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OS MAPAS CLIMÁTICOS URBANOS DE RECOMENDAÇÕES (UC-REMAP) NO BRASIL

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ABSTRACT

Climate change represents a significant issue for most countries. For actions to combat changes in a specific place, it is necessary to know which scientific studies are underway. This paper presents a survey of scientific research on developing climatic maps in Brazil, based on German methodology. National works published in Portuguese and English were used. The objective is to identify areas of the country with scientific production on this subject, verify the progress of methodological adaptations and highlight their importance for regional development. This review creates a bibliographic collection to identify climate initiatives in different regions of the country. The proposal seeks to include studies on the use of Brazilian climatic analysis maps (UC-AnMap) and urban climatic maps (UC-Map). It also aims to incorporate relevant recommendations through research in scientific databases and systematic literature review. As a result, 19 maps were found, nine in the Northeast, eight in the Southeast, one in the North, and one in the Midwest part of Brazil. Of this total, 13 maps are located in ten capitals: São Paulo, Salvador, Natal, Maceió, João Pessoa, Belo Horizonte, Fortaleza, Manaus, Vitória, and Recife. Despite the increasing number of studies on urban climate in Brazil in recent years, and some municipalities having financial resources for their development, conducting studies to create climatic maps is still rare in the country. There are no references to the use of urban climatic maps for decision-making by municipal public administration in the cities mentioned in this paper.

Keywords: Urban climate. Urban climatic maps. Urban planning.

RESUMO

As mudanças climáticas representam assunto relevante para a maioria dos países. Para que haja ações de combate às alterações em determinado local, é necessário saber quais trabalhos científicos estão em andamento. Este artigo apresenta um levantamento de pesquisas científicas sobre o desenvolvimento de mapas climáticos no Brasil, baseados em metodologia alemã. Foram utilizados trabalhos nacionais, publicados em português e inglês. O objetivo é identificar áreas do país que possuem produção científica a cerca desta temática, verificando o andamento de adaptações da metodologia e evidenciar sua importância para o desenvolvimento regional. Esta revisão cria um acervo bibliográfico para identificar iniciativas climáticas em diferentes regiões do país. A proposta busca incluir estudos sobre a utilização de mapas climáticos analíticos (UC-AnMap) e mapas climáticos urbanos (UC-Map) brasileiros. Buscou-se, também, contemplar as respectivas recomendações através da pesquisa em bancos de dados científicos e revisão sistemática da literatura. Como resultado, foram encontrados 19 mapas, sendo nove no Nordeste, oito no Sudeste, um no Norte e um no Centro-Oeste. Deste total, 13 mapas se encontram em dez capitais: São Paulo, Salvador, Natal, Maceió, João Pessoa, Belo Horizonte, Fortaleza, Manaus, Vitória e Recife. Apesar de o número de estudos sobre clima urbano estar aumentando no Brasil nos últimos anos e de alguns municípios possuírem recursos financeiros sua elaboração, a realização de estudos para criação de mapa climático, ainda é rara no país. Não existem referências sobre o uso de mapas climáticos urbanos para a tomada de decisão pela administração pública municipal nas cidades citadas neste artigo.

Palavras-chave: Clima urbano. Mapas climáticos urbanos. Planejamento urbano.

INTRODUCTION

Urban climate can be defined as local climate variations caused by urbanization (Vieira, 2020). The process of urban occupation and population growth in city centers disrupts the natural configuration of a region, leading to heat concentration. This results from the modification of the natural environment, various anthropogenic activities, and increased circulation of people. Cities, in addition to producing distinct climates in urbanized areas, also impact regional climates and extreme events beyond their physical boundaries, exacerbating the effects of heatwaves and causing changes in the water cycle, for example, whose effects extend to regional spatial scales (Nazarian et al., 2024).

The increase in population density in large cities compromises heat dissipation through natural ventilation, negatively affecting the distribution of temperature and worsening levels of human comfort and urban environmental quality. Dorigon and Amorim (2019) highlight other factors, such as population

density, vegetation, building layout, and socioeconomic aspects, as directly responsible for the complexity of the system that constitutes the urban climate. Thermal, humidity, and heat island studies often analyze typical urban climate phenomena, as they are related to events that contribute to temperature increases at specific points in the city (Gartland, 2010).

According to Lucena and Peres (2017), the evolution of urban climate analysis methods has improved using meteorological station data, remote sensing techniques, and climate models. The development of measurement technologies and the growing demand for data on climate conditions have allowed the improvement of methodologies applicable to each region. Therefore, Ferreira (2014) showed that the concept of the "Climatic Urban Map" (UC-Map), introduced by Knoch (1951), integrates knowledge about urban climate with geographical factors to contribute to urban planning. This concept emerged from the proposal to relate climatic knowledge on a map with surface and land use data.

Souza (2010) notes that among the several locations where the UC-Map has been adapted over the years, Germany has established itself as a reference in the field due to public administration support with the creation of specific legislation. Several climate studies conducted between the 1970s and 1990s were considered in the country's urban and environmental planning (Ng; Ren, 2015).

The German UC-Map methodology was originated from the demand for managing rapid population growth, occupation of urban areas, and also due to the negative impact on the environment and air quality that urban areas were presenting. According to Ren, Ng, and Katzschner (2011), over fifteen countries began using thematic maps developed from planning studies to reduce the impact caused by urban occupation and assist public administrators in decision-making. In the Americas, the cities of Vancouver and Buenos Aires stood out as pioneers in such implementation. The climatic map methodology was also employed in various cities in Asian countries, such as China, Japan, Vietnam, Singapore, and in European cities located in Switzerland, Spain, and the Netherlands (Ng; Ren, 2015). Furthermore, it has been integrated with other techniques to advance the development of climate recommendations for the urban context, as was the case in a recent study in Toulouse, France (Yin et al., 2024)

According to Ren, Ng, and Katzschner (2011), the urban climatic map system, presented as UC-Map, consists of two main steps. The first involves the development of an analytical climatic map (UC-AnMap) of the reference area, based on collected information about climatic elements (temperature, humidity,

wind speed, precipitation, air pollution), geographic elements (topography, vegetation), and physical elements (land use, building data) of the region. Based on this information, areas with homogeneous climate characteristics are defined and categorized as climatopes. Each climatope is defined according to the surface energy balance analysis of its area, considering all the mentioned elements of the study area. The analyzed energy balance can be positive or negative and considers characteristics such as intensity, direction, and wind patterns, referred to as dynamic potential in the maps, and heat support and dissipation capacity, referred to as thermal load. The second stage in the development of the UC-Map involves creating the recommendation map (UC-ReMap). In this stage, planning guidelines and instructions are developed to respond to local demands and mitigate the negative impacts caused by urban climate.

Urban climatic maps can be considered important tools for regional planning and development, offering a detailed view of local climate conditions and their variations within urban areas. According to Oliveira, Santos, and Fisch (2024), each region of the country has specific characteristics that require general guidelines to be adapted to local demands. Regional development is based on interdisciplinarity regarding relevant research topics and the dissemination of climate knowledge. Thus, studying the location and local impact of Brazilian climatic maps using the UC-Map methodology can contribute to the development of policies aimed at efficient land management and sustainability.

METHODOLOGY

The aim of this study was to gather existing information on the number of Urban Climatic Maps developed in Brazil and their alignment with the UC-Map methodology, due to the lack of comprehensive data on this subject. The goal was to assess the degree of fidelity of Brazilian works to the original model, highlight the main Brazilian contributions to adapting the methodology to local realities, and quantify research across each region of the country. The approach involved comparing the German proposal presented by Katzschner (1997) with its application in Brazil, starting with a pioneering study conducted in the city of Salvador (BA), and examining subsequent maps developed in the country.

After identifying the research gap, the first step in defining the theoretical framework of the research was to conduct a bibliographic review on urban climatic maps. This investigation was carried out through a systematic literature review, as the authors were interested in determining the number of

studies related to the topic. The limited number of references on Brazilian maps facilitated the organization and application of the research. Listing the items along with their geographic locations was sufficient to relate the collected data to the expected research outcomes.

Identifying the analysis phases and recommendations in each map determines whether the German methodology was implemented as originally designed or if adaptations were made. The methodology may start with the analytical map without recommendations linked to it or include climate recommendations without analyzing all map layers from the original model.

SELECTION OF BIBLIOGRAPHIC PORTFOLIO

The systematic literature review was conducted according to the article selection guidelines presented by Azevedo et al. (2013) and Azevedo, Ensselin, and Jungles (2014). The research aimed to ensure academic validity and efficiency by selecting a relevant database for the work's development. The first step involved defining the research question. The increasing number of climatic maps studied in the country in recent years and the methodology used contributed to determining the research theme. Surveying the number of climatic maps developed in the country, their geographic locations, and their similarity to international works helped identify patterns in national studies, which in turn defined the study focus and research keywords.

Two main axes were established for selecting the bibliography from the database: existing climatic maps in the country and the main objectives behind their development. Keywords were combined for analysis in publication titles and abstracts. The first axis, focusing on the research topic, included "urban climate" and "UC-Map", while the second axis considered "UC-Map" and "urban climatic recommendation map."

The website of the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES) was used to search for databases by area of knowledge. Due to the interdisciplinary nature of the review, no specific areas and sub-areas were selected; however, priority was given to works related to Architecture and Urbanism and Civil Engineering. Consequently, all publications meeting the research criteria were considered. The analysis covered the period between 2012 and 2022 (10 years).

Initially, 124 articles were selected, forming the research universe. The relevance of each article for the systematic review was assessed based on CAPES database results. Due to the limited number of relevant results, additional research was conducted using Google Scholar. Initially, only climatic maps developed in Brazil and published in Portuguese were included in the CAPES database analysis. Later, due to a scarcity of useful references, the search was expanded to include works published in Portuguese and English from 2000 to 2022, involving map development in Brazilian cities. Once relevant articles were identified, no further searches were required. In the end, 179 articles related to climate studies and the development of climatic maps were selected.

The refinement criterion used after database searches was analyzing the alignment of titles with the research field. Articles not fitting the study's focus were discarded, reducing the bibliographic set to 117 articles. The scientific recognition of the articles was then assessed on Google Scholar by checking citation counts to determine relevance. The abstracts of the remaining 96 most-cited articles were analyzed for alignment with the research focus. After this analysis, 19 articles were deemed suitable based on theme, title, and abstract. Urban climate studies were present in 53 articles, of which 24 were outside the research scope and were discarded. Impact factors were not considered for exclusion criteria due to limited number of citations available after filtering.

After finalizing the bibliography, the maps were individually reviewed to determine adherence to the German methodology. The focus was solely on whether Brazilian maps contributed to urban planning, as motivations for map development may vary by country. Finally, the maps' locations within the country's territory were examined to understand the current application of the methodology.

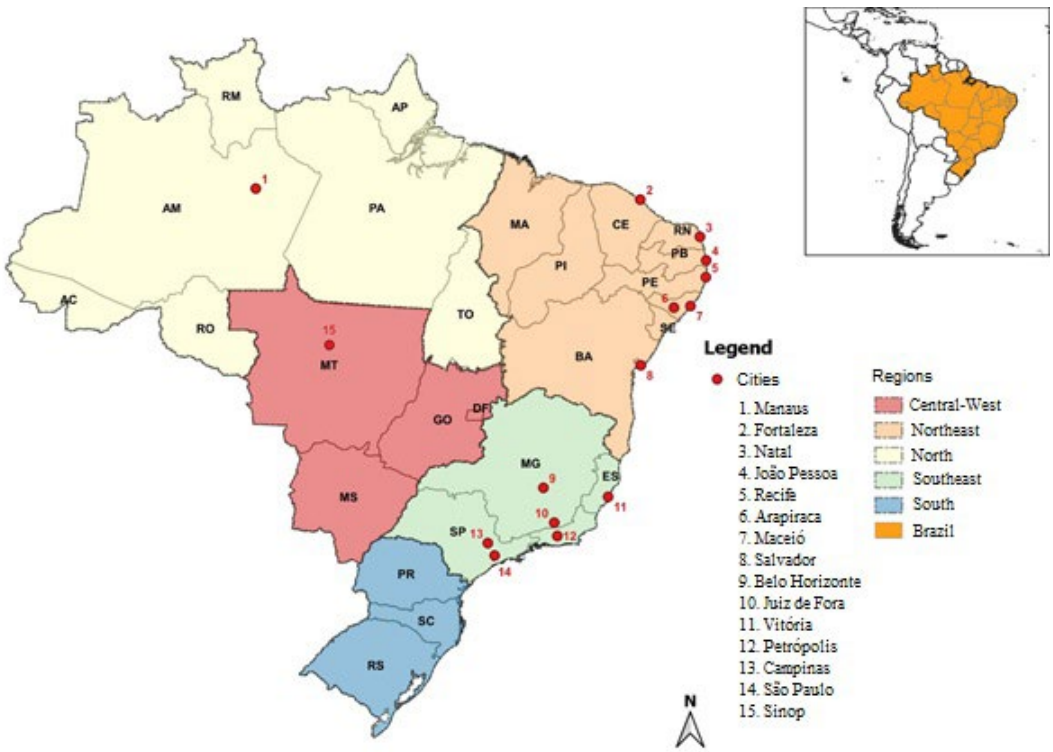
RESULTS

Despite the growing concern among researchers about developing climatic maps for Brazilian municipalities, most works in the country, as addressed in this paper, do not include the development of recommendation climatic maps in their original proposals. The complexity of the topic and the difficulties encountered during map design, combined with the nature of each study, often limit the research to theoretical functionalities within the academic sphere, halting progress before recommendations for urban planning can be proposed for public administration.

According to Kern and Aber (2008), local governments have become key actors in the area of climate change policy over recent decades. During this period, several cities worldwide have developed various strategies and action plans. Nowadays, both mitigation and adaptation actions are found on local political agendas. Climatic maps are essential tools for integrating data on local and regional climate variations into public policies for sustainable development. When associated with public policies, they can significantly contribute to regional development by informing strategic decisions in areas such as urban planning, natural resource management, and climate change mitigation.

There are 19 urban climatic maps in Brazil, with 16 using the UC-Map methodology, distributed across 15 cities (see Figure 1). The cities of Salvador and João Pessoa have updated climatic maps based on previous studies, and the city of Juiz de Fora, Minas Gerais, has two maps. The Northeast region has the highest number of urban climatic maps, with a total of nine works. The Southeast region has six maps, while the North and Midwest regions have only one each. It was also noted that four urban climatic maps were developed in the country over the past two years, indicating a significant increase since 2006.

Figure 1 | Location of Urban Climatic Maps in Brazil



Source: Prepared by the authors.

DISCUSSION

From a local perspective, Monteiro (1976) states that the climate of a city is complex and can be considered a comprehensive system with various implications for the space it encompasses, as well as for the urbanization of the area. Monteiro's work was a key reference for urban climate studies in Brazil until the early 2000s. Lima, Pinheiro, and Mendonça (2012) found that from 1990 to 2000, there were 137 theses and dissertations related to urban climate in Brazil, and from 2001 to 2010, there were 130 completed works. According to the Thesis and Dissertation Catalog of the Coordination for the Improvement of Higher Education Personnel (CAPES), from 2011 to 2021, the number of theses and dissertations related to urban climate increased to 282, indicating a significant rise in interest over the past decades (CAPES, 2022). This increase may be related to the growing social demand for studies involving urban climatic maps.

Dechezleprêtre et al. (2022) explain that the three main factors influencing support for climate public policies and investment in science are the population's perceived efficacy in reducing emissions, its impact on low-income families, and its effect on the families of decision-makers. Social expectations for improving quality of life in response to climate impacts are directly related to decision-makers' interests in implementing public policies.

Considering that the development of urban climatic maps depends on the collection of climatic and geographical data (Ren; Ng; Katzschner, 2011), there is a trend toward creating increasingly comprehensive maps integrated with other methodologies applicable to the urban scale (Yin et al., 2024). Campos and Danelichen (2021) note that remote sensing has proven to be a promising practice for understanding urban microclimates. In Brazil, this technique was first used in the 1980s for heat island analysis in São Paulo (Lombardo, 1985). Campos and Danelichen (2021) also show that countries such as Israel, China, the Netherlands, Japan, Taiwan, Indonesia, Italy, and Spain study air temperature and humidity through remote sensing for climate analysis.

However, the trend to integrating technology with climate research requires a long period of study. According to Santos (2021), the use of the UC-Map methodology is still rare in Brazil, though it is increasingly discussed among scientists. Santos compiled key works on the technique and compared them based on research objectives and study nature, highlighting relevant articles,

dissertations, and theses for the methodology's development. Most Brazilian urban climatic maps are found in large cities or state capitals, particularly in regions with research groups focused on the German methodology.

The Brazilian urban climatic maps discussed in this article are based on the German methodology of overlaying climatic and spatial information to develop planning guidelines, with the exceptions of the works by Tarifa and Armani (2000), Sanches (2015), and Rocha and Barbosa (2016). Among these, only the climatic maps of Sinop (MT) (Sanches, 2015), Arapiraca (AL) (Rocha; Barbosa, 2016), Recife (PE) (Freitas et al., 2021), Petrópolis (RJ) (Fernandes, 2021) and Belo Horizonte (Ferreira; Assis; Katzschner, 2017; Damas, 2023) include a recommendation map (UC-ReMap) combined with an analytical map (UC-AnMap). However, only the maps from Recife, Petrópolis and Belo Horizonte are directly related to the German methodology.

The climate recommendation maps of Sinop (MT) (Sanches, 2015) and Arapiraca (AL) (Rocha; Barbosa, 2016) were not considered derived from the UC-Map methodology in this article. Sanches' work is a thesis, and Rocha and Barbosa's work does not explicitly reference the UC-Map methodology. Nevertheless, both works suggest urban planning improvement guidelines. Sinop has its methodology for obtaining climate recommendations to enhance urban planning, identifying key issues faced by public administration, and relating them to municipal planning instruments for adaptation. Arapiraca's map, while not explicitly mentioning the UC-Map methodology, uses it as a basis through derivative works. It includes a recommendation map providing guidelines for eight climate classes with suggestions for preserving, maintaining, or improving conditions in response to urban growth, similar to the Recife and Petrópolis maps (Rocha; Barbosa, 2016; Sanches, 2015).

According to Souza (2010), São Paulo was the first city in Brazil to use climatic mapping to assist public administration. Analytical work began in 1999 as part of the Atlas Ambiental project for São Paulo - Phase 1. Tarifa and Armani (2000) analyzed São Paulo's urban climate using cartographic data, altitude, wind direction, distance from the Atlantic Ocean, and topography to create a document consolidating this information. The Urban Climate Units map categorized the city into four regions, considering urban controls and climatic attributes for structuring each area.

Nery et al. (2006) and Araújo and Caram (2006) showed qualitative climate analysis maps of the city of Salvador (BA) and the Ribeira neighborhood in Natal (RN), respectively, aiming to determine thermal comfort due to heat islands and unfavorable climatic areas. Melo (2009) and Barbosa and Rocha (2016) developed climatic maps for Maceió (AL) and Arapiraca (AL) to contribute to urban planning in these cities. Souza (2010) created the climatic map for João Pessoa (PB), and Ribeiro (2013) updated it with land use and building information. Ferreira (2014) analyzed the thermal behavior of Juiz de Fora's central area (MG). Prata-Shimomura, Lopes and Correia (2015) focused on urban ventilation when creating the climatic map for Campinas (SP). The analytical map of Belo Horizonte (MG) was created by Ferreira, Assis, and Katzschner (2017), and was used for the creation of the climate recommendations map (UC-ReMap) conducted by Damas (2023) for the city. Lima Júnior (2018) developed the climatic map for Fortaleza (CE) (Santos, 2021).

Several other Brazilian cities have developed climatic maps using the German methodology to contribute to urban planning. Benedetto (2019) analyzed Manaus (AM) using the city's climate units and applied the topoclimate scale to overlay maps, obtaining results on land use, surface temperature, population density, and climatological data based on the UC-Map methodology. Ferreira, Pimentel, and Vianna (2019) created a second map for Juiz de Fora to identify existing thermal fields. Freitas et al. (2021) adapted the climatope classification to map urban microclimates in Recife (PE) and proposed actions to improve urban thermal comfort and environmental management. Santos (2021) mapped the microclimatic scale of the Jardim Camburi neighborhood in Vitória (ES) to enhance thermal conditions. Fernandes (2021) created a climatic map for Petrópolis (RJ) based on socio-environmental variables influencing the urban environment. Moura et al. (2022) continued climate studies in Salvador (BA) with an analytical climatic map based on the German methodology using the Land Occupation Patterns Map.

Given the predominance of climatic maps in the Northeast, Southeast, North, and Midwest regions, and considering the potential connection between climatic mapping and other urban climate studies in Brazil, it is observed that remote sensing for urban climate studies has expanded in these regions in recent years. This may be suggested by the fact that remote sensing studies have been conducted in areas near climatic maps, as seen in Juiz de Fora (MG) (Borges; Zaidan;

Martins, 2009), Goiânia (GO) (Nascimento; Oliveira, 2011), Recife (PE) (Moreira, 2014), Manaus (AM) (Correa, 2016), Rio de Janeiro (RJ) (Lucena; Peres, 2017), Vitória (ES) (Barboza; Neto; Caiana, 2020), and Eusébio (CE) (Castro et al., 2021). No references were found regarding the presence or ongoing development of urban climatic maps in the Southern region.

The cities of Recife (PE) (Freitas et al., 2021) and Petrópolis (RJ) (Fernandes, 2021) have recommendation maps based on the UC-Map methodology, and they are similar in how recommendations are suggested. The Recife map features eight urban climate classes derived from an environmental unit map and proposes specific recommendations for each class according to their impacts on the urban environment. Recommendations include protection, preservation, maintenance, or incorporation of areas and natural resources, and promoting studies for adapting public spaces (Freitas et al., 2021). The Petrópolis map's recommendations are based on eight climatopos associated with urban climate classes. Each climatope has assigned levels of climate sensitivity, physical characteristics, and strategies for finalizing recommendations, alternating between preservation, maintenance, control, or mitigation according to natural characteristics (Fernandes, 2021).

One of the main challenges in implementing the UC-Map methodology in Brazil is its lack of integration with public policies. Despite academic efforts to develop climatic maps in cities like São Paulo, Salvador, and Belo Horizonte, these data are not incorporated into urban management and land use planning decisions. According to Alcoforado et al. (2009) and Monteiro (2013), the reasons include insufficient or non-continuous investment in applied research, technical difficulties in translating climatic maps for urban planners, and a gap between technical data and practical implementation, with public administrators being unfamiliar with these tools. No references were found on the use of Brazilian climatic maps based on the UC-Map methodology for public policy development in urban planning at any level of government. Table 1 provides a summary of Brazilian climatic maps and their implementation status by responsible management.

Table 1 | Implementation of Brazilian UC-Maps by Local Public Administration

Urban Climatic Maps in Brazil					
Year	**References**	**City/State**	**Coverage**	**Map**	**Implementation**
2000	Tarifa and Armani	São Paulo/São Paulo	City	-	-
2006	Nery *et al.*	Salvador/Bahia	City	UC-AnMap	NO
2006	Araújo and Caram	Natal/Rio Grande do Norte	Ribeira neighborhood	UC-AnMap	NO
2009	Melo	Maceió/Alagoas	City	UC-AnMap	NO
2010	Souza	João Pessoa/Paraíba	City	UC-AnMap	NO
2013	Ribeiro	João Pessoa/Paraíba (atualização)	City	UC-AnMap	NO
2014	Ferreira	Juiz de Fora/Minas Gerais	Downtown area	UC-AnMap	NO
2015	Prata-Shimomura, Lopes and Correia	Campinas/São Paulo	City	UC-AnMap	NO
2015	Sanches	Sinop/Mato Grosso	City	-	-
2016	Rocha and Barbosa	Arapiraca/Alagoas	City	-	-
2017	Ferreira, Assis and Katzschner	Belo Horizonte/Minas Gerais	City	UC-AnMap	NO
2018	Lima Júnior	Fortaleza/Ceará	City	UC-AnMap	NO
2019	Ferreira, Pimentel and Vianna	Juiz de Fora/Minas Gerais	City	UC-AnMap	NO
2019	Benedetto	Manaus/Amazonas	City	UC-AnMap	NO
2021	Freitas *et al.*	Recife/Pernambuco	Boa Vista and Soledade neighborhoods	UC-Map	NO
2021	Santos	Vitória/Espírito Santo	Jardim Camburi neighborhood	UC-AnMap	NO
2021	Fernandes	Petrópolis/Rio de Janeiro	City	UC-Map	NO
2022	Moura *et al.*	Salvador/Bahia (continuation)	City	UC-AnMap	NO
2023	Damas	Belo Horizonte/Minas Gerais	City	UC-ReMap	NO

Source: Prepared by the authors.

CONCLUSION

Brazilian scientific production is increasingly recognizing the importance of climate in developing policies and adapting land use in urban centers. However, the application of climatic map methodology in the country remains limited, often confined to academic studies, with little evidence of its integration into projects, urban plans, or practical applications in the cities where these studies were conducted.

Urban climate analysis has become crucial for urban planning and human comfort. Therefore, it is essential to explore alternatives that enhance spatial organization, prioritize the common good, and improve overall quality of life. In recent decades, the development of urban climate studies in Brazil has grown, with an increasing trend of research extending beyond national capitals.

Urban climatic maps based on the UC-Map methodology have emerged due to concerns for environmental quality and in response to the rising number of studies on climate and urban comfort. Although this article reviews 19 maps, of which 16 are based on the UC-Map methodology, only the cities of Recife (PE), Petrópolis (RJ) and Belo Horizonte (MG) have developed recommendation maps linked to their analytical climatic maps. Therefore, it is crucial to invest in the implementation of these studies across the country, so existing research can be fully realized, and additional municipalities can benefit from the advantages of this methodology.

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