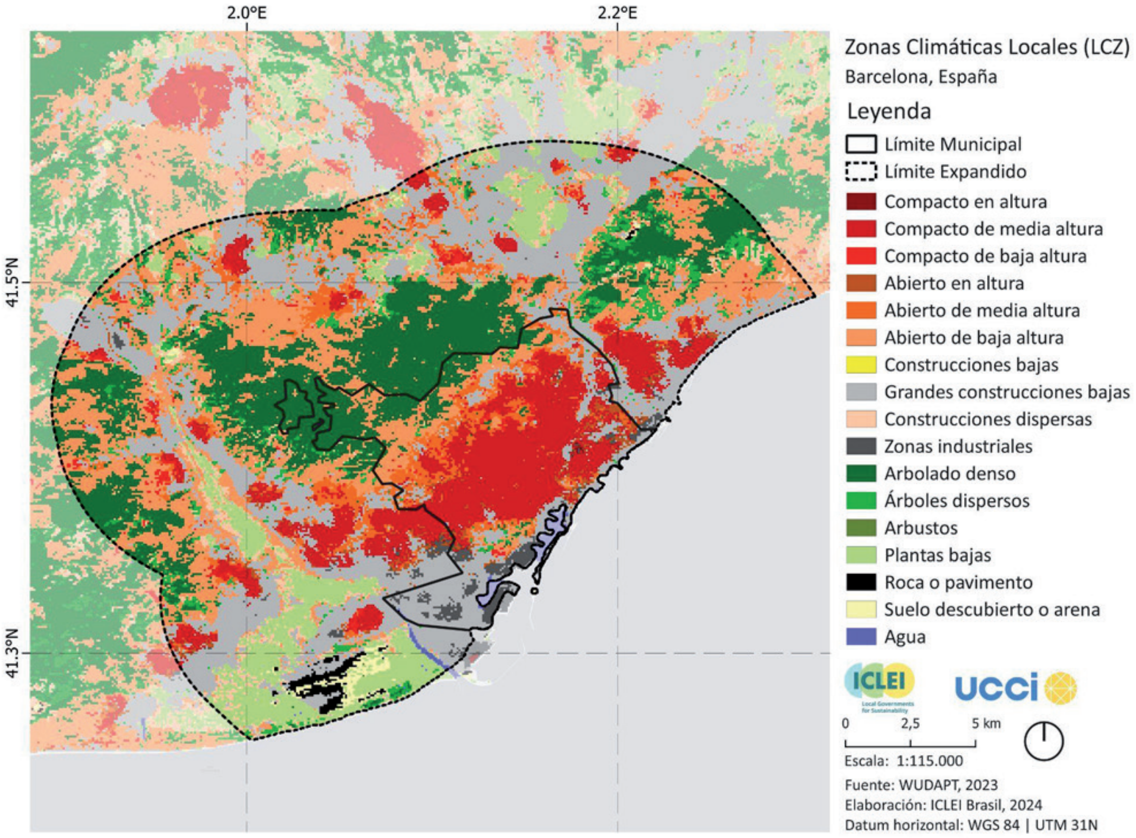
Barcelona, one of Spain's major cities, has a population of 1,702,814 inhabitants and covers an area of 101.7 km^2. The city has a strong commitment to combating climate change, with government bodies and councils that include representatives from civil society to address the climate agenda. In addition, Barcelona has a Climate Action Plan and a Risk Assessment for heat islands and heat waves, with financial resources allocated to these actions. The city also oversees protected areas, such as Parc de la Collserola, and has multiple meteorological monitoring stations strategically distributed.

3.1.1 Analysis of Local Climate Zones

Barcelona, one of the major cities in Europe and one of the largest in Spain, has a notable diversity of urban landscape typologies within its municipal perimeter, which directly impacts the formation and intensity of heat islands. Compact high-rise and medium-rise landscape areas dominate much of the city, contributing to heat retention and the formation of intense urban heat islands, particularly in more densely built-up areas.

In the southern part of the city, near the municipal boundary and coastline, an extensive gray area is characterized by large low-rise buildings and industrial zones. This area corresponds to the Zona Franca, which includes the Port of Barcelona. It is primarily composed of logistics infrastructure and warehouses, creating conditions conducive to heat accumulation. On the other hand, areas of dense and scattered tree cover are mainly concentrated in the northern boundary of the city, in Parc de la Collserola. This protected natural park, part of the Natura 2000 network, serves as a crucial thermal mitigator, helping to lower temperatures in surrounding areas and counteract the warming effects of nearby urban zones (Figure 4).

Figure 4: Barcelona Local Climate Zones



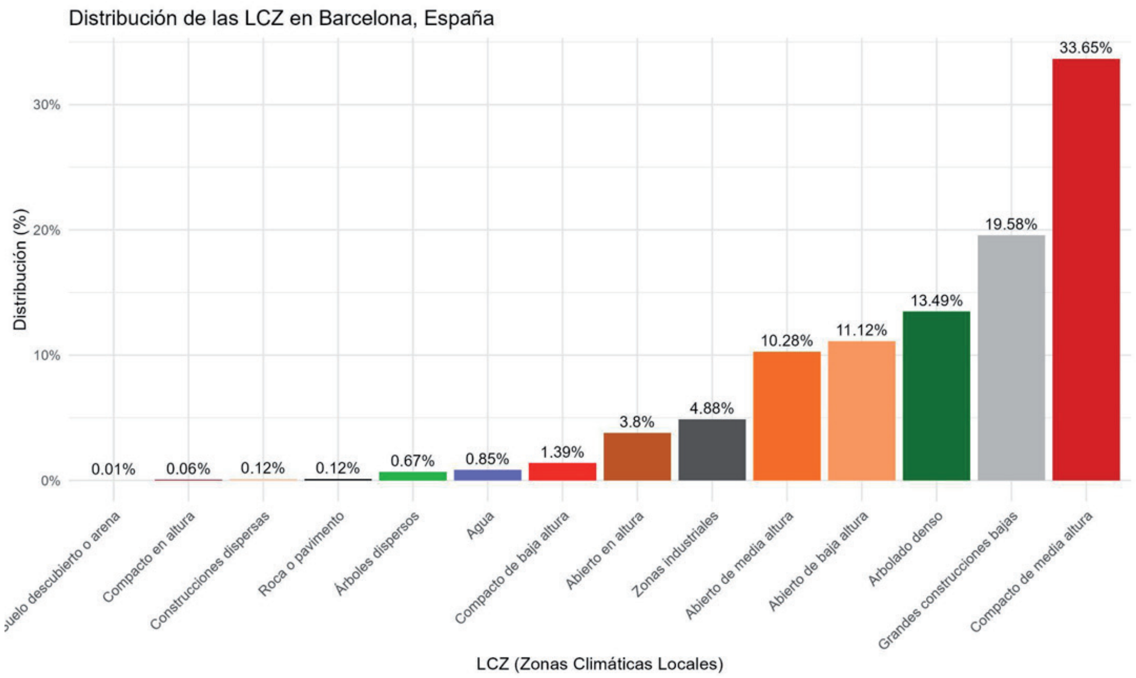
3.1.2 Local Climate Zones Distribution

Approximately 85% of the city's area — around 86 km² — consists of urban landscape typologies, while dense tree cover occupies less than 15% of the municipal territory, roughly 14 km². Notably, tree masses are sparsely represented within urbanized areas. These zones are mainly concentrated to the north. According to the LCZ distribution chart for Barcelona in Figure 5, the following characteristics are observed:

- **Compact mid-rise (33.65%):** This is the predominant LCZ in Barcelona. It represents densely urbanized blocks, often featuring buildings without side and front setbacks, typical of the city's design. While vegetation is generally present along sidewalks, the substantial built volume of the blocks can intensify the heat island effect due to the predominance of construction materials with high heat retention capacities, such as concrete and asphalt.
- **Large low-rise buildings (19.58%):** Approximately 20% of Barcelona's area consists of this urban landscape typology. Similar to compact mid-rise landscapes, this type of Local Climate Zone (LCZ) can also intensify the heat island effect.

- **Dense tree cover (13.49%):** These zones serve as important thermal regulators, helping to lower surface temperatures and mitigate the effects of heat islands in surrounding areas. However, the largest masses of dense vegetation are located outside the more intensely urbanized area.
- **Water (0.85%):** This is the second most representative natural LCZ in Barcelona. Areas with water bodies are located in the southern part of the city, near the city's port.

Figure 5: Local Climate Zones Distribution in Barcelona

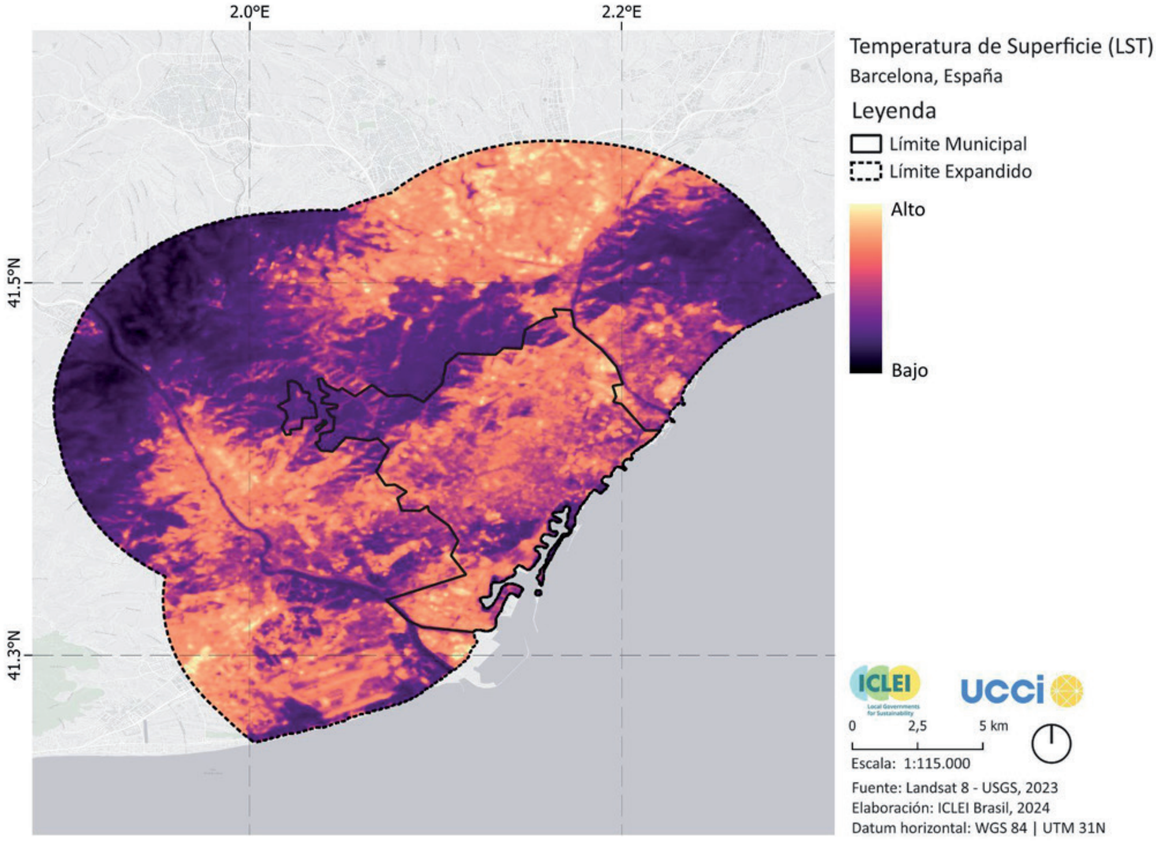


3.1.3 Heat Island Analysis

The LST map for Barcelona illustrates the city's thermal range. The warmest areas, indicated in yellow, are located along the southern municipal boundaries, corresponding to industrial zones and the city's port. Similar hotspots are found in the north, in the Eix Besòs industrial zones, where large low-rise buildings dominate, concentrating industrial and economic activity The pinkish-orange areas, which also retain heat, primarily correspond to densely built urban zones with compact, high-rise construction, as indicated on the LCZ map.

Conversely, the cooler areas, marked in dark blue and violet, are primarily located outside the municipal boundaries in zones with dense vegetation and in compact mid-rise areas. Barcelona benefits from relatively uniform urbanization throughout the city, with mid-rise buildings and blocks featuring internal greenery, as well as a notable amount of street vegetation. This vegetation plays a crucial role in thermal mitigation, which can significantly reduce the heat island effects. As a result, much of the urbanization is in zones outside the extremes.

Figure 6: Surface Temperatures in Barcelona



3.1.4 Heat Island Behavior by Landscape Typology

- **Industrial Zones:** Industrial zones in Barcelona show some of the highest values, with a notable concentration in the "very strong" category and even some areas classified as "extreme." Although these industrial areas are limited in surface area, they significantly contribute to heat islands due to dense infrastructure, minimal vegetation, and extensive heat-retaining artificial surfaces.
- **Compact Low- and Mid-Rise Areas:** These typologies also show a strong contribution to heat islands, with much of their density concentrated in the "moderate" and "strong" categories. Compact high-rise areas, such as skyscrapers or tall buildings, lacking adequate ventilation or sufficient green spaces, tend to intensify the heat island phenomenon, which is evident in the higher values shown in this chart.
- **Open High-, Mid-, and Low-Rise Areas:** These typologies show relatively similar behavior, with values mainly concentrated in the "mild" to

“moderate” categories. Although these areas benefit from improved ventilation due to building separation, which partially mitigates heat, peaks of heat retention are still observed in certain locations. The limited vegetation in certain areas contributes to higher temperatures, although their overall thermal impact remains lower compared to more compact zones.

- **Dispersed Buildings:** This class shows a more distributed pattern, with values mostly in the “mild” to “moderate” categories. This typology, characterized by lower construction density and a higher presence of vegetation, serves as a buffer against the heat island phenomenon, although certain areas still show moderate levels of heat contribution.

Figure 7: Heat Island Behavior by Landscape Typology in Barcelona

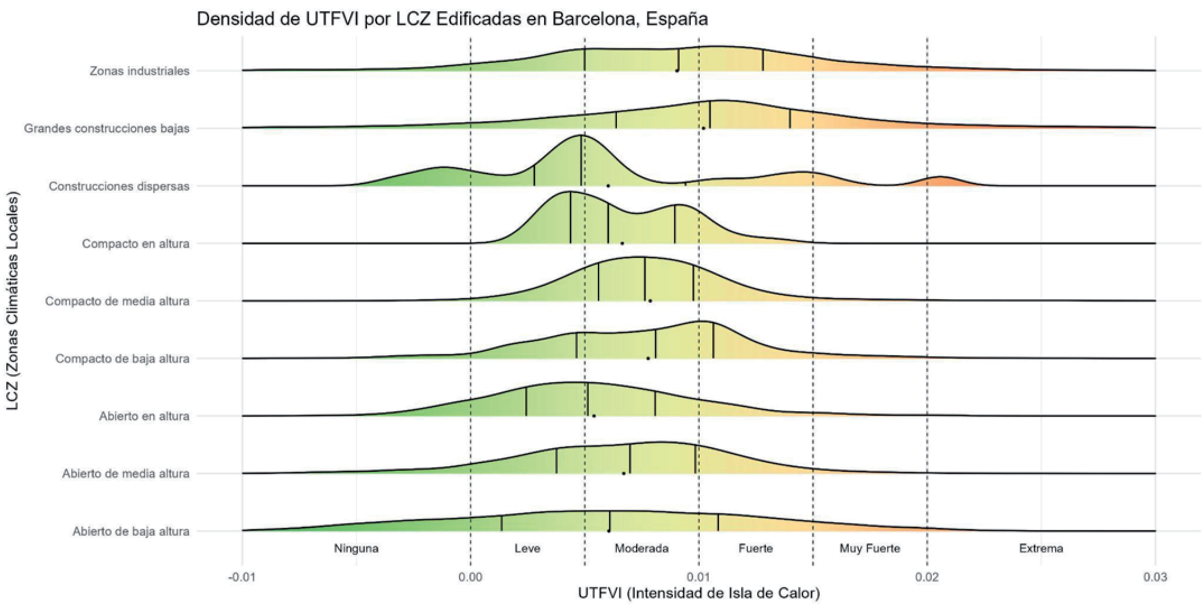


Photo Belém do Pará: Bruna Brandão - MTUR

3.2 Belém do Pará, Brazil

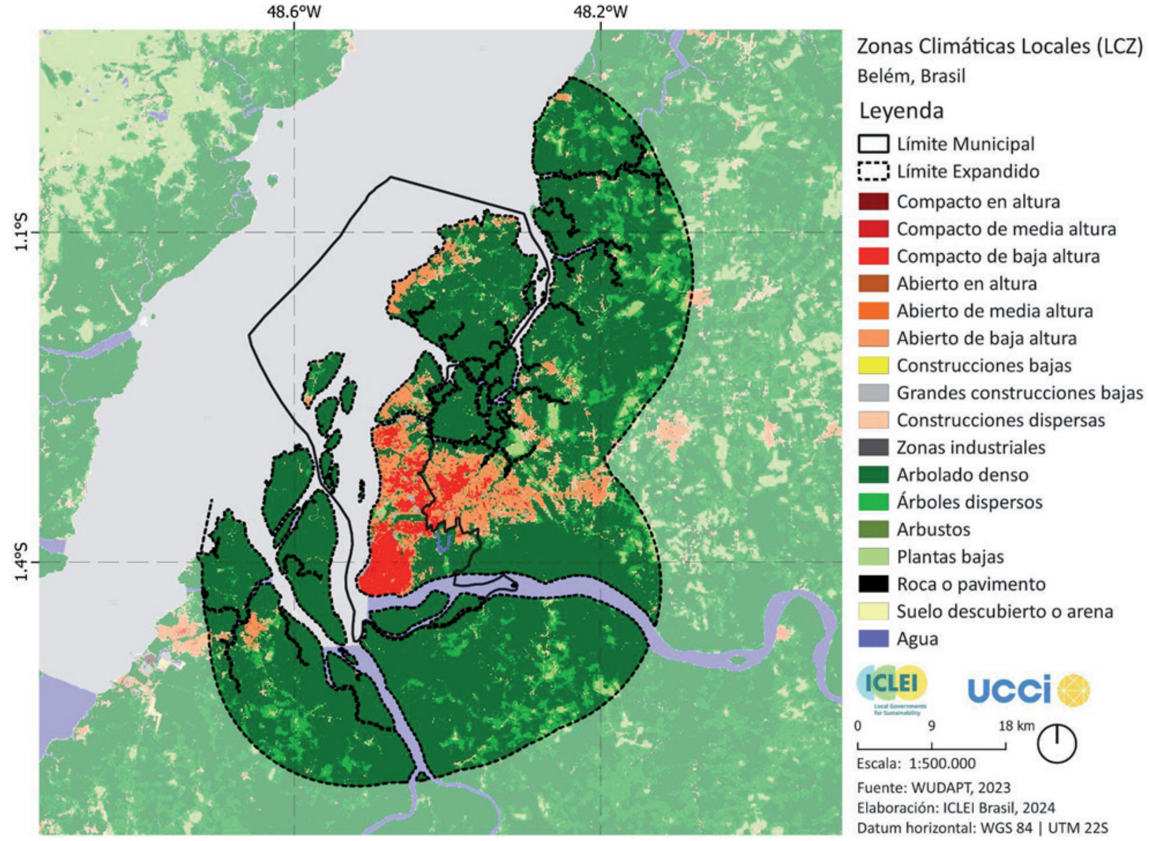
Belém do Pará, located in Brazil's Amazon region, covers an area of 1,059.458 km² and has a population of 1,303,403 inhabitants (IBGE, 2022). The municipality has a governmental structure that addresses the climate agenda and is committed to coordinating actions for disaster prevention and management. Although Belém do Pará lacks a specific risk assessment for heat waves, it has implemented certain environmental conservation measures, including public green spaces and an urban reforestation plan. However, limited resources allocated to the climate agenda remain one of the biggest challenges in developing plans and actions to address this issue.

3.2.1 Analysis of Local Climate Zones

Belém do Pará, one of the most important cities in Brazil's Amazon region, is distinguished by its unique location, encompassing both a continental area and a group of 42 islands within its municipal boundaries. In the continental area, the Local Climate Zones map primarily highlights compact high- and mid-rise areas, represented in shades of red and orange, concentrated in the city's most urbanized sections. These densely built areas contribute the most to the formation of heat islands.

In contrast, areas with dense tree cover, shown in green, dominate the islands. Some dispersed urbanization is also present, particularly in the northern part of the map, which includes Ilha de Caratateua and Ilha do Mosqueiro. To the south of the continental area lies an extensive green space, the Parque Estadual do Utinga Camillo Vianna—an important environmental protection area that serves as a natural barrier against rising temperatures in the region (Figure 8).

Figure 8: Local Climate Zones of Belém do Pará



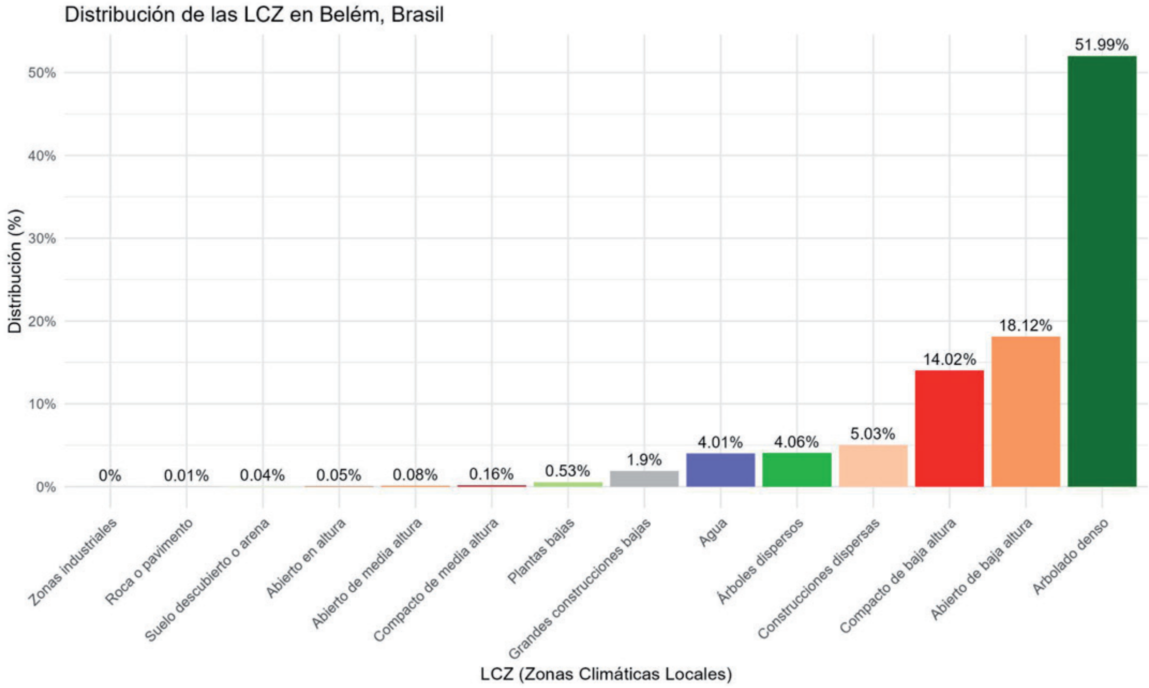
3.2.2 Local Climate Zones Distribution

Approximately 40% of the city's area — around 417 km² — consists of urban landscape typologies, while over 50% of the entire municipal territory, roughly 550 km², is covered by dense vegetation Notably, tree masses are sparsely represented within urbanized areas. These zones are mainly concentrated on the edges. According to the LCZ distribution chart for Belém do Pará in Figure 9, the following characteristics are observed:

- **Dense tree cover (51.99%):** This is the predominant typology in Belém do Pará. It represents areas of Amazonian biome vegetation, which are naturally very dense and robust. These zones play an important role in cooling. However, it's important to note that both average air temperatures and relative humidity are quite high in this region, meaning these areas are generally warm — though cooler than urban zones.
- **Open Low-Rise (18.12%):** This is the main urban landscape in the city. Its less compact nature allows for the presence of tree masses, which can favor urban cooling.
- **Compact Low-Rise (14.02%):** Compact low-rise areas are very common typologies in Brazilian cities. They are characterized by high-density buildings and few open spaces. The lack of vegetation in these areas can intensify heat retention.

- **Scattered Trees (4.06%):** The presence of vegetation in these areas can help maintain cooler temperatures. However, they are generally located outside the urbanized patches of Belém do Pará.

Figure 9: Local Climate Zones Distribution in Belém do Pará

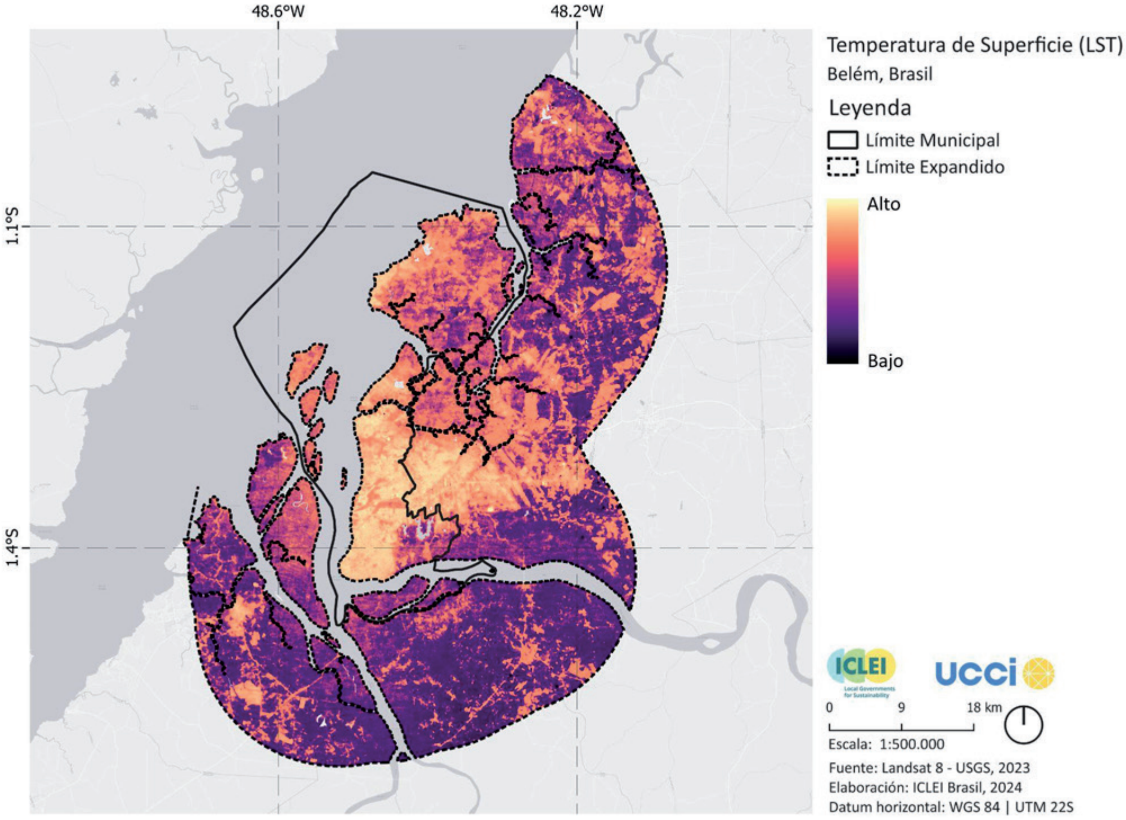


3.2.3 Heat Island Analysis

The LST (Land Surface Temperature) map for Belém do Pará highlights the city's thermal range. The warmest areas, shown in yellow, largely coincide with densely built urban zones, such as compact high-rise and mid-rise areas in the city center, as identified on the LCZ map.

On the other hand, the areas identified as cooler, marked in dark blue and violet, primarily correspond to zones with dense and scattered tree cover, located in regions outside the city. In these zones, the presence of vegetation acts as a thermal mitigation factor.

Figure 10: Surface Temperatures in Belém do Pará



3.2.4 Heat Island Behavior by Landscape Typology

- **Large Low-Rise Buildings and Compact Low-and Mid-Rise Areas:** These typologies show a notable concentration of values in the "strong" category, suggesting that areas with low- and mid-rise buildings contribute significantly to heat island formation. Heat retention in these zones is high due to the large amount of impermeable surfaces and limited vegetation.
- **Open Low-, Mid-, and High-Rise Areas:** These typologies show values concentrated in the "mild" to "strong" categories, indicating that these areas, due to their lower building density and greater ventilation, have a reduced impact on heat island formation. Air circulation in these zones helps mitigate temperature increases.
- **Dispersed Buildings:** In this typology, values are mainly in the "mild" category, indicating that these areas, although urbanized, have lower building density and greater ventilation, which helps reduce thermal impact.

Figure 11: Heat Island Behavior by Landscape Typology in Belém do Pará

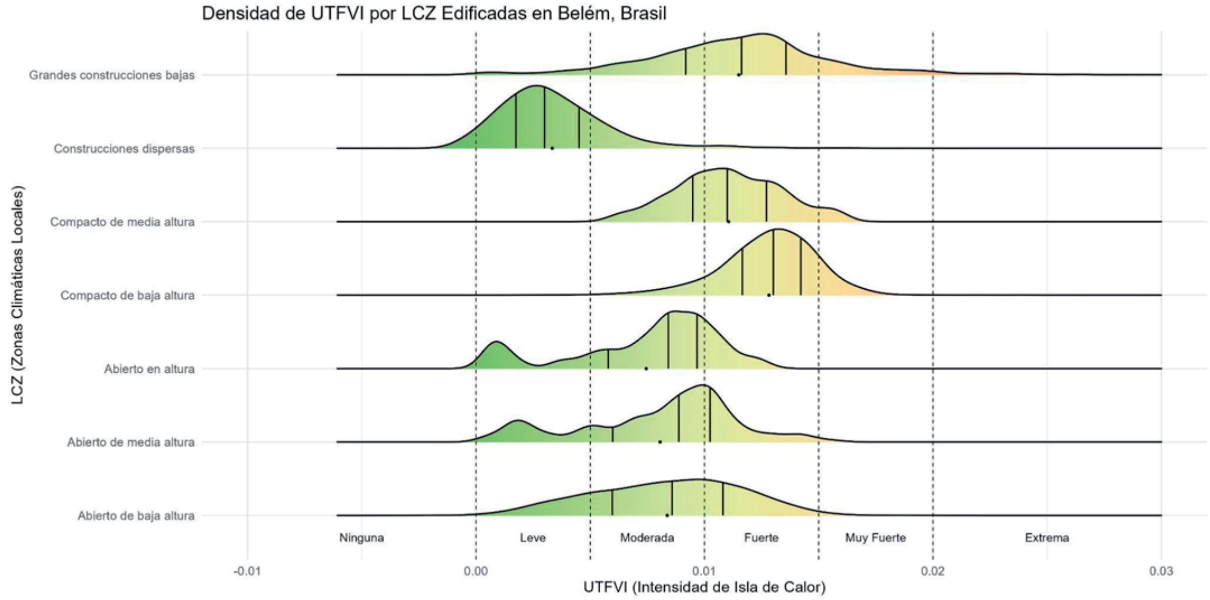


Photo Bogotá: Julian Zapata - Pixabay

3.3 Bogotá, Colombia

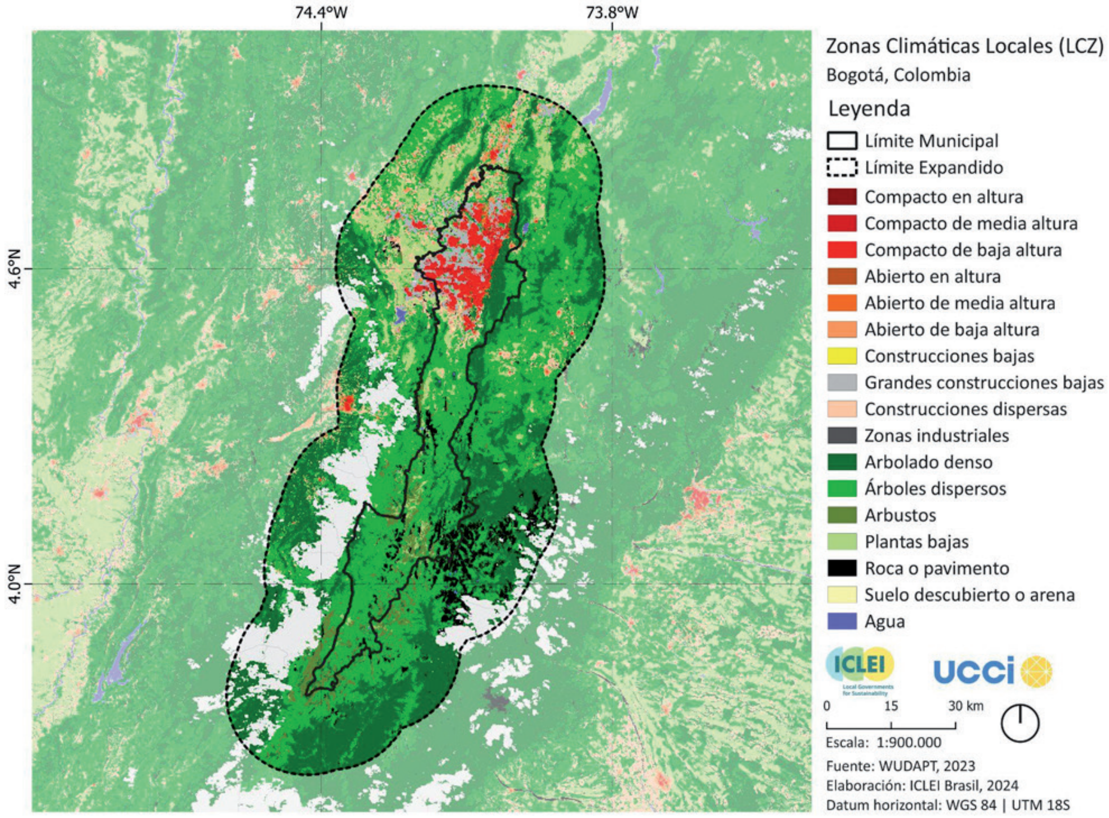
Bogotá, encompassing 1,636.36 km² with a population of 7,929,539 (Mayor's Office of Bogotá, 2021; DANE, 2024), has developed a robust framework to address climate challenges. The city has implemented a Climate Action Policy, a Land Use Plan, and a Climate Risk Assessment. Additionally, Bogotá maintains urban forests and protected areas and operates 19 air quality and hydrometeorological monitoring stations. Despite these measures for the climate agenda and disaster management, no heat waves or related fatalities have been recorded in the past five years.

3.3.1 Analysis of Local Climate Zones

Bogotá, the capital and largest city of Colombia, has a concentration of compact low- and mid-rise areas, as well as large low-rise buildings in its urbanized zone to the north of the municipal boundary. Near the urbanization boundaries, there are areas with dispersed and low-rise buildings.

To the east of the dense urban area, there is a zone of dense and scattered tree cover that corresponds to the Eastern Hills[5]. These hills act not only as a vegetative barrier but also as a physical one, forming a mountain range that serves as a natural boundary for the city. To the south, the landscape is characterized by scattered trees, small patches of dense tree cover, rocky or paved surfaces, and low-rise buildings. This area, located south of Bogotá and encompassing part of the Sumapaz páramo, comprises most of the city's rural zone, representing 75% of its total territory.

Figure 12: Local Climate Zones of Bogotá



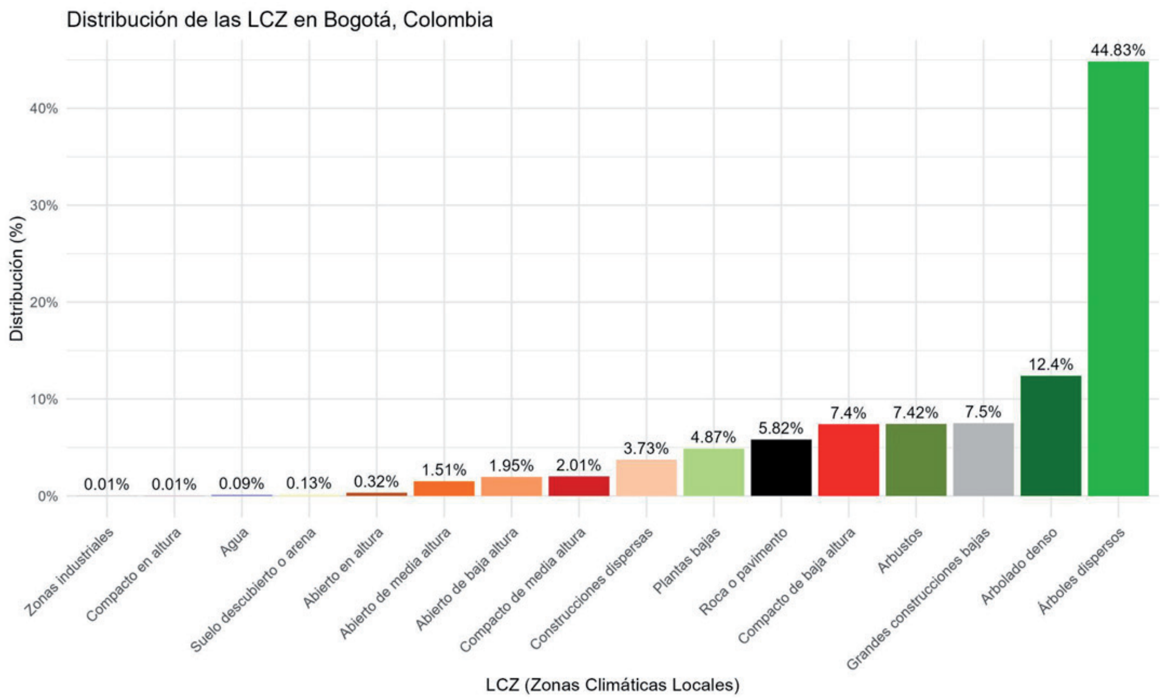
5 The Eastern Forest Protective Reserve of Bogotá (RFPBOB) covers approximately 13,140 hectares and is a nationally protected area.

3.3.2 Local Climate Zones Distribution

Approximately 25% of the city's area — around 400 km² — consists of urban landscape typologies, while nearly 60% of the entire municipal territory has vegetation cover, of which more than 12% is dense tree cover, totaling approximately 203 km². Notably, tree masses are sparsely represented within urbanized areas. Additionally, some zones could not be accurately mapped due to excessive cloud cover in the satellite images, which prevented proper characterization of those areas. According to the LCZ distribution chart for Bogotá in Figure 13, the following characteristics are observed:

- **Scattered Trees (44.83%):** This is the predominant typology in Bogotá. The municipality has the largest area among the cities analyzed in this Atlas. Vegetation, both scattered and dense, is generally located outside urban areas.
- **Dense tree cover (12.4%):** There is a large area of dense forest to the east of the urban zone, with the potential to reduce temperatures in nearby areas.
- **Large low-rise buildings (7.5%):** This is the most significant urban landscape typology in the city, covering nearly 123 km². Due to their density, these areas can intensify the heat island effect.
- **Compact Low-Rise (7.4%):** This typology covers a similar area to that of large low-rise buildings and has a similar effect on heat retention, as it is not typically associated with significant vegetation.

Figure 13: Local Climate Zones Distribution in Bogotá

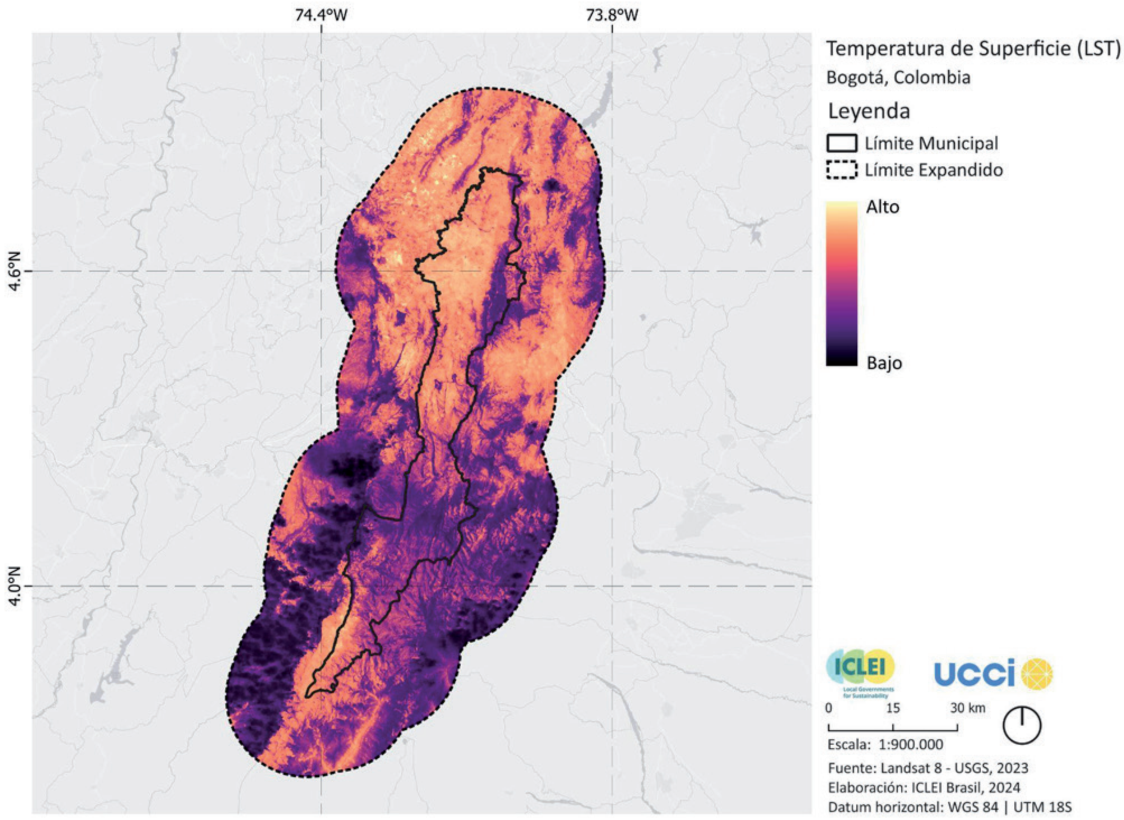


3.3.3 Heat Island Analysis

The LST mapping for Bogotá shows a predominance of higher temperatures in the city's more densely urbanized zones. This thermal intensity affects not only built-up areas but also extends southward, encroaching on rural zones closer to urbanized areas.

The warmest areas are observed at the southernmost part of the municipality. Although this area is not urbanized, the presence of exposed rock surfaces appears to be a key factor, as these surfaces accumulate and retain significant amounts of heat, contributing substantially to the region's high temperatures. This observation highlights how both urbanization and geographical features can influence the formation of heat islands. Another notable point is the geomorphological characteristic at the municipal boundaries and the expanded area analyzed in this Atlas, where a forested mountainous area with cooler temperatures may interfere with the estimation of heat island effects through remote sensing.

Figure 14: Surface Temperatures in Bogotá



3.3.4 Heat Island Behavior by Landscape Typology

- **Large Low-Rise Buildings:** According to the analysis, this landscape typology is the primary contributor to generating and intensifying the heat island effect in Bogotá. As previously mentioned, it is a highly dense urban morphology, covering more than 120 km² — a substantial area.
- **Compact Low-Rise:** Similar to the previous typology, this LCZ is very common in Bogotá, covering approximately 120 km². Its lack of green spaces contributes to the intensification of the heat island phenomenon. This is a common urban landscape across Latin America.
- **Compact Mid-Rise:** This typology displays a wider distribution in terms of heat concentration, with much of its area corresponding to the highest intensity levels of the heat island effect. Its altitude characteristics can create wind blockages and corridors.

Figure 15: Heat Island Behavior by Landscape Typology in Bogotá

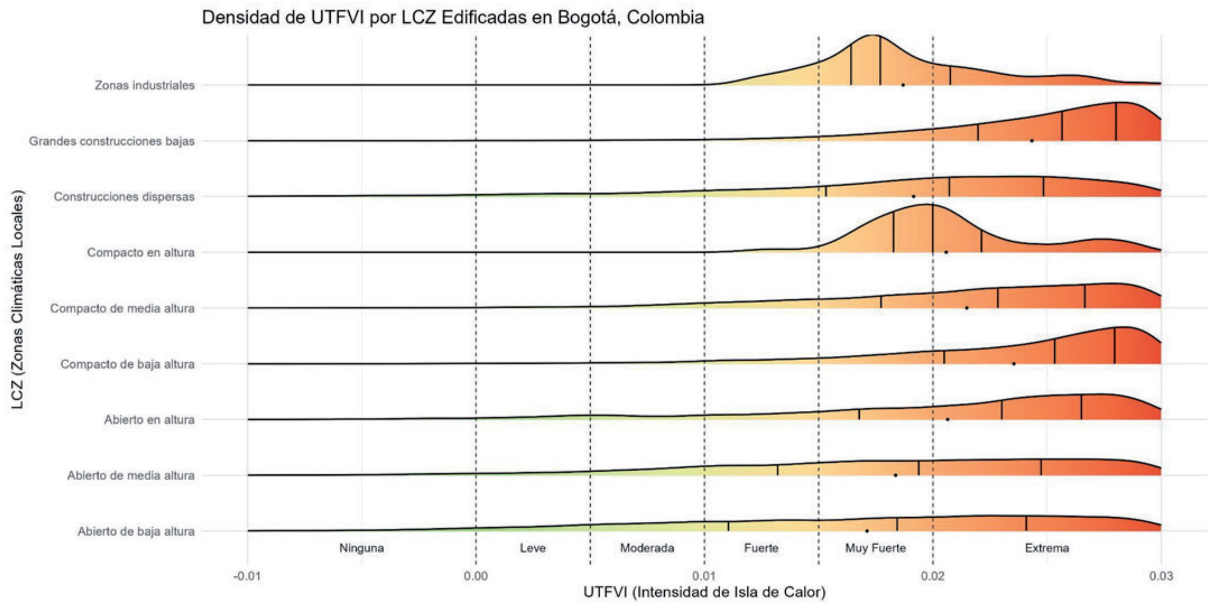


Photo Buenos Aires: buenosaires.gob.ar

3.4 Buenos Aires, Argentina

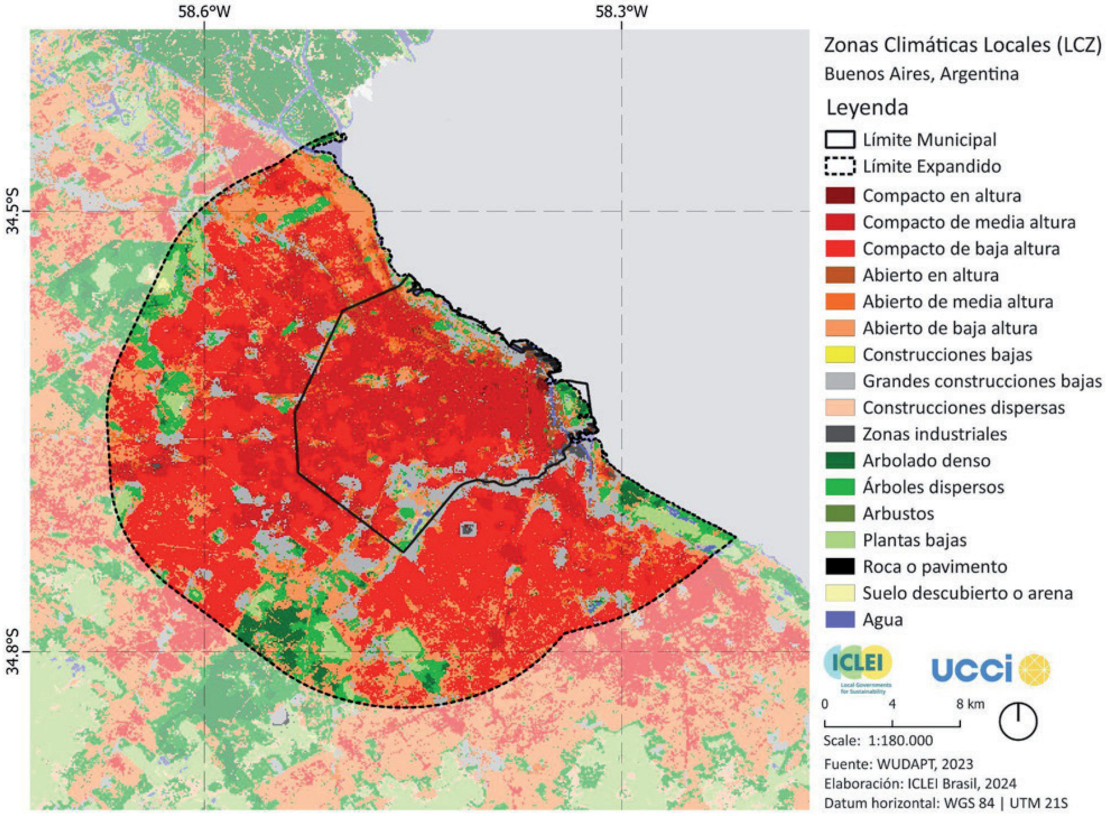
The Autonomous City of Buenos Aires, with an area of 200 km^2 and a population of 3,121,707 (Census 2022), has a robust institutional framework to address the climate agenda. The city is supported by government bodies, councils with civil society representation, and committees that coordinate climate change strategies across various departments. The Autonomous City of Buenos Aires has implemented its third Climate Action Plan, which includes heat wave risk assessment and the management of protected areas. Additionally, the city provides open and enclosed spaces that serve as climate shelters and has developed a Tree Planting Plan. For environmental monitoring, the city is equipped with air and water quality measurement devices, ensuring a comprehensive and responsible approach to climate challenges.

3.4.1 Analysis of Local Climate Zones

The Autonomous City of Buenos Aires is both an autonomous city and the Federal Capital of Argentina, located on the southern shore of the Río de la Plata. The Local Climate Zones (LCZ) map for Buenos Aires shows a strong predominance of urbanized areas within its jurisdictional boundaries and in peri-urban areas, especially mid- and low-rise zones, highlighted in shades of red.

In the southeast of the city, there is an area dominated by large low-rise and dispersed buildings, with some scattered tree zones. Near the banks of the Río de la Plata, a similar landscape prevails, where large low-rise and dispersed buildings are combined with a greater presence of trees and low-lying vegetation. This region includes key structures such as the airport, university campus, port, and numerous plazas and parks.

Figure 16: Local Climate Zones of Buenos Aires



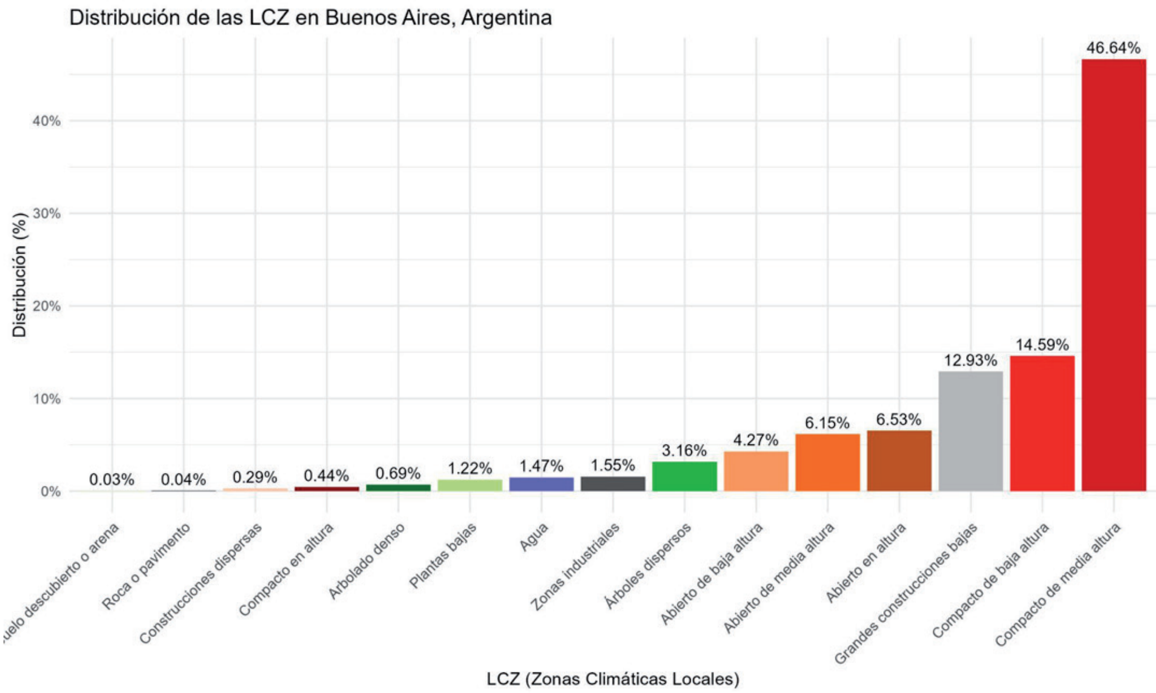
3.4.2 Local Climate Zones Distribution

Over 93% of the city's area corresponds to urban landscape typologies—approximately 187 km²—while less than 5% of the entire territory is classified as vegetation cover typology, covering around 8 km². Notably, tree masses are sparsely represented within urbanized areas. However, the City of Buenos Aires has numerous parks and street trees. According to the LCZ distribution chart for Buenos Aires in Figure 17, the following characteristics are observed:

- **Compact mid-rise (46.64%):** The City of Buenos Aires is densely built in terms of constructed environment. A large portion of its area is characterized by an intensive presence of buildings up to 12 stories high, typically without front or side setbacks.
- **Compact Low-Rise (14.59%):** These are primarily residential areas with single-family buildings, where high-rise towers are uncommon. However, these are also very dense areas with low level of soil permeability.
- **Scattered Trees (3.16%):** The typology scheme indicates a low presence of vegetation in the city, with scattered trees as the most significant natural landscape typology by area. However, as previously mentioned, each pixel on the LCZ map has a 100m resolution—about the size of a city block, which generally contains more construction than vegetation — and is therefore sensitive to the presence of street trees.

- **Water (1.47%):** This is the second most common natural typology in the city. It generally corresponds to lakes in the south and the Dársena Sur River, which runs through the Puerto Madero region.

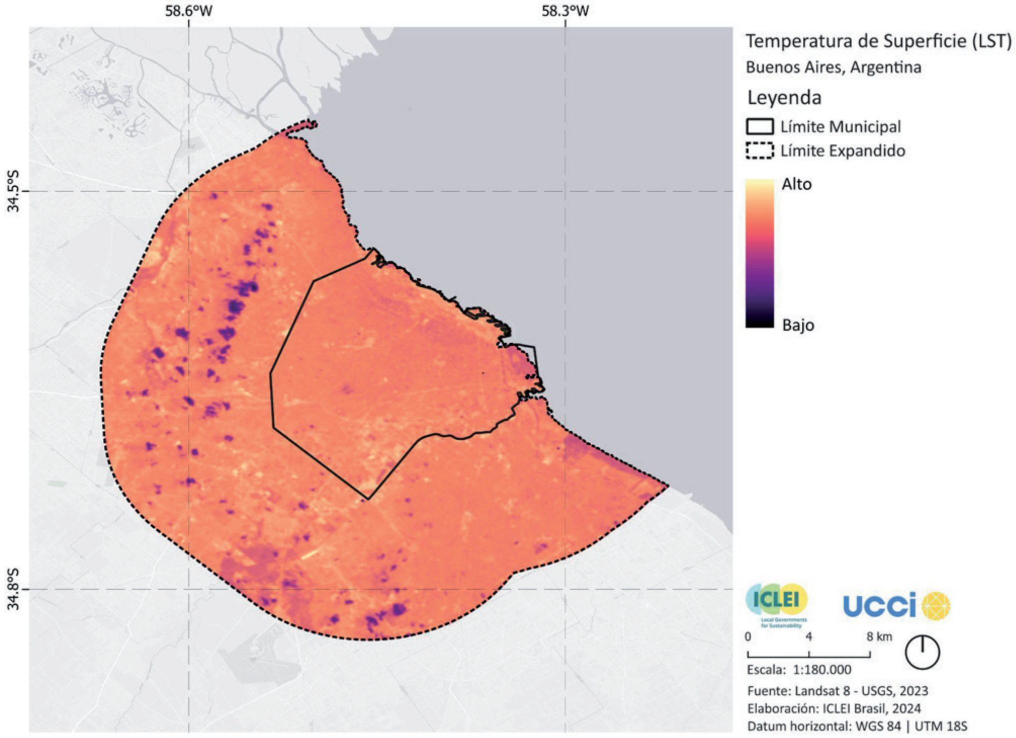
Figure 17: Local Climate Zones Distribution in Buenos Aires



3.4.3 Heat Island Analysis

The LST map for Buenos Aires shows the city's thermal range. It is important to note that, unlike the other cities in this Atlas, Argentina's Federal Capital and its expanded boundaries — according to the adopted criteria — are almost entirely urbanized. As a result, there is minimal presence of dark violet tones, those that indicate low temperatures. These zones are sparse and are generally associated with vegetation or building shading. The warmest areas, shown in yellow, are located along major roadways, such as 9 de Julio and 25 de Mayo avenues. Conversely, the less warm zones are observed in neighborhoods with more tree cover, like Palermo, or near the Río de la Plata, such as in Puerto Madero.

Figure 18: Surface Temperatures in Buenos Aires

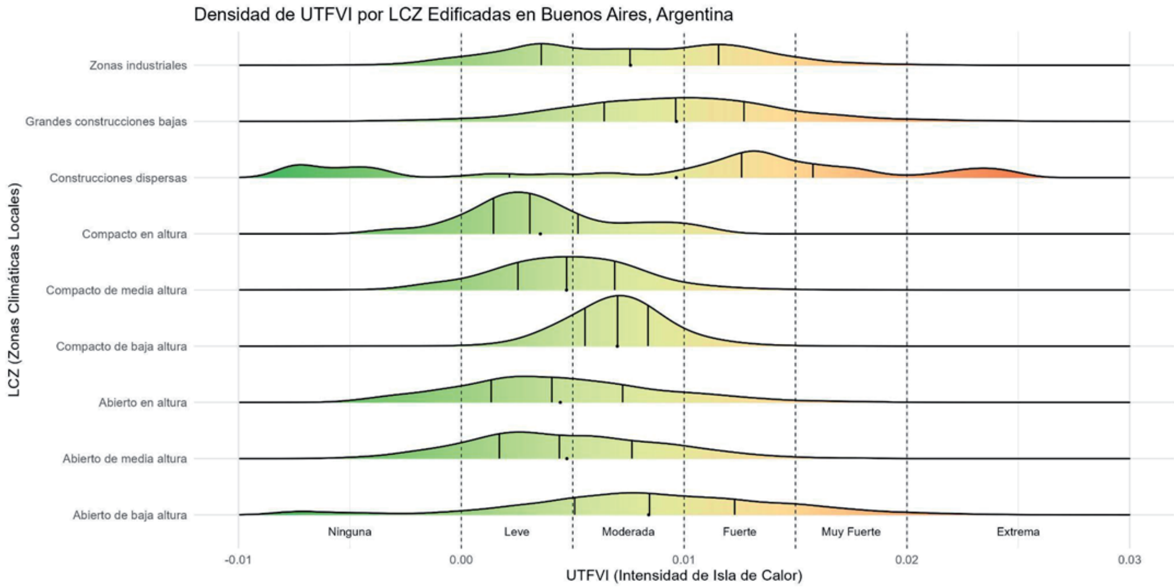


3.4.4 Heat Island Behavior by Landscape Typology

- **Industrial Zones:** This typology shows a higher concentration of values in the moderate to strong categories, indicating a significant contribution to heat islands. The lack of vegetation and the predominance of impermeable surfaces intensify heat retention in these areas.
- **Compact and Open (High, Mid, and Low-Rise):** These typologies show behavior mostly concentrated in the mild to strong categories, indicating significant heat retention, though not as extreme as in industrial zones. Ventilation is limited in compact areas, but taller buildings provide some shade, which helps slightly reduce temperatures, though not enough to mitigate the heat island phenomenon.
- **Large Low-Rise Buildings:** Values are primarily distributed in the mild to strong categories, with less heat retention compared to industrial zones. However, the lack of vegetation and the presence of low-rise buildings still contribute to the heat island phenomenon.
- **Dispersed Buildings:** In Buenos Aires, this typology shows an interesting variation in values, with a notable concentration in the mild category and some peaks in the strong and very strong categories. This behavior reflects lower heat retention compared to denser typologies, thanks to greater spacing between buildings and the presence of more open areas.

The variation in values indicates that, although these areas are generally cooler, there are specific points where the lack of vegetation or paved surfaces may contribute to higher-than-expected heat retention.

Figure 19: Heat Island Behavior by Landscape Typology in Buenos Aires



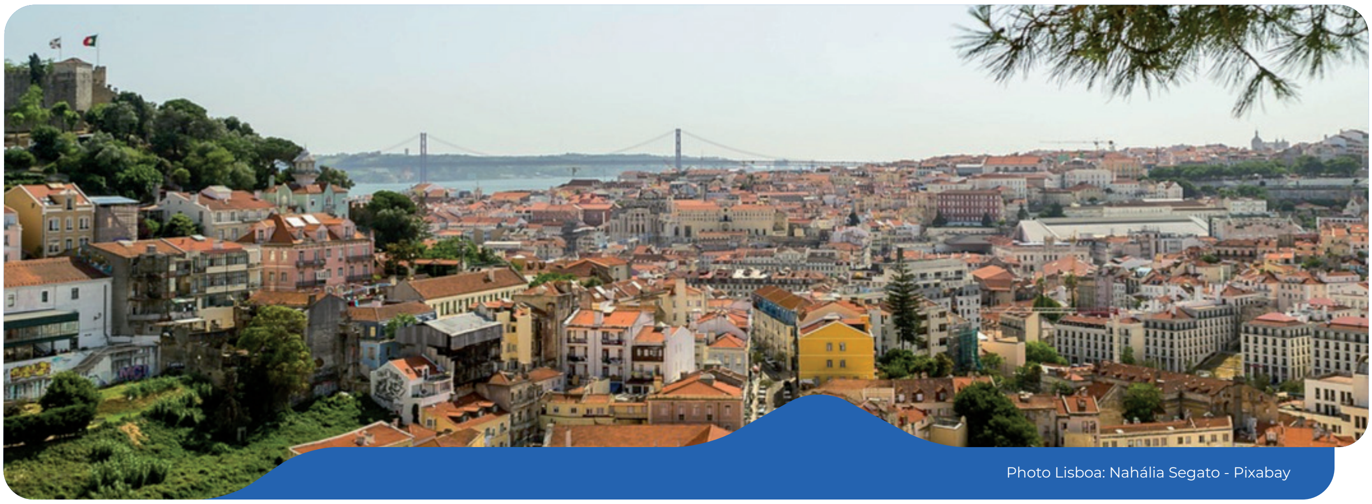


Photo Lisboa: Nahália Segato - Pixabay

3.5 Lisbon, Portugal

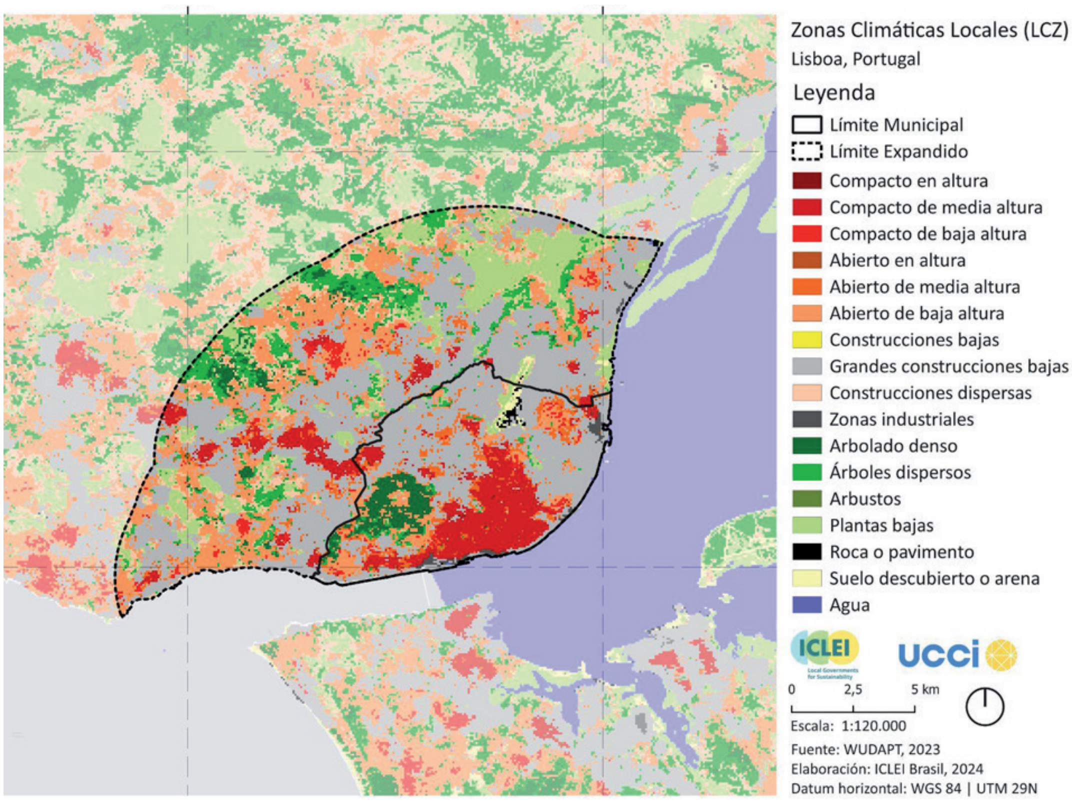
Lisbon, the capital of Portugal, has a population of approximately 547,773 and covers an area of about 100 km² (INE, 2022). Although the city has shown a strong commitment to urban and environmental issues on various international platforms, local authorities did not respond to the survey sent regarding climate governance, risk management, and urban-environmental planning within the framework of this study.

3.5.1 Analysis of Local Climate Zones

Lisbon, the largest city and capital of Portugal, is situated on the northern bank of the Tagus River. The entire area within its municipal boundary is urbanized. On the LCZ map, a large central red area stands out, representing a compact mid-rise zone corresponding to the city's central area, including the downtown and historic center. This area is characterized by dense buildings of historical significance.

In the western part of the city, where the neighborhoods of Ajuda, Belém, and Alcântara are located, there is an extensive green area that corresponds to the Monsanto Forest Park, one of the most significant densely tree-covered areas. Closer to the river, areas classified as "open mid-rise," along with large low-rise and dispersed buildings, represent major urban infrastructures such as the University of Lisbon, the stadium, the Jerónimos Monastery, several palaces, museums, and other important cultural sites. To the north of the city, a more dispersed urbanization with large low-rise buildings and open spaces predominates, characterized by longer, less compact buildings.

Figure 20: Local Climate Zones of Lisbon

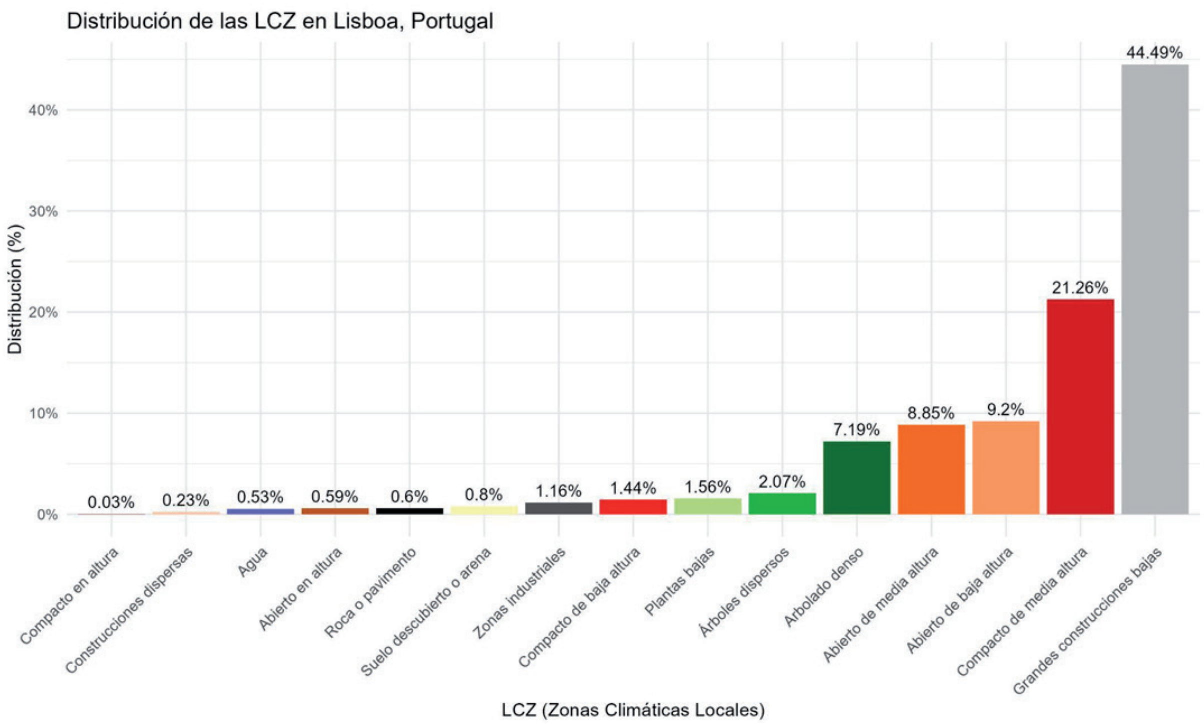


3.5.2 Local Climate Zones Distribution

Over 87% of the city's area corresponds to urban landscape typologies—approximately 87 km²—while less than 10% of the entire municipal territory is classified as vegetation cover, covering around 9 km². Notably, tree masses are sparsely represented within urbanized areas. The largest treed area is an urban park. According to the LCZ distribution chart for Lisbon in Figure 21, the following characteristics are observed:

- **Large low-rise buildings (44.49%):** This is the predominant typology, representing densely urbanized areas with building blocks that occupy entire city blocks. This morphology tends to intensify the heat island effect.
- **Compact mid-rise (21.26%):** Like large low-rise buildings, this is a common urban typology in Portugal. It is characterized by dense built-up areas with minimal vegetation.
- **Dense tree cover (7.19%):** Much of the dense vegetation corresponds to the Monsanto Forest Park, which has substantial cooling potential.
- **Scattered Trees (2.07%):** This is the second most observed natural landscape typology in Lisbon. It is found near the Forest Park and around the urbanized area.

Figure 21: Local Climate Zones Distribution in Lisbon

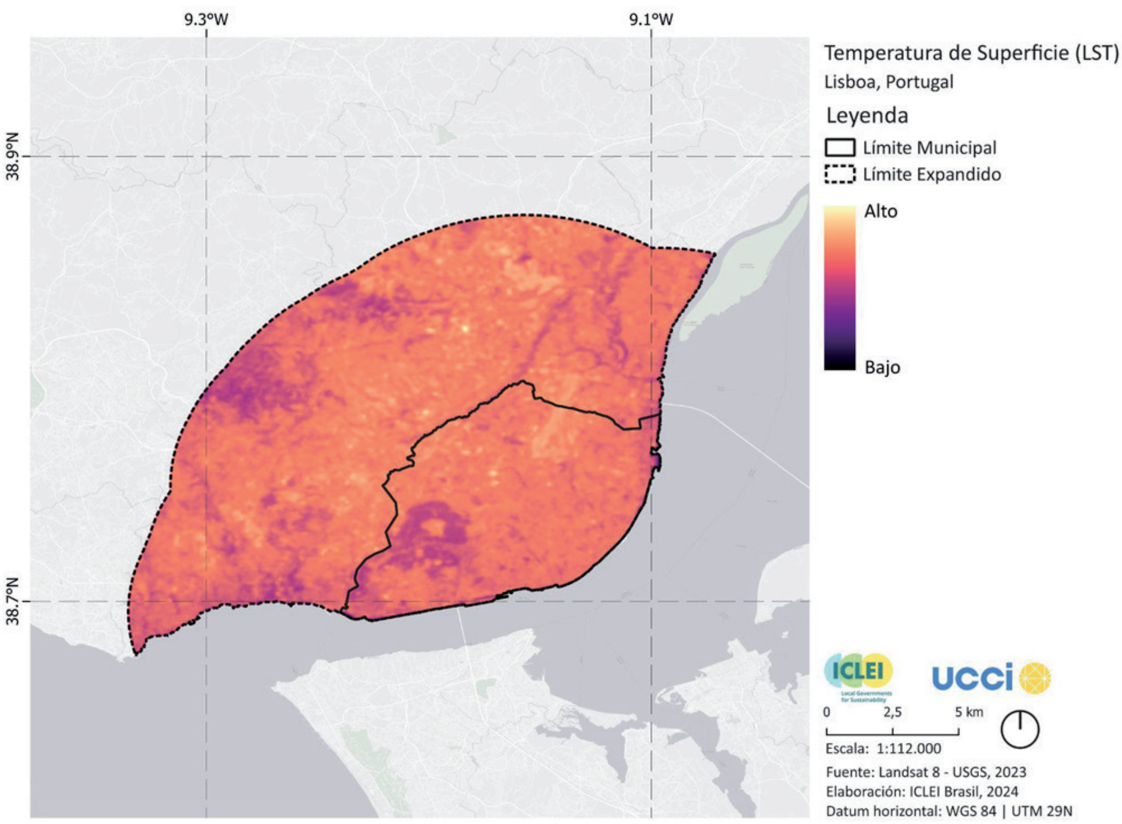


3.5.3 Heat Island Analysis

The LST map shows the thermal range in the city. The warmest areas, shown in yellow, are located in regions with exposed rocks and fields of low-lying vegetation. The pinkish-orange areas, which also retain heat, are distributed throughout the urbanized area and display similar behavior due to its more uniform morphology. The observed differences may be related to urban forestry and the presence of plazas or other open spaces.

On the other hand, the cooler areas, marked in dark blue and violet, are primarily located in urban LCZs with dispersed or open low-rise buildings mostly to the north — and at the city's boundaries, in regions like Monsanto Forest Park or green corridors, highlighting their importance as temperature regulation zones.

Figure 22: Surface Temperatures in Lisbon



3.5.4 Heat Island Behavior by Landscape Typology

- **Industrial Zones:** This typology shows a high concentration of values in the moderate to strong categories, indicating that industrial zones are significant contributors to heat islands. The lack of vegetation and the extensive amount of impermeable surfaces intensify heat retention in these areas.
- **High-Rise Compact:** This typology has a notable concentration of values in the moderate category, suggesting less heat accumulation compared to other open typologies, although the presence of tall buildings may create shadows that reduce heat retention in these areas.
- **Mid-and Low-Rise Compact:** These typologies show values ranging from strong to very strong, with considerable heat retention due to the density of compact buildings and lack of adequate shade. The absence of significant vegetation and the prevalence of heat-absorbing surfaces contribute to warming in these areas, as the buildings do not provide enough shade to mitigate the heat island effect.
- **Large Low-Rise Buildings:** Values in these areas are primarily distributed between strong and very strong, indicating that these areas are also major sources of heat due to the lack of vegetation and the prevalence of paved surfaces.
- **Dispersed Buildings:** This typology shows an interesting range, with most values concentrated in the strong category and some peaks in the very strong category. Although these areas benefit from greater ventilation due to the spacing between buildings, there are still points where heat retention is significant, possibly due to the lack of vegetation in certain parts.

Figure 23: Heat Island Behavior by Landscape Typology in Lisbon

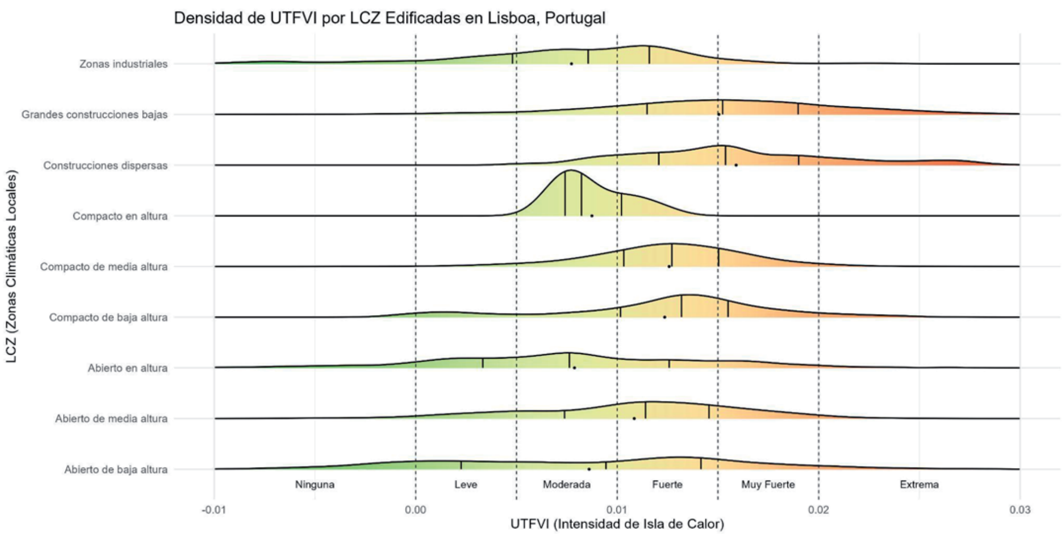


Photo Madrid: Pixabay

3.6 Madrid, Spain

Madrid covers an area of 604.3 km² and has a population of 3,460,491 (2024). The city has established a robust infrastructure to tackle climate challenges. The municipality has government bodies and interdepartmental committees dedicated to the Climate Agenda, although there is no specific civil society council to address this issue. Madrid has implemented a Climate Action Plan and conducted risk assessments related to heat waves. Additionally, it has 24 monitoring stations that measure various climate variables, ensuring continuous tracking of air quality and other environmental conditions. The city has also developed an Urban Forestry Plan and designated green areas as climate shelters. No heat wave-related deaths were recorded in the past five years, indicating ongoing effective risk management.

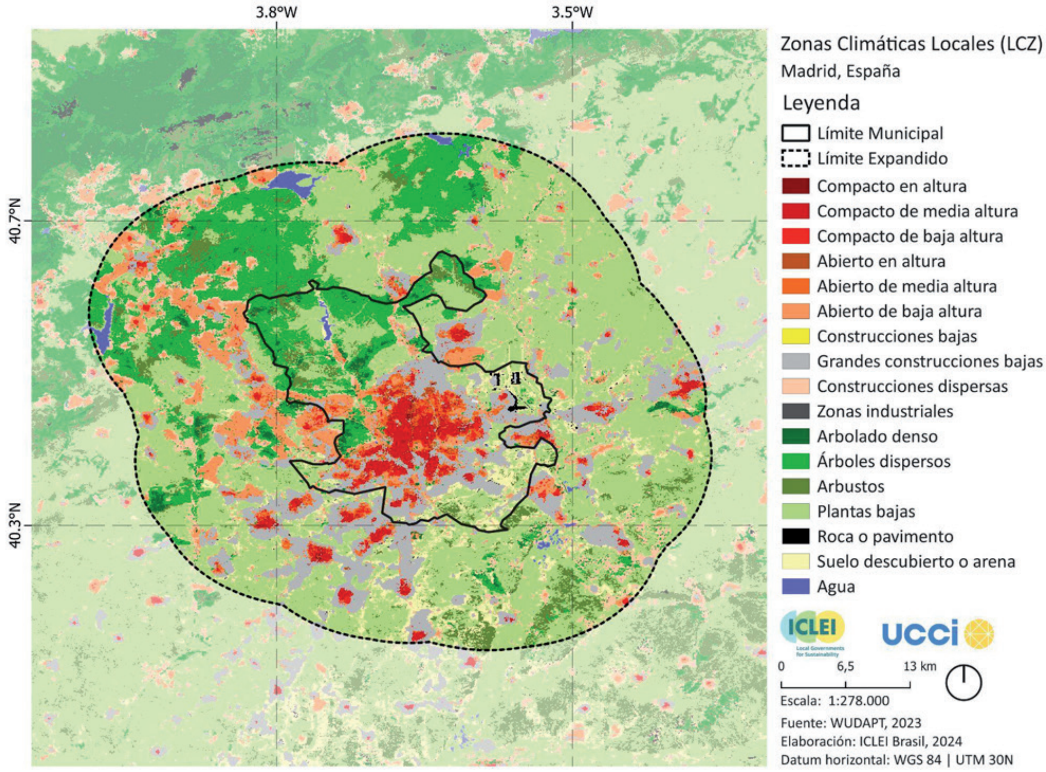
3.6.1 Analysis of Local Climate Zones

Madrid, the capital and largest city of Spain, is located in the central area of the Iberian Peninsula on a predominantly flat plateau. The city's Local Climate Zones (LCZ) map reveals a dense center with compact mid- and low-rise areas, particularly in neighborhoods like the Historic Center and Chamberí. High-rise compact zones, such as those in Tetuán near Paseo de la Castellana, contribute significantly to heat retention and the formation of intense heat islands in that region. In more peripheral areas, such as Vallecas and Carabanchel, low-rise buildings are predominant, while more dispersed buildings appear closer to the city's limits.

To the west, the area is largely residential and dispersed, especially beyond Casa de Campo Park, an important green zone. In the north, dense tree-covered areas stand out, particularly in the district of Fuencarral-El Pardo, where Monte de El Pardo occupies 26.4% of the city's area. Rural zones are mainly concentrated to the south and northeast of the city, identified as low-lying vegetation areas, some interspersed with shrubs or bare soil.

Although the mapping resolution does not capture bodies of water, such as the Manzanares River, major urban parks like El Retiro help mitigate the heat island effect in the urban area (Figure 24).

Figure 24: Local Climate Zones of Madrid



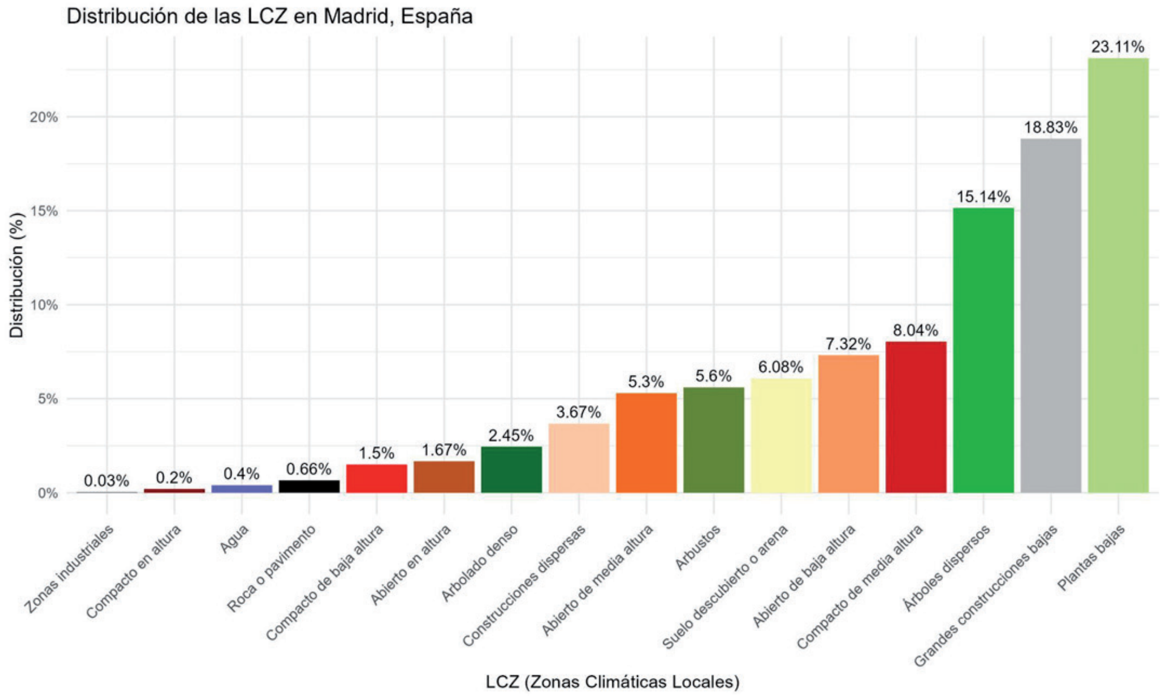
3.6.2 Local Climate Zones Distribution

Over 45% of the city's area corresponds to urban landscape typologies — approximately 281 km² — while nearly 18% of the entire municipal territory is covered by vegetation, totaling around 106 km². It is important to note that tree masses are not highly represented within urbanized areas, which is related to the region's biome. These zones are mainly concentrated in the north. According to the LCZ distribution chart for Madrid in Figure 25, the following characteristics are observed:

- **Low Vegetation (23.11%):** This is the predominant typology in the city's territory. This LCZ represents landscapes dominated by crops, low-lying vegetation, and/or grass, with few trees. It also includes urban park areas with sparse vegetation. Grass or open fields do not provide significant soil permeability and cannot cool their surroundings as dense vegetation does. They are a major contributor to rising urban temperatures, especially in residential neighborhoods with a high proportion of impermeable surfaces and generally limited vegetation. However, their heat island intensity is more moderate than in more compact or high-rise areas. Some of these zones are located on hills, particularly in the south.

- **Large low-rise buildings (18.83%):** Also common in Lisbon and Barcelona, this urban landscape typology is the most prevalent in Madrid. Characterized by high building density and sparse vegetation, it has the potential to contribute to local warming.
- **Scattered Trees (15.14%):** This is the second most common natural landscape typology in Madrid, characteristic of the region where the city is located. It is observed in the north, around the El Pardo Dam. These areas have irregularly distributed trees, typically found in parks, plazas, or along streets. Although trees help reduce the heat island effect, their scattered distribution limits their positive impact on the microclimate. In Madrid, green areas like Valdebebas Forest Park, Juan Carlos I Park, and El Retiro serve as small urban oases, offering thermal relief on a small scale but with limited capacity to mitigate heat on a larger scale.
- **Compact mid-rise (8.04%):** Similar to large low-rise buildings, this landscape typology is characterized by high soil impermeability, a high volume of constructed space, and consequently, an intensified heat island effect.

Figure 25: Local Climate Zones Distribution in Madrid

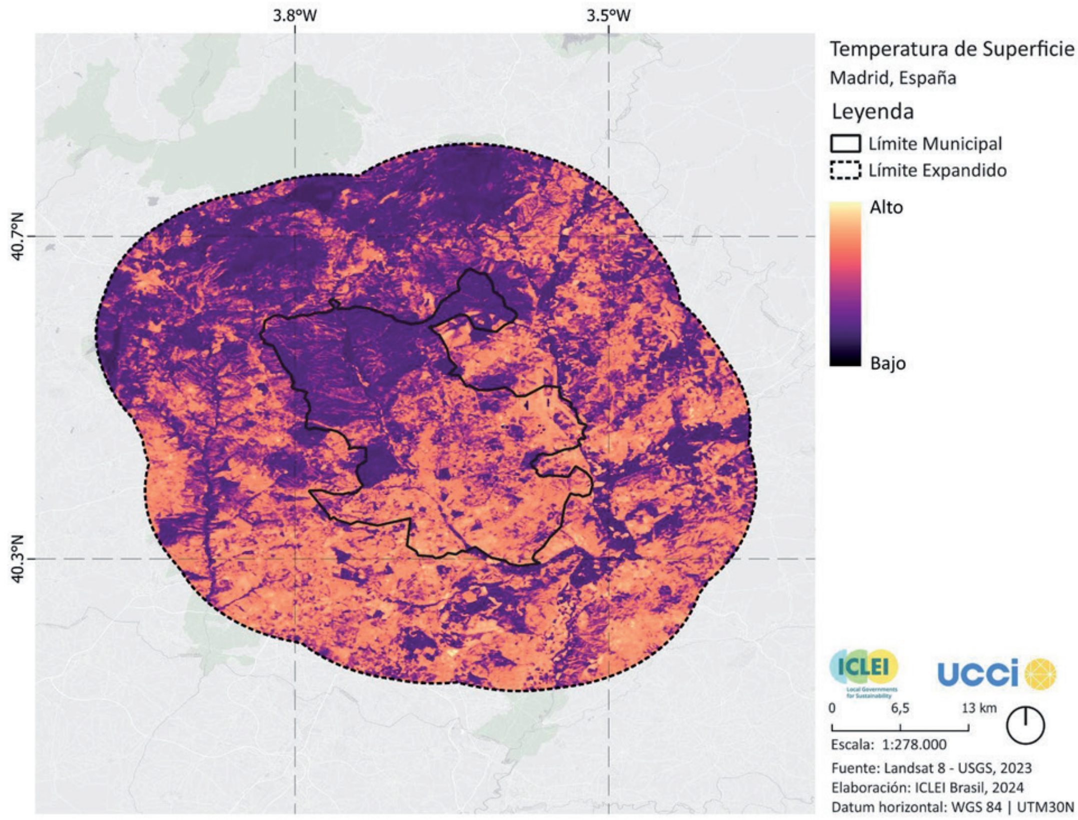


3.6.3 Heat Island Analysis

The LST map highlights the warmest and coolest areas in Madrid, with a notable contrast between the peripheral regions in the west-northwest and east-southeast (Figure 26). The warmest regions, shown in yellow, are concentrated in the southeast of the peri-urban perimeter. This may be related not only to the type of land use, marked by exposed soil and areas with some building density, but mainly to the type of construction materials, which have high thermal capacity. These regions indicate significant heat accumulation.

The central area of Madrid predominantly falls within the moderate classification—shades of orange and violet. While not as extreme as the more industrial or exposed soil areas, these zones still experience substantial heat retention due to the high density of buildings and impermeable surfaces, typical of a large metropolis. In contrast, the northwest part of the city has the coolest areas. Thanks to extensive vegetation cover, these regions show significant mitigation of heat effects.

Figure 26: Surface Temperatures in Madrid



3.6.4 Heat Island Behavior by Landscape Typology

The chart reveals the intensity of heat islands across different LCZs. The UTFVI indicates the severity of heat islands, with classifications ranging from "None" to "Extreme" (Figure 27).

- **Industrial Zones:** This typology exhibits some of the highest values, with classifications reaching "Very Strong" and "Extreme." Although these areas are not the most widespread in the city, they are focal points of the most intense heat islands and therefore require attention, especially considering their potential link to other socio-environmental impacts, such as pollution.
- **Large Low-Rise Buildings:** In this typology, values are primarily distributed in the "strong" category. This suggests that areas with low-rise buildings make a significant contribution to the heat island phenomenon, though not as intense as in more compact or industrial zones.
- **Compact and Open (High, Mid, and Low-Rise):** The skyscraper typologies, both compact and open, show a similar pattern, with values concentrated in the moderate and strong categories, also reaching "Very Strong," with a slightly more pronounced effect for compact skyscrapers. On the other hand, the low-rise LCZ, while also showing a concentration in the "moderate" and "strong" classifications, exhibits a less pronounced pattern, exhibits a less pronounced pattern, which relates to a greater cooling capacity due to generally having at least some vegetation. Similarly, typologies such as open low-rise and, even more so, dispersed buildings, which usually include intra-urban areas with more vegetation, showed better results.
- **Dispersed Buildings:** This class shows more moderate values, primarily in the mild to moderate temperature categories. Although these areas tend to have more vegetation and a lower degree of urbanization, which reduces the intensity of heat islands, they still contribute to the phenomenon, especially in zones where building dispersion is insufficient to allow significant natural cooling.

Considering the combination of natural and human factors that favor the formation of heat islands in the city, it would be beneficial to invest more heavily in an urbanization pattern that incorporates greenery in a more distributed and strategic way. Using plant species adapted to local conditions that also support biodiversity would enhance the effectiveness of these green spaces.

Figure 27: Heat Island Behavior by Landscape Typology in Madrid

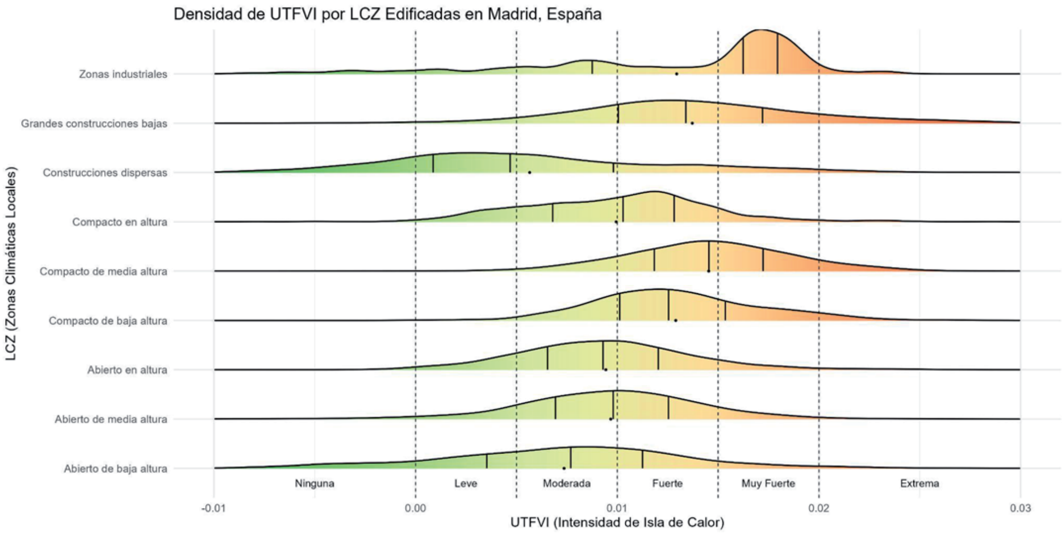


Photo Montevideo: Anton Lukin - Pixabay

3.7 Montevideo, Uruguay

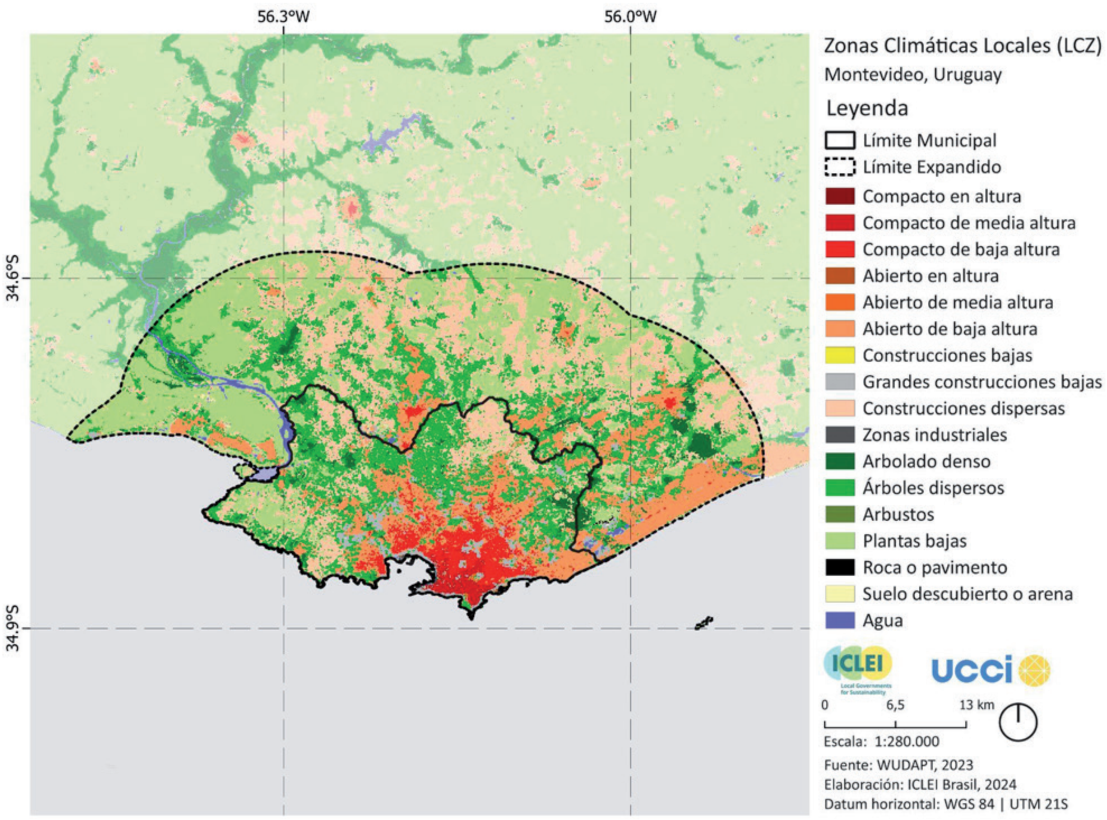
Montevideo has an area of 530 km² and an estimated population of 1,383,965 inhabitants (National Institute of Statistics, 2022). The city has developed a comprehensive approach to address climate challenges, with government bodies and interdepartmental committees facilitating the implementation of the Climate Agenda, although it does not have a specific council with civil society representation. A Climate Action Plan has been established, and there are 6 monitoring stations that track various environmental variables, such as temperature, relative humidity, and precipitation. However, no heat waves or related deaths have been documented in the past five years, reflecting ongoing risk management. Additionally, Montevideo has protected areas and has implemented an Urban Forestry Plan, supporting the conservation of its green spaces.

3.7.1 Analysis of Local Climate Zones

Montevideo, the capital of Uruguay, is located in the south of the country, along the coast of the Río de la Plata. On the city's Local Climate Zones (LCZ) map, compact and open zones are mainly concentrated in the central-southern part of the municipal area, which aligns with the most established urbanization. A color gradient illustrates the transition from compact mid- and low-rise central zones to more open areas, and eventually to vegetated zones with dispersed buildings. The gray patches of large low-rise buildings mostly correspond to predominantly industrial areas or large infrastructure zones.

In the northern and western areas beyond the municipal boundary, dispersed buildings and vegetation zones predominate, corresponding to the Departments of Canelones to the east and San José to the west. Both areas are predominantly rural and governed by mixed-use land legislation that combines agricultural use with environmental protection, ensuring a balance between development and conservation.

Figure 28: Local Climate Zones in Montevideo



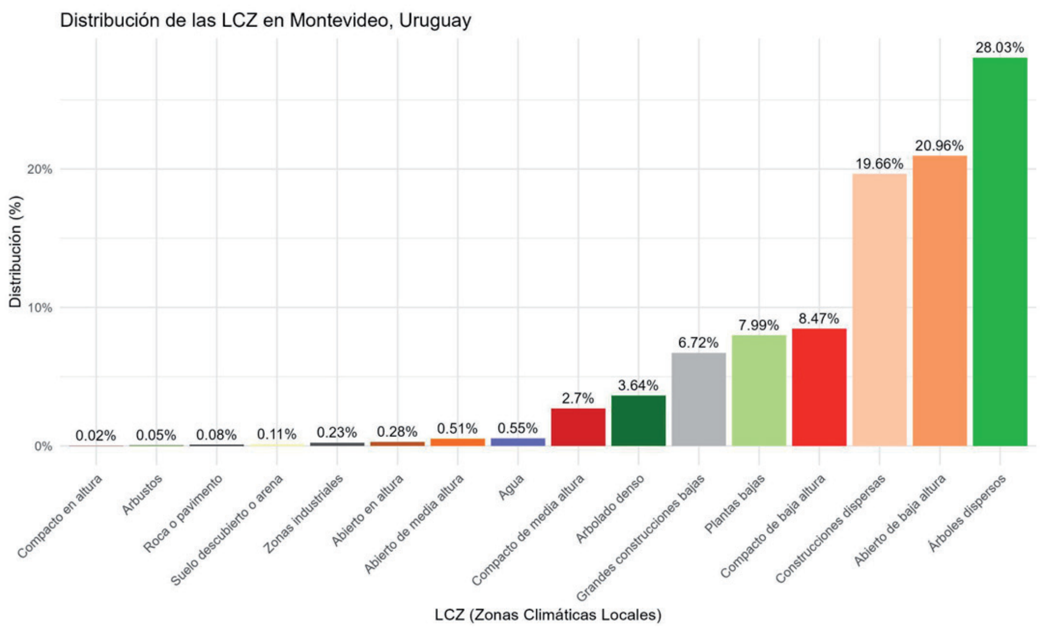
3.7.2 Local Climate Zones Distribution

Almost 60% of the city's area corresponds to urban landscape typologies — approximately 315 km² — while over 30% of the entire municipal territory is covered by vegetation, totaling around 168 km². It is important to note that tree masses are not highly representative in the city's territory — and in the expanded boundary — as this is a characteristic of the local Pampa biome. According to the LCZ distribution chart in Figure 29, the following characteristics are observed:

- **Scattered Trees (28.03%):** The city's area does not only include urbanized land. In this regard, scattered tree cover —characteristic of the Pampa biome — is identified as the most common landscape typology in Montevideo.

- **Open Low-Rise (20.96%):** This is the most common urban typology. These zones feature spaced buildings and maintain environmental quality through soil permeability and vegetation presence. As a result, they are less susceptible to heat islands.
- **Dispersed Buildings (19.66%):** This is an urban landscape typology with low impact in terms of heat retention. Denser and more vertical zones, which typically retain more heat, are less common in Montevideo.
- **Low Vegetation (7.99%):** Fields and areas covered by natural grass, similar to scattered trees, are endemic to the Pampa biome. This is the second most common natural landscape typology in the city and does not provide urban cooling capacity.

Figure 29: Local Climate Zones Distribution in Montevideo

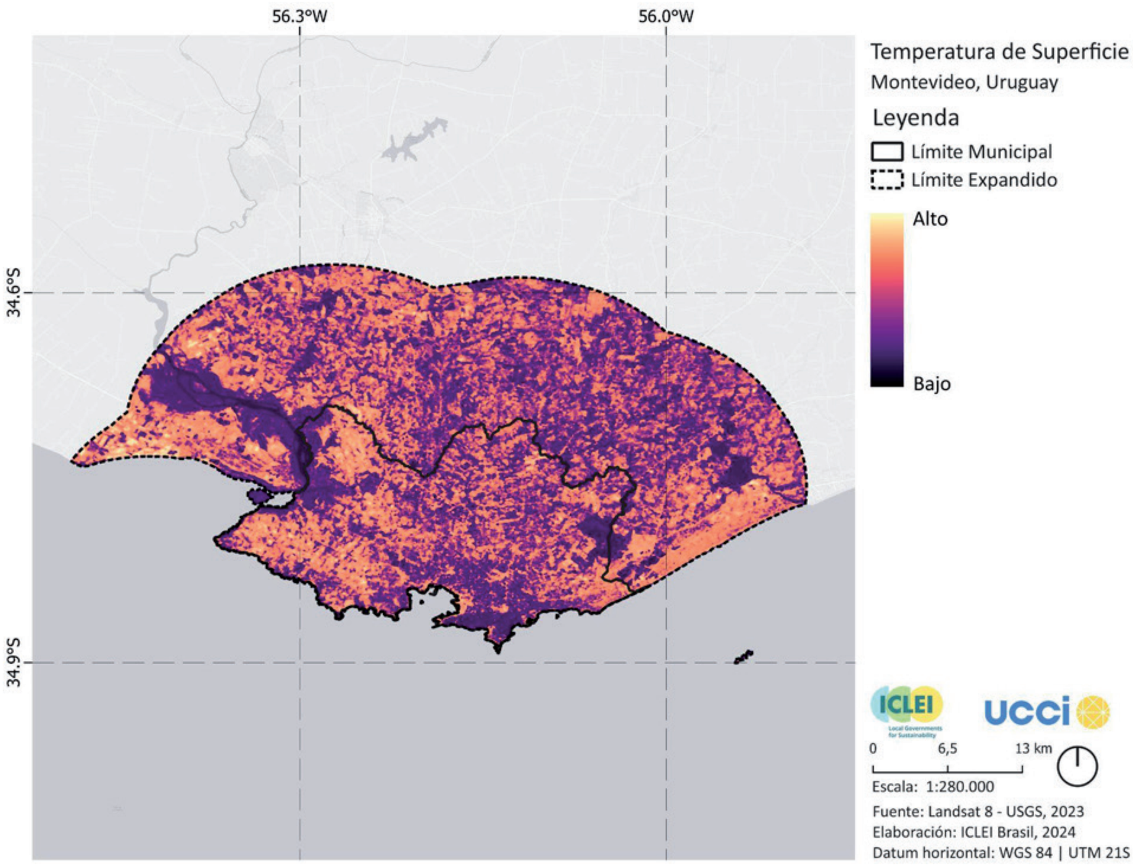


3.7.3 Heat Island Analysis

The LST map for Montevideo shows the thermal range across the city. The warmest areas, shown in yellow, are located in fields and low-lying vegetation zones associated with agricultural areas, particularly prominent in the north. The pinkish-orange areas, also heat-retaining, extend along the eastern coast.

The central area of the city, with more vertical and urbanized structures, shows lower temperatures compared to other urban areas in the city. However, it is important to highlight that this is related to shadows cast by tall buildings, which can impact the analysis—especially because radiation in these areas has a lower capacity to dissipate at night due to the number of obstacles in the built environment. Conversely, the coolest areas, marked in dark blue and violet, are primarily located along the Santa Lucia River and in other densely tree-covered areas, such as the Botanical Garden.

Figure 30: Surface Temperatures in Montevideo



3.7.4 Heat Island Behavior by Landscape Typology

- **Industrial Zones:** These areas exhibit a high concentration of readings in the "strong" and "very strong" categories, indicating that industrial zones are major contributors to the heat island phenomenon in Montevideo. The combination of impermeable surfaces and limited vegetation intensifies heat retention in these areas.
- **Open High-Rise:** This typology shows values primarily in the "mild" category, indicating that these areas, though densely built, do not retain as much heat as other typologies. This is because tall buildings create shadows that help reduce direct sun exposure, mitigating warming in some areas. Despite the building density, the shadows cast by taller buildings help keep these areas cooler compared to lower, more compact zones, where the lack of shade increases heat retention.
- **Open Low-, Mid-, and High-Rise:** Open zones show a distribution of values in the "none" to "moderate" categories, indicating better ventilation and less heat retention compared to more compact areas. However, in certain spots, the lack of vegetation or shade can cause these areas to accumulate moderate levels of heat.
- **Mid-and Low-Rise Compact:** These typologies show fairly consistent behavior, with most values concentrated in the "mild" to "moderate" categories. This indicates significant heat retention, though not as extreme as in industrial zones. The density of buildings and lack of sufficient shade cause these areas to heat up, especially on sunny days, when limited ventilation is insufficient to dissipate accumulated heat. The absence of vegetation and heat-retaining surfaces intensifies this effect, making these zones contributors to the heat island phenomenon in the city.

Figure 31: Heat Island Behavior by Landscape Typology in Montevideo

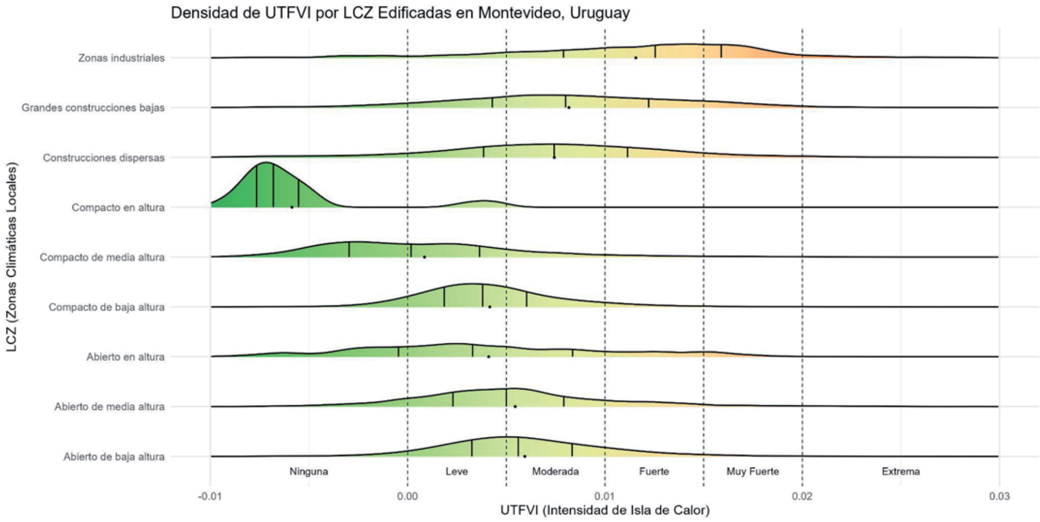


Photo Quito: Pixabay

3.8 Quito, Ecuador

The city of Quito, located in the Metropolitan District, covers 420.09 km^2 and has a population of 2,679,722 (INEC, 2022). The city's commitment to the Climate Agenda is reflected in the presence of government bodies dedicated to this cause, although it lacks a civil society council and an interdepartmental committee. Quito has its 2020 Climate Risk Assessment (CRA), which identifies potential climate impacts from Droughts, Heat Waves, Floods, and Landslides. This CRA was developed as input for Quito's 2020 Climate Change Action Plan. The city has protected areas under the Metropolitan Subsystem of Protected Natural Areas (SMANP) and public green spaces as climate shelters, as well as an Urban Forestry Plan. Quito's Metropolitan Network for Atmospheric Monitoring (REMMAQ) operates with 9 stations that provide real-time climate data, complemented by 89 stations from the Metropolitan Public Company of Drinking Water and Sanitation (EPMAPS), an important climate monitoring tool.

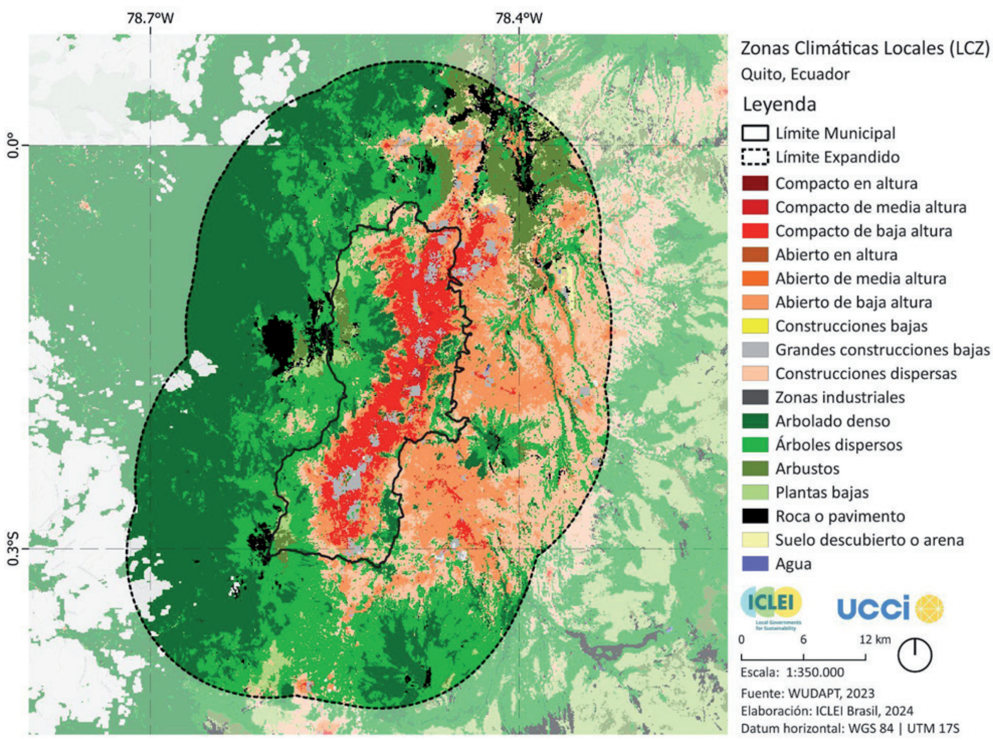
3.8.1 Analysis of Local Climate Zones

Quito's Local Climate Zones map reveals a significant concentration of high-rise and mid-rise compact areas, especially in the central and eastern zones of the city, representing the most urbanized sections. These densely built areas are the main contributors to heat retention, aligning with the warmest zones observed on the UTFVI map.

In contrast, dense and scattered tree-covered areas are primarily found to the west, on the slopes of the Guagua Pichincha volcano, and to the east, in parishes such as Iñaquito, Itchimbía, and Puengasí. These zones are found in more dispersed residential areas with low-rise buildings and a significant presence of green spaces, such as the Guangüiltagua Metropolitan Park.

Additionally, open low-rise and mid-rise areas serve as transitional zones between the more compact areas and the peri-urban green areas. While these areas also retain heat, they do so to a lesser extent than denser urban areas, providing a cushion that helps mitigate the heat island effects in more densely built sectors.

Figure 32: Local Climate Zones of Quito

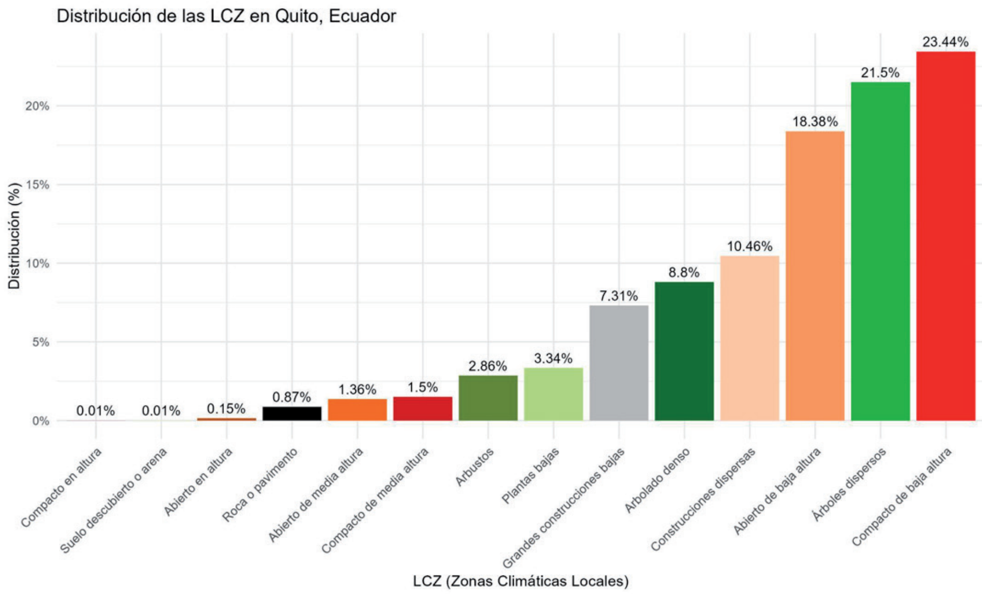


3.8.2 Local Climate Zones Distribution

More than 60% of the city's area corresponds to urban landscape typologies — approximately 263 km² — while over 30% of the entire municipal territory has vegetation cover — approximately 127 km². Notably, tree masses are sparsely represented within urbanized areas. These zones are mainly concentrated on the edges. According to the LCZ distribution chart for Quito in Figure 33, the following characteristics are observed:

- **Compact Low-Rise (23.44%):** This is the predominant typology in Quito. Areas with low-rise, high-density buildings are responsible for significant heat retention due to the lack of vegetation and abundance of impermeable surfaces. These zones directly contribute to the heat island phenomenon in the city.
- **Scattered Trees (21.5%):** Scattered tree areas cover a considerable part of the territory, especially in peri-urban areas and eastern parts of the city. Although not as effective as dense tree areas, these zones help reduce heat accumulation compared to urbanized areas, moderating heat island effects.
- **Open Low-Rise (18.38%):** Open low-rise areas offer a mix of urbanization and open spaces. They are primarily located in the southern and eastern urban areas. Although they contribute to heat retention, they do so less than compact zones. They also serve as a transition between densely built areas and green spaces.
- **Dense tree cover (8.8%):** Although less extensive, densely tree-covered areas play a crucial role in mitigating heat. These areas are mainly located in the northwest and southeast of the city. Dense vegetation acts as a thermal regulator, creating cooler microclimates and helping to counteract the effects of hotter urban zones.

Figure 33: Local Climate Zones Distribution in Quito

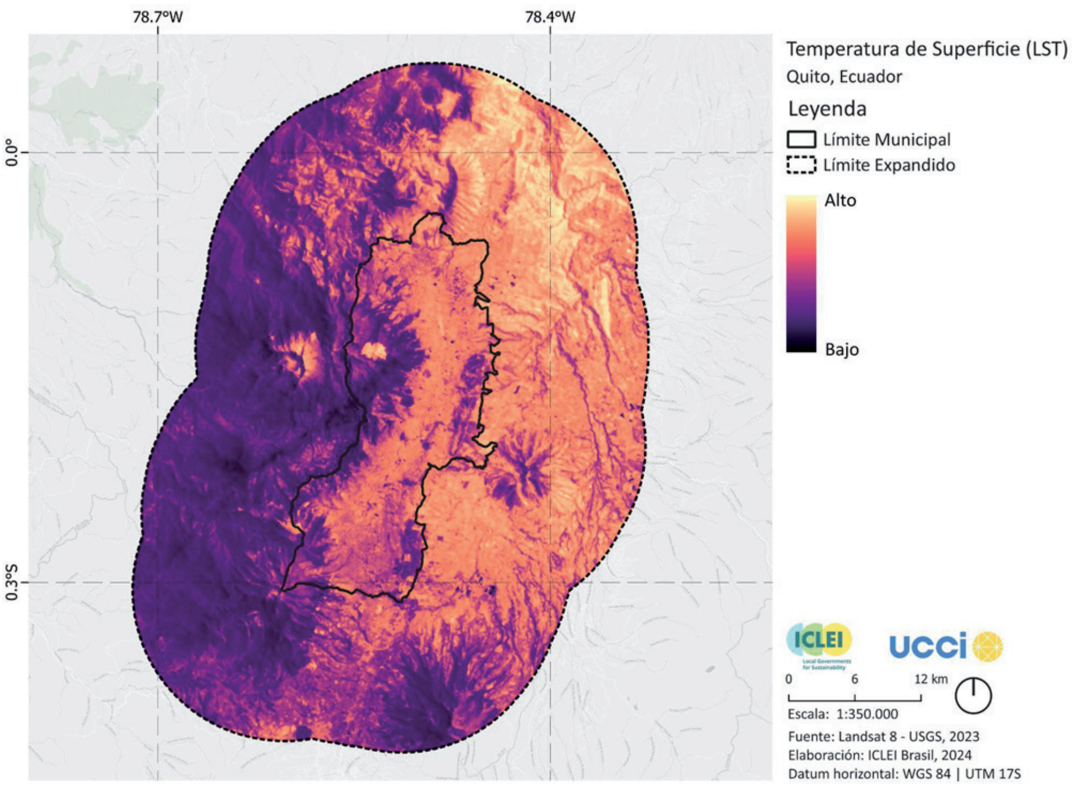


3.8.3 Heat Island Analysis

The LST mapping for Quito, Ecuador, shows that the warmest areas are primarily concentrated in the central, eastern, and urban perimeter zones. These zones correspond to built-up urban areas, where high building density and lack of vegetation contribute to greater heat accumulation.

In contrast, the areas marked in dark violet are predominantly located in the southern and western peri-urban zones. In these areas, vegetation and lower building density help mitigate the effects of heat, providing a cooler environment compared to urbanized zones. However, these zones are also characterized by the presence of hills, which can interfere with the estimation of heat island effects through remote sensing.

Figure 34: Surface Temperatures in Quito



3.8.4 Heat Island Behavior by Landscape Typology

- **High-Rise Compact:** This is the densest and most vertical landscape typology in Quito, characterized by the presence of skyscrapers. Although it accounts for less than 1% of the city's total area, it contributes to the zones with the highest concentration in the "extreme" classification according to the UTFVI.

- **Compact Mid-Rise:** Although this urban landscape typology represents about 1.5% of Quito's total area, it has a significant impact on increasing the heat island effect due to its heat retention. Located in the geographic center of the urban area, it is characterized by a lack of open and green spaces and by obstructing and creating wind corridors.

- **Large Low-Rise Buildings:** This class has a more distributed pattern, with its UTFVI values primarily concentrated in the "extreme" and "very strong" categories. This typology has minimal vegetation, and its solid structure contributes significantly to the heat island effect.

Figure 35: Heat Island Behavior by Landscape Typology in Quito

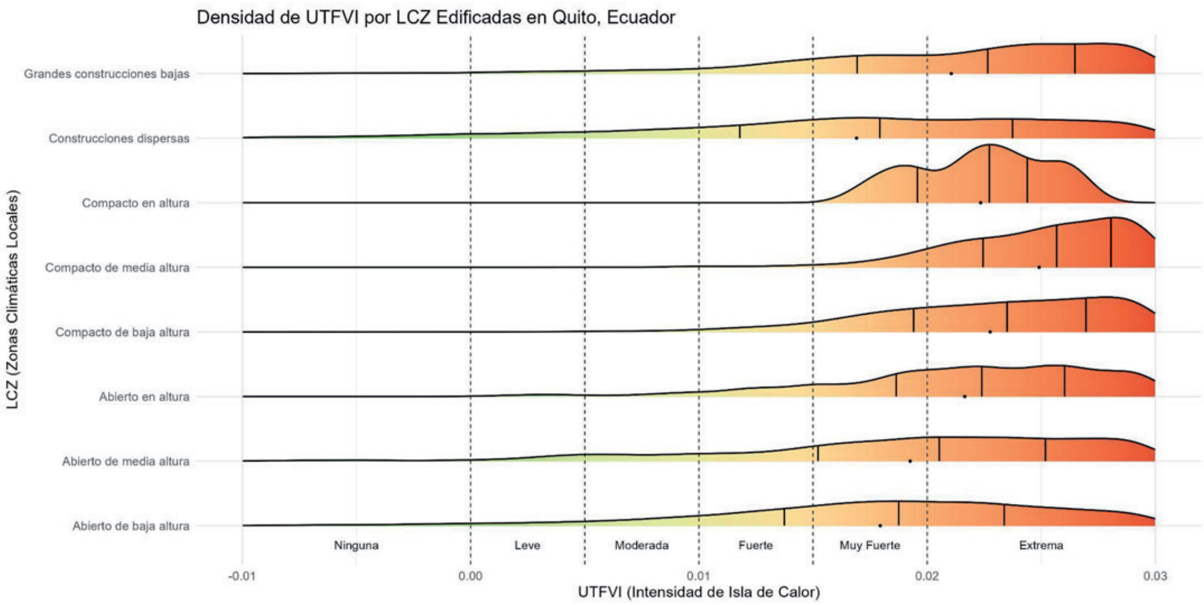


Photo Rio de Janeiro: Luciola Vilella - MTUR

3.9 Rio de Janeiro, Brazil

The city of Rio de Janeiro, with an area of 1,200.329 km² and a population of 6,211,223 (IBGE, 2022), demonstrates a notable commitment to the Climate Agenda. The municipality has governmental bodies and councils involving civil society in this area, as well as an interdepartmental committee to address climate-related issues. It also has an agency responsible for coordinating disaster prevention and management actions, with dedicated financial resources for the climate agenda. Rio de Janeiro has conducted risk assessments for heat islands and heat waves and has a Climate Action Plan. The city maintains protected areas and parks that serve as climate shelters and is committed to sustaining an Urban Forestry Plan. Additionally, it operates 149 rain gauge stations, 8 of which also function as meteorological stations, along with an environmental monitoring team to ensure compliance with regulations.

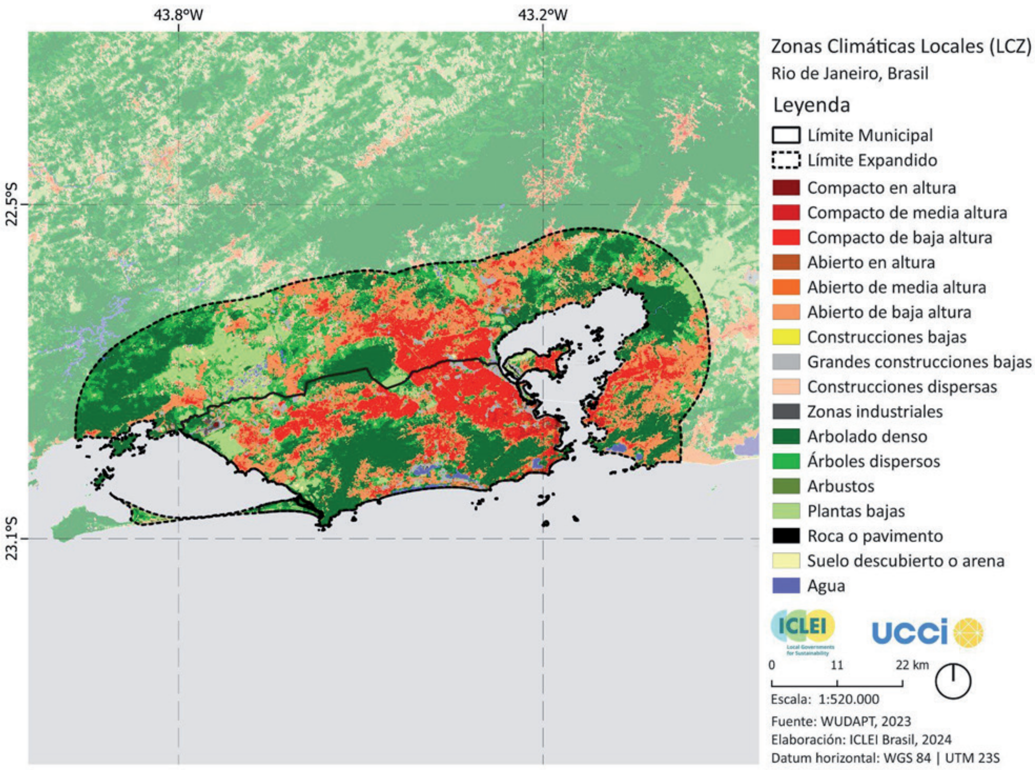
3.9.1 Analysis of Local Climate Zones

Rio de Janeiro, one of Brazil's major cities, displays a notable diversity of urban typologies within its municipal boundaries. The Local Climate Zones (LCZ) map shows a clear concentration of compact low- and mid-rise areas in the city's urban core, where dense buildings are largely responsible for heat retention, significantly contributing to the formation of heat islands.

In contrast, areas with scattered trees are mainly located in the southwestern part of the city, particularly in the Santa Cruz neighborhood — a sparsely urbanized region with an industrial district featuring dispersed developments. The densely tree-covered areas, represented by two large green patches in the central area of the map, correspond to Pedra Branca State Park in the west and Tijuca National Park in the east. These areas serve not only as thermal barriers but also as topographic barriers, limiting urban expansion due to their rugged terrain.

Likewise, the "open low- and mid-rise" zones occupy a significant part of the city, serving as transitional areas between densely built zones and green spaces. However, in some locations, there is no gradual transition, as urbanization extends to the possible limits where hilly topography and dense vegetation prevent further expansion, highlighting the crucial role of these natural barriers in shaping Rio de Janeiro's urban configuration.

Figure 36: Local Climate Zones of Rio de Janeiro



3.9.2 Local Climate Zones Distribution

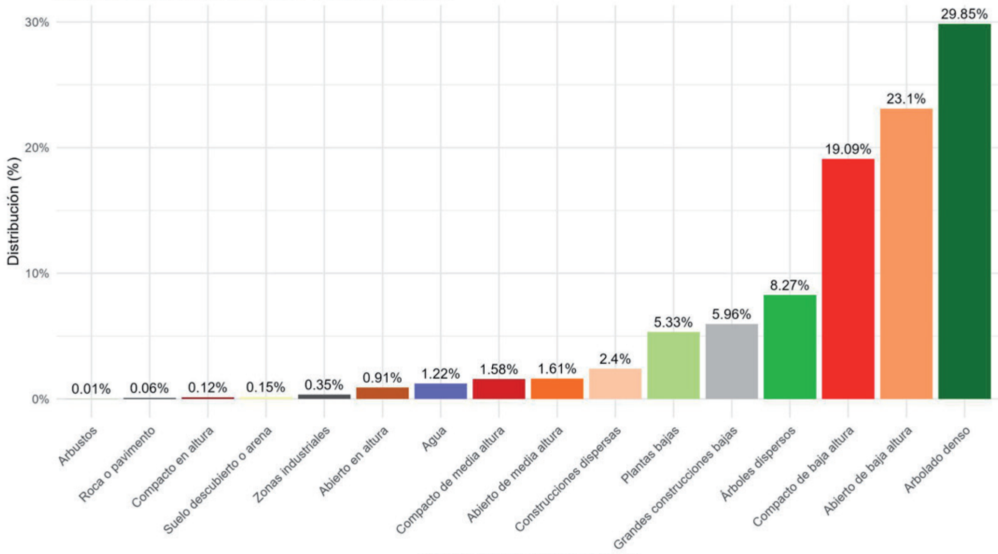
Approximately 55% of the city's area corresponds to urban landscape typologies — around 662 km² — while nearly 40% of the entire municipal territory has vegetation cover — around 457 km². These zones are concentrated in protected areas, such as Tijuca National Park and Pedra Branca State Park, and are often associated with hills. According to the LCZ distribution chart for Rio de Janeiro in Figure 37, the following characteristics are observed:

- **Dense tree cover (29.85%):** About 30% of Rio de Janeiro's area consists of densely vegetated areas. These zones serve as important thermal regulators, helping to reduce surface temperature and mitigating the heat island effects in surrounding areas.
- **Open Low-Rise (23.1%):** This is the predominant urban typology in Rio de Janeiro. It represents densely urbanized areas with low-rise buildings

and high soil impermeability. These zones are directly linked to intense heat islands due to the lack of significant vegetation and the prevalence of construction materials with high heat retention, such as concrete and asphalt.

- **Compact Low-Rise (19.09%):** Open low-rise areas are characterized by low-density buildings and open spaces. The presence of vegetation in these zones helps maintain cooler temperatures compared to compact areas.
- **Scattered Trees (8.27%):** These are field areas primarily located in the far west of the city and do not play a major role in climate regulation. However, they may be replaced by urban land through formal or informal expansion processes, which may overlook environmental quality considerations.

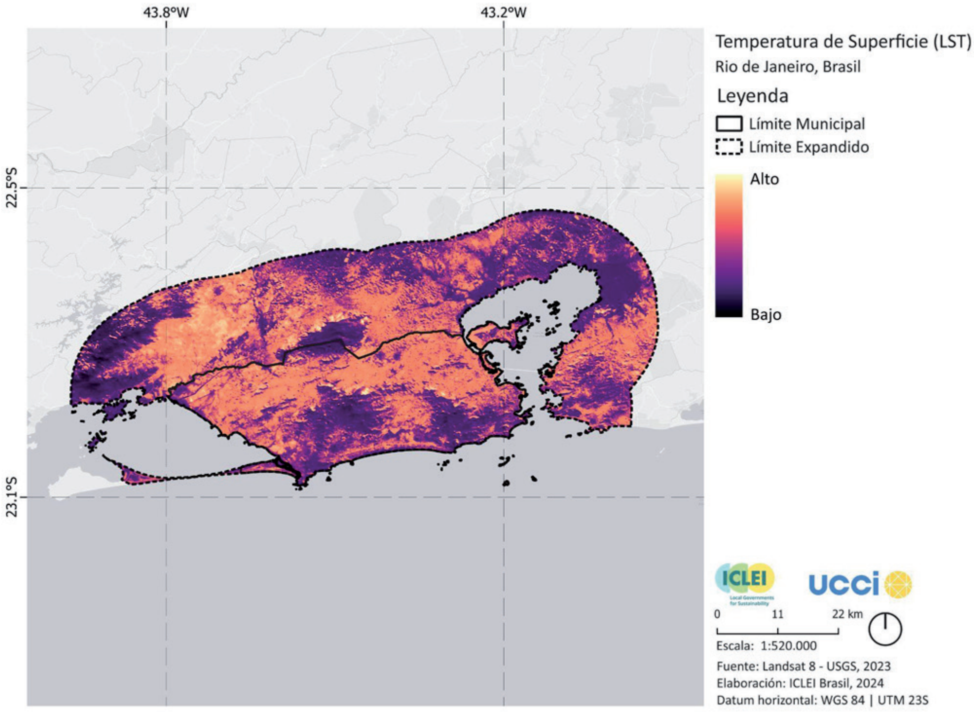
Figure 37: Local Climate Zones Distribution in Rio de Janeiro



3.9.3 Heat Island Analysis

The LST map of the city shows that the warmest zones are concentrated in densely built urban areas, especially in the northern part of the city. These zones are characterized by high building density and limited vegetation, which promotes heat accumulation. On the other hand, the areas marked in violet are mainly located in the southern part of the city, where coastal areas and various protected zones classified as dense tree covered areas are found, as well as in the peri-urban perimeter, which significantly contributes to heat mitigation in the area.

Figure 38: Surface Temperatures in Rio de Janeiro



3.9.4 Heat Island Behavior by Landscape Typology

- **Industrial Zones:** These areas exhibit significant readings, primarily falling within the "moderate" to "very strong" categories. Industrial zones, with a high density of paved surfaces and minimal vegetation, are key contributors to heat island formation in the city. The lack of shading and the high heat retention of industrial materials amplify their thermal impact.
- **Compact and Open (High, Mid, and Low-Rise):** These areas exhibit significant heat retention, with values primarily in the "mild" to "moderate" categories. Tall buildings provide some shade, but not enough to fully mitigate the heat, especially in zones with limited vegetation and ventilation. The open high-rise typology displays a distinct pattern with a wider range of values, suggesting better ventilation but still showing heat retention in specific areas.
- **Large Low-Rise Buildings:** Values in these areas are primarily within the "mild" to "strong" categories, suggesting that these zones also contribute to the heat island phenomenon, though to a lesser extent than industrial areas.
- **Dispersed Buildings:** Areas with dispersed buildings show values primarily concentrated in the "mild" category. This suggests that, due to the greater spacing between buildings and the possible presence of vegetation, these zones tend to retain less heat and have a more limited contribution to the heat island effect.

Figure 39: Heat Island Behavior by Landscape Typology in Rio de Janeiro

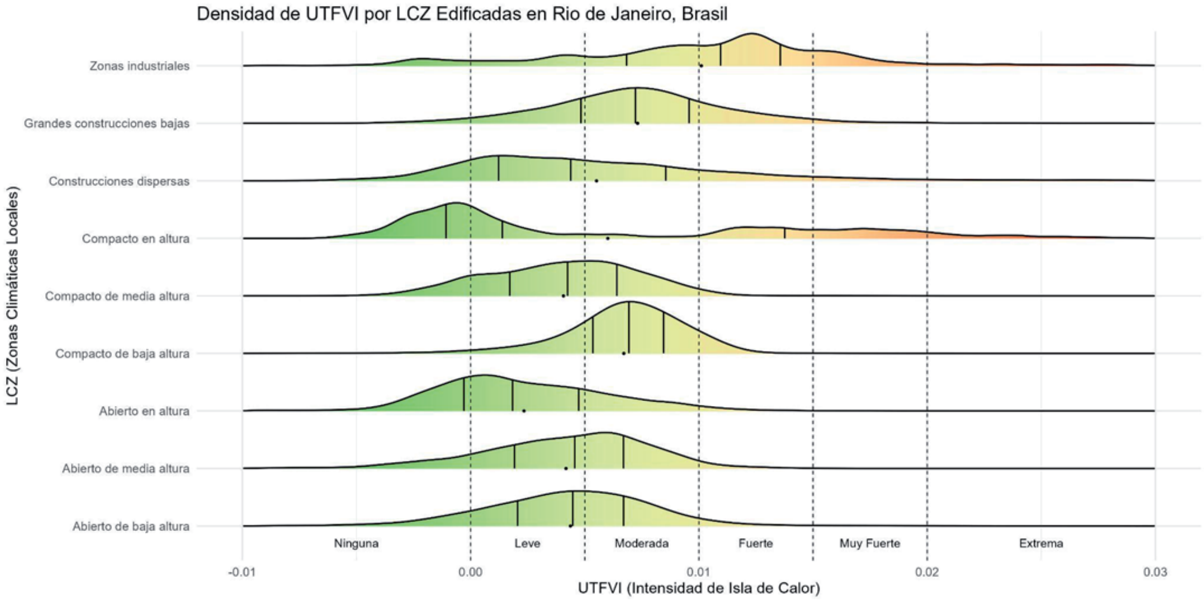


Photo San Salvador: Envato

3.10 San Salvador, El Salvador

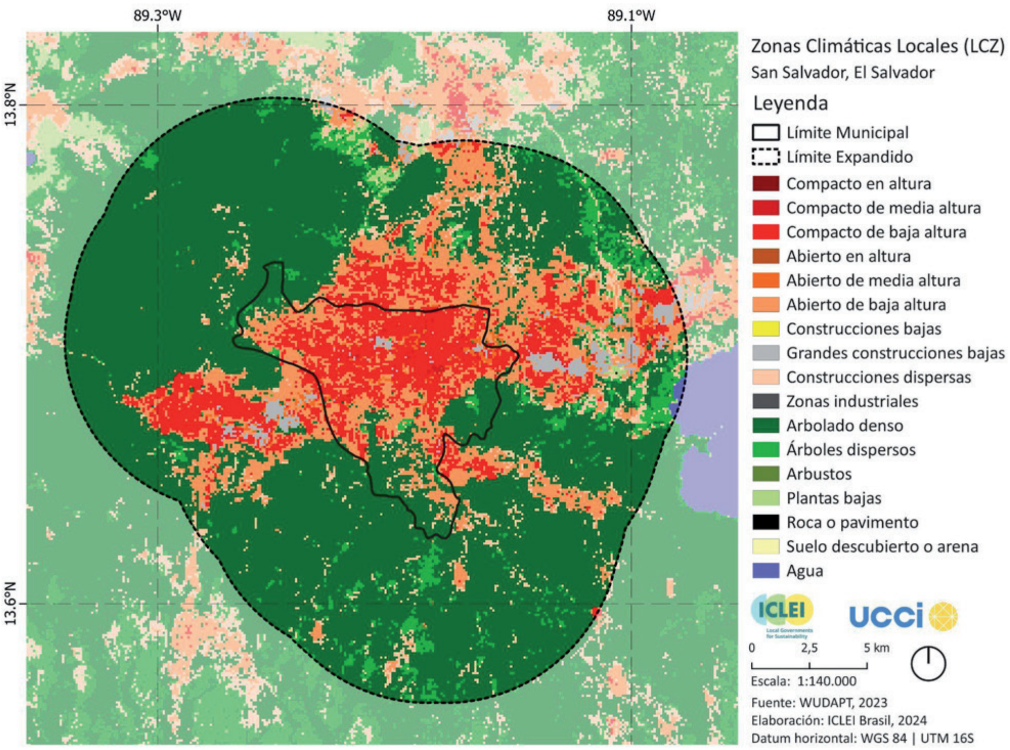
The city of San Salvador, with an area of 141.6 km² and a population of 705,858 according to 2023 estimates (ONEC), faces challenges concerning the Climate Agenda. Although the municipality has an entity responsible for coordinating disaster prevention and management actions, it does not have governmental bodies or councils with civil society representation to address this agenda. Additionally, there are no committees, working groups, or forums that integrate different departments to tackle these issues. No heat waves or related deaths have been reported in the past five years, but the city does have protected areas. Despite lacking an Urban Forestry Plan or specific laws for green area conservation, San Salvador has equipment to measure environmental variables, although details on the quantity and type of equipment were not specified. However, limited resources allocated to the climate agenda remain one of the biggest challenges in developing plans and actions to address this issue.

3.10.1 Analysis of Local Climate Zones

San Salvador, the capital and largest city of El Salvador, shows a marked concentration of compact low-rise areas on its LCZ map. This urbanized cluster extends beyond the city's boundary, indicating a high density of buildings and limited vegetation, both of which significantly contribute to heat retention and the formation of heat islands. In the center of the map, a gray area stands out, representing large low-rise buildings, such as shopping centers, hospitals, and government buildings.

In contrast, densely tree-covered areas are mainly located in the northwest and south of the urbanized area, corresponding to less developed regions near hills and higher elevations. These zones are essential for thermal mitigation, as vegetation plays a crucial role in reducing surface temperatures. Additionally, "open low-rise" areas cover a substantial part of the territory and are associated with lower density compared to the urban core, providing some thermal relief relative to the city's more compact areas.

Figure 40: Local Climate Zones of San Salvador

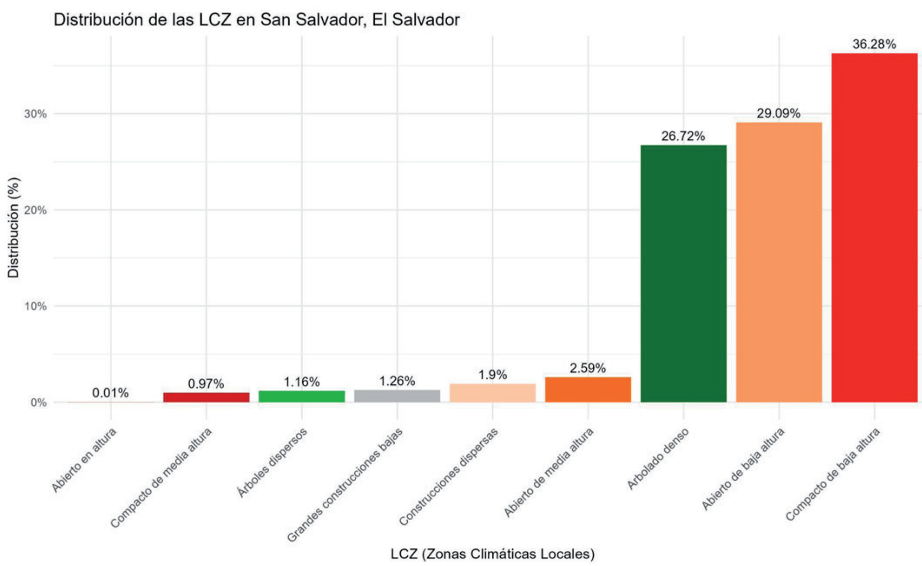


3.10.2 Local Climate Zones Distribution

Over 70% of the city's area corresponds to urban landscape typologies—approximately 102 km²—while nearly 28% of the entire municipal territory has vegetation cover—approximately 40 km². Notably, tree masses are sparsely represented within urbanized areas. These zones are mainly concentrated on the edges. According to the LCZ distribution chart for San Salvador in Figure 41, the following characteristics are observed:

- **Compact Low-Rise (36.28%):** This is the predominant typology in San Salvador, covering more than a third of the territory. Compact low-rise areas are the main contributors to heat island formation in the city due to high building density and limited vegetation. The abundance of impermeable surfaces increases heat retention, leading to higher temperatures in these zones.
- **Open Low-Rise (29.09%):** Open low-rise areas represent a significant portion of San Salvador's territory. Although urbanized, these zones have lower density than compact areas, which helps moderate heat accumulation compared to denser zones. They serve as a transition between compact areas and green zones, providing some heat relief.
- **Dense tree cover (26.72%):** Dense tree covered areas are essential for hear mitigation in San Salvador, occupying a significant part of the territory. These zones, characterized by abundant vegetation, help reduce surface temperatures and counteract heat island effects, creating cooler microclimates.
- Scattered Trees (1.16%) This is the second most common natural landscape typology in the city, without a specific distribution pattern. They do not play a major role in climate regulation but may be replaced by urban land.

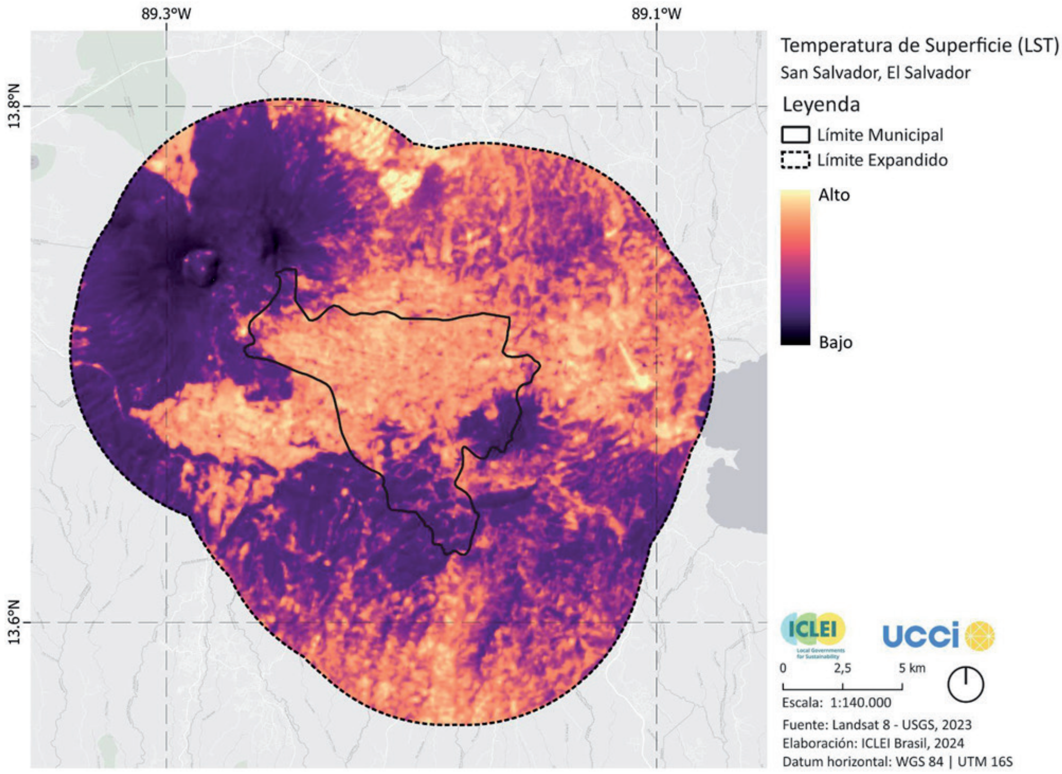
Figure 41: Local Climate Zones Distribution in San Salvador



3.10.3 Heat Island Analysis

The LST map reveals that the warmest zones in San Salvador are concentrated mainly in the city center, aligning with high-rise and compact low-rise areas. These zones have a high density of buildings and impermeable surfaces, which promotes heat accumulation. In contrast, the peripheral areas marked in violet correspond to densely tree-covered zones, where vegetation helps mitigate heat effects, creating a cooler environment.

Figure 42: Surface Temperatures in San Salvador



3.10.4 Heat Island Behavior by Landscape Typology

- **Large Low-Rise, Compact Low- and Mid-Rise:** These areas show values ranging from "strong" to "very strong", indicating that zones with large low-rise and mid-rise buildings contribute significantly to heat islands. The lack of adequate shading and the extensive amount of paved surfaces intensify the thermal effect in these zones.
- **Open Low-, Mid-, and High-Rise Areas:** These typologies fall within the intermediate range, with most values concentrated in the "moderate" to "very strong" categories. The spacing between buildings allows for greater air circulation, which helps mitigate heat island formation to some extent. Although heat retention still occurs due to paved surfaces, these areas

are somewhat cooler compared to compact zones, which tend to have higher density and less ventilation.

- **Dispersed Buildings:** This typology primarily shows values in the “none” category, with a few records in the “mild” range. This suggests that areas with dispersed buildings, due to greater ventilation and possibly more vegetation, tend to retain less heat compared to more densely built zones. While they contribute to heat islands, their impact is smaller, indicating that these areas have better conditions for heat dissipation and surface temperature reduction.

Figure 43: Heat Island Behavior by Landscape Typology in San Salvador

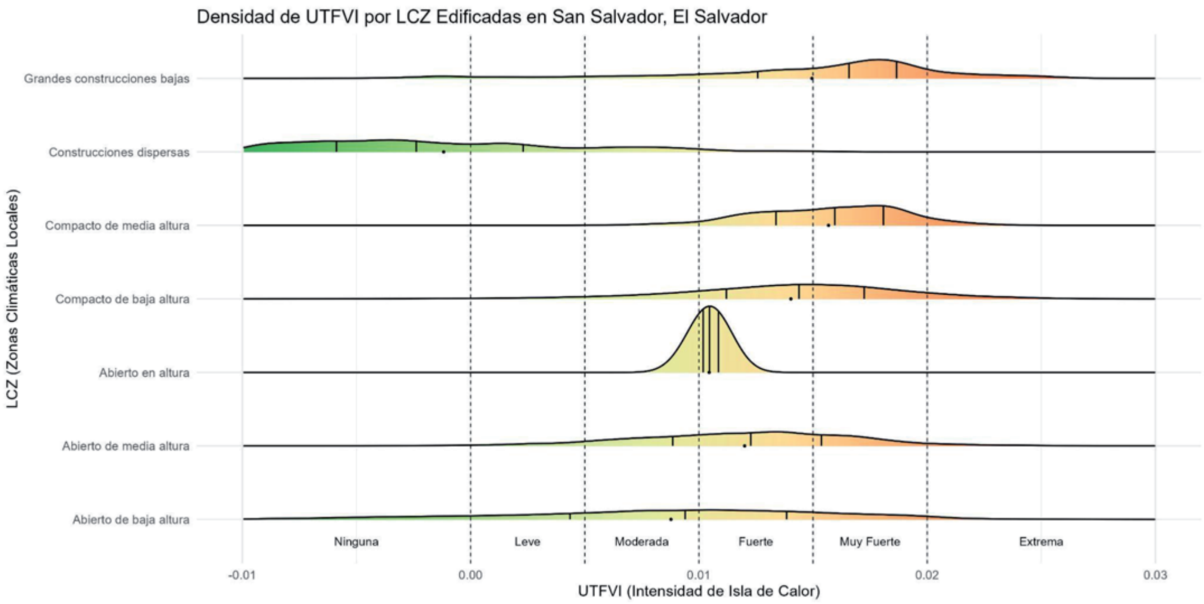


Photo São Paulo: Rogério Cassimiro - MTUR

3.11 São Paulo, Brazil

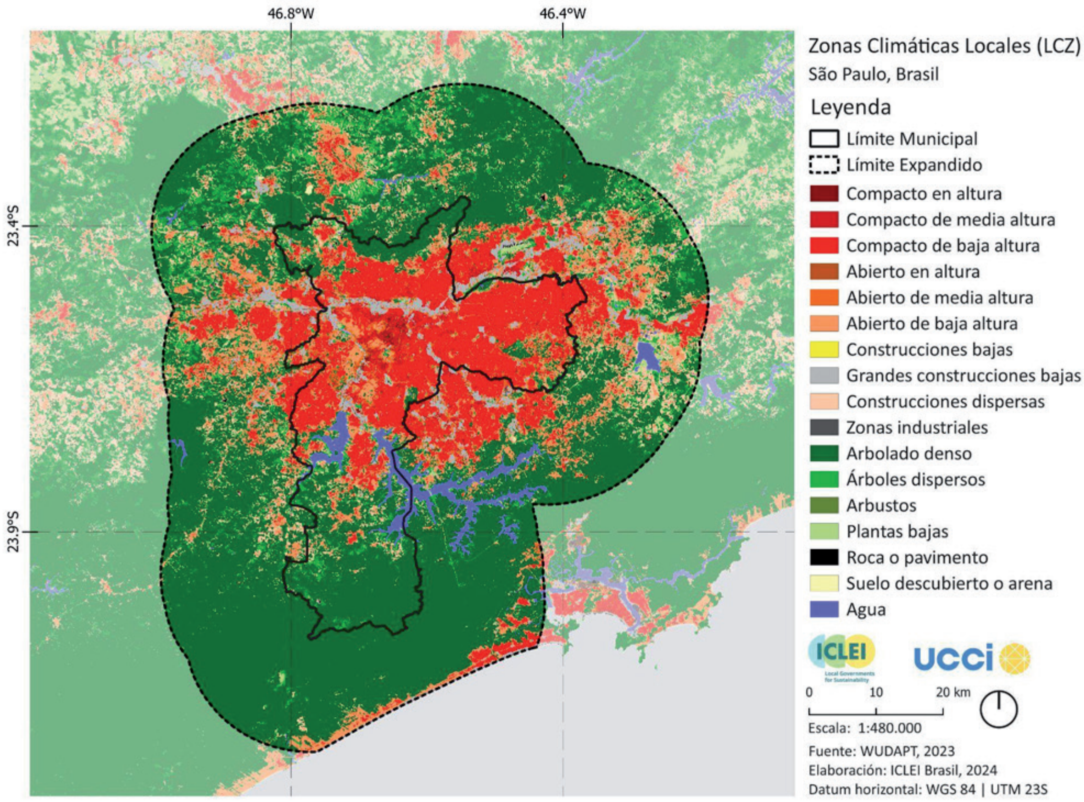
The city of São Paulo, with an area of 1,521.202 km² and a population of 11,451,999 (IBGE, 2022), has several initiatives related to the Climate Agenda. The municipality has government agencies, committees, and working groups dedicated to this issue, as well as an entity responsible for coordinating disaster prevention and management actions. São Paulo has financial resources allocated to the climate agenda and conducts risk assessment related to heat islands and heat waves, with records of these occurrences in the past five years. The city maintains protected areas and public green spaces that serve as climate shelters, along with an Urban Forestry Plan and legislation focused on conserving and restoring green spaces. In terms of environmental monitoring, the city operates 35 stations for measuring temperature, humidity, and other climate variables. It also has an environmental monitoring team that utilizes various tools, including a reporting channel and an automated system for enforcing violations.

3.11.1 Analysis of Local Climate Zones

São Paulo, one of the largest metropolises in Latin America, shows a notable diversity of urban landscapes within its municipal boundaries, significantly impacting the formation and intensity of urban heat islands. In the central area of the municipality, compact high-rise and mid-rise zones dominate, corresponding to the city's expanded center, characterized by vertical urbanization. This density pattern contributes to heat retention and the creation of intense urban heat islands. The linear gray zone in the north-central part of the map indicates the banks of the Tietê River, an area occupied by expressways and large low-rise buildings, mostly commercial and warehouses.

In contrast, densely tree-covered areas are mainly concentrated near the northern and southern boundaries of the city. In the north, the wooded area corresponds to the Serra da Cantareira State Park, a forested region with mountainous topography that acts as a natural barrier, limiting urban expansion. In the south, there is a mix of dispersed and low-rise urbanization alongside protected environmental areas, which form part of the municipality's rural zone. These green areas on the city's outskirts are essential for thermal mitigation, providing a contrast to the more densely built-up areas in the center.

Figure 44: Local Climate Zones of São Paulo



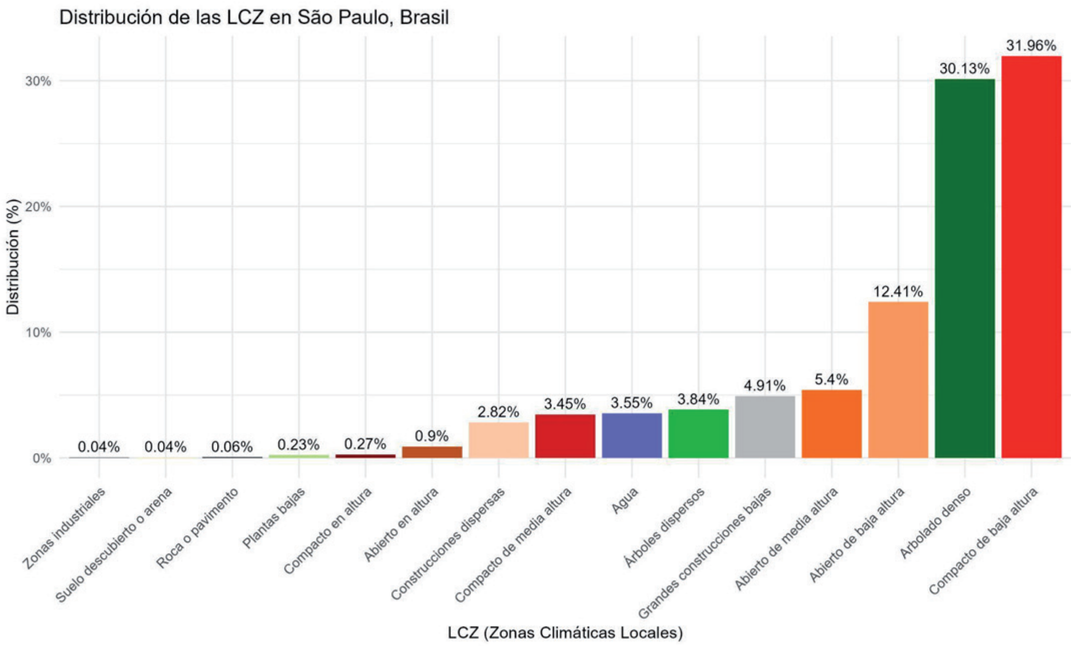
3.11.2 Local Climate Zones Distribution

More than 60% of the city's area corresponds to urban landscape typologies — approximately 945 km² — while nearly 34% of the entire municipal territory has vegetation cover — approximately 517 km². Notably, tree masses are sparsely represented within urbanized areas. They are mostly concentrated around the edges and towards the south. According to the LCZ distribution chart for São Paulo in Figure 46, the following characteristics are observed:

- **Compact Low-Rise (32.22%):** This is the predominant typology in São Paulo. It represents densely urbanized areas with low-rise buildings and high soil impermeability. These zones are directly linked to intense heat islands due to the lack of significant vegetation and the prevalence of construction materials with high heat retention, such as concrete and asphalt.

- **Dense tree cover (29.93%):** About 30% of São Paulo's area consists of densely vegetated areas. These zones serve as important thermal regulators, helping to reduce surface temperature and mitigating the heat island effects in surrounding areas.
- **Open Low-Rise (12.36%):** Open low-rise areas are characterized by low-density buildings and open spaces. The presence of vegetation in these zones helps maintain cooler temperatures compared to compact areas.
- **Scattered Trees (3.84%):** This natural landscape typology does not significantly contribute to urban cooling. It is usually located in public spaces for collective use, such as parks.

Figure 45: Local Climate Zones Distribution in São Paulo



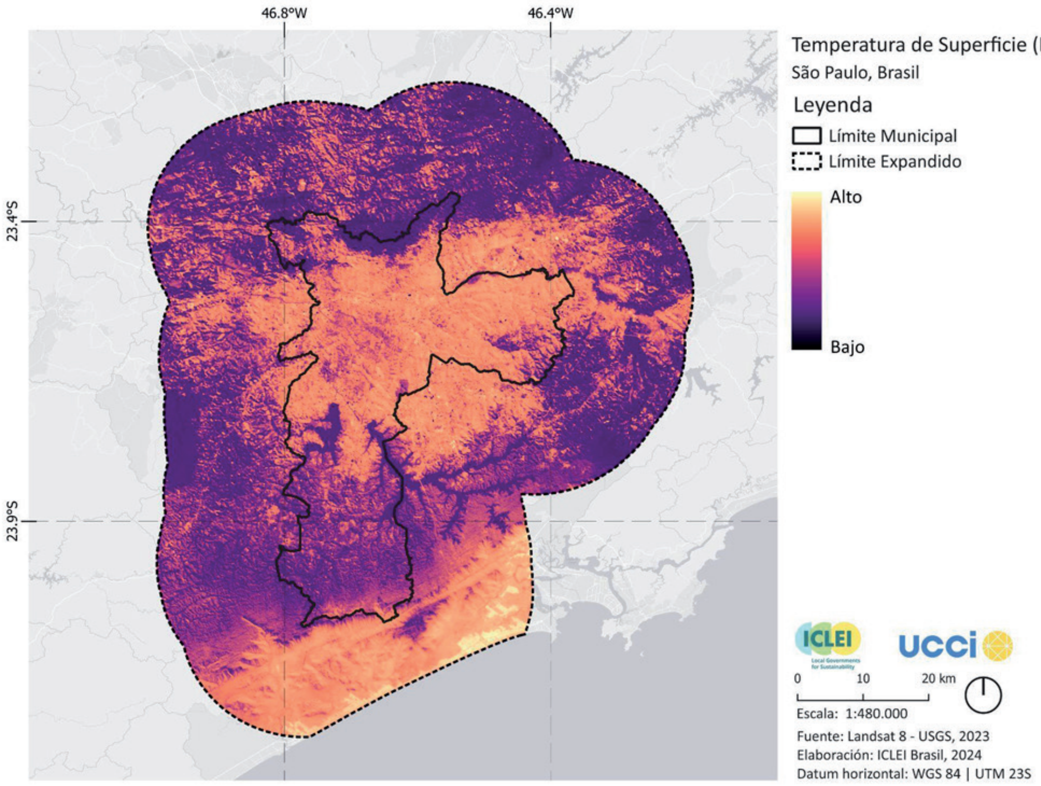
3.11.3 Heat Island Analysis

São Paulo's LST map clearly highlights a significant difference between the urban core and peripheral regions—Figure 46. The warmest regions, shown in yellow, are concentrated in the southeastern peri-urban perimeter, especially in areas near the coast. These regions indicate significant heat accumulation.

In contrast, the central area of São Paulo shows predominantly moderate temperatures. Although not as extreme as coastal areas, these zones still experience heat retention due to the high density of buildings and impermeable surfaces typical of a large metropolis.

In contrast, the coolest areas, identified in violet, are primarily located around the city's outskirts and in zones with more abundant vegetation. These regions show notable mitigation of heat effects due to the greater vegetation cover and fewer buildings.

Figure 46: Surface Temperatures in São Paulo



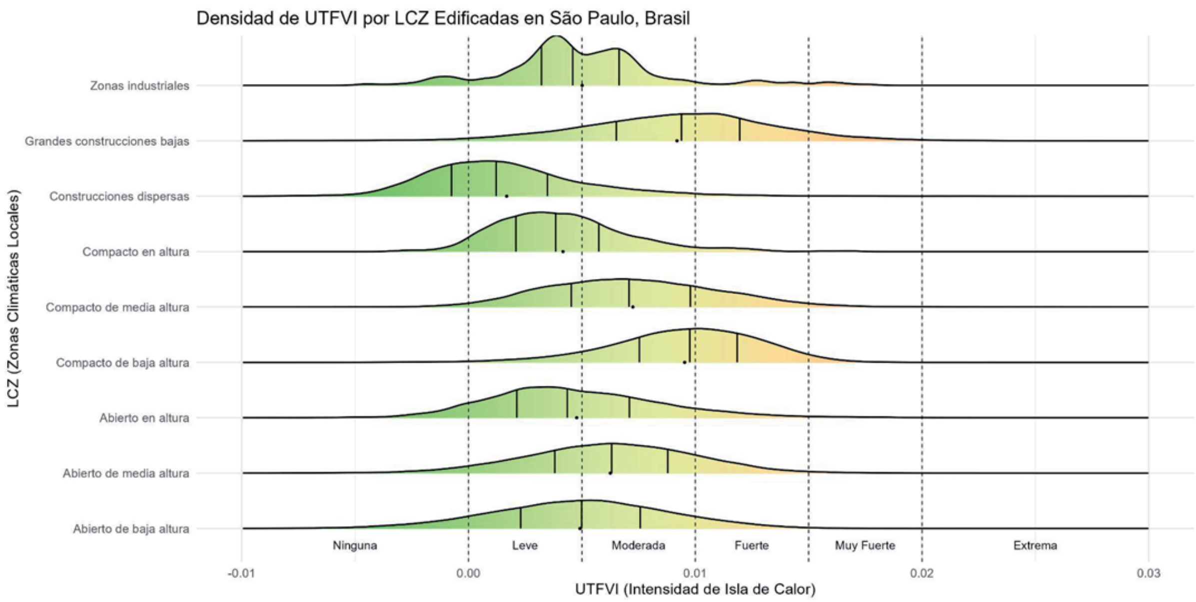
3.11.4 Heat Island Behavior by Landscape Typology

The chart reveals the intensity of heat islands across different LCZs. The UTFVI indicates the severity of heat islands, with classifications ranging from "None" to "Extreme" (Figure 47).

- **Industrial Zones:** This typology shows a concentration of values in the "mild" to "moderate" categories. The high concentration of heat-retaining materials, combined with the low presence of vegetation, makes these areas susceptible to heat islands.
- **Large Low-Rise Buildings:** Values in this typology are primarily distributed in the moderate and strong categories, indicating that these areas contribute to the heat island phenomenon. The lack of vegetation, combined with low-rise buildings, significantly increases heat retention.

- **Compact and Open (High, Mid, and Low-Rise):** These typologies show relatively homogeneous heat intensity, with values predominantly in the "mild" to *"moderate"* categories, with compact low-rise showing higher values. Heat retention increases due to the high density of buildings. Although taller buildings provide some shade that may slightly reduce nearby temperatures, the overall compact design contributes significantly to urban warming.
- **Dispersed Buildings:** This typology shows the lowest value, with most records concentrated in the "none" and "mild" categories. This suggests that areas with dispersed buildings, due to greater spacing between structures and the potential presence of vegetation, contribute minimally to heat island formation. These zones benefit from better air circulation and more moderate temperatures compared to denser typologies.

Figure 47: Heat Island Behavior by Landscape Typology in São Paulo



4. Key Observations

The analysis carried out for the 11 Iberoamerican cities indicated substantial results with regard to the urban heat island phenomenon and its relation with landscape typologies. In densely built urban areas, such as industrial zones and high-rise compact typologies, the highest surface temperature values were observed. In these regions, the abundance of artificial surfaces, such as concrete and asphalt, combined with a lack of vegetation, contributes to heat retention. The typical materials in these areas, with a high capacity for heat absorption and radiation, exacerbate the creation of warmer urban microclimates, especially in zones lacking vegetation that could help regulate temperature.

On the other hand, landscape typologies with dense vegetation and scattered trees play a key role in creating cooler microclimates. Vegetation helps shade surfaces and reduce local temperatures, contributing to lower heat in the surrounding areas. This effect is especially noticeable in the cities' dispersed green areas, where zones with greater vegetation cover show lower surface temperature values, underscoring the importance of these spaces in reducing urban temperatures.

Another important factor to consider is the impact of tall buildings on cities' thermal dynamics. High-rise buildings can, on one hand, intensify heat islands due to the concentration of heat-retaining materials, but they can also act as shading barriers. Cities like Barcelona and Montevideo are notable examples where the shadows cast by tall buildings can reduce direct sun exposure in adjacent areas. As seen in these cities, Landsat image resolution can underestimate certain zones in dense and compact areas. While this tool is very useful and provides valuable information for larger cities, small green areas may not be clearly visible in Landsat images.

Additionally, cities' topographic characteristics also play an important role. In regions with rugged terrain, such as Quito and Bogotá, mountains and hills can create natural shadows that reduce surface temperature intensity. These mountainous regions offer a unique thermal dynamic, where shadows cast by geographic elevations can diminish heat accumulation in certain areas, creating cooler climates. This suggests that both artificial elements, like tall buildings, and natural elements, such as mountains and hills, can significantly influence the spatial distribution and intensity of heat islands, depending on the time of day.

Thus, if satellite images are captured during peak sunlight hours, the influence of building shadows will be minimized, leading to a higher observed intensity of heat islands, as seen in the case of São Paulo. On the other hand, if images are captured when buildings cast significant shadows, typically in the morning or late afternoon, this could underestimate heat intensity in certain areas.

It is also important to highlight that the capitals evaluated here are highly heterogeneous in terms of geographic location, geomorphology, area, population, biome, etc. In this sense, it is worth noting that the LCZ scheme, which is a generalized approach aimed at creating a universal pattern for comparative urban climate studies, does not specifically encompass the urban typologies present worldwide—such as those seen in Latin America. The method's authors indicate that adjustments can be made for greater alignment with local morphological realities, such as mixing two or more LCZs; however, this observation was not considered in this Atlas due to its comparative and panoramic nature. Furthermore, the 100m resolution of the LCZ scheme prevents the observation and inclusion of small green spaces. Thus, specific studies within this methodological framework are recommended to achieve more detailed results.

However, a key limitation of this study is that, by default, there is no control over when satellite images are captured, which directly affects the results and the accuracy of the heat island analysis, and therefore, some observed patterns. Given this, it is essential for each city to conduct more specific and detailed studies. This will help overcome these limitations and produce more accurate results that more faithfully reflect local thermal dynamics. Nevertheless, the present study holds significant value by providing a comparative and preliminary view of heat islands in Ibero-American cities. It offers a useful foundation for identifying common patterns and priority areas for urban heat mitigation.

While this analysis is not intended to replace comprehensive local studies, it provides an initial framework for decision-making and emphasizes the importance of conducting more in-depth research at the local level. This approach can be key for developing policies and strategies tailored to the specific characteristics of each city, leveraging regional knowledge as a starting point.

5 Conclusions

5.1 Strategic Recommendations

Based on the analyses conducted, the main factors influencing the intensity and distribution of heat islands in the Ibero-American cities studied were identified. These factors include urban morphology, predominant building materials, and vegetation distribution. Cities with densely built areas, such as industrial zones and compact urban centers, face the greatest challenges regarding heat retention and high-temperature mitigation. Conversely, spaces that effectively integrate green areas and natural cooling infrastructure, such as dense tree cover, demonstrate a greater capacity to mitigate heat island effects. Additionally, the presence of tall buildings and varied topography, as seen in the cases of Quito and Bogotá, contributes to the creation of urban microclimates with specific conditions, including shaded areas that can reduce high temperatures at certain times of the day. This analysis reinforces what has already been suggested by advocates of urban planning that better integrates urbanization, green areas, and hydrological resources.

Understanding the location and intensity of the warmest areas within cities is crucial to identify locations that require greater attention during heat island events, especially in a time of climate change when Heat Waves may pose a significant threat to these spaces, with rising temperatures over consecutive days. These regions require more urgent mitigation and adaptation measures. Monitoring these areas can aid in creating public policies that prioritize tree planting and the establishment of green infrastructure, in addition to helping identify the most vulnerable populations needing immediate support during extreme heat events.

Based on these conclusions, we can identify three main types of actions: (1) In cities with preventive and structured planning, it is essential to control urban expansion, avoid the loss of green areas, and promote the creation of new vegetated spaces. (2) Corrective actions in already established urban areas should focus on restoring natural areas, implementing cooling structures, and creating thermal comfort islands in zones with higher heat concentration. (3) Support strategies to address heat wave events aim to provide adequate assistance to the populations most vulnerable to this climate risk.

These systems should be connected to local action plans that include specific measures to protect public health during extreme heat events. It is important to adopt a long-term approach, integrating preventive actions into urban planning to reduce the impact of extreme heat. Another key point is the need for effective climate monitoring networks. Cities should invest in meteorological stations that allow real-time monitoring of extreme heat conditions and generate accurate data for rapid response.

In the context of climate change, the increase in global temperatures intensifies the frequency and severity of heat island phenomena, exacerbating challenges faced by urban areas. This creates a higher demand for cooling energy and increases water consumption, as well as greenhouse gas emissions if renewable energy sources and energy efficiency are not promoted. Therefore, cities should invest in clean energy sources and energy efficiency strategies so that increased cooling demand does not worsen the climate crisis. Furthermore, adopting construction materials with good thermal performance is a crucial measure to reduce heat absorption in buildings and improve thermal comfort.

Similarly, strategic urban actions for better urban cooling are essential. Urban development plans should consider creating permeable surfaces, open water bodies, and increasing urban tree cover in strategic locations. These elements play a fundamental role in reducing ambient temperature and improving thermal comfort. Cities should also integrate construction projects that prioritize thermal comfort, ensuring that new urban developments are sustainably designed, taking into account natural ventilation and minimizing retained heat.

When we talk about vulnerable populations, it is evident that certain groups, such as the elderly, children under 5 years old, those with chronic illnesses, and residents in densely built areas, are at greater risk during extreme heat events. It is essential for cities to identify these populations and implement suitable climate shelters, such as cooled public spaces or temporary shelters, to protect these individuals during heat islands. Additionally, training health care professionals and community agents to respond to these climate challenges must be a priority, ensuring that these populations receive the necessary assistance. The creation of alert systems and public education is also crucial to inform citizens on how to cope with extreme temperatures and protect themselves from their harmful health effects.

Finally, it is important to highlight that all these actions must be coordinated across multiple scales and with various stakeholders. The participation of different sectors—such as health, urban planning, social assistance, and education—is essential for the success of heat wave and heat island mitigation and adaptation strategies. These recommendations are vital to ensure that Ibero-American cities can efficiently address the challenges posed by these phenomena, promoting a more resilient and sustainable urban environment.

5.2 Current Initiatives in Ibero-American Cities

Ibero-American cities have developed various initiatives to mitigate the effects of urban heat islands and limit the adversities caused by heat waves, with a focus on innovative and collaborative policies. Cities such as Rio de Janeiro, São Paulo, Belém do Pará, Montevideo, Madrid, and Barcelona are making efforts to tackle the heat island problem through local strategies that combine public health, urban planning, and environmental strategies. Madrid, Barcelona, Montevideo, Quito, Buenos Aires, Bogotá, Rio de Janeiro, and São Paulo have conducted climate risk and vulnerability assessment focusing on heat island research, and their Climate Action Plans or Policies include adaptation measures that help reduce the effect. For instance, in recent years, Barcelona has experienced an increase in heat wave frequency, with 9 affected summers between 2003 and 2024. The city has mapped the temperature distribution during these extreme episodes, using this information as a tool to implement adaptation measures in neighborhoods most vulnerable to heat.

Montevideo faces a fragmentation issue in addressing the problem, as the Health, Planning, and Environmental Departments address heat islands and heat waves but not in a coordinated and cross-cutting manner. A similar situation was observed in ICLEI-UCCI cities in Brazil. However, project funding is also an obstacle to implementing these actions.

In general, cities have invested in mitigation measures, such as increasing shaded areas in public spaces and adjusting work hours to minimize heat exposure at critical times. They have also invested in adaptation efforts, such as expanding green areas and implementing nature-based solutions—green corridors, park creation, and urban reforestation.

5.3 Diagnosis of Local Climate Strategies

As previously mentioned, in addition to mapping and analyzing the heat island phenomenon, surveys were sent to the cities to understand their governance structure and preparedness for climate risks, particularly heat islands and heat waves. Analyzing the responses, we can identify key patterns regarding infrastructure, public policies, and available resources in Ibero-American cities.

In terms of the presence of government bodies dedicated to the climate agenda, 9 out of 10 cities (90%) reported having some formal structure in place. Cities such as Madrid, Buenos Aires, Quito, Barcelona, Rio de Janeiro, and São Paulo also indicated the existence of interdepartmental committees addressing climate issues, while only 40% of Spanish-speaking cities have councils that include civil society participation, compared to 100% of surveyed Brazilian cities.

Regarding the availability of financial resources dedicated to the climate agenda, 70% of the cities, including Madrid, Bogotá, Buenos Aires, Barcelona, Rio de Janeiro, and São Paulo, indicated having resources for implementing climate actions. This is a positive indicator, although some cities like Belém do Pará and San Salvador still face limitations in this area.

A notable data point is that 6 out of 10 cities (60%) already conduct risk analyses related to heat islands and/or heat waves, including Madrid, Buenos Aires, Barcelona, Bogotá, Rio de Janeiro, and São Paulo. However, a considerable portion of cities have yet to implement such analyses, indicating a gap that needs to be addressed.

In terms of climate action plans, 7 out of 10 cities (70%) reported having a plan in place to address climate change challenges. Nevertheless, in some cities, such as Montevideo and Quito, no heat waves have been recorded in the past five years, which may indicate a lower risk perception of these extreme events.

Among the cities surveyed, 5 out of 10 (50%) confirmed having recorded heat waves in the past five years. This group includes Buenos Aires, Barcelona, Madrid, Rio de Janeiro, and São Paulo, of which 3 (30%) also reported deaths associated with these extreme events, highlighting the urgency of implementing more robust mitigation and adaptation strategies.

Regarding protected and green areas, 80% of the cities have public green areas designed or used as climate shelters, while 70% have some conservation and green space recovery program. Cities such as Madrid, Buenos Aires, Barcelona, Rio de Janeiro, and São Paulo lead in implementing these areas, which are essential for mitigating heat island effects. However, Belém do Pará and San Salvador still lack these spaces specifically designed for this purpose.

Finally, in terms of climate monitoring capacity, 8 out of 10 cities (80%) indicated that they have meteorological stations to measure variables such as temperature, humidity, and wind speed. Madrid, Barcelona, Rio de Janeiro, and São Paulo stand out for having well-developed networks, with 149 stations in Rio de Janeiro and 35 stations in São Paulo, distributed among different agencies. These infrastructures are essential for assessing climatic conditions and managing risks.

Among the cities evaluated through the survey, which considers the management character and adaptive capacity of local governments, San Salvador emerges as the most vulnerable to the risk of heat islands. With high average temperatures year-round, the city lacks a specific committee or council to address climate change, reflecting a structural organizational gap in this area. Additionally, San Salvador does not have dedicated financial resources for the climate agenda, nor does it have a climate action plan or a heat island risk assessment, which diminishes its ability to respond to these events. The lack of its own protected areas and the scarcity of public green spaces serving as climate shelters further exacerbate the potential impact on its population, especially in its most vulnerable sectors. Other cities, such as Belém do Pará and Montevideo, also present moderate risks due to gaps in green infrastructure and the absence of specific risk analyses for heat islands, placing them in considerable risk situations, albeit with different nuances.

5.4 The Role and Advocacy of Local Governments and their Networks in the Global Climate Conferences

Every year, 198 countries, governments, international organizations, companies and global citizens convene to discuss the future of the planet in the face of the climate crisis at the Climate Change Conference of the Parties of the United Nations Framework Convention on Climate Change, known as the COP.

In this multilateral decision-making conference at the highest level, under the framework of the Paris Agreement, commitments and climate goals are accounted for, while the most urgent priorities are defined in the face of the challenges posed by adaptation and mitigation to limit global warming and mitigate its effects with an impact, above all, from the territories.

Regarding the Ibero-American region, which includes countries in both Europe and Latin America, this community covers 15.3% of the planet's surface and is home to 8.7% of the world's population (Economic Commission for Latin America and the Caribbean - ECLAC). The region contains over 25% of the world's tropical forests, one-third of its freshwater resources, and half of its biodiversity. Its greenhouse gas (GHG) emissions are comparatively low. However, the region is one of the most affected by climate change (SEGIB).

Towards climate neutrality, local governments are at the forefront of implementing concrete and effective actions together with citizens. Promoting the inclusion of cities in the decision-making process on climate change is therefore crucial to articulate multilevel agendas with assertive results. UCCI and ICLEI, alongside their member cities, present this IberAtlas prepared collaboratively with a view to COP 30 in Belém do Pará, Brazil (2025). A strategic document intended to be widely disseminated and used by the cities participating in the project and stakeholders as a tool to inform decision-making and facilitate the implementation of concrete actions that can not only support cities in protecting their population from the extreme effects of the climate crisis and urban heat islands, but also inspire other cities to follow suit.

The agenda of local governments at the COPs is getting stronger with each edition, and this progress can be seen in the last few years, when several initiatives have been launched that dialogue with the leadership of cities and states in implementing the climate agenda.

In November 2023, the COP 27 presidency, in collaboration with various agencies, launched the Sharm-El-Sheikh Adaptation Agenda (SAA), which sets 30 global adaptation goals to be achieved by 2030. These goals aim to enhance the resilience of 4 billion people by focusing on five key impact systems: food and agriculture; water and nature; coastal zones and oceans; human settlements and infrastructure, as well as planning and financing solutions. The COP 27 presidency monitors the progress of SSA's implementation, and the document serves as a guide for global climate action with a focus on adaptation. Other strategic local-level initiatives include the Making Cities Resilient (MCR2030) by the United Nations Office for Disaster Risk Reduction and the Global Covenant of Mayors for Climate and Energy (GCoM).

In the following year, at COP 28, in Dubai, with support from Bloomberg Philanthropies and networks and organizations of local leaders worldwide, the Local Climate Action Summit (LCAS) was the first summit organized by the COP presidency to officially recognize the importance of local leaders in the fight against climate change. The summit's goal was to bring together national and subnational climate leaders to discuss and promote emissions reductions, climate risk management, and adaptation. The topics discussed included transforming climate financing, accelerating the energy transition and strengthening local resilience and adaptation efforts.

Similarly, at COP 28, 74 national governments committed to the Coalition for High Ambition Multilevel Partnerships (CHAMP) initiative, aimed at enhancing cooperation with subnational governments in the planning, financing, implementation, and monitoring of climate strategies, to foster more effective climate action. The goal is also to form coalitions that will engage in collective efforts to strengthen adaptation and resilience to climate change.

At COP 29 in Baku, the Azerbaijani presidency launched the "Multisectoral Action Pathways (MAP) for Resilient and Healthy Cities" and the "Baku Continuity Coalition for Urban Climate Action", highlighting how partnerships between cities, sub-national actors and national governments can support compliance with the Paris Agreement. Within this context, on November 20, 2024, ICLEI and UCCI, together with the International Federation of Red Cross and Red Crescent Societies and the Executive Secretariat for Climate Change of the São Paulo City Hall, launched the IberAtlas Position Paper/ Call to Action at the Multilevel Action and Urbanization Pavilion, based in the Blue Zone thanks to the support of ICLEI, UN-Habitat and other partners (Government of Azerbaijan Government of Turkey, Zero Waste Foundation and Bloomberg Philanthropies).

During the event, Rodrigo Corradi, Executive Secretary of ICLEI South America, highlighted the importance of working in partnership to position the voice of cities at the highest level of climate agendas. On behalf of UCCI, Francisco Mugaburu, Deputy Director of International Relations and Cooperation, highlighted the value of IberAtlas as a concrete product of public policy and data analysis, essential to raise awareness and influence through cooperation.

Other speakers included José RenatoNalini, Executive Secretary for Climate Change of São Paulo; Ninni Nyman, Climate and Resilience Leader of the International Federation of Red Cross and Red Crescent Societies; and María Pilar García, International Relations and Cooperation Area of the UCCI.

The Rio de Janeiro Earth Summit (1992), held in the Ibero-American region, marked a turning point in global awareness of the importance of protecting both people and the environment. At that time, the world came together to establish key commitments in the fight against environmental degradation, climate change and the limitation of greenhouse gas emissions, highlighting the urgency of global action to ensure a more sustainable future.

More than three decades later, COP 30 in Belém do Pará is expected to be a crucial moment for the Ibero-American climate agenda, it will mark a significant milestone in global climate negotiations, especially as it will be the first COP hosted in the Amazon. It is essential that debates on adaptation and financing lead to concrete actions, particularly regarding the urban heat island phenomenon, which disproportionately affects urban areas and the most vulnerable people.

This Urban Climate Atlas of Ibero-American is, without a doubt, a contribution to the management of knowledge about the context of the cities of the region to contribute to the implementation of better local public policies. It is also a strategic cooperation initiative between UCCI and ICLEI to promote and raise the voice of local governments in partnership as part of the collective effort to advance sustainable urban development.

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