ReGeo
ISSN: 2177-3246

LOCAL CLIMATE ZONES AND URBAN MORPHOLOGICAL PARAMETERS IN PARANÁ, BRAZIL: CONTRIBUTIONS TO URBAN CLIMATE RESEARCH USING THE LCZ4r PACKAGE

ZONAS CLIMÁTICAS LOCAIS E PARÂMETROS MORFOLÓGICOS URBANOS NO PARANÁ: CONTRIBUIÇÕES PARA OS ESTUDOS DO CLIMA URBANO COM O PACOTE LCZ4r

ZONAS CLIMÁTICAS LOCALES Y PARÁMETROS MORFOLÓGICOS URBANOS EN PARANÁ, BRASIL: CONTRIBUCIONES A LOS ESTUDIOS DEL CLIMA URBANO MEDIANTE EL PAQUETE LCZ4r

https://doi.org/10.56238/revgeov17n11-023

Data de submissão: 04/10/2026 **Data de publicação:** 04/11/2026

Elisa Aparecida Dias[1], Ricardo Aparecido Campos[2], Jorge Sobral da Silva Maia[3], Fábia Elaine Ferreira de Melo[4], Luana Cássia Souza Coutinho de Oliveira[5], Ederson Marcos Sgarbi[6], Josiane Petenaci de Araújo[7], Érica Patente Nascimento[8], Marcela Ribeiro de Albuquerque[9], Inajara Adão Carvalho[10]

ABSTRACT

This study comparatively analyzes the distribution of Local Climate Zones (LCZ) and reference Sky View Factor (SVF) parameters in the municipalities of Curitiba, Londrina, and

[1] Doctoral Candidate in Computer Science. Universidade Estadual Paulista Júlio de Mesquita Filho – Campus de Bauru –SP (UNESP). E-mail: elisaapdias@gmail.com Orcid: https://orcid.org/0000-0002-3113-3688 Lattes: https://lattes.cnpq.br/4592999118999600
[2] Doctor in Geography. Faculty Member and Senior Research Productivity Fellow PQ-Sr (FA). Universidade Estadual do Norte do Paraná (UENP). E-mail: rcampos@uenp.edu.br Orcid: https://orcid.org/0000-0002-8969-4787 Lattes: https://lattes.cnpq.br/5869296136601055
[3] Doctor in Science Education. Universidade Estadual do Norte do Paraná (UENP). E-mail: sobralmaia@uenp.edu.br Orcid: https://orcid.org/0000-0003-4066-738X Lattes: https://lattes.cnpq.br/9841385363737957
[4] Doctor in Science Education. Centro Universitário Invest (UNIVEST). E-mail: fabiaelainemelo@gmail.com Orcid: https://orcid.org/0000-0002-0287-3740 Lattes: https://lattes.cnpq.br/3508932483086890
[5] Doctor in Science Education. Secretaria de Educação e Desporto de Roraima (SEED-RR). E-mail: luana.coutinho@unesp.br Orcid: https://orcid.org/0009-0009-3768-3195 Lattes: https://lattes.cnpq.br/6391830297923024
[6] Doctor in Computer Science. Universidade Estadual do Norte do Paraná (UENP). E-mail: sgarbi@uenp.edu.br Orcid: https://orcid.org/0009-0004-7460-7283 Lattes: https://lattes.cnpq.br/4999862994006825
[7] Doctoral Candidate in Business Administration. Universidade Estadual do Norte do Paraná (UENP). E-mail: josiane@uenp.edu.br Orcid: https://orcid.org/0009-0003-9527-4484 Lattes: https://lattes.cnpq.br/2784706993202184
[8] Doctor in Economics. Universidade Estadual do Norte do Paraná (UENP). E-mail: enascimento@uenp.edu.br Orcid: https://orcid.org/0000-0001-9633-5371 Lattes: https://lattes.cnpq.br/1891339514954792
[9] Doctor in Business Administration. Universidade Estadual de Norte do Paraná (UENP). E-mail: marcelaalbuquerque@uenp.edu.br Orcid: https://orcid.org/0000-0002-0710-4895 Lattes: https://lattes.cnpq.br/4695047983675665
[10] Undergraduate Student in Biological Sciences Education. Universidade Estadual do Norte do Paraná (UENP). E-mail: inajaraadao@gmail.com Orcid: https://orcid.org/0009-0004-1031-2654 Lattes: https://lattes.cnpq.br/5753138423285114

Maringá, in the state of Paraná, Brazil, using the LCZ4r package. The research is a quantitative, spatial, and descriptive study based on geospatial data, thematic mapping, and geoprocessing techniques. Global LCZ maps were clipped to municipal boundaries to calculate the relative area occupied by each class and map the SVF parameters associated with the classification. The results reveal differences in the territorial composition of the three municipalities. In Curitiba, LCZ 6 accounts for approximately 40% of the municipal area, while LCZ 3 represents 23.5%. In Londrina, LCZ 14 accounts for approximately 42.9% of the territory, while LCZ 12 and LCZ 11 represent about 28% and 16.3%, respectively. In Maringá, LCZ 14 accounts for approximately 57.6%, followed by LCZ 6, at 14.1%, and LCZ 12, at 12.7%. The SVF analysis helps characterize spatial differences in reference parameters associated with sky openness. The percentages were calculated using the total municipal area, and the SVF values represent reference parameters linked to LCZ classes. As no air or land surface temperature data were used, the study does not measure urban heat island intensity. The findings indicate that combining LCZ classification and SVF parameters contributes to the comparative characterization of urban morphology and provides a basis for future urban climate research.

Keywords: Local Climate Zones. LCZ4r. Urban Morphology. Sky View Factor. Urban Climate.

RESUMO

Este estudo analisa comparativamente a distribuição das Zonas Climáticas Locais (Local Climate Zones - LCZ) e dos parâmetros de referência do Fator de Vista do Céu (Sky View Factor - SVF) nos municípios de Curitiba, Londrina e Maringá, no estado do Paraná, utilizando o pacote LCZ4r. A pesquisa caracteriza-se como um estudo quantitativo, espacial e descritivo, baseado em dados geoespaciais, cartografia temática e técnicas de geoprocessamento. Foram utilizados mapas globais de LCZ, recortados pelos limites territoriais municipais, para calcular a participação relativa das classes e representar os parâmetros de SVF associados à classificação. Os resultados evidenciam diferenças na composição territorial dos municípios. Em Curitiba, destacam-se as classes LCZ 6, com aproximadamente 40% da área municipal, e LCZ 3, com 23,5%. Em Londrina, a classe LCZ 14 representa cerca de 42,9% do território, enquanto as classes LCZ 12 e LCZ 11 correspondem a aproximadamente 28% e 16,3%. Em Maringá, a LCZ 14 alcança cerca de 57,6%, seguida pelas classes LCZ 6, com 14,1%, e LCZ 12, com 12,7%. A análise do SVF permite caracterizar diferenças espaciais nos parâmetros associados à abertura da abóbada celeste. Ressalta-se que os percentuais foram calculados sobre a área municipal total e que os valores de SVF são parâmetros de referência vinculados às classes LCZ. Como não foram utilizados dados de temperatura do ar ou da superfície, o estudo não mensura a intensidade das ilhas de calor urbanas. Conclui-se que a integração entre LCZ e SVF contribui para a caracterização comparativa da morfologia urbana e oferece subsídios para pesquisas futuras sobre clima urbano.

Palavras-chave: Zonas Climáticas Locais. LCZ4r. Morfologia Urbana. Fator de Vista do Céu. Clima Urbano.

RESUMEN

Este estudio analiza comparativamente la distribución de las Zonas Climáticas Locales (Local Climate Zones - LCZ) y de los parámetros de referencia del Factor de Visión del Cielo (Sky View Factor - SVF) en los municipios de Curitiba, Londrina y Maringá, en el estado de

Paraná, Brasil, mediante el paquete LCZ4r. La investigación se caracteriza como un estudio cuantitativo, espacial y descriptivo, basado en datos geoespaciales, cartografía temática y técnicas de geoprocesamiento. Se utilizaron mapas globales de LCZ, recortados según los límites territoriales municipales, para calcular la participación relativa de las clases y representar los parámetros de SVF asociados a la clasificación. Los resultados muestran diferencias en la composición territorial de los municipios. En Curitiba, destacan las clases LCZ 6, con aproximadamente el 40 % del área municipal, y LCZ 3, con el 23,5 %. En Londrina, la clase LCZ 14 representa alrededor del 42,9 % del territorio, mientras que las clases LCZ 12 y LCZ 11 corresponden aproximadamente al 28 % y al 16,3 %, respectivamente. En Maringá, la LCZ 14 alcanza cerca del 57,6 %, seguida por las clases LCZ 6, con el 14,1 %, y LCZ 12, con el 12,7 %. El análisis del SVF permite caracterizar diferencias espaciales en los parámetros asociados a la apertura de la bóveda celeste. Cabe señalar que los porcentajes se calcularon sobre la superficie municipal total y que los valores de SVF son parámetros de referencia vinculados a las clases LCZ. Como no se utilizaron datos de temperatura del aire ni de la superficie, el estudio no mide la intensidad de las islas de calor urbanas. Se concluye que la integración de las LCZ y los parámetros de SVF contribuye a la caracterización comparativa de la morfología urbana y ofrece elementos para futuras investigaciones sobre el clima urbano.

Palabras clave: Zonas Climáticas Locales. LCZ4r. Morfología Urbana. Factor de Visión del Cielo. Clima Urbano.

1 INTRODUCTION

Urban growth transforms the landscape and alters the interactions between the Earth's surface and the atmosphere. The replacement of vegetation cover with buildings, pavements, and other built structures affects energy exchanges, water availability, and the geometry of urban spaces. These transformations contribute to environmental differentiation among sectors within the same city and constitute one of the foundations of Urban Climatology studies (OKE, 1987).

Within the Brazilian tradition of Geographical Climatology, Monteiro (1976) and Monteiro and Mendonça (2003) emphasize the importance of understanding urban climate in relation to spatial organization and the transformations brought about by society. This perspective makes it possible to analyze the city as a heterogeneous environment whose physical characteristics result from interactions between natural conditions and patterns of land occupation. Building density, construction materials, vegetation distribution, and the configuration of streets and open spaces are relevant elements for characterizing this diversity.

Among the phenomena associated with urbanization, urban heat islands (UHIs) are particularly noteworthy. They are characterized by temperature differences between urbanized areas and less urbanized reference areas. Their occurrence is associated with several factors, including the thermal properties of materials, soil sealing, building geometry, vegetation cover, and meteorological conditions (OKE, 1987; GARTLAND, 2010). However, the physical configuration of an urban area does not, by itself, determine its thermal conditions. Investigating urban heat islands requires temperature data appropriate to the phenomenon under study, whether air temperature or land surface temperature (VOOGT; OKE, 2003).

In this context, the Local Climate Zone (LCZ) system, proposed by Stewart and Oke (2012), provides a standardized framework for characterizing different urban configurations and land-cover types. The classification considers attributes such as building height and density, the proportion of built surfaces, vegetation cover, and material characteristics. Its application makes it possible to describe and compare the spatial organization of different environments, providing a basis for investigating relationships between urban morphology and climate. However, LCZ classes represent the physical characteristics of the landscape and do not constitute direct temperature measurements.

The development of computational tools has expanded the possibilities for applying this system. Among these tools, the LCZ4r package, developed for the R programming language, enables the retrieval and analysis of Local Climate Zone maps and the extraction of parameters related to urban structure and land cover (ANJOS et al., 2025). In this study, the package is used to characterize the distribution of LCZ classes and examine the Sky View Factor (SVF), a parameter associated with the proportion of the sky hemisphere visible from a given location and with the geometric configuration of the surrounding environment. Although this information contributes to the morphological characterization of cities, it does not replace the thermal data required to identify and quantify urban heat islands.

Applying this approach to the state of Paraná makes it possible to compare municipalities with different spatial configurations. The study focuses on Curitiba, Londrina, and Maringá, which were selected to examine the distribution of LCZ classes and parameters associated with urban morphology across distinct municipal contexts. The comparison also takes into account that class percentages were calculated relative to the total territorial area of each municipality, rather than exclusively to the urbanized area. This distinction is necessary because the presence of rural, vegetated, and transitional areas affects the relative proportions of the classes and conditions the interpretation of the results.

Against this background, the research question guiding this study is: how are Local Climate Zones and parameters associated with urban configuration distributed in Curitiba, Londrina, and Maringá, and to what extent does this characterization contribute to discussions of morphological features relevant to urban climate studies in Paraná?

The study is based on the hypothesis that the municipalities differ in the distribution of LCZ classes and in parameters associated with urban configuration, reflecting the characteristics of land occupation and surface cover. These differences may indicate spatial configurations relevant to subsequent investigations of urban thermal behavior; however, they do not, on their own, demonstrate the occurrence or establish the intensity of urban heat islands.

Accordingly, the general objective of this study is to comparatively analyze the distribution of Local Climate Zones and parameters associated with urban configuration in Curitiba, Londrina, and Maringá using the LCZ4r package. Specifically, the study aims to: (a) identify and characterize the main LCZ classes present in the municipalities; (b) examine the spatial distribution of these classes and their share of the total municipal area; (c) analyze the Sky View Factor patterns provided for the classes under investigation; and (d) compare the

observed spatial configurations, discussing their contribution to the morphological characterization of urban environments and to the development of future research in Urban Climatology.

By focusing on spatial classification and morphological parameters, this study provides a comparative characterization of the three municipalities and explicitly defines the limits of the inferences that can be drawn from these data. Direct assessment of thermal conditions and the intensity of urban heat islands remains a potential avenue for future research integrating air temperature measurements or land surface temperature data.

2 THEORETICAL FRAMEWORK

2.1 URBAN CLIMATE AND URBAN HEAT ISLANDS

Urban climate results from interactions between atmospheric dynamics, the physical characteristics of the surface, and the transformations brought about by urbanization. Within the Brazilian tradition of Geographical Climatology, Monteiro (1976) proposes understanding urban climate in relation to spatial organization and human activities. This perspective, further developed by Monteiro and Mendonça (2003), makes it possible to recognize that cities exhibit differentiated environmental conditions associated both with the natural characteristics of their sites and with the ways in which their territories are occupied and transformed.

Urbanization modifies energy exchanges between the surface and the atmosphere. The replacement of vegetation with pavements and buildings alters soil permeability, water availability for evapotranspiration, and the radiative and thermal properties of materials. At the same time, building height and arrangement affect solar radiation incidence, shading, air circulation, and radiative exchanges. The combination of these factors contributes to environmental heterogeneity within cities, although their effects vary according to local characteristics and meteorological conditions (OKE, 1987; MENDONÇA; DANNI-OLIVEIRA, 2007).

Among the phenomena associated with these transformations are urban heat islands, characterized by temperature differences between urbanized areas and less urbanized reference areas. It is necessary to distinguish the atmospheric urban heat island, identified through differences in air temperature, from the surface urban heat island, which is associated with differences in the radiometric temperature of land surfaces. Although related, these phenomena are not equivalent and may exhibit distinct spatial and temporal patterns (GARTLAND, 2010; VOOGT; OKE, 2003).

Land Surface Temperature (LST), obtained through remote sensing procedures, makes it possible to investigate the spatial distribution of surface heating. Its interpretation, however, is not equivalent to the assessment of air temperature, as these variables represent distinct components of the urban thermal system. Identifying and quantifying urban heat islands therefore requires thermal data appropriate to the phenomenon under investigation and procedures that account for spatial scale, observation period, and atmospheric conditions (VOOGT; OKE, 2003).

This distinction is fundamental to the present study. Characterizing urban structure makes it possible to identify configurations that may be relevant to climate research, but it does not, by itself, demonstrate temperature differences. In this case, the analysis of Local Climate Zones and morphological parameters should be understood as an approach to spatial characterization rather than as a direct measurement of the occurrence or intensity of urban heat islands.

2.2 AND USE AND LAND COVER AND REMOTE SENSING

Land use and land cover are important dimensions for understanding the environmental organization of cities. The distribution of built-up areas, impervious surfaces, vegetated spaces, exposed soils, and water bodies influences energy and water exchanges between the surface and the atmosphere. These effects, however, cannot be explained by a simple opposition between urbanized and natural areas, as they depend on material properties, moisture availability, radiation exposure, and the configuration of the surrounding environment (OKE, 1987; VOOGT; OKE, 2003).

Vegetation can contribute to thermal mitigation through shading and evapotranspiration, while also helping maintain permeable surfaces. Its effects vary according to vegetation type, height, density, and spatial distribution within the urban environment. Similarly, built surfaces exhibit different responses depending on their physical properties and exposure to environmental conditions. Landscape characterization therefore requires consideration of the spatial distribution and diversity of surface elements, without attributing complex climatic processes to a single factor (MENDONÇA; DANNI-OLIVEIRA, 2007).

Remote sensing and Geographic Information Systems (GIS) make it possible to characterize these elements at different spatial scales. Resources used in environmental studies include spectral indices such as the Normalized Difference Vegetation Index (NDVI), which is used to examine vegetation-cover characteristics, and the Normalized Difference

Built-up Index (NDBI), which can help identify surfaces associated with built-up areas. These indicators, however, are not direct measurements of temperature. Their contribution to thermal analysis depends on the objectives of the study and, where appropriate, on their integration with suitable thermal data.

Land Surface Temperature can also be estimated from remote sensing data, making it possible to investigate thermal differences among land-cover and land-use types. This requires consideration of image characteristics, spatial resolution, acquisition date and time, and processing procedures. Integrating land-cover data, spectral indices, and surface temperature can improve understanding of the relationships between urbanization and heating, provided that the variables are actually obtained and analyzed using compatible methods (VOOGT; OKE, 2003).

In the present study, NDVI and NDBI were not calculated, and land surface temperature data were not incorporated into the analysis. Land-cover and urban-structure characterization was carried out using LCZ classes and selected parameters from the LCZ4r package. Accordingly, potential relationships between surface cover and thermal behavior are discussed on the basis of the literature and are not presented as thermal findings empirically demonstrated by this research.

2.3 LOCAL CLIMATE ZONES AND THE LCZ4R PACKAGE

The Local Climate Zone (LCZ) system, proposed by Stewart and Oke (2012), was developed to standardize the characterization of environments used in urban temperature studies. The classification comprises 17 classes: ten primarily associated with built configurations and seven related to land-cover types. The classes distinguish combinations of attributes such as building height and density, the proportion of built surfaces, vegetation cover, and surface-cover characteristics.

An important contribution of the LCZ system is that it enables the comparable description of environments with different physical configurations. Rather than relying solely on generic categories such as city center, periphery, or residential area, the system organizes the landscape according to attributes relevant to the characterization of urban surfaces. This approach facilitates comparisons between cities and between sectors within the same municipality, provided that classification criteria, spatial scale, and data characteristics are taken into account (STEWART; OKE, 2012; STEWART; OKE; KRAYENHOFF, 2014).

LCZ classes can support investigations into relationships between urban form, surface cover, and thermal behavior. However, they do not correspond to fixed temperature ranges, nor do they independently determine the occurrence of heating. The thermal response associated with an urban configuration also depends on meteorological conditions, material properties, moisture availability, and the observation period. Thermal comparisons between classes therefore require temperature data and procedures appropriate to the variable being analyzed.

The application of the system has been expanded through computational tools that enable the retrieval, organization, and analysis of spatial information. These tools include the LCZ4r package, developed for the R programming language and presented by Anjos *et al.* (2025). The package provides resources for working with LCZ maps, examining class distributions, and obtaining parameters associated with surface structure and cover. It also includes functions designed for thermal analysis, whose application depends on the availability of the required data.

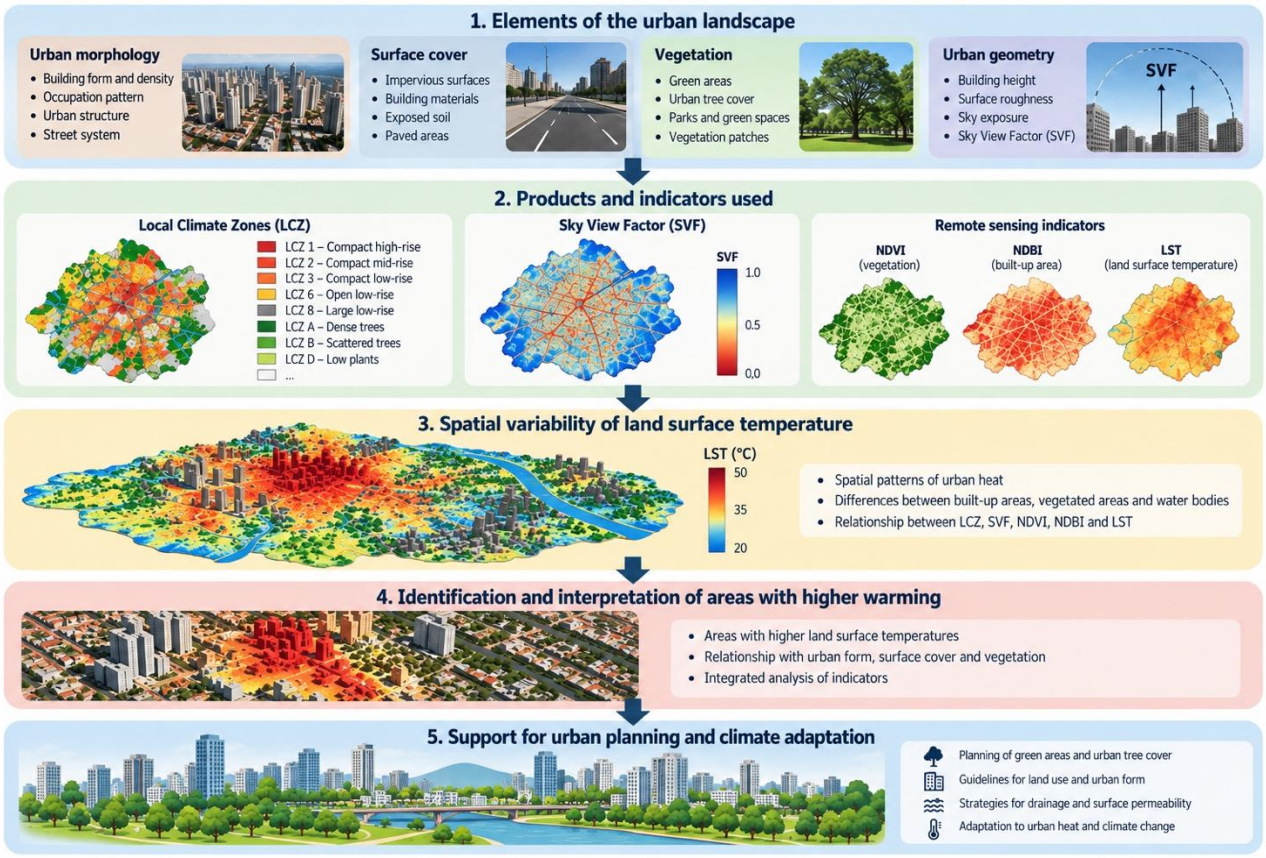
It is important to distinguish a tool's capabilities from the procedures actually implemented in a research study. In the present study, LCZ4r was used to analyze the spatial distribution of classes, calculate their share of each municipality's total territorial area, and examine the Sky View Factor parameters provided by the package. No air temperature or land surface temperature data were used, and the functions designed to analyze thermal anomalies or estimate urban heat island intensity were not executed.

The interpretation of class percentages requires an additional qualification. Because the calculations are based on the total territorial area of each municipality, the results include rural, vegetated, and transitional areas rather than only the urbanized footprint. Consequently, the percentage occupied by a given class should not be interpreted in isolation as a measure of the density or compactness of the urban fabric. This consideration is essential when comparing Curitiba, Londrina, and Maringá.

Integrating Local Climate Zones, urban-configuration parameters, and spatial-analysis tools provides a framework for characterizing urban environments. This approach distinguishes the identification of the physical characteristics of the landscape from the investigation of their potential relationships with thermal behavior. Figure 1 summarizes this framework, highlighting both the elements used in the present study and the complementary steps required for a direct assessment of urban heating.

Figure 1

Conceptual model of the integrated approach to urban-heating analysis.



Source: Prepared by the authors (2026), based on Stewart and Oke (2012), Anjos *et al.* (2025), and remote sensing data.

The figure presents a conceptual model that is broader than the procedures implemented in this study. The analyses conducted here covered the distribution of LCZ classes, their share of each municipality's total territorial area, and the Sky View Factor parameters provided by LCZ4r. Identifying surface-temperature patterns, calculating spectral indices, and quantifying urban heat island intensity represent potential avenues for complementary research that depend on obtaining and processing specific datasets.

2.4 URBAN MORPHOLOGY AND SKY VIEW FACTOR

Urban morphology refers to the form and spatial organization of buildings, streets, open spaces, and other elements that make up the built environment. In Urban Climatology, these attributes are relevant because they affect solar radiation exposure, shading, air circulation, and radiative exchanges between surfaces and the atmosphere. Their effects, however,

depend on the combined influence of urban geometry, material properties, vegetation cover, and meteorological conditions (OKE, 1987; STEWART; OKE, 2012).

One of the parameters used to characterize urban geometry is the Sky View Factor (SVF). This indicator represents the proportion of the sky hemisphere visible from a given point or environment, taking into account obstruction by buildings, trees, and other landscape elements. On a normalized scale ranging from zero to one, values close to one indicate greater sky openness, whereas values close to zero indicate greater visual obstruction (OKE, 1987; DIRKSEN et al., 2019).

The SVF helps describe aspects of spatial configuration that influence radiation exposure and radiative exchanges. In environments with greater visual obstruction, for example, urban geometry may limit direct solar radiation at certain times while also modifying the loss of longwave radiation at night. Conditions may differ in more open areas. The relationship between SVF and thermal behavior is therefore neither linear nor uniform: it depends on the time of day, season, surface orientation, material properties, and vegetation cover (DIRKSEN et al., 2019).

Combining LCZ and SVF makes it possible to characterize the urban landscape from two complementary perspectives. LCZ classes organize environments according to predominant attributes of built structure and surface cover, whereas SVF represents a specific dimension of urban geometry. Joint analysis of these elements supports morphological comparisons between areas but does not replace temperature data when the objective is to demonstrate thermal differences or quantify urban heat islands.

In this study, SVF values are used to complement the characterization of LCZ classes in the municipalities analyzed. Their interpretation must account for the origin and nature of the parameters provided by LCZ4r, without assuming that they represent direct measurements taken along every street or within every urban block. The results allow discussion of spatial-configuration characteristics and their potential implications for Urban Climatology research, but they do not allow specific temperatures to be assigned to the environments represented.

Taken together, LCZ classification and SVF analysis provide a basis for comparing the spatial organization of Curitiba, Londrina, and Maringá. This characterization may guide future investigations incorporating thermal data to directly assess relationships among urban morphology, surface cover, and heating. Within the scope adopted here, the contribution of

the study lies in describing and comparing the observed spatial attributes while respecting the limitations of the available information.

3 STUDY AREA

The spatial scope of this research is the state of Paraná, in southern Brazil, focusing on the municipalities of Curitiba, Londrina, and Maringá. The selection of these municipalities makes it possible to compare the distribution of Local Climate Zones (LCZ) across distinct urban contexts using a common classification and spatial-analysis procedure.

Curitiba, the state capital, has an urban structure characterized by a diversity of land uses and occupation patterns. Londrina and Maringá, in turn, are important urban centers in the interior of the state, each with its own spatial configuration. Comparing the three municipalities makes it possible to examine differences in the proportion and distribution of LCZ classes and in parameters associated with urban configuration, without assuming that these differences necessarily correspond to temperature variations.

The regional climatic context must also be considered when interpreting the landscape. Paraná exhibits a diversity of environmental conditions influenced by factors such as latitude, altitude, relief, and atmospheric dynamics. This diversity constitutes the regional context in which the municipalities under investigation are situated, although this research did not include meteorological measurements or temperature estimates to compare their thermal behavior (MENDONÇA; DANNI-OLIVEIRA, 2007).

The analysis uses municipal administrative boundaries as its spatial extent. Accordingly, the percentages of LCZ classes are calculated relative to the total area of each municipality, including urbanized, rural, agricultural, vegetated, and transitional areas. This choice must be considered when interpreting the results, since the share of a class within a municipality does not necessarily correspond to its proportion within the urbanized footprint.

The study area was therefore defined to enable the characterization and comparison of the spatial distribution of LCZ classes and Sky View Factor (SVF) parameters in Curitiba, Londrina, and Maringá. The results provide a comparative account of the spatial organization of these municipalities, limited to the attributes represented in the datasets used and without direct measurement of the occurrence or intensity of urban heat islands.

4 METHODOLOGY

This research is characterized as a quantitative, spatial, and descriptive study based on geospatial data analysis and geoprocessing techniques to characterize Local Climate Zones (LCZ) and parameters associated with urban morphology in the municipalities of Curitiba, Londrina, and Maringá, in the state of Paraná, Brazil.

Data processing and cartographic representation were performed using ArcGIS, developed by Esri. The software was used as a Geographic Information System (GIS) environment to organize geospatial layers, clip the study areas, inspect the spatial distribution of the data, and produce cartographic outputs.

LCZ data retrieval and analysis were conducted using version 0.1.0 of the LCZ4r package, described by Anjos et al. (2025) and based on the classification system proposed by Stewart and Oke (2012). The functions used were those designed to retrieve LCZ maps, calculate the area occupied by each class, and extract Sky View Factor (SVF) parameters.

The procedure involved retrieving the LCZ maps, clipping them to municipal boundaries, calculating the distribution of classes, and producing cartographic representations of the SVF values associated with the identified classes. Percentages were calculated relative to the total territorial area of each municipality, including both urbanized and non-urbanized areas.

Although LCZ4r provides functions for thermal analysis, these features were not used because the research did not incorporate air temperature or land surface temperature data. Consequently, the procedures adopted allow the spatial distribution of LCZ classes and selected morphological parameters to be characterized, but they do not allow urban heat island intensity to be calculated or thermal differences between classes to be demonstrated.

4.1 LCZ DATA ACQUISITION

The Local Climate Zone maps were obtained using the lcz_get_map() function in the LCZ4r package (ANJOS *et al.*, 2025), which provides access to the global LCZ map, version 3, described by Demuzere *et al.* (2022) and made available in the Zenodo repository. The product consists of a raster file in which pixels represent LCZ classes.

The data were clipped according to the administrative boundaries of Curitiba, Londrina, and Maringá, as provided by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* - IBGE). This procedure defined the areas used in the analysis and made it possible to examine the distribution of classes within each municipality.

The area occupied by each class was calculated using the lcz_cal_area() function, which provides absolute and percentage values. The percentages used in the graphs represent each class's share of the total municipal area, rather than exclusively the urbanized area. This characteristic was taken into account when interpreting the results and comparing the municipalities.

The lcz_plot_map() function was used for the cartographic representation of the classes. SVF parameters were retrieved using lcz_get_parameters() and spatially represented using lcz_plot_parameters(). The resulting products were organized in the GIS environment for spatial inspection, map production, and integration of the information required for comparative analysis. In the manuscript, the LCZ maps correspond to Figures 2, 3, 5, and 7, whereas the SVF maps correspond to Figures 4, 6, and 8.

4.1.1 Analysis of LCZ classes and sky view factor

The Local Climate Zone classification was used to describe the spatial distribution of environments with different predominant characteristics of built structure and surface cover. The analysis considered the absolute and percentage values obtained using the lcz_cal_area() function, which were used to prepare comparative graphs and identify classes with larger or smaller shares of the municipal territory.

The interpretation of the percentages takes into account that the denominator corresponds to the total territorial area of each municipality. Thus, the values express the share of each class within the entire municipal territory, including urbanized and non-urbanized areas, rather than only the internal composition of urbanized areas.

In addition to LCZ classes, the Sky View Factor (SVF) was analyzed. This parameter represents the proportion of the sky hemisphere visible from a given environment. In the LCZ4r package, the values used correspond to reference parameters associated with LCZ classes, as described by Anjos *et al.* (2025). The values were retrieved using the lcz_get_parameters() function, and their cartographic representation was produced using lcz_plot_parameters().

It is important to emphasize that the SVF values used do not correspond to measurements taken directly along individual streets, within urban blocks, or at specific points in the municipalities. The maps represent reference values associated with the identified LCZ classes. Therefore, the results allow the spatial distribution of class-related parameters to be visualized, but they do not replace detailed local measurements of urban geometry.

The joint analysis of LCZ and SVF maps was used to characterize the spatial distribution of classes and patterns of sky openness in Curitiba, Londrina, and Maringá. The interpretation of the results was based on the LCZ system proposed by Stewart and Oke (2012) and on the literature concerning urban climate, urban morphology, and remote sensing (OKE, 1987; VOOGT; OKE, 2003; GARTLAND, 2010). The identified patterns were discussed as spatial characteristics potentially relevant to urban climatic processes, while respecting the limitations of the data and procedures employed.

The LCZ4r package also provides specific functions for analyzing land surface temperature, thermal anomalies, and urban heat island intensity, including lcz_ts(), lcz_anomaly(), lcz_anomaly_map(), and lcz_uhi_intensity() (ANJOS *et al.*, 2025). These functions were not used in this research because no air temperature or land surface temperature data were incorporated. Therefore, the results do not allow urban heat island intensity to be calculated or quantitative thermal differences between classes to be established.

4.2 USE OF GENERATIVE ARTIFICIAL INTELLIGENCE AND SCIENTIFIC INTEGRITY

During the preparation of this article, Generative Artificial Intelligence (GAI) tools, including ChatGPT, were used as auxiliary resources to support text organization, language revision, improvements in clarity of presentation, and the consideration of possible approaches to structuring the manuscript. Their use was limited to supporting the preparation and refinement of the scientific text and did not replace the definition of the research problem, the selection of methodological procedures, consultation of bibliographic and documentary sources, or interpretation of the results obtained from cartographic representations and data relating to Local Climate Zones (LCZ).

These tools were used under the supervision of the authors, who remain responsible for selecting and verifying information, developing arguments, ensuring the appropriateness of interpretations, and preparing the final version of the article. Suggestions generated by GAI were critically assessed, and their incorporation into the manuscript was subject to the authors' evaluation. The tools are not considered authors of the work, and their use does not transfer responsibility for the scientific content to them.

The declaration of GAI use is grounded in the principles of transparency, accountability, and scientific integrity, taking into account guidance from the Brazilian National Council for Scientific and Technological Development (*Conselho Nacional de*

Desenvolvimento Científico e Tecnológico - CNPq) on the responsible use of these tools in scientific research, as well as recommendations from the United Nations Educational, Scientific and Cultural Organization (UNESCO) concerning human oversight, transparency, and accountability in the use of artificial intelligence systems (CNPq, 2026; UNESCO, 2022).

In this study, GAI did not replace bibliographic and documentary research, was not used as an independent source of evidence concerning the spatial configuration of the cities analyzed, and was not employed to validate geospatial datasets, calculate LCZ class proportions, or demonstrate the occurrence and intensity of urban heat islands. Data acquisition and organization, analysis of LCZ classes and Sky View Factor (SVF) values, and interpretation of cartographic representations remained grounded in the methodological procedures described in the article. It should also be emphasized that the analysis focuses on the morphological and spatial characterization of LCZ classes and their associated parameters and does not include direct measurements of air temperature or land surface temperature.

Accordingly, GAI was used as an auxiliary resource in scientific writing, while the authors retained responsibility for theoretical and methodological decisions, analysis of the material consulted, verification of references, and the final version of the manuscript.

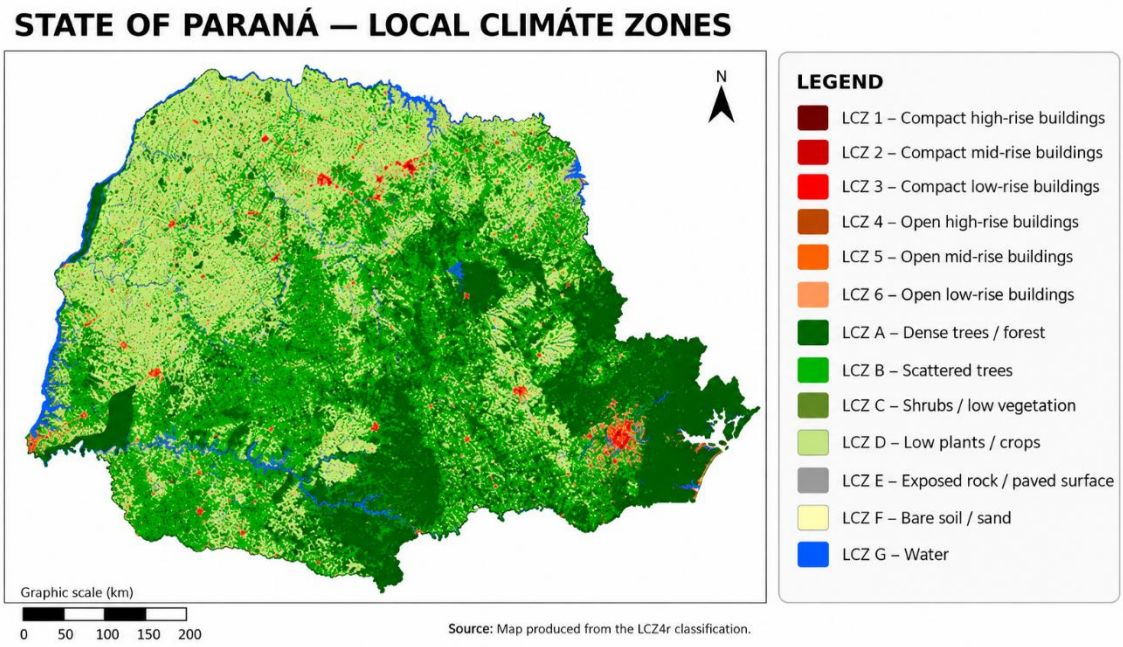
5 RESULTS AND DISCUSSION

The analysis of Local Climate Zones (LCZ) makes it possible to characterize the spatial distribution of different land-occupation and surface-cover patterns in the municipalities under investigation. The maps generated using the LCZ4r package distinguish classes associated with built environments, vegetated areas, and other forms of surface cover, providing a representation of the spatial organization of the territory.

In the regional representation of the state of Paraná (Figure 2), classes shown in shades of green visually predominate and are associated mainly with different types of vegetation cover and non-built areas. In contrast, red and orange shades identify built classes, with variations in urban configuration and development density. This distribution reveals the presence of urban centers surrounded by extensive areas belonging to other surface-cover classes.

Figure 2

Thematic map of Local Climate Zones in the state of Paraná.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

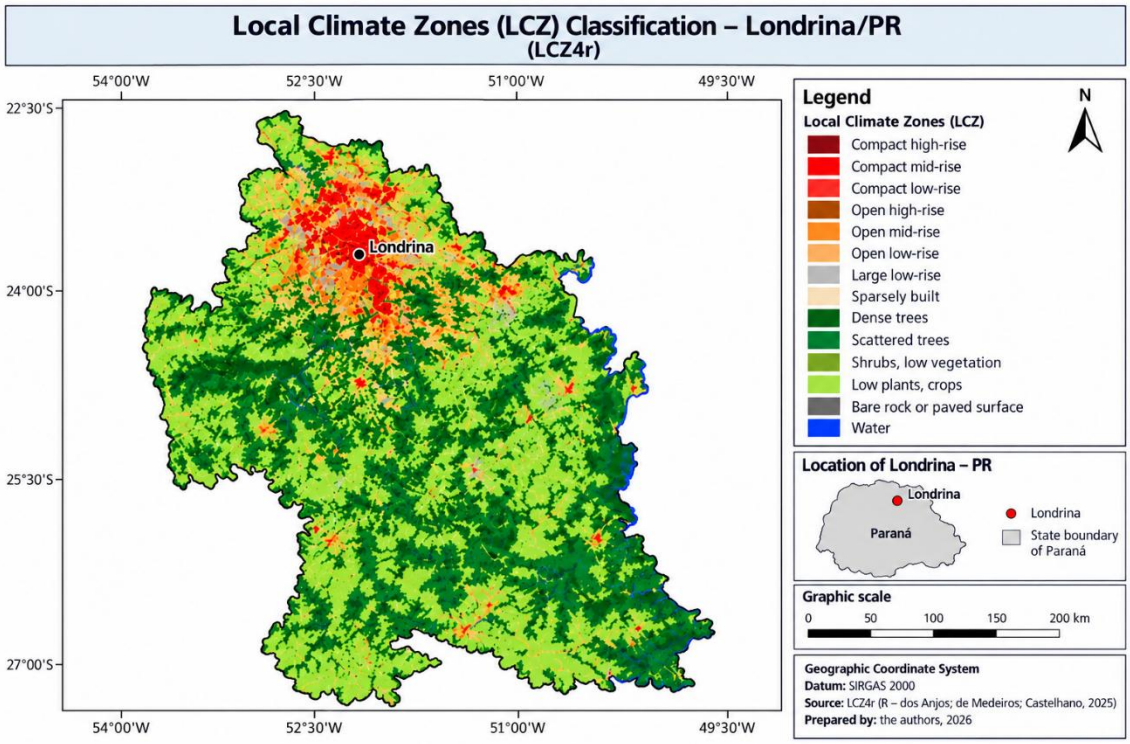
The spatial concentration of built classes around urban centers, such as Londrina, Maringá, and Curitiba, highlights differences between urbanized areas and predominantly vegetated areas. This distinction is relevant to landscape characterization and to the investigation of relationships between urbanization and climate. However, LCZ classification does not directly represent land surface or air temperature. Thus, although certain urban configurations may exhibit characteristics associated with different energy-exchange conditions, identifying areas that are actually warmer requires thermal data, which were not included in this study.

5.1 ANALYSIS OF LONDRINA, PARANÁ, BRAZIL

The distribution of Local Climate Zones in Londrina, shown in Figure 3, reveals the coexistence of built classes and areas predominantly covered by vegetation. The map identifies differences in the municipality's spatial organization, distinguishing sectors with a greater presence of built environments from areas dominated by classes associated with vegetation and other non-urbanized land covers.

Figure 3

Local Climate Zones in Londrina, Paraná, Brazil, by LCZ class.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

In the northern portion of the urbanized area represented on the map, built classes shown in red and orange shades stand out. These classes are associated with different configurations of building density and height. They include categories described in the LCZ system as compact low-rise, compact mid-rise, and compact high-rise. These categories help characterize the morphology of the sectors represented, although the classification alone does not establish specific levels of surface sealing or temperature.

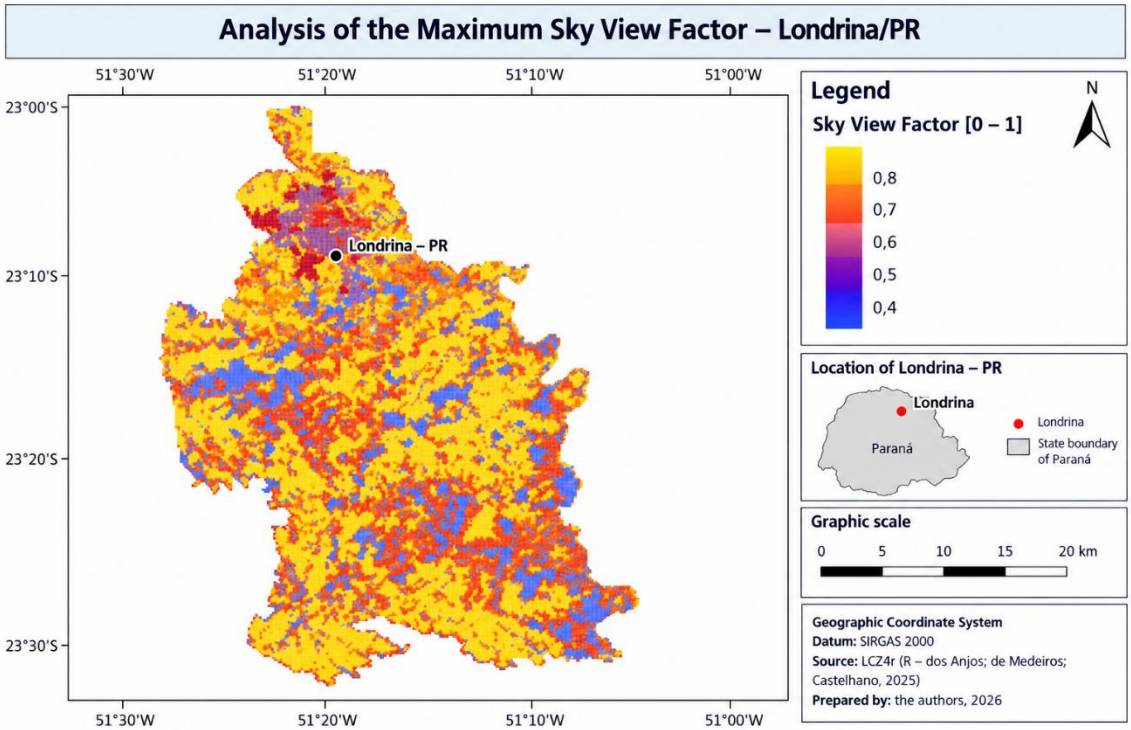
In other parts of the municipal territory, green shades are prominent and are associated with different types of vegetation cover and non-built areas. The coexistence of these classes with built environments demonstrates the spatial heterogeneity of the municipality. Vegetation and surface permeability are relevant elements in urban climate studies because of their roles in shading, evapotranspiration, and energy exchange. However, the specific thermal effects of these areas cannot be quantified using the LCZ classification alone.

The spatial distribution of the classes must also be interpreted in light of the territorial extent adopted. Because the percentages reported in this study refer to the total municipal area, the substantial share of vegetated classes may reflect both the presence of vegetation

within the urbanized area and the extent of non-urbanized areas within the municipality. This distinction is important to avoid confusing the composition of the entire territory with that of the urbanized footprint alone.

Figure 4

Sky View Factor associated with LCZ classes in Londrina, Paraná, Brazil.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

Figure 4 shows the spatial distribution of the Sky View Factor (SVF) associated with the LCZ classes identified in Londrina. The indicator ranges from zero to one and represents the proportion of the sky hemisphere visible from a given location. Higher values indicate greater sky openness, whereas lower values indicate greater obstruction.

Higher values, represented by yellowish and orange shades, visually predominate across much of the area shown on the map. In contrast, lower values occur in localized sectors associated with LCZ classes whose reference parameters indicate greater sky obstruction. This distribution makes it possible to examine geometric differences among the environments represented.

The presence of lower SVF values in sectors containing denser built classes is consistent with the relationship between built-environment configuration and obstruction of the sky hemisphere. However, it is important to consider that the values provided by LCZ4r

are derived from reference parameters associated with LCZ classes rather than from measurements taken directly at each location. Consequently, the maps represent the spatial distribution of these parameters according to the classification adopted, rather than detailed measurements of the geometry of individual streets or urban blocks.

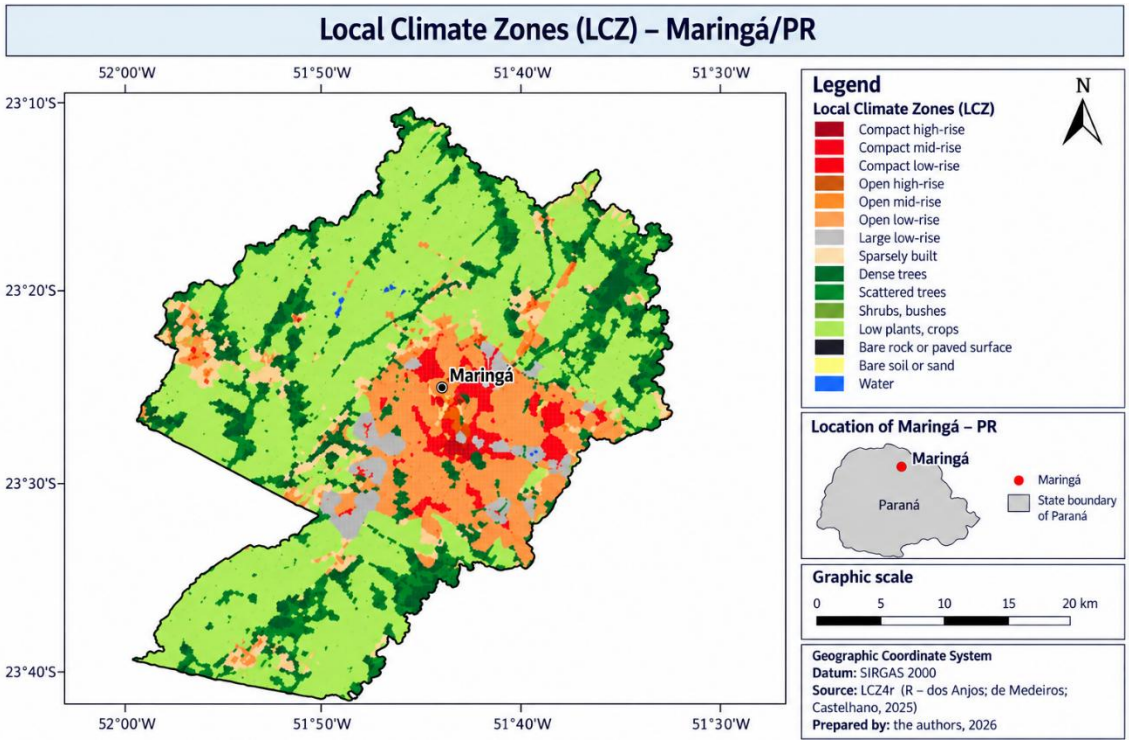
From an urban climatology perspective, sky openness is relevant to the analysis of radiative exchanges and exposure to solar radiation. Its thermal effects, however, vary according to the time of day, season, surface orientation, material properties, and vegetation cover. Therefore, the SVF patterns identified in Londrina contribute to the morphological characterization of the municipality but do not, by themselves, support the conclusion that sectors with lower values have higher temperatures or greater urban heat island intensity.

5.2 ANALYSIS OF MARINGÁ, PARANÁ, BRAZIL

The distribution of Local Climate Zones in Maringá, shown in Figure 5, makes it possible to examine the spatial organization of built classes and areas predominantly covered by vegetation. On the map, red and orange shades represent classes associated with different configurations of the built environment, whereas green shades correspond mainly to classes associated with vegetation and other non-built land covers.

Figure 5

Local Climate Zones in Maringá, Paraná, Brazil, by LCZ class.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

Within the urban area represented, built classes are concentrated in central sectors and along areas of urban development. This distribution makes it possible to identify differences in the spatial configuration of the built environment, including variations between more compact classes and others with distinct land-occupation characteristics. These patterns must be interpreted according to the information actually represented by the classification, without assuming that a color or class alone demonstrates a specific degree of surface sealing or a particular thermal condition.

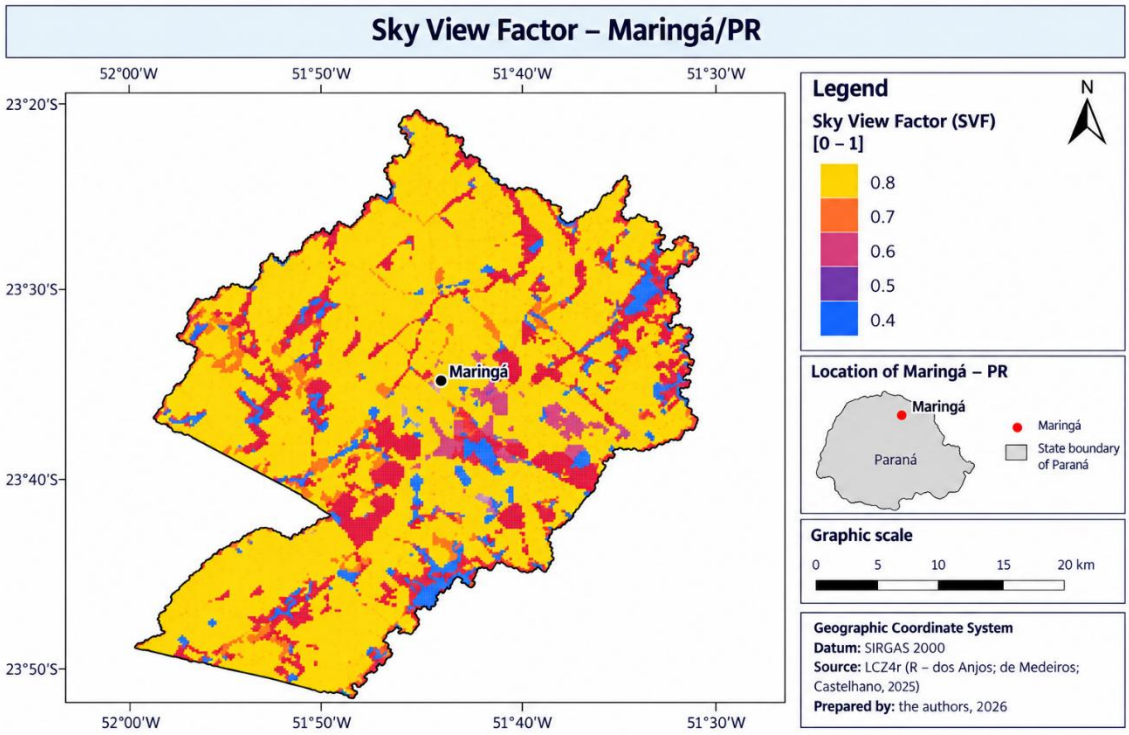
In the peripheral portions of the municipal territory, the map also displays classes associated with vegetation. The coexistence of these areas with built classes highlights the heterogeneity of surface cover in Maringá. Urban vegetation is a relevant component of climate studies, particularly because of its relationship with shading and evapotranspiration. Nevertheless, the actual contribution of these areas to temperature reduction in specific sectors cannot be confirmed using the data employed in this research.

A visual comparison with the map of Londrina suggests differences in the spatial distribution of LCZ classes between the two municipalities. This comparison is useful for characterizing their territorial configurations, but it must account for the fact that class

percentages were calculated relative to the total municipal area. Therefore, the share of vegetated classes also depends on the extent of non-urbanized areas included within each municipality's spatial boundaries.

Figure 6

Sky View Factor associated with LCZ classes in Maringá, Paraná, Brazil.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

Figure 6 presents the reference values of the Sky View Factor (SVF) associated with the LCZ classes identified in Maringá. Yellowish shades, corresponding to higher values in the representation used, visually predominate, whereas lower values appear in specific sectors.

The spatial distribution of SVF values makes it possible to examine differences in sky openness among the environments represented. The lower values identified in central sectors spatially coincide with areas classified as more compact built categories on the LCZ map. This correspondence is consistent with the geometric relationship between built-environment configuration and obstruction of the sky hemisphere.

It is important to emphasize, however, that the SVF values shown do not correspond to direct measurements taken along the streets or within the urban blocks of Maringá. Under

the methodological procedure adopted, these values are derived from reference parameters associated with LCZ classes. Accordingly, the spatial coincidence between more compact built classes and lower SVF values should be interpreted as a characteristic of the cartographic products generated by the procedure used.

From a theoretical perspective, urban geometry can affect radiative exchanges and exposure to solar radiation. The magnitude and direction of thermal effects, however, depend on other factors, including the time of day, season, surface materials, and atmospheric conditions. Since no temperature data were used in this study, it is not possible to conclude that sectors with lower SVF values are actually warmer or exhibit greater urban heat island intensity.

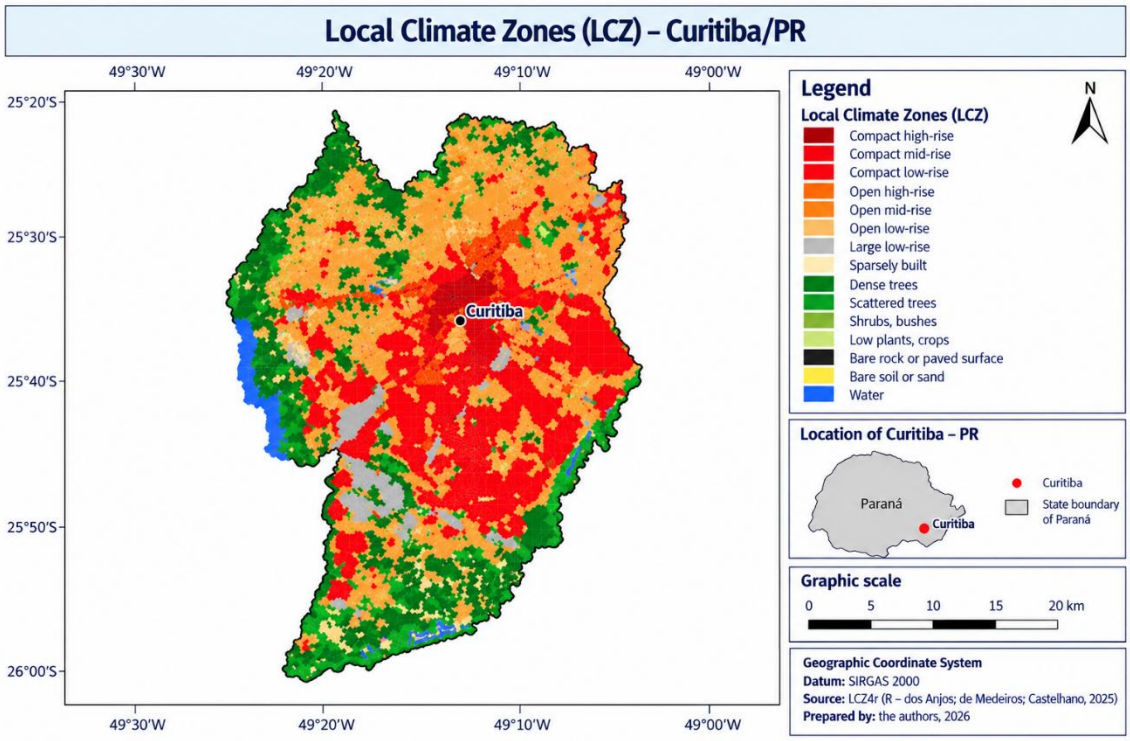
5.3 ANALYSIS OF CURITIBA, PARANÁ, BRAZIL

The distribution of Local Climate Zones in Curitiba, shown in Figure 7, makes it possible to identify different configurations of the built environment and surface cover within the municipal territory. In the central area represented, built classes shown in red and orange shades stand out, including compact categories with different building heights. These classes characterize sectors with morphological configurations distinct from those found in areas classified as open or predominantly vegetated.

In the intermediate portions of the municipality, the map shows urban classes with different degrees of openness and building configurations, including categories such as open mid-rise, open low-rise, and open, according to the nomenclature adopted in the LCZ classification. The presence of these classes highlights the morphological diversity of the territory and makes it possible to distinguish environments with different patterns of land occupation.

Figure 7

Local Climate Zones in Curitiba, Paraná, Brazil, by LCZ class.



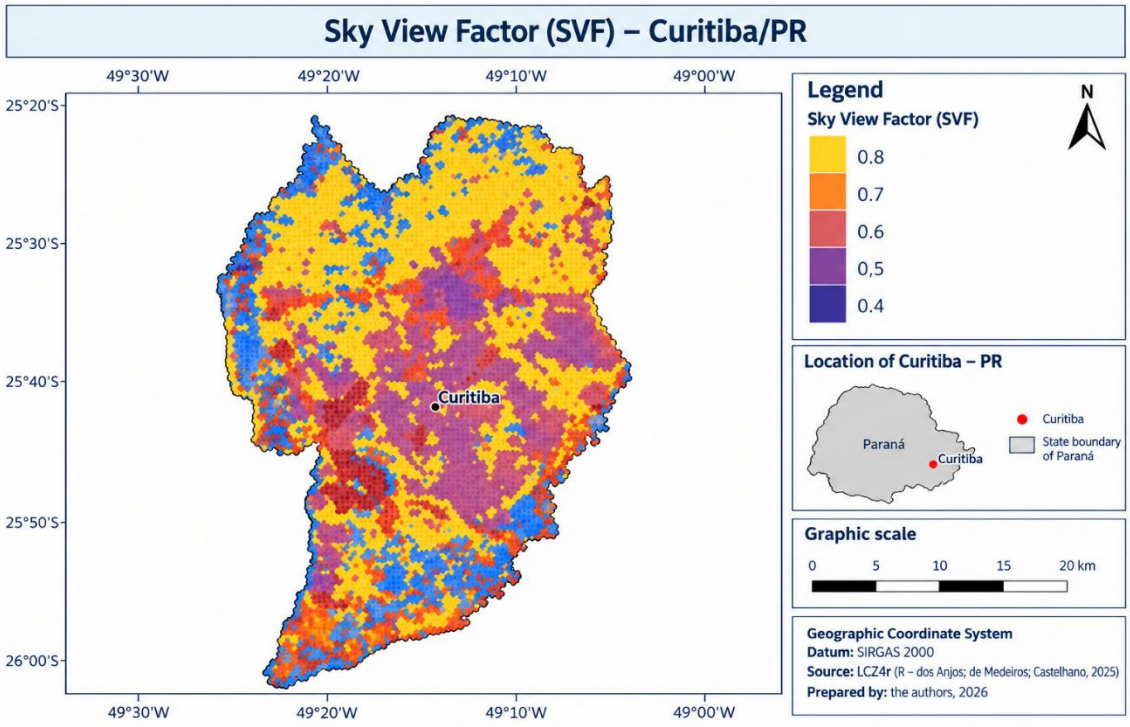
Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

In the peripheral areas represented, classes associated with vegetation, including dense trees and scattered trees, can be observed. The distribution of these classes demonstrates that vegetation cover forms part of the municipality's spatial composition and coexists with built areas. Although vegetation is relevant to processes such as shading and evapotranspiration, the data used do not allow its effects on temperature in the identified sectors to be quantified.

The map must be interpreted with the understanding that the classification represents categories of surface cover and configuration rather than direct measurements of surface sealing, temperature, or urban heat island intensity. Accordingly, the results characterize Curitiba's spatial organization but do not, by themselves, demonstrate that certain sectors exhibit more pronounced thermal conditions than others.

Figure 8

Sky View Factor associated with LCZ classes in Curitiba, Paraná, Brazil.



Source: Prepared by the authors (2026) using the LCZ4r package, based on Demuzere et al. (2022) and IBGE territorial data.

Figure 8 shows the distribution of reference Sky View Factor (SVF) values associated with the LCZ classes identified in Curitiba. Intermediate to high values visually predominate across a substantial portion of the area represented, whereas lower values are concentrated in certain sectors, particularly in the central area.

A visual comparison of the LCZ and SVF maps reveals a spatial correspondence between sectors classified as more compact and lower SVF values. This configuration is consistent with the geometric relationship between built-environment form and obstruction of the sky hemisphere. However, because the SVF values used are derived from reference parameters associated with LCZ classes, this correspondence must be interpreted within the framework of the classification employed rather than as the result of detailed local measurements.

Sky openness is a relevant parameter for investigations into urban geometry and radiative exchanges. Nevertheless, the thermal effects of this configuration depend on factors such as the time of day, season, surface orientation, construction materials, and vegetation

cover. Without temperature data, it is not possible to conclude that sectors of Curitiba with lower SVF values are actually warmer or exhibit greater urban heat island intensity.

Taken together, the LCZ and SVF maps make it possible to characterize the morphological heterogeneity of Curitiba and identify spatial differences in the distribution of classes and parameters associated with sky openness. This characterization may support future urban climate investigations, provided that it is complemented by thermal data and specific analytical procedures.

5.4 COMPARATIVE ANALYSIS OF CURITIBA, MARINGÁ, AND LONDRINA, PARANÁ, BRAZIL

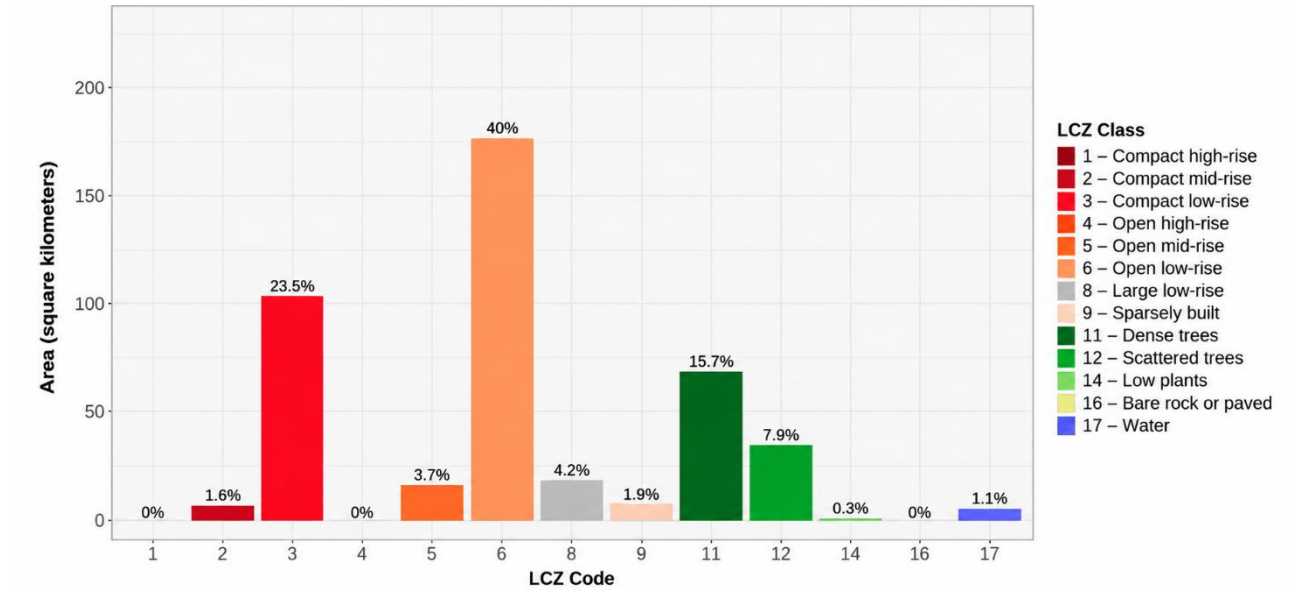
Comparing the distributions of Local Climate Zones across the three municipalities reveals differences in the relative proportions of built and vegetated classes. The graphs generated using the lcz_cal_area() function make it possible to examine the territorial composition of each municipality and identify contrasts between the represented land-cover and land-use patterns.

In Curitiba, Figure 9 highlights the contribution of LCZ 6, described in the manuscript as open low-rise, which accounts for approximately 40% of the municipal area. LCZ 3, identified as compact low-rise, represents approximately 23.5%. Substantial proportions are also recorded for LCZ 11, dense trees, at approximately 15.7%, and LCZ 12, scattered trees, at around 7.9%.

These percentages indicate the coexistence of built and vegetated classes within the municipal territory. The diversity of the represented categories characterizes Curitiba as a municipality with a heterogeneous spatial composition according to the LCZ classification. However, these data alone do not demonstrate the occurrence or intensity of urban heat islands.

Figure 9

Distribution of LCZ classes in Curitiba, Paraná, Brazil.



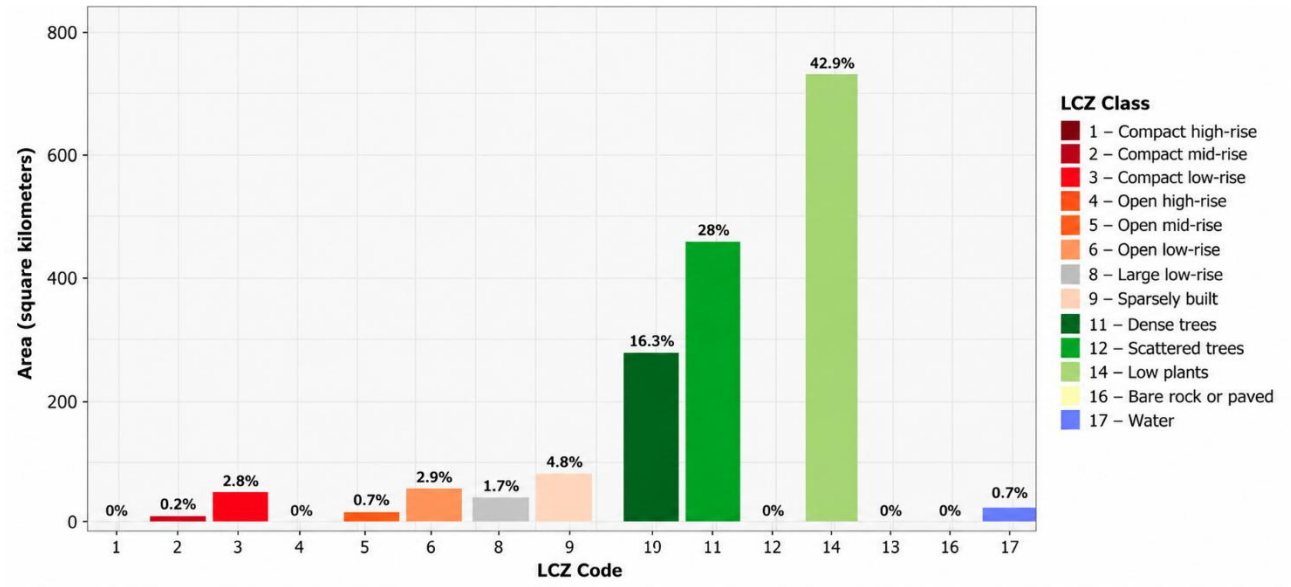
Source: Prepared by the authors (2026).

In Londrina, Figure 10 shows a substantial proportion of LCZ 14, corresponding to low plants, which accounts for approximately 42.9% of the municipal area. LCZ 12, scattered trees, and LCZ 11, dense trees, represent approximately 28% and 16.3%, respectively. According to the values presented in the manuscript, the compact and open built classes each account for less than 5%.

The percentage distribution indicates the predominance of non-built classes within the total municipal territory analyzed. Nevertheless, it is important to consider that this result refers to the entire municipal area rather than exclusively to the urban footprint. Therefore, the high proportion of LCZ 14 should not automatically be interpreted as indicating that low vegetation predominates in Londrina's urbanized neighborhoods.

Figure 10

Distribution of LCZ classes in Londrina, Paraná, Brazil.



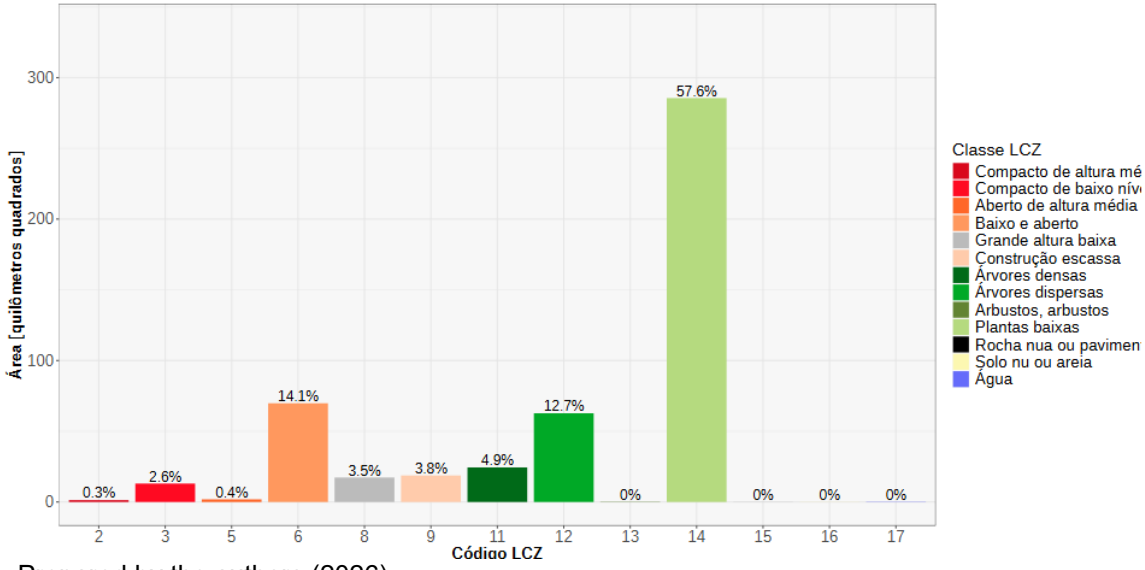
Source: Prepared by the authors (2026).

In Maringá, Figure 11 shows LCZ 14 as the class with the largest share, accounting for approximately 57.6% of the municipal area. LCZ 12 represents around 12.7%, while LCZ 6 accounts for approximately 14.1%. The manuscript also records relatively small proportions of compact built classes.

These results indicate that classes associated with non-built areas occupy a substantial share of the municipal territory considered. As in Londrina, this composition must be interpreted in light of the inclusion of rural and peri-urban areas in the percentage calculations. The values do not, in isolation, support the conclusion that Maringá's urbanized area has a low building density throughout its entire extent.

Figure 11

Distribution of LCZ classes in Maringá, Paraná, Brazil.



Source: Prepared by the authors (2026).

Considering the percentages presented in the manuscript, Curitiba is distinguished by the substantial proportions of built classes, particularly LCZ 6 and LCZ 3, as well as by the diversity of the classes represented. Londrina shows a high proportion of LCZ 14, followed by classes associated with scattered and dense trees. In Maringá, LCZ 14 is also predominant, with a higher percentage than that recorded for Londrina.

These differences describe the territorial composition of the three municipalities according to the global LCZ map used in this study. Their interpretation must account for the fact that the percentages were calculated using the total municipal area and that the classification has its own spatial resolution, which limits the level of detail available for characterizing specific sectors of the urban footprints.

The SVF maps, in turn, allow comparison of the reference values associated with the LCZ classes. In all three municipalities, the manuscript describes lower values in central sectors that spatially coincide with more compact built classes. This correspondence constitutes a relevant morphological observation, but it does not demonstrate temperature differences among the municipalities or support a ranking of which city is warmer or cooler.

In summary, the comparison reveals differences in the spatial distribution of LCZ classes and SVF parameters in Curitiba, Londrina, and Maringá. The results contribute to the morphological and territorial characterization of these municipalities and provide a basis for future investigations incorporating land surface or air temperature data.

6 FINAL CONSIDERATIONS

This study used the LCZ4r package to characterize and compare the distribution of Local Climate Zones (LCZ) and the reference parameters of the Sky View Factor (SVF) in the municipalities of Curitiba, Londrina, and Maringá, in the state of Paraná, Brazil. The analysis identified differences in the territorial composition of LCZ classes and in the spatial distribution of parameters associated with sky openness, contributing to the characterization of the spatial organization and morphology of the municipalities investigated.

The results reveal differences in the relative proportions of LCZ classes among the municipalities. In Curitiba, LCZ 6, accounting for approximately 40% of the municipal area, and LCZ 3, representing around 23.5%, stand out, alongside LCZ 11 and LCZ 12, associated with dense and scattered trees, respectively, with approximate proportions of 15.7% and 7.9%. In Londrina, LCZ 14, corresponding to low plants, represents approximately 42.9% of the municipal territory, while LCZ 12 and LCZ 11 account for around 28% and 16.3%, respectively. In Maringá, LCZ 14 represents approximately 57.6% of the municipal area, followed by LCZ 6, at around 14.1%, and LCZ 12, at approximately 12.7%.

These results demonstrate differences in the territorial composition of the municipalities according to the classification used. Their interpretation, however, requires consideration of the fact that the percentages were calculated relative to the total municipal area rather than exclusively to the urbanized footprints. The substantial proportions of non-built classes in Londrina and Maringá may be partly related to the inclusion of rural, agricultural, vegetated, and peri-urban areas within the spatial boundaries used. This characteristic limits direct comparisons between the territorial composition of the municipalities and the internal structure of their effectively urbanized areas and must be considered when interpreting the results.

The analysis of the SVF maps also revealed spatial differences in the reference values associated with the LCZ classes. In all three municipalities, lower values were observed in central sectors that spatially coincide with more compact built classes. This correspondence contributes to the geometric characterization of the environments represented and demonstrates the usefulness of jointly analyzing LCZ classes and SVF parameters to describe aspects of urban configuration. It is important to emphasize, however, that the SVF values used derive from reference parameters associated with LCZ classes rather than from measurements conducted directly in each street or city block. Therefore, the identified patterns must be interpreted in accordance with the nature of the data employed.

One contribution of this study is the application of a standardized procedure for the spatial characterization and comparison of LCZ classes in three Paraná municipalities with distinct territorial configurations. The use of LCZ4r made it possible to organize thematic maps, calculate the relative proportions of classes within the municipal territory, and spatially represent the SVF parameters associated with the classification. Integrating these outputs provides a basis for recognizing morphological differences and expands the possibilities for investigating relationships among urban configuration, surface cover, and climate.

Despite these contributions, the scope of the results must be clearly defined. The study did not use air temperature or land surface temperature data and, therefore, did not measure urban heat island intensity, directly identify areas of greater heating, or establish whether Curitiba, Londrina, or Maringá is warmer or cooler than the others. The relationships between urban morphology, surface cover, and thermal conditions discussed throughout the paper should be understood as theoretical foundations and avenues for further investigation, rather than as thermal effects empirically demonstrated by the procedures performed.

The methodological limitations include the absence of thermal data, the calculation of percentages based on the total territorial area of the municipalities, and the use of a global LCZ map and the nature of the SVF values associated with the classes. These aspects must be considered when assessing the spatial resolution of the outputs and interpreting patterns in specific sectors of the urbanized areas. In particular, using municipal boundaries as the unit of analysis enables a broad territorial comparison but does not necessarily represent the internal composition of the urban footprints.

Future studies could deepen this investigation by incorporating land surface temperature (LST) data and, depending on the research objectives, air temperature data. Including vegetation-cover indicators, such as the Normalized Difference Vegetation Index (NDVI), and indices related to built surfaces, such as the Normalized Difference Built-up Index (NDBI), could also expand the analysis of relationships among surface cover, urban morphology, and thermal conditions. Another possibility would be to recalculate the proportions of LCZ classes considering only urbanized areas, allowing a more direct comparison of the internal structure of the urban footprints of Curitiba, Londrina, and Maringá.

It can be concluded that Local Climate Zone classification, combined with the analysis of Sky View Factor parameters, constitutes a relevant resource for characterizing urban spatial structure. Within the scope of this research, its main contribution lies in identifying and comparing differences in the territorial composition and morphological configuration of the

three municipalities in Paraná. Demonstrating relationships between these characteristics and the occurrence or intensity of urban heat islands, however, remains a question for future investigation through the integration of thermal data and specific analytical procedures.

REFERENCES

ACOSTA-FERNÁNDEZ, G. A.; MARTÍNEZ-TORRES, K. E.; GONZÁLEZ-TREVIZO, M. E.; SANTAMOURIS, M. Advances in urban mapping of local climate zones for heat mitigation: a systematic review. **Land Use Policy**, v. 153, art. 107540, 2025. DOI: https://doi.org/10.1016/j.landusepol.2025.107540.

ANJOS, M. W. B. dos et al. LCZ4r package R for local climate zones and urban heat islands. **Scientific Reports**, v. 15, art. 7710, 2025. Disponível em: https://www.nature.com/articles/s41598-025-92000-0. Acesso em: 8 out. 2026. DOI: 10.1038/s41598-025-92000-0.

ANJOS, M. W. B. dos; MEDEIROS, D. C. de; CASTELHANO, F. J. LCZ4r, um pacote R para análise de zonas climáticas locais e ilhas de calor urbanas. **Revista da ANPEGE**, v. 21, n. 44, 2025. DOI: https://doi.org/10.5418/ra2025.v21i44.19763.

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO (CNPq). **Diretrizes.** Brasília, DF: CNPq, 2016. Atualizado em 13 mar. 2026. Disponível em: https://www.gov.br/cnpq/pt-br/composicao/comissao-de-integridade/diretrizes. Acesso em: 9 set. 2026.

DEMUZERE, M.; KITTNER, J.; MARTILLI, A.; MILLS, G.; MOEDE, C.; STEWART, I. D.; VAN VLIET, J.; BECHTEL, B. A global map of local climate zones to support earth system modelling and urban-scale environmental science. **Earth System Science Data**, v. 14, p. 3835–3873, 2022. DOI: https://doi.org/10.5194/essd-14-3835-2022.

DIRKSEN, M.; RONDA, R. J.; THEEUWES, N. E.; PAGANI, G. A. Sky view factor calculations and its application in urban heat island studies. **Urban Climate**, v. 30, art. 100498, 2019. DOI: https://doi.org/10.1016/j.uclim.2019.100498.

GARTLAND, Lisa. **Ilhas de calor:** como mitigar zonas de calor em áreas urbanas. São Paulo: Oficina de Textos, 2010.

IPCC. **Mudanças climáticas 2021:** a base científica física. Cambridge: Cambridge University Press, 2021.

MENDONÇA, Francisco; DANNI-OLIVEIRA, Inês Moresco. **Climatologia:** noções básicas e climas do Brasil. São Paulo: Oficina de Textos, 2007.

MONTEIRO, Carlos Augusto de Figueiredo. **Teoria e clima urbano.** São Paulo: Instituto de Geografia da Universidade de São Paulo, 1976.

MONTEIRO, Carlos Augusto de Figueiredo; MENDONÇA, Francisco (org.). **Clima urbano.** São Paulo: Contexto, 2003.

OKE, T. R. **Boundary Layer Climates.** 2. ed. London: Routledge, 1987.

ORGANIZAÇÃO DAS NAÇÕES UNIDAS PARA A EDUCAÇÃO, A CIÊNCIA E A CULTURA (UNESCO). **Recommendation on the Ethics of Artificial Intelligence.** Paris: UNESCO, 2022. Disponível em: https://www.unesco.org/ethics-ai/en/recommendation. Acesso em: 9 out. 2026.

RAHMANI, Neshat; SHARIFI, Ayyoob. Urban heat dynamics in Local Climate Zones (LCZs): a systematic review. **Building and Environment**, v. 267, art. 112225, 2025. DOI: https://doi.org/10.1016/j.buildenv.2024.112225. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0360132324010679>. Acesso em: 8 out. 2026.

RESENDE, Carlos Eduardo; HASEGAWA, Marcos Minoru. Caracterização da estrutura produtiva do Estado do Paraná: uma análise shift-share entre 2002 e 2018. **Revista Paranaense de Desenvolvimento**, Curitiba, v. 41, n. 139, jul./dez. 2020.

STEWART, I. D.; OKE, T. R. Local Climate Zones for Urban Temperature Studies. **Bulletin of the American Meteorological Society**, v. 93, n. 12, p. 1879-1900, 2012.

STEWART, I. D.; OKE, T. R.; KRAYENHOFF, E. S. Evaluation of the “local climate zone” scheme using temperature observations and model simulations. **International Journal of Climatology**, v. 34, p. 1062-1080, 2014.

VOOGT, J. A.; OKE, T. R. Thermal remote sensing of urban climates. **Remote Sensing of Environment**, v. 86, n. 3, p. 370-384, 2003.