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Challenges of Climate Change Adaptation in Brazilian Municipalities: A Systematic Literature Review

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Desafios da Adaptação às Mudanças Climáticas nos Municípios Brasileiros: Uma Revisão Sistemática de Literatura

RESUMO

Objetivo – Identificar desafios dos municípios brasileiros na implementação de ações de adaptação climática.

Metodologia – Revisão sistemática de 77 artigos (2014-2024) nas bases ScienceDirect, Scopus e Web of Science.

Originalidade/relevância – Preenche lacuna sobre implementação de políticas municipais de adaptação climática no Brasil.

Resultados – Dos 77 artigos analisados, envolvendo 309 pesquisadores, predominam estudos de caso (39%) e métodos quantitativos, concentrados em São Paulo e Rio de Janeiro, evidenciando desafios na integração entre políticas urbanas e climáticas.

Contribuições teóricas/metodológicas – Revela fragmentação científica e concentração regional da pesquisa.

Contribuições sociais e ambientais – Demonstra desconexão entre políticas públicas e demandas locais. Indica fragilidade na governança climática municipal e necessidade de superar desigualdades regionais técnico-financeiras.

PALAVRAS-CHAVE: Mudanças climáticas. Governança climática. Resiliência urbana.

Challenges of Climate Change Adaptation in Brazilian Municipalities: A Systematic Literature Review

ABSTRACT

Objective – To identify the challenges faced by Brazilian municipalities in the implementation of climate adaptation actions.

Methodology – Systematic review of 77 articles (2014–2024) from the databases ScienceDirect, Scopus and Web of Science.

Originality/relevance – Fills a gap regarding the implementation of municipal climate adaptation policies in Brazil.

Results – Among the 77 articles analysed, involving 309 researchers, case studies (39%) and quantitative methods prevail, with a focus on São Paulo and Rio de Janeiro, highlighting challenges in integrating urban and climate policies.

Theoretical/methodological contributions – Reveals scientific fragmentation and regional concentration of research.

Social and environmental contributions – Demonstrates a disconnect between public policies and local demands. Indicates weaknesses in municipal climate governance and the need to overcome regional technical and financial inequalities.

KEYWORDS: Climate change. Climate governance. Urban resilience.

Desafíos de la Adaptación al Cambio Climático en los Municipios Brasileños: Una Revisión Sistemática de la Literatura Article title in Spanish

RESUMEN

Objetivo – Identificar los desafíos que enfrentan los municipios brasileños en la implementación de acciones de adaptación climática.

Metodología – Revisión sistemática de 77 artículos (2014-2024) en las bases ScienceDirect, Scopus y Web of Science.

Originalidad/relevancia – Llena una brecha respecto a la implementación de políticas municipales de adaptación climática en Brasil.

Resultados – De los 77 artículos analizados, que involucraron a 309 investigadores, predominan los estudios de caso (39%) y los métodos cuantitativos, concentrados en São Paulo y Río de Janeiro, poniendo en evidencia los desafíos para integrar las políticas urbanas y climáticas.

Contribuciones teóricas/metodológicas – Revela la fragmentación científica y la concentración regional de la investigación.

Contribuciones sociales y ambientales – Demuestra la desconexión entre las políticas públicas y las demandas locales. Indica la fragilidad de la gobernanza climática municipal y la necesidad de superar desigualdades técnicas y financieras regionales.

PALABRAS CLAVE: Cambio climático. Gobernanza climática. Resiliencia urbana.

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1 INTRODUCTION

Climate change is a global challenge that represents serious threats, making it crucial for the municipalities to implement urban planning that incorporates mitigation and resilience measures for this changing reality. A complex interaction between socio-economic, environmental and political factors influences urban vulnerability to the impact of extreme weather events, especially in Brazil where many urban areas are characterized by inadequate habitation and infrastructure, increasing their risk of exposure.

The Brazilian federal government allocated an average of only 0.11% of national gross domestic product and 0.26% of the total annual expenditure to the environmental sector between 2001 and 2022 - low rates compared to other Latin American countries (Viana et al., 2020; Viana, 2024). These numbers demonstrate the low budget priority given to environmental policies. Additionally, the recent disasters, such as those faced by the states of Rio Grande do Sul and Espírito Santo - which left behind thousands of people displaced and cities entirely submerged - reinforce the urgent need for Brazil to increase its investments in the prevention of and adaptation to climate change.

Developing countries' quick urban expansion, determined by political and economic dynamics, has led to the establishment of informal settlements, in which access to the most basic services - such as water, sewage and electricity - is often inadequate (Mesquita; Almeida, 2024; Bezerra; Bobyleva; Mello, 2025). These settlements, in which around a third of the world's population resides - approximately 850 million people - are particularly vulnerable due to their location in sensitive ecological areas (Vasconcelos, 2024). As a result, they are especially susceptible to the impacts of extreme weather events, such as floods, landslides and heat waves (Rogers, 1997; James, 2023; Dodman et al., 2023).

In Brazilian cities, the climate change adaptation agenda is still in its infancy. In 2021, just seven - Salvador (BA), São Paulo (SP), Rio de Janeiro (RJ), Curitiba (PR), Fortaleza (CE), Belo Horizonte (MG) and Recife (PE) - of the 27 state capitals, presented climate change action plans (Barbi; Rei, 2021; Espíndola; Ribeiro, 2020). All of these municipalities also have local climate committees and are part of at least one of the main transnational networks of municipalities (TMN), which are essential for this issue to be placed on the local political agenda and strengthening climate governance in local governments (Barbi; Rei, 2021). By 2024, this number had risen to 12, including the municipalities of Teresina (Pi), João Pessoa (PB), Brasília (DF), Florianópolis (SC) and Rio Branco (AC) (IJSN, 2024).

In this scenario, little articulation is observed between municipal master plans and climate action plans, when existing, revealing problems in the implementation of adaptive measures (Espíndola; Ribeiro, 2020; Carvalho et al., 2020). Masiero, Menegaldo and Tavares (2023) and Marques et al. (2023) have identified, respectively, discrepancies between proposals and the actual implementation of measures to mitigate the impacts of climate change, as well as gaps in master plans that require the creation of specific plans for climate action - even if they contain environmental guidelines. Furthermore, the governments have adopted a reactionary stance in the face of these challenges (Teixeira; Pessoa, 2021), neglecting long-term planning and the effective incorporation of climate concerns.

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In the light of the aforementioned, the aim of this article is to provide, based on a systematic literature review and bibliometric analysis, an overview of the challenges faced by Brazilian municipalities in the implementation of actions for climate change adaptation.

2 METHODOLOGY

A qualitative and quantitative theoretical study was conducted using a systematic literature review (SLR). SLRs use explicit methods to analyze primary studies in to address clearly formulated research queries (Neves *et al.*, 2017; Galvão; Ricarte, 2019). For this study, a method was adopted based on the proposal by Dresch, Lacerda e Antunes (2015), correlating it to the approaches used by some researchers to conduct SLR (Bavaresco *et al.*, 2021; Nico-Rodrigues; Bussolotti, 2020; Pellegrini *et al.*, 2023; Salvalaio *et al.*, 2023; Lucarelli; Oliveira; Carlo, 2023).

An RSL characterization must be pragmatic and precise, differing from a narrative review due to its objective approach (Dresche; Lacerda; Antunes, 2015). It involves stages such as a set protocol, definition of inclusion and exclusion criteria, and data extraction (Junior; Oliveira; Zorzal, 2021). Its aim is to highlight the state of the art by examining general principles at a conceptual level of abstraction (Lopes; Silva, 2019). In addition, the RSL must be coherent in order to provide a critical reading of a specific topic, and thus identify gaps related to on the issue in question (Neves *et al.*, 2017).

Morandi e Camargo (2015) have proposed a protocol for developing SLR. It defines the context, theoretical field, problem, type, eligibility criteria, databases and research horizon based on a main theme. Following this approach, adaptation practices in Brazilian cities were investigated in the context of climate change, with the aim of establishing a state of the art in the country's climate governance. To achieve this, a ten-year horizon was defined for the collection of papers in the ScienceDirect, Scopus and Web of Science databases, restricting itself to cases applied to urban areas in Brazil.

Board 1 - Protocol applied to RSL adopted in this research based on the structure suggested by Morandi and Camargo (2015).

Main theme	Adaptation and resilience of Brazilian cities to the climate change
Context	In Brazil, the climate change adaptation agenda is recent. The action plans are limited to few metropolitan area.
Problem	How the climatic governance can be properly implemented towards the resilience of Brazilian cities to the climate change?
Databases	ScienceDirect; Scopus; Web of Science
Theoretical field	Urban planning; Climate governance
Horizon	2014-2024
Adherence	Urbanized area approach; Research applied to Brazilian municipalities.

Source: the authors.

SLR therefore consists of mapping primary studies that address a specific research topic, followed by a critical evaluation and arrangement of these studies in order to identify patterns and gaps to be observed in its synthesis (Neves et al., 2017; Lopes; Silva, 2019; Lucarelli;

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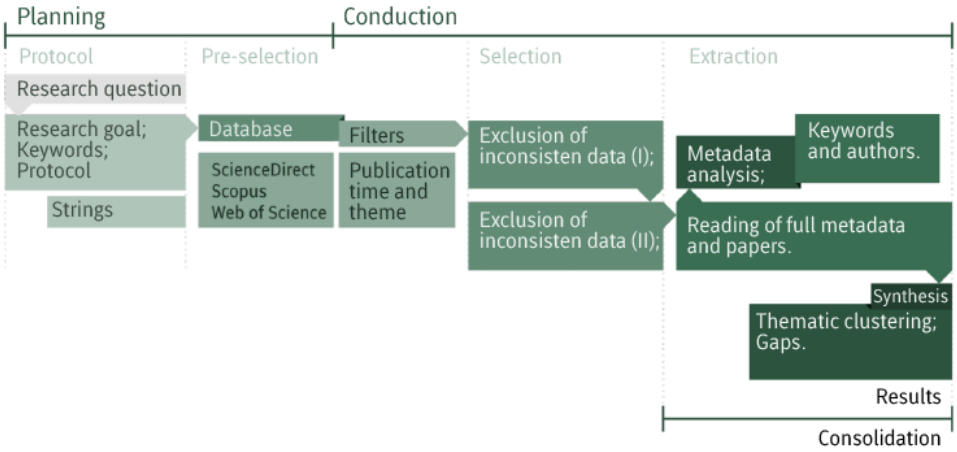
Oliveira; Carlo, 2023). Its development is defined by three stages: planning, conduction and consolidation. The planning stage consists in the definition of the databases where these primary studies are collected based on the relationship between a set of strings (search terms), and their scope through the application of a research protocol. The conduction stage checks which papers meet the inclusion and exclusion criteria defined for the sample that will comprise the review. Finally, the consolidation stage consists of carrying out a bibliometric analysis to quantify the most frequent keywords and relevant authors in the sample using the VosViewer software (version 1.6.20) and summarizing the results.

Figure 1 – Flowchart with structure for developing the review adopted in this research.
pesquisa.



Source: the authors.

The search terms used to compose the syntax were: climate change, urban, adaptation, resilient, resilience, Brazil and Brazilian. To avoid superficial and generic output data, the search key "climate change" was grouped in parentheses, so that its composing terms were not searched separately. The relationship between the terms resilient, resilience and adaptation and the terms Brazil and Brazilian was established using the Boolean operator OR, so that only one of them was considered in the search syntax at a time. Thus, the search keys are connected by the Boolean operator AND, resulting in the following search syntax: "climate change" AND (resilient OR resilience OR adaptation) AND (Brazil OR Brazilian).

In both databases used in this research, the syntax for searching by topic was used. In this way, the occurrence of the strings was detected only in the titles, keywords or abstracts. Next, the resulting number of papers was filtered by horizon, restricting them to those published between 2014 and 2024 and framed within the areas of study: Engineering, Environmental Sciences, Energy and Social Sciences. **Erro! Fonte de referência não encontrada.** Table 1 below shows the number of papers pre-selected in the databases according to the filters adopted in each one.

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Table 1 – Search syntax and number of articles found by database according to period, type and research area.

Sintaxe	Base	Horizonte e tipo	Áreas de pesquisas	Qtd.
TS="climate change" AND urban AND (resilient OR resilience OR adaptation) AND (Brazil OR Brazilian OR Brasil)	Science Direct	the entire period (2017-2024), research and review articles[1]	Environmental Science, Social Sciences, Energy, Engineering	21
	Web of Science	2014-2024, research and review articles	Environmental Sciences, Environmental Studies, Green Sustainable Science Technology, Engineering Environmental, Urban Studies, Engineering Civil, Construction, Building Technology	73
	Scopus	2014-2024, research and review articles	Environmental Science , Social Sciences, Energy, Engineering	105
				133*

Source: the authors. * duplicated source were excluded

The bibliographic management of the papers retrieved from the databases and the extraction of their metadata was performed using the Zotero software (version 7.0.2), also used to exclude duplicates or references with inconsistent data. Then, by cross-referencing the metadata of the pre-selected papers, a spreadsheet was drawn up, arranging the papers by type of approach, main theme, application in Brazilian municipalities, synthesis and method, with the aim of relating them and building a state of the art on the established issue.

Studies applied to specific Brazilian municipalities were within the scope of the research, excluding those that mentioned only the state or geographical region. After defining the population of adherent articles, a quantitative analysis was carried out to identify the number of productions by approach, year, state and theme.

Figure 2 - Organization of the pre-selected articles based on their metadata.

Metadata	Title Year Authorship		Abstract Keywords		Abstract Results Method	
	Paper	Approach	Theme	City	Synthesis	Adherent
	AUTHOR (YEAR)	Qualitative Quantitative Quali-quantitative Exploratory	Climate governance Climate change perception Resilience Mitigation and adaptation Socioeconomic vulnerability Nature-based solutions	Municipality (UF)		[ ] Adherent to the research scope [ ] Not adherent to the research scope

Source: the authors.

1 For this database, restricted to the research areas indicated, only articles within the 2017 to 2024 timeframe were identified.

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3 RESULTS

Besides the number of articles identified in the database which complied with the scope of the research, the results show the main topics covered, discussed subsequently, and others which were not properly explored, identifying possible research gaps. Of a total of 133 articles found in the set of databases considered, 16 presented inconsistent data, and only 77 were selected because they met the scope of the research, published by 309 researchers.

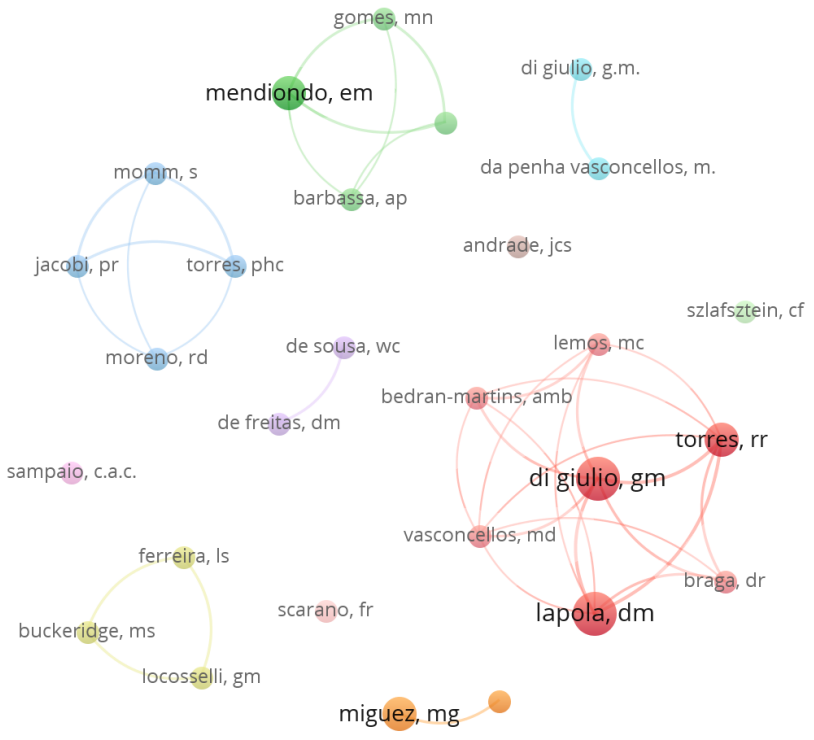
3.1 Bibliometric analysis

3.1.1 Main keywords and authors

The most important authors and frequently occurring keywords in the publications were considered in the pre-selection phase. A maximum of fifteen authors per document and a minimum of two articles per author were adopted. As for the analysis of the occurrence of keywords, a minimum of five occurrences was established for each keyword.

The names represented by larger circles indicate a higher occurrence frequency of in relation to the occurrence than the others, while the lines illustrate the networks of authors and co-authors. Of the 670 authors responsible for the publications, only 38 have two or more records, and only 6 have published three or more times. The lack of connections between some authors suggests research in different or unrelated areas.

Figure 3 - Co-authorship analysis.



Source: the authors

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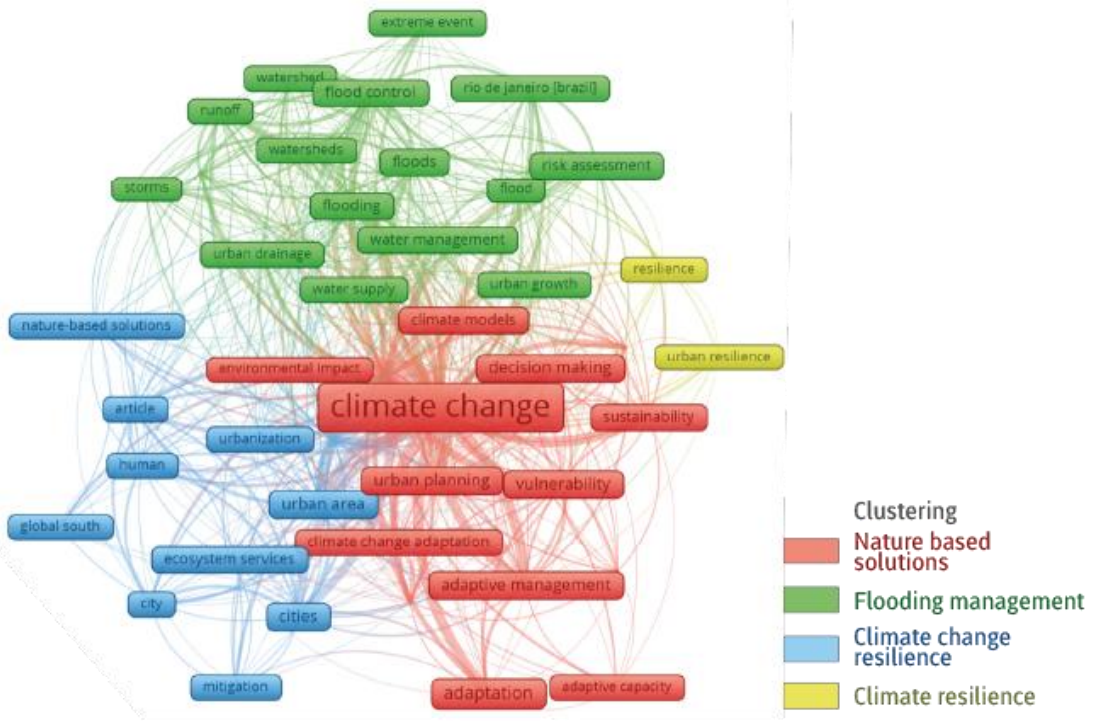
From the 992 keywords present in the sample, only 45 had at least five occurrences, distributed in four thematic groupings: “Adaptation to climate change”, “Flood management”, “Nature-based solutions” and “Resilience”. It was noted, however, that the five keywords with the highest number of instances - “climate change”, “Brazil”, “Sao Paulo”, “urban area” and “adaptive management” - were not equivalent to the terms used to formulate the search syntax adopted in the research.

Figure 4 - Keywords with the highest occurrence in the sample of pre-selected articles.



Source: the authors

3.1.2 Artigos aderentes ao escopo da pesquisa

Out of the 133 articles retrieved in the pre-selection stage, 16 items were excluded due to inconsistent or irrelevant metadata. It was found that 77 articles were in line with the scope of the review, presented in the following table by topic classification.

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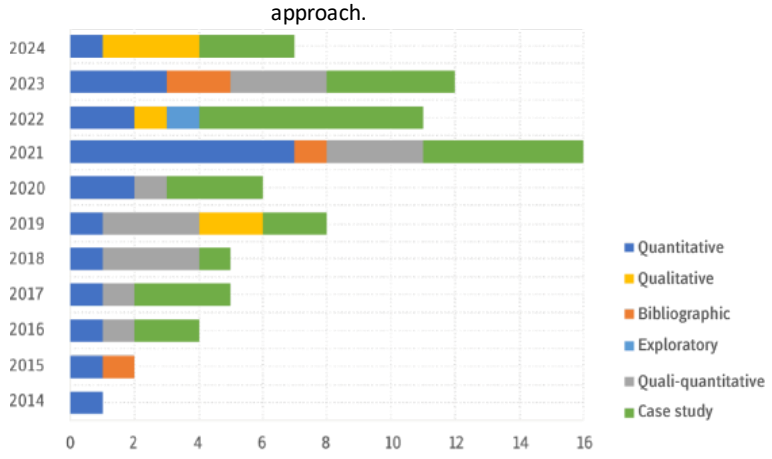
Table 1 - Thematic grouping of articles adhering to the scope of the review.

Papers complying with the scope of the research	Topics	Qty.
(Obraczka *et al.*, 2017; Di Giulio *et al.*, 2019; Coates, 2021; Leao; Andrade; Nascimento, 2021; Mendes, 2022; Ferreira, M. *et al.*, 2023; Schmidt *et al.*, 2024)	Climate governance	7
(Moreno; Braga; Xavier, 2021; Lampis *et al.*, 2022; Rodrigues; Molina Junior; Canteras, 2023; Ferreira, M. L. *et al.*, 2023; Torres, P. H. C. *et al.*, 2023; Raimondi *et al.*, 2023; Lisboa *et al.*, 2024)	Green infrastructure and nature-based solutions	7
(Petit-Boix *et al.*, 2015; Moura; Pellegrino; Martins, 2016; Miguez; Veról, 2017; Fava *et al.*, 2022; de Saboia *et al.*, 2020; Francisco *et al.*, 2023)	Flood management	6
(Zanetti; de Sousa; De Freitas, 2016; de Andrade; Szlafsztein, 2018; Freitas; D'Avignon; Castro, 2019; Lapola *et al.*, 2019; de Oliveira *et al.*, 2020; Cavalcanti *et al.*, 2022a; Mello *et al.*, 2023)	Climate change perception and socio-economic vulnerability	7
(Duarte *et al.*, 2014; Scarano; Ceotto, 2015; Bacalhau; Neto; Montenegro, 2016; Marengo *et al.*, 2017; Sant'Anna, 2018; Simões *et al.*, 2017; Mansur *et al.*, 2018; Locosselli *et al.*, 2019; Santos, A. *et al.*, 2020; Szlafsztein; de Araújo, 2021; Fitchett; Raik, 2021; Barbieri; Guedes; dos Santos, 2021; Chaves *et al.*, 2021; Costa *et al.*, 2021; Feitosa *et al.*, 2021; Roca-Barceló, Aina *et al.*, 2022; de Oliveira Rolo *et al.*, 2022; Araújo *et al.*, 2024; Herrera-Franco *et al.*, 2024)	Adaptation and mitigation	24
(Young, 2016; Paterson *et al.*, 2017; Washburn, 2018; Collazo *et al.*, 2019; Rezende *et al.*, 2019; Bertilsson *et al.*, 2019; Barata *et al.*, 2020; de Moura; Carvalho, 2020; Santos, T. *et al.*, 2020; Okumura *et al.*, 2021; Nieto; Cubillos; Barrios, 2021; de Carvalho; Iensen; dos Santos, 2021; Cerbaro *et al.*, 2022; de Magalhães *et al.*, 2022; Ferranti; Oberling; Quinn, 2022; Rodrigues Prado *et al.*, 2022; Silva *et al.*, 2022; Guzmán; Mohor; Mendiondo, 2023; Krelling *et al.*, 2023; Oliveira; Fath, 2023; Pereira; Miranda, 2023; Pardal; Christofoletti; Martinez, 2024; Rodrigues *et al.*, 2023; de Castro; Alvim, 2024; Locosselli *et al.*, 2024)	Climate resilience	26
Source: the authors.		77

When analyzing the distribution of publications complying with the scope of the research over the last decade, we can see an increase in the number of publications until 2021 (Figure 5**Erro! Fonte de referência não encontrada.**). In the following years, there has been a decrease in the publication volume, although there is a trend of growth. In this scenario, there is a predominance of publications involving case studies, representing 39% of the total, followed by 27% of publications of a qualitative nature. In addition, there is a significant discrepancy between the number of studies applied to municipalities in the states of São Paulo and Rio de Janeiro compared to the other regions of the country (Figure 6).

Figure 5 - Number of articles published per year, respectively distributed by research approach.



Source: the authors

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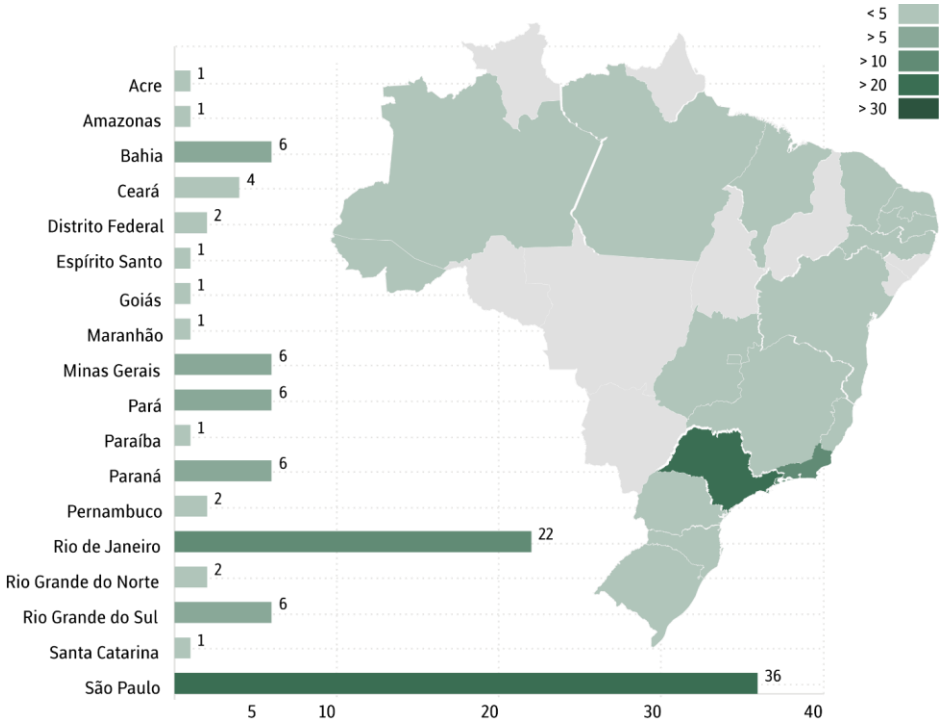
Figure 1 - Articles distributed by application context.



Source: the authors

3.2 Discussão dos resultados

This section discusses and summarizes the papers adhering to the research by thematic grouping. For each group, we sought to identify common trends among the research and, consequently, knowledge gaps that could provide a basis for future research and guidelines for more effective public policies.

3.2.1 Resilience

The selected papers address various aspects of resilience and climate change adaptation in Brazilian cities. Bertilsson et al. (2019), Rezende et al. (2019) e Okumura et al (2021) have proposed indicators and methods to assess and improve flood resilience in Rio de Janeiro. Similarly, Iensen et al. (2021) and Cerbaro et al. (2022) analyze flood vulnerability in Belém and Rio Branco, respectively, identifying significant variations between rich and poor areas. Fernandez-Guzman *et al.* (2023) examines drought resilience in São Paulo, evaluating the costs of interrupting water supply.

Another research group focuses on resilient design related to nature-based solutions. Rodrigues et al. (2023) investigate urban furniture solutions for shading in Belo Horizonte, aimed at mitigating heat islands. Boom et al. (2024) examine the use of drought-resistant species in São Paulo. In the field of thermal resilience in buildings, Hong et al. (2023) proposed a framework

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for evaluation in São Luís, while Barrios et al. (2021) demonstrate the effectiveness of compressed earth blocks (CEB) in social housing in specific climates.

A number of studies focus on the adoption of integrated planning to improve urban resilience. Ferranti et al. (2022) and Santos *et al.* (2020) examined the urban transport resilience in Rio de Janeiro, identifying greater robustness in central areas and vulnerability linked to socioeconomic factors - which underscores the need for integration in urban planning. Young (2016) and Pardal et al. (2024) emphasize the importance of integrated planning and the incorporation of different urban typologies to mitigate vulnerabilities and disaster risks in São Paulo's coastal regions.

Finally, some studies emphasize the importance of integrated and holistic approaches. Silva *et al.* (2022) highlight the need to integrate social and environmental actions in Salvador, a crucial aspect in poverty and inequality contexts. Fath and Oliveira (2023) present a comparative index of urban resilience with 29 indicators, highlighting the role of cultural identity in cities. Paterson *et al.* (2017) examined the adaptive capacity of smaller coastal cities, highlighting the need to redistribute decision-making power. These studies converge in pointing out the importance of considering multiple factors and stakeholders when planning for urban resilience in the face of climate change.

3.2.2 Mitigation and Adaptation

Some studies in this theoretical framework have highlighted climate vulnerability and the importance of ecosystem-based adaptations. Ceotto and Scarano (2023), in their observation of the vulnerability of biodiversity in the Atlantic Forest due to climate, and Rolo *et al.* (2022), in their investigation of the perception of ecosystem services in São Paulo, emphasized the need for ecosystem-based adaptations, underlining the importance of increasing local resilience through practices that improve public management and urban resilience. Bacalhau et al. (2016) also contributed by proposing strategies to mitigate water scarcity in the Metropolitan Region of Recife through adaptive management, demonstrating the effectiveness of ecosystem-based approaches in different contexts.

Some other studies have shown the importance of vegetation in climate mitigation. Duarte et al. (2014) and Locosselli et al. (2019) analyzed, respectively, the influence of vegetation on improving the microclimate in dense built-up areas and the impact of air pollution on the growth of urban trees in São Paulo. Roca-Barceló *et al.* (2022), on the other hand, analyzed mortality associated with high temperatures, identifying trends in minimum temperatures and cumulative risk, underscoring the need for specific interventions.

A third set of papers addresses community integration and participation in adaptation strategies. Herrera-Franco (2024) identifies strategies that balance economic growth and environmental impact by promoting community participation in adaptive actions. Marengo *et al.* (2017), in the METROPOLE project, used a participatory approach to evaluate sea level rise adaptation in Santos, identifying community adaptation preferences. Araujo *et al.* (2024) highlighted the precarious housing situation in João Pessoa, stating that over half of the habitations are located in disaster-prone areas, proposing interventions to improve the resilience of these areas and, consequently, their social and environmental conditions.

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3.2.3 Green infrastructures and nature-based solutions

In this context of green infrastructure and nature-based solutions, several studies have highlighted innovative approaches to improving urban resilience and environmental management. Ferreira *et al.* (2023) research assessed the expansion of urban parks in São Paulo, indicating a significant increase in protected areas, despite socio-spatial segregation. Braga, Moreno and Xavier (2021) explored the implementation of a green corridor in the São Paulo Metropolitan Region through a qualitative-quantitative approach, emphasizing the significance of including green infrastructure in order to reduce social inequality and safeguard of the Atlantic Forest.

Lisboa *et al.* (2024) research analyzes the flora of urban squares in Ceará, underlining its importance in carbon capture and evidencing squares' potential in mitigating greenhouse gas (GHG) emissions. Similarly, Rodrigues, Molina Junior and Canteras (2023) examine the implementation of green infrastructure in a Fortaleza neighborhood, identifying solutions such as rain gardens, which provide environmental benefits and essential ecosystem services.

On the other hand, studies such as Lampis' (2022) examine the ecological repair in Latin America, demonstrating that local initiatives in low-income areas promote nature-based urban adaptations, contributing to social justice and resilience. Torres et al. (2023) discussed risks related to nature-based solutions, drawing attention to the importance of planning in order to mitigate the risk of intensifying social inequalities. Raimondi et al. (2023) evaluated the efficiency of adopting permeable sidewalks under urban trees to improve stormwater management and mitigate urban drainage problems.

3.2.4 Flood management, socioeconomic vulnerability and climate change perception

In relation to the flood management, Petit-Boix (2015) evaluated a system of infiltration in São Carlos as a feasible alternative for water runoff reduction of up to 95%, highlighting its effectiveness compared to traditional infrastructures. Saboia et al. (2020) addressed the uncertainties in forecasting precipitation and proposed a decision tool to improve the design of drainage systems in Fortaleza. Miguez and Veról (2015) developed a Flood Resilience Index that supports the combination of sustainable drainage and river restoration, outperforming a reservoir alternative.

Also in this area, Moura *et al.* (2016) explored rainwater management techniques in São Paulo, showing the effectiveness of permeable sidewalks, which are capable of retaining 41% of the volume of a reservoir. In São Carlos, the research by Fava *et al.* (2022) shows that low-impact practices improved the resilience of the Gregório basin in São Carlos, SP, but with limitations during intense storms. Francisco et al. (2023) highlighted challenges to improving urban drainage systems in Brazil, underlining the need for public policies to overcome inadequate infrastructure and lack of investment.

In relation to climate change perception, Oliveira et al. (2020) pointed to the population's recognition of the increase in temperature and precipitation in Belém, attributing these changes to the urban development model. Environmental awareness is crucial to guide

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actions to mitigate these effects. Zanetti and Júnior (2016) developed a Socio-environmental Vulnerability Index for coastal areas, revealing that 70% of the municipality of Santos (SP) is highly vulnerable to flooding and rising sea levels. Lapola and Braga (2019) analyzed vulnerability to heat stress in six Brazilian capitals, with Manaus and Natal showing the highest indices, highlighting the need for effective risk communication and increased urban vegetation.

Freitas, D'Avignon and Castro (2019) identified a correlation between socio-spatial segregation and vulnerability to extreme weather events, highlighting the need for urban policies in Rio de Janeiro. According to Mello et al. (2018), more than 80% of the area of the municipality of Santarém is highly vulnerable to flooding, highlighting the need for structural and social interventions due to its low adaptive capacity. Mello *et al.* (2023) pointed out the high socio-environmental vulnerability to landslides in Brusque, establishing the relationship between environmental susceptibility and housing in risk areas. Cavalcanti *et al.* (2022) analyzed how social movements in Natal and São Paulo use vacant buildings in central areas to claim the right to the city and housing in the face of climate risks.

3.2.5 Climate governance

Regarding climate governance, several studies have highlighted its importance for municipalities to adapt to climate change. Mendes (2022) and Di Giulio *et al.* (2019) analyzed, respectively, urban transformation in Rio de Janeiro, where the climate agenda privileges financial interests over social well-being, and in São Paulo municipalities, highlighting the need for effective governance strategies and more transparency in data collection. Similarly, Schmidt *et al.* (2024) state that the limitations to climate action are due to a lack of political capacity and resources, highlighting the inadequate use of data and the need for a more holistic approach. Nascimento et al. (2021) examined how urbanization in Recife amplifies climate risks, highlighting governance and financing as essential for climate action.

Obraczka et al. (2017), Ferreira et al. (2023), and Coates (2021) emphasize the importance of transparency and public participation in environmental governance. Obraczka et al. (2017) compare coastal management practices in Rio de Janeiro, illustrating the effectiveness of a national model that integrates stakeholders in decision-making. Coates (2021) has examined how disaster awareness in the state of Rio de Janeiro depends on the political context, revealing how effectiveness in risk reduction is affected by governance structures. Ferreira et al. (2023) investigated environmental policies in 78 municipalities in the Green Belt Biosphere Reserve in the state of São Paulo, highlighting the positive correlation between the Human Development Index (HDI) and environmental policies, as well as the importance of municipal management for the sustainable development of the region.

3.3 Gaps

Among the common gaps across all the thematic groups is the need to establish accurate indices to better assess the efficiency of certain adopted adaptation strategies, especially in vulnerable communities, integrating socio-economic and cultural factors in policy

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implementation, as a function of their risks. In addition, there is a demand for studies, with long-term projections, about the impacts of urban vegetation on the microclimate and public health.

Similarly, in the context of flood management and green infrastructure, there is a need to better understand social and environmental interactions in informal urban areas. There is also a need to integrate local data into predictive models, assessing the impact and feasibility of the adoption of adaptive approaches.

Finally, studies on climate governance and urban resilience indicate the need to evaluate the effectiveness of participatory approaches in climate policies. In this context, there is also a demand for investigations into community participation in the implementation of resilience actions and projects, as well as the effectiveness of nature-based solutions in different Brazilian urban contexts.

4 Conclusão

The review showed a growing approach to the subject, in recognition of the challenges that cities have faced in recent years. Broadly speaking, there is a greater emphasis on the relevance of adopting nature-based solutions and inclusive policies. However, the absence of more effective methods for evaluating the effectiveness of these strategies and integrating socio-economic factors represents a significant gap.

In order to make progress in this field, it is crucial to develop research that evaluates the long-term impact of adaptive measures, taking into account local specificities and socio-economic inequalities. In addition, it is necessary to improve community participation in the formulation and implementation of climate policies, ensuring effective and equitable solutions for all segments of the Brazilian urban population.

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STATEMENTS

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CONFLICTS OF INTEREST STATEMENT

We, **Adriano Felipe Oliveira Lopes and Edna Aparecida Nico Rodrigues**, declare that the manuscript entitled **"Challenges of Climate Change Adaptation in Brazilian Municipalities: A Systemati Literature Review"**:

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