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Influence of urban greenery on thermal comfort: a case study in a tropical city

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ABSTRACT
This case study focused on the city of São Luís (MA), aiming to analyze the role of urban greenery in the thermal comfort of São Luís, identifying urban and landscape planning strategies that promote the integration of urban vegetation to create a more livable and thermally comfortable environment in the city. To do so, a research methodology with an exploratory and quantitative-qualitative character was employed, involving data collection on temperature and precipitation provided by INMET, as well as a floristic survey in the central region of São Luís, considering the significant impact of urban vegetation on the city's temperature and precipitation. The results showed a strong association between the urbanization process and the increase in urban temperatures, a phenomenon known as the "urban heat island," while urban greenery has been proven as an effective strategy to mitigate this effect, even under conditions aggravated by the El Niño phenomenon. In this context, the research also revealed that an increase in urban vegetation can have positive impacts on reducing temperature and improving the thermal comfort of residents, with the analysis of climate data from 2018 to 2023 being crucial in understanding the relationship between urban vegetation and thermal conditions in the city. The results emphasize the importance of the quantitative-qualitative approach, which allows for a comprehensive and in-depth analysis of the studied phenomenon. Furthermore, the use of climate data provides a solid foundation for analysis and encourages the exploration of specific urban and landscape planning strategies, taking into consideration the effectiveness of these strategies in enhancing thermal comfort within urban centers.

KEYWORDS: Urban Greenery. Temperature. Urbanization.

1 Introduction

The rapid and unchecked urbanization has led to a series of environmental challenges, including the increase in urban temperature, known as the 'urban heat island' (Oke, 1982). This phenomenon has significant implications for the thermal comfort of city residents, particularly in tropical regions where temperatures are already high (Emmanuel, 2005). Urban greenery, which includes parks, gardens, street trees, and other forms of vegetation, has been recognized as an effective strategy to mitigate the urban heat island effect and improve thermal comfort (Bowler *et al.*, 2010; Gill *et al.*, 2007).

Urban vegetation can reduce air and surface temperatures, increase humidity, and provide shade, all contributing to a cooler and more comfortable urban environment (Akbari *et al.*, 2001; Shashua-Bar; Hoffman, 2000). Furthermore, studies show that the perception of thermal comfort can be more influenced by non-physical and subjective factors, such as the sight of nature and a peaceful environment, than by actual thermal conditions (Mutani; Todeschi, 2020).

This case study focuses on São Luís, a specific tropical city, exploring the influence of urban greenery on thermal comfort. The research was motivated by the need to understand how urban vegetation can be used to address the challenges of rising urban temperatures in São Luís and contribute to the creation of a more comfortable urban environment, considering the scarcity of research exploring urban and landscape planning strategies for the effective use of urban vegetation, among other unmentioned aspects (Mutani; Todeschi, 2021).

The research is based on the assumption that increasing urban vegetation in São Luís can have positive impacts on reducing urban temperature and the thermal comfort of residents. To investigate this hypothesis, climatological temperature and precipitation variables were collected between 2018 and 2023 to analyze the relationship between urban vegetation and thermal conditions in the city (Wong *et al.*, 2003).

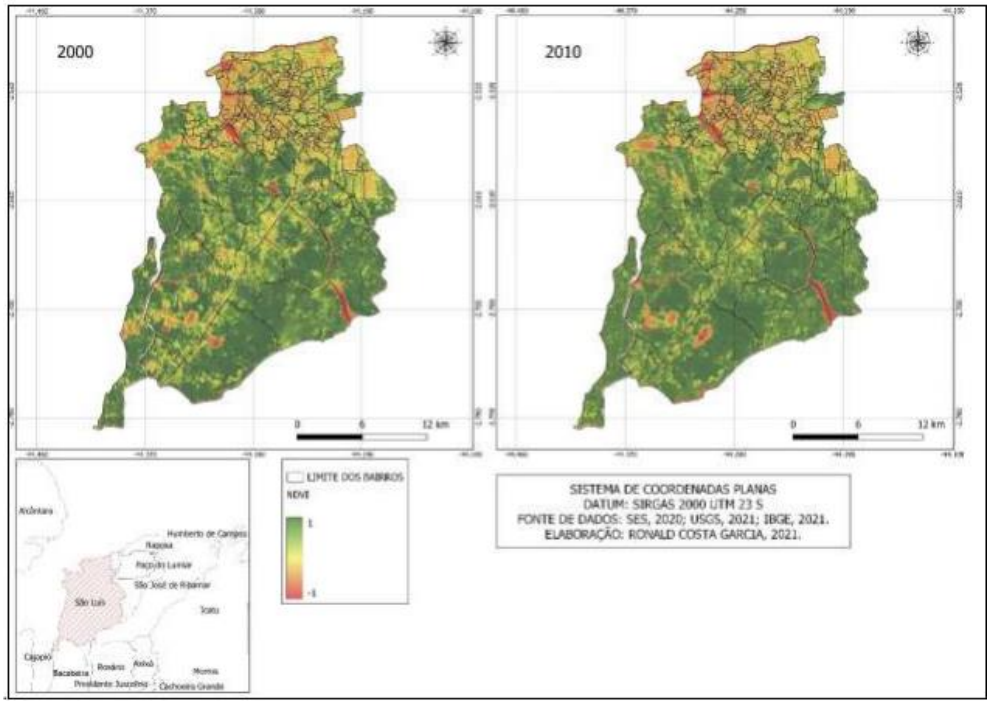
The general objective of this study is to analyze the role of urban greenery in the thermal comfort of São Luís and identify urban and landscape planning strategies that can promote the integration of urban vegetation to create a more habitable and thermally comfortable environment in the city, considering the characteristics of the tropical climate (Santamouris, 2014).

2 Methodology

2.1 Study Area

The study was conducted in the city of São Luís, a tropical city located in the northeastern region of Brazil (Figure 1). São Luís is a rapidly growing city with a variety of urban green spaces, making it an ideal location for this study (Di Leo; Escobedo; Dubbeling, 2016).

Figure 1 - NDVI Map of São Luís-MA, generated from LANDSAT satellite bands 3 and 4, 2021.



Source: Garcia e Araujo (2021).

2.2 Research Nature

This research had an exploratory and quantitative-qualitative nature. Quantitative-qualitative research, also known as mixed methods research, is an approach that combines elements of quantitative and qualitative research to provide a more comprehensive understanding of a research phenomenon. Quantitative research focuses on collecting and analyzing numerical data and employs statistical methods to test hypotheses. On the other hand, qualitative research is focused on understanding the meaning of human experiences and often involves the collection of non-numerical data, such as interviews, observations, and text analysis. Combining these two approaches allows researchers to leverage the strengths of both and minimize their limitations, providing a richer and contextualized insight into the research phenomenon (Fassinger; Morrow, 2013).

The study explored the relationship between urban vegetation and thermal comfort in the city of São Luís, quantifying the impact of urban vegetation on the city's temperature and precipitation.

2.3 Data Collection and Analysis

Thus, the research consisted of two phases. In the first phase, temperature and precipitation data were collected annually from the National Institute of Meteorology (INMET) platform, available at (https://tempo.inmet.gov.br/), for the period from 2018 to 2023. The temporal analysis of temperature and precipitation data was conducted to identify trends and seasonal variations.

In the second phase, a floristic survey was conducted in the center of São Luís, with geographical coordinates (-2.529840, -44.303418), in 2021 and 2023. Within a 100-meter radius, all individuals were surveyed using the methodology proposed by Falcão *et al*. (2020), which allowed for the identification of all individuals present in the study area. The identification of individuals was carried out in accordance with the taxonomic classification of botanical families recognized by the Angiosperm Phylogeny Group IV (APG IV, 2016).

The tree and palm species found in the areas were identified with respect to their origin (native or exotic), growth habit (tree or palm), and use. Validation of the scientific nomenclature and origin of the species, whether native to Brazil or exotic, was conducted using the Flora do Brasil 2020 database (BFG, 2021).

In addition, measurements of DBH (diameter at breast height), stem height (hf), and total height were collected. However, DBH and hf measurements were not obtained for the palms. Stem height represents the height of the first bifurcation and was classified into three categories: Class I ($0.0 \leq hf < 1.8$ m), Class II (1.81 m $\leq hf < 3.6$ m), and Class III (3.6 m $\leq hf$). Total height was determined using the angle projection technique, a method adapted from Santos and Teixeira (2001), and the plants were classified as small (height between 1.01 m and 3 m), medium (between 3 m and 6 m), or large (over 6 m).

To assess the crown size, a 30-meter tape measure was used to measure the diameter of the crown projection in the north-south and east-west directions. The values were summed, divided by two, and categorized into the following classes: Class 1 - small crown (up to 3 m), Class 2 - medium crown (from 3 m to 7 m), and Class 3 - large crown (over 7 m). Furthermore, the quantitative data were tabulated in Excel 2016 and analyzed descriptively.

3 Results and Discussion

The following discussion is based on the analysis of climate data (temperature and precipitation) from 2018 to 2023 in São Luís, focusing on the role of urban greenery in thermal comfort. Rapid urbanization has been associated with an increase in urban temperatures, a phenomenon known as the 'urban heat island' (Oke, 1982). This phenomenon is particularly concerning in tropical regions, where temperatures are already high (Santamouris, 2014). Urban greenery, which includes parks, gardens, street trees, and other forms of vegetation, has been recognized as an effective strategy to mitigate the urban heat island effect and improve thermal comfort (Bowler *et al.*, 2010; Cao *et al.*, 2010; Kong *et al.*, 2014).

Urban vegetation can reduce air and surface temperatures, increase humidity, and

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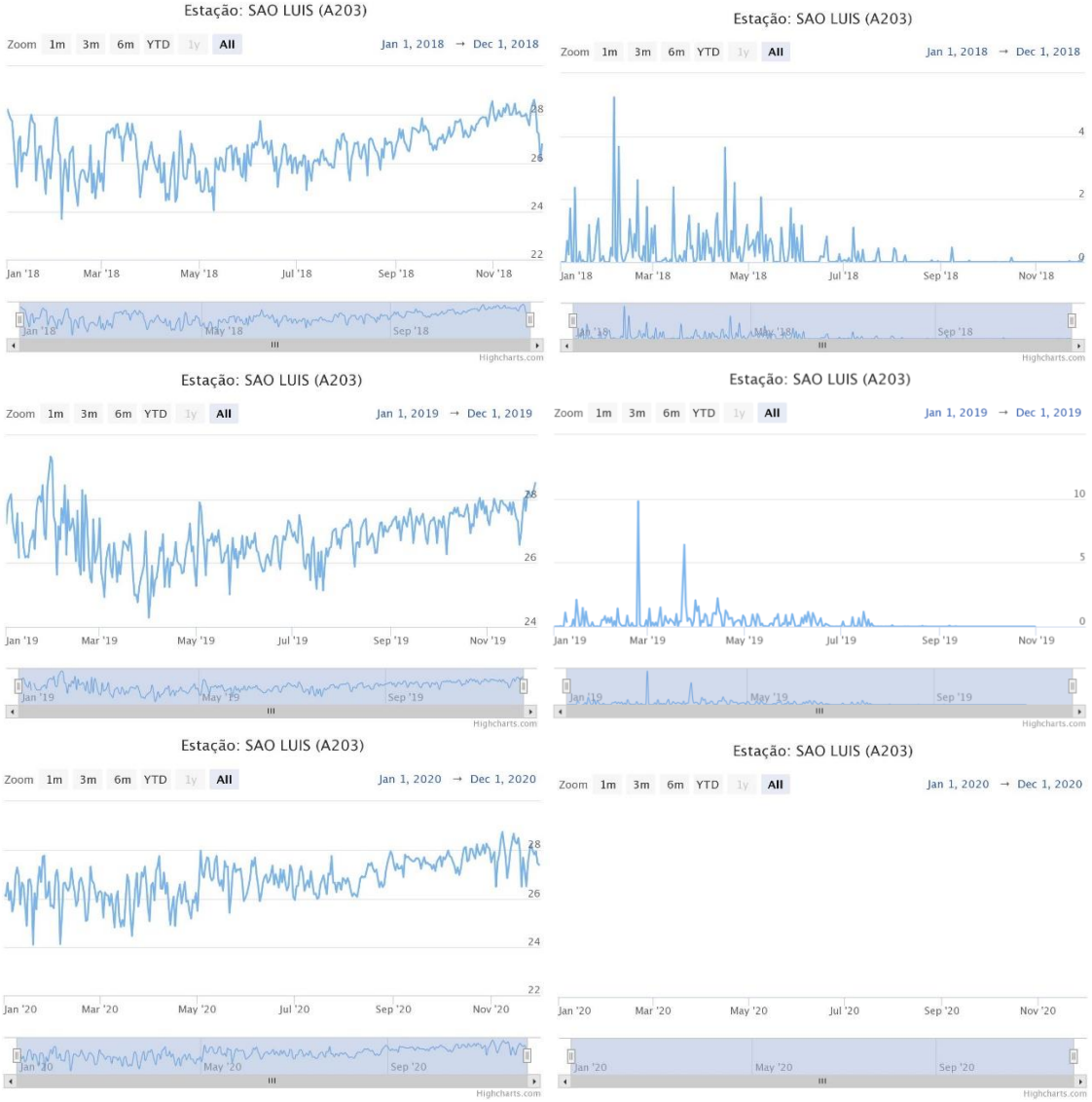
provide shade, all contributing to a cooler and more comfortable urban environment (Chen *et al.*, 2013; Zhang; Murray; Turner II, 2014; Li *et al.*, 2015). Furthermore, studies show that the perception of thermal comfort can be more influenced by non-physical and subjective factors, such as the sight of nature and a peaceful environment, than by actual thermal conditions (Kong *et al.*, 2014; Li *et al.*, 2017).

In this context, the research in São Luís revealed that an increase in urban vegetation can have positive impacts on reducing urban temperature and the thermal comfort of residents (Zhang; Murray; Turner II, 2014). The analysis of climate data from 2018 to 2023 confirmed the relationship between urban vegetation and thermal conditions in the city (Zhang; Murray; Turner II, 2014; Li *et al.*, 2015). Figure 2 shows the temperature and precipitation data collected over five years in São Luís to analyze local climate variations.

Figure 2 - Temperature and Precipitation Data between the years 2018 to 2023 in São Luís, MA, 2023.



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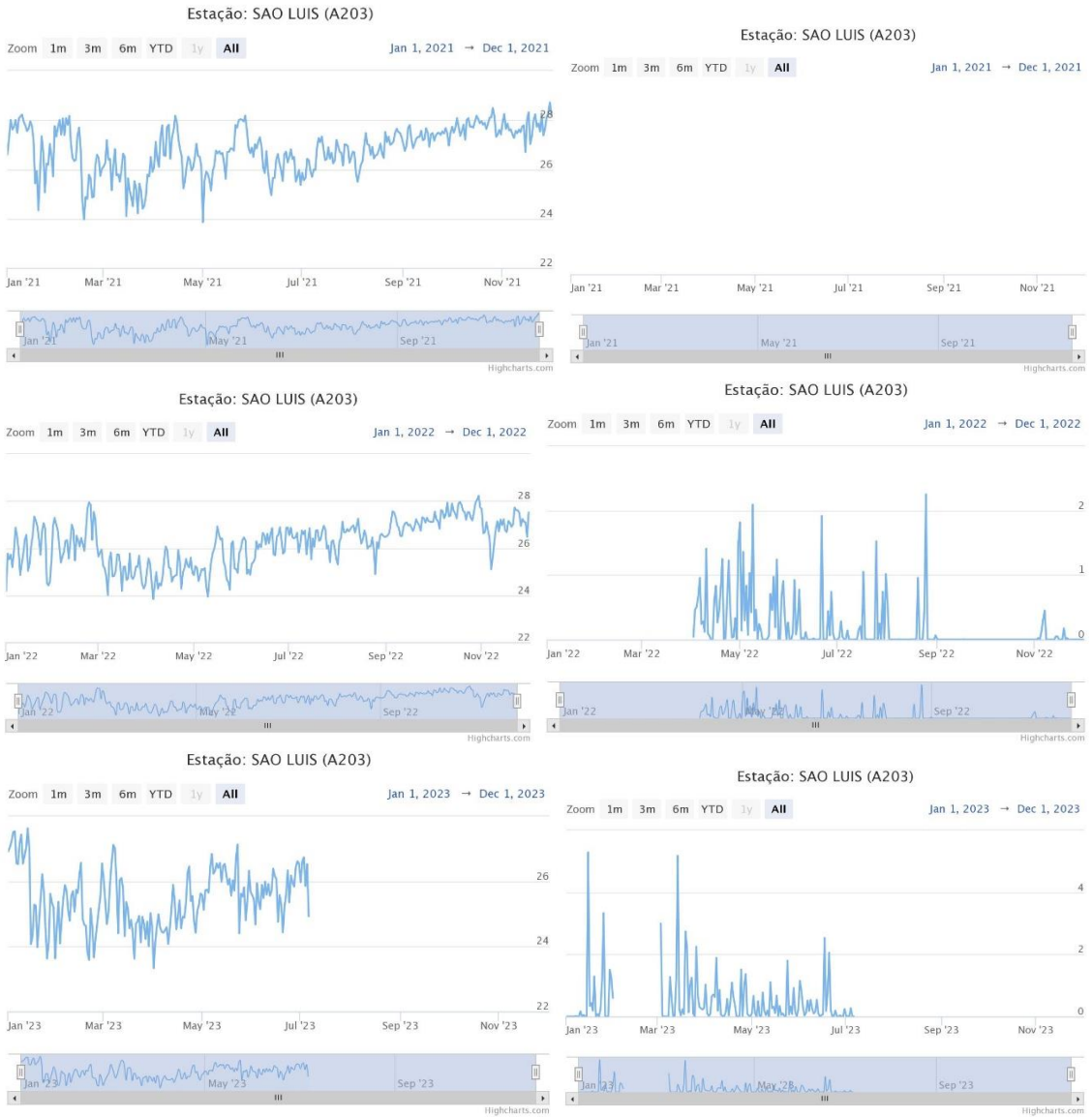

Source: INMET (2023a).

According to the INMET report (2023b), August 2023 in São Luís had below-average precipitation. The conventional weather station recorded only 17.0 millimeters (mm) of rainfall, representing only 76% of the historical average for August, which is 22.5 mm, calculated based on the period from 1991 to 2020. The highest daily rainfall was 6.8 mm, observed on August 4, 2023.

Regarding temperatures, the average minimum and maximum temperatures recorded in August 2023 were 24.6°C and 31.9°C, respectively. The lowest minimum temperature of the month was 23.0°C, observed on August 18, 24, and 25. It's essential to note that, up to that point, the lowest temperature ever recorded in August in the last 34 years was 20.9°C, which occurred on August 5, 2006. On the other hand, the highest maximum temperature reached 32.5°C, observed on August 17, 21, 22, and 29. In the last 34 years, the highest maximum temperature recorded in August was 35.5°C, which occurred in 2012.

However, it is crucial to highlight the influence of the El Niño phenomenon from 2023 to 2024 in the Maranhão region. This will result in low soil moisture levels due to the predicted reduction in rainfall in the Northeast and part of the Northern Region, including areas of Matopiba, which encompasses the states of Maranhão, Tocantins, Piauí, and Bahia (INMET,

2023c).

The El Niño phenomenon has substantial impacts on global vegetation and ecosystems, as documented in various studies. Dai (2013), Moreira *et al.* (2018), Nascimento and Senna (2020), and Aires *et al.* (2023) point out that global warming intensifies drought during El Niño events, increasing the risk of forest fires. Changes in rainfall patterns related to El Niño, as mentioned by Ropelewski and Halpert (1987), Trenberth *et al.* (1998), and McPhaden *et al.* (2006), also affect agriculture, as discussed by Adam *et al.* (1999) and Iizumi and Sakuma (2014). Furthermore, such climate changes can impact the range of various species (Chen *et al.*, 2011; Junk *et al.*, 2020; Lucon, 2022).

Aligned with the meteorological data, the floristic survey revealed the predominance of species that contribute to mitigating the effects of urban heat islands, promoting thermal comfort. In the survey conducted, 19 individuals were identified, including 12 individuals of the species *Licania tomentosa* (Benth.) Fritsch. In the evaluation, of the 19 tree components sampled, 74% were classified as native and 26% as exotic. This area is located near the João Francisco Lisboa Square and the Largo do Carmo in São Luís, Maranhão.

In contrast to these findings, Ramalho *et al.* (2020) observed that Dr. Hélio Rocha Guimarães Square in Almenara, Minas Gerais, had a predominance of exotic species (55.6%) compared to natives (44.4%), a common phenomenon in Brazilian municipalities, as indicated by Martins and Correia (2016). The presence of exotic species can lead to control issues since many of them have a high invasive potential (Hoppen *et al.*, 2014). Thus, it is possible to understand that the invasion of exotic trees can affect the natural functioning of ecosystems, causing changes in ecological processes and economic losses due to their pressure and aggressiveness (Paes, 2016).

Species diversity is crucial in urban tree planning to minimize threats of vegetation loss due to pests (CEMIG, 2011). However, in the studied square, Licania tomentosa was the most prevalent species, representing 55.3% of all trees, which goes against diversity recommendations. The research by Ramalho *et al.* (2020) emphasizes that the square had good tree coverage and good tree health, providing favorable environmental conditions and thermal comfort. Still, it highlights the need for more appropriate planning for the gradual replacement of exotic species with natives.

Considering the size of the trees, 68% were classified as large (over 7m), 21% as medium (2 to 7m), and 11% as small (up to 3m), with most individuals having a height between 7 and 14 meters. The maintenance of the canopies of large trees, including practices like pruning, is essential, although it should be carried out carefully to avoid damage to the plant and its health (CEMIG, 2011). In the mentioned study, only 2% of trees were in decline due to pruning, while the majority underwent light pruning (Ramalho *et al.*, 2020).

In 2023, Santos *et al.* (2021) highlighted the relevance of native species for afforestation and reforestation practices in Peru, especially considering the occurrence of anomalous climate events like El Niño, due to the adaptability of these species to such conditions. Additionally, the floristic survey in São Luís not only revealed the positive influence of urban greenery on the city's thermal comfort but also the imperative need for additional research to fully unravel the composition of local urban vegetation and its potential use in mitigating the effects of urban heat islands.

In a related context, La Barrera *et al.* (2019) explored the relationship between urbanization and vegetation in the Metropolitan Area of Santiago, focusing on ecosystem

services provided by El Panul, a biodiverse peripheral area. By quantifying ecosystem services, the study allows us to understand how urban green areas can be impacted by climatic variables and how they, in turn, can mitigate certain climatic impacts in urban areas.

Furthermore, the integration of urban greenery through urban and landscape planning strategies, including the preservation of mature trees and the adoption of alternative mobility strategies (Kong *et al.*, 2014), presents a significant challenge, especially from the perspective of climate change (Jim; Chen, 2003). The research in São Luís, although valuable for its quantitative and qualitative approach and the use of climate data over a five-year period, has limited applicability due to its narrow geographical focus, suggesting that future investigations may expand their scope to other tropical cities and explore specific strategies for integrating urban vegetation, simultaneously evaluating their effectiveness in promoting thermal comfort.

4 Conclusion

Finally, it is worth noting that the constant and accelerated process of urbanization, especially in large urban centers, has triggered numerous challenges in maintaining human well-being, and, at the same time, there is growing societal concern about the quality of life for the current generation and future generations. Within this context, it is also essential to consider the constant changes in global climate patterns, such as the occurrence of phenomena like El Niño, which is directly related to temperature increases. During El Niño events, some regions may experience higher temperatures due to the warming of the surface of the Equatorial Pacific Ocean, leading to changes in precipitation patterns, impacts on public health, and consequently exacerbating urban heat islands.

On the other hand, it has been scientifically proven that green environments within urban spaces bring different sensations of comfort. Considering the data presented in this study, there is a clear need for further research focused on the planning and integration of urban greenery, as well as monitoring and maintenance, taking into account the understanding of interactions generated by changes in climate patterns as a tool for urban planning. This aims to meet the demands of large urban centers, contribute to the reduction of urban heat islands, and ultimately improve the quality of life in these areas.

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