UNIVERSIDADE ESTADUAL DE CAMPINAS
Instituto de Geociências

LARISSA VIEIRA ZEZZO

CIÊNCIA, EDUCAÇÃO E COMUNICAÇÃO CLIMÁTICA: DAS MUDANCAS CLIMÁTICAS AO FENÔMENO DAS ILHAS DE CALOR URBANO

SCIENCE, EDUCATION AND CLIMATE COMMUNICATION: FROM CLIMATE CHANGE TO THE PHENOMENON OF URBAN HEAT ISLANDS

CAMPINAS
2025

LARISSA VIEIRA ZEZZO

CIÊNCIA, EDUCAÇÃO E COMUNICAÇÃO CLIMÁTICA: DAS MUDANCAS CLIMÁTICAS AO FENÔMENO DAS ILHAS DE CALOR URBANO

SCIENCE, EDUCATION AND CLIMATE COMMUNICATION: FROM CLIMATE CHANGE TO THE PHENOMENON OF URBAN HEAT ISLANDS

TESE APRESENTADA AO INSTITUTO DE GEOCIÊNCIAS DA UNIVERSIDADE ESTADUAL DE CAMPINAS COMO PARTE DOS REQUISITOS EXIGIDOS PARA OBTENÇÃO DO TÍTULO DE DOUTORA EM CIÊNCIAS

THESIS PRESENTED TO THE INSTITUTE OF GEOSCIENCES OF THE STATE UNIVERSITY OF CAMPINAS AS PART OF THE REQUIREMENTS FOR OBTAINING THE DEGREE OF DOCTOR OF SCIENCES

ORIENTADORA: PROFA. DRA. PRISCILA PEREIRA COLTRI

COORIENTADOR: PROF. DR. VINCENT DUBREUIL

ESTE EXEMPLAR CORRESPONDE À VERSÃO FINAL DA TESE APRESENTADA PELA ALUNA LARISSA VIEIRA ZEZZO E ORIENTADA PELA PROFA. DRA. PRISCILA PEREIRA COLTRI E PELO PROF. DR. VINCENT DUBREUIL.

CAMPINAS

2025

Ficha catalográfica
Universidade Estadual de Campinas (UNICAMP)
Biblioteca do Instituto de Geociências
Marta dos Santos - CRB 8/5892

Z61s

Zezzo, Larissa Vieira, 1992-
Science, education and climate communication : from climate change to the phenomenon of urban heat islands / Larissa Vieira Zezzo. – Campinas, SP : [s.n.], 2025.

Orientador: Priscila Pereira Coltri.
Coorientador: Vincent Dubreuil.
Tese (doutorado) – Universidade Estadual de Campinas (UNICAMP), Instituto de Geociências.

1. Serviços meteorológicos. 2. Comunicação na ciência. 3. Alfabetização científica. 4. Climatologia. I. Coltri, Priscila Pereira, 1980-. II. Dubreuil, Vincent. III. Universidade Estadual de Campinas (UNICAMP). Instituto de Geociências. IV. Título.

Informações complementares

Título em outro idioma: Ciência, educação e comunicação climática : das mudanças climáticas ao fenômeno das ilhas de calor urbano
Palavras-chave em inglês:
Meteorological services
Science communication
Scientific literacy
Climatology
Área de concentração: Ensino e História de Ciências da Terra
Titulação: Doutora em Ciências
Banca examinadora:
Priscila Pereira Coltri [Orientador]
André Munhoz de Argollo Ferrão
Jurandir Zullo Junior
Margarete Cristiane de Costa Trindade Amorim
Ercília Torres Steinke
Data de defesa: 10-03-2025
Programa de Pós-Graduação: Ensino e História de Ciências da Terra

Objetivos de Desenvolvimento Sustentável (ODS)
ODS: 13. Ação contra a mudança global do clima
ODS: 4. Educação de qualidade

Identificação e informações acadêmicas do(a) aluno(a)
- ORCID do autor: https://orcid.org/0000-0001-7953-650X
- Currículo Lattes do autor: http://lattes.cnpq.br/2644283040353257

EXAMINADORES:

Profa. Dra. Priscila Pereira Coltri - Presidente

Profa. Dra. Ercília Torres Steinke

Profa. Dra. Margarete Cristiane de Costa Trindade Amorim

Prof. Dr. André Munhoz de Argollo Ferrão

Prof. Dr. Jurandir Zullo Junior

A Ata da defesa com as respectivas assinaturas dos membros encontra-se no SIGA/Sistema de Fluxo de Dissertação/Tese e na Secretaria do Programa da Unidade.

Campinas, 10 de Março de 2025.

À minha avó Terezinha, por sua sabedoria que me inspira diariamente; aos meus pais, Conceição e Celmo, por seu amor incondicional e pelo encorajamento constante; e ao meu marido, Rafael, por seu companheirismo inestimável durante essa jornada.

AGRADECIMENTOS

O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) - Código de Financiamento 001. Também ao Campus France, pela bolsa de doutorado sanduíche concedida para realização da pesquisa em Rennes (França).

À minha orientadora, Profa. Dra. Priscila Pereira Coltri, por ser simplesmente quem ela é, um ser humano incrível que se destaca como pesquisadora, professora e amiga. É extremamente difícil dimensionar sua importância para a realização desse trabalho, então só posso agradecer pela sorte que tive em tê-la por 5 anos na minha vida e desejar que outros pesquisadores tenham a oportunidade de conhecê-la e também ao seu trabalho incrível.

Ao meu coorientador, Prof. Dr. Vincent Dubreuil, pelo auxílio e suporte em todos os momentos que precisei, desde o ponto em que decidi pela temática de clima urbano, até meu retorno ao Brasil. Além disso, não poderia deixar de agradecer pelos ensinamentos e pelas boas e prazerosas conversas que tivemos.

À Jéssica de Oliveira, minha primeira amiga do doutorado, por quem tenho um carinho enorme e com quem compartilhei minhas primeiras experiencias na climatologia.

À Daniela Resende, pela sua força e determinação na área da educação. Obrigada pelas trocas e por colocar "fogo no parquinho". Agradeço também pelo suporte nos trabalhos de campo, você foi incansável até o fim.

Ao Guilherme Torres, pela clareza com que ele comandou nossos trabalhos e pelas nossas trocas durante a escrita de trabalhos científicos. Obrigada também pelo auxílio nos trabalhos de campo.

Ao Rafael São José, por ter sido sempre um amigo tão querido. Levarei sempre com carinho cada uma das suas sábias palavras.

Ao Marcelo Soeira por ter entrado de cabeça comigo na construção de abrigos meteorológicos, na realização dos testes e todas as demais etapas metodológicas relacionadas a minha tese, compartilhando comigo seu conhecimento em todos os momentos. Você foi essencial para essa pesquisa como um todo, obrigada.

Aos demais amigos e colegas que o doutoramento me deu, todos foram especiais nessa jornada.

Aos funcionários da pós graduação em Ensino e História das Ciências da Terra da UNICAMP, por todo o suporte que me forneceram em diferentes questões ao longo desses 5 anos.

Aos meus pais Celmo e Conceição, e ao meu marido Rafael, que se aventuraram comigo em todos os momentos que solicitei, desde a instalação dos sensores em diferentes pontos de Indaiatuba, até mesmo a manutenção e construção de novos sensores. Família, vocês são absolutamente tudo pra mim.

Ao meu marido (novamente), por toda paciência e parceria durante os anos de doutoramento, em que muitas vezes tive que abrir mão do tempo em casal e me dedicar a pesquisa. Agradeço também pelas noites em que você se aventurou comigo em Indaiatuba, fazendo transectos móveis pela cidade e ouvindo “A Voz do Brasil” - um clássico do horário noturno.

À energia do universo, que me guiou durante todo o doutoramento e nos processos que o envolveram. Foi um crescimento pessoal e acadêmico imensurável, e, ao olhar para trás, sinto uma grande alegria por tudo o que fui capaz de realizar e conquistar. Obrigada!

E, por fim, mas não menos importante, agradeço a mim mesma, por não ter desistido, mesmo quando o cansaço era grande e os obstáculos pareciam intransponíveis. Desde os pequenos desafios, como um artigo rejeitado, até os maiores, como uma pandemia, cada um deles contribuiu para a minha jornada. Tudo valeu a pena.

"Na natureza, nada existe sozinho."
Primavera Silenciosa, 1962
Rachel Carson

UNICAMP

RESUMO

As mudanças climáticas têm se consolidado como um tema central no debate público devido aos seus impactos significativos na sociedade e nos recursos naturais. No entanto, a complexidade da climatologia, somada a lacunas na comunicação e na educação científica, dificulta a compreensão do tema nas suas diferentes escalas de atuação. A hipótese do trabalho considerou que trabalhar o clima em escala local, por meio de dados meteorológicos de qualidade, poderia ser uma abordagem eficiente para promover a ciência, a educação e a comunicação em clima. Este estudo propôs uma abordagem prática para explorar fenômenos climáticos, como as Ilhas de Calor Urbano (ICU), utilizando dados de estações meteorológicas. Buscou-se conectar a ciência climática ao cotidiano de uma comunidade em escala local-regional e identificar soluções para reduzir as lacunas na coleta de dados meteorológicos no Brasil. Além de uma abordagem multi escala, almejou-se adentrar outras dimensões da climatologia, como a educação e a comunicação. Os capítulos iniciais contextualizam os objetivos, a hipótese e a estrutura da tese. Em seguida, o capítulo 3 apresenta uma revisão integrativa sobre a influência da mídia na disseminação de conceitos relacionados às mudanças climáticas no Brasil ao longo de 50 anos, evidenciando a evolução da cobertura da mídia em questões ambientais e climáticas e os desafios na comunicação. No capítulo 4, discute-se o ensino de mudanças climáticas no Brasil, destacando como os principais achados, a falta de preparo dos professores e de materiais pedagógicos adequados. O capítulo 5 aborda um estudo de caso sobre educação em mudanças climáticas durante a pandemia, com dados coletados através de um questionário online. Os resultados indicaram um forte interesse por parte dos participantes, majoritariamente de alta escolaridade, mas também revelaram persistentes erros conceituais. A partir da análise sobre os desafios educacionais e comunicativos, o estudo avança nos demais capítulos para investigar aspectos complementares em escala local, com foco na relevância de dados meteorológicos de campo e na compreensão do fenômeno das ICUs. Assim, o capítulo 6 apresenta uma revisão sistemática sobre o uso de modelos em microescala para avaliar ICU, ressaltando a importância de dados de campo e os desafios enfrentados no Brasil devido à falta de investimentos em pesquisa. No capítulo 7, analisou-se dados de campo coletados em Indaiatuba (SP) em 2022, revelando maior ocorrência de ICU durante a estação seca, especialmente em julho, com eventos menos intensos na estação chuvosa. Neste estudo também destacamos a questão de uso e cobertura do solo assim como as características atmosféricas. O capítulo 8 aborda o desenvolvimento e validação de um abrigo meteorológico de baixo custo, construído com materiais acessíveis e conforme padrões da Organização Meteorológica Mundial (OMM), demonstrando confiabilidade e replicabilidade, ideal para instituições com recursos limitados. Os resultados gerais da tese destacaram a necessidade de uma abordagem interdisciplinar na climatologia, essencial para promover discussões mais amplas e profundas. A pesquisa também sublinhou a importância da formação complementar para professores, dada a complexidade dos temas climáticos, e reconheceu o papel relevante, embora limitado, da mídia na comunicação científica. Por fim, enfatizou-se a relevância dos dados de campo no hemisfério sul, particularmente em áreas tropicais, discutindo-se como os dados locais podem contribuir para a alfabetização científica, a comunicação das ciências climáticas, o apoio a políticas públicas e a mitigação e adaptação às mudanças climáticas.

Palavras-chave: Serviços meteorológicos; Comunicação na ciência; Alfabetização científica; Climatologia.

UNICAMP

ABSTRACT

Climate change has become a central theme in public debate due to its significant impacts on society and natural resources. However, the complexity of climatology, combined with gaps in communication and scientific education, hinders the understanding of the subject across its different scales of operation. The hypothesis of this work considered that addressing climate at the local scale, through high-quality meteorological data, could be an effective approach to promoting science, education, and climate communication. This study proposed a practical approach to exploring climatic phenomena, such as Urban Heat Islands (UHI), using data from meteorological stations. It sought to connect climate science to the daily lives of a community on a local-regional scale and identify solutions to reduce gaps in meteorological data collection in Brazil. In addition to a multi-scale approach, the study aimed to delve into other dimensions of climatology, such as education and communication. The initial chapters contextualize the objectives, hypothesis, and structure of the thesis. Chapter 3 presents an integrative review of the influence of media in disseminating concepts related to climate change in Brazil over 50 years, highlighting the evolution of media coverage on environmental and climate issues and the challenges in communication. Chapter 4 discusses the teaching of climate change in Brazil, emphasizing the main findings, such as the lack of teacher preparedness and suitable educational materials. Chapter 5 examines a case study on climate change education during the pandemic, with data collected through an online questionnaire. The results indicated a strong interest among participants, predominantly highly educated, but also revealed persistent conceptual errors. Based on the analysis of educational and communicative challenges, the study progresses in subsequent chapters to investigate complementary aspects at the local scale, focusing on the relevance of field meteorological data and understanding the UHI phenomenon. Chapter 6 presents a systematic review of the use of microscale models to assess UHI, emphasizing the importance of field data and the challenges faced in Brazil due to a lack of research funding. In Chapter 7, field data collected in Indaiatuba (SP) in 2022 was analyzed, revealing a higher occurrence of UHI during the dry season, especially in July, with less intense events in the rainy season. This study also highlighted issues related to land use and coverage, as well as atmospheric characteristics. Chapter 8 addresses the development and validation of a low-cost meteorological shelter, built with accessible materials and in accordance with World Meteorological Organization (WMO) standards, demonstrating reliability and replicability, ideal for institutions with limited resources. The overall findings of the thesis highlighted the need for an interdisciplinary approach in climatology, essential for fostering broader and deeper discussions. The research also underscored the importance of complementary training for teachers, given the complexity of climate topics, and recognized the relevant but limited role of the media in scientific communication. Finally, it emphasized the importance of field data in the southern hemisphere, particularly in tropical areas, discussing how local data can contribute to scientific literacy, climate science communication, public policy support, and climate change mitigation and adaptation.

Keywords: Meteorological services; Science communication; Scientific literacy; Climatology.

LISTA DE FIGURAS

Capítulo 8

LISTA DE TABELAS

SUMÁRIO

CAPÍTULO 1: APRESENTAÇÃO DA TESE

Essa tese de doutorado começou a tomar forma em março de 2019, durante meu primeiro semestre no Programa de Ensino e História das Ciências da Terra do Instituto de Geociências da UNICAMP, quando tive a oportunidade de cursar a disciplina de climatologia com a professora Priscila Coltri. Naquele momento, eu havia iniciado o doutorado com um foco completamente diferente, mas meu primeiro semestre mudaria radicalmente meus planos — e para melhor.

Foi nessa disciplina que escrevi um artigo sobre o uso de jogos no ensino de climatologia, que posteriormente resultou em um capítulo de livro e em um projeto no programa da Pro-Reitoria de Pesquisa da UNICAMP, intitulado CAF (Ciências e Artes nas Férias), realizado no início de 2020. Esse período foi transformador, pois abriu as portas para projetos que me levaram a compreender que a climatologia era o caminho que eu deveria seguir.

Sempre fui uma estudante curiosa, fascinada por diversos temas. Porém, a climatologia, somada à inspiração proporcionada pela professora Priscila, mostrou-se singular. Quando percebi, meus esforços estavam voltados quase que exclusivamente para essa área, e os projetos da pesquisa inicial haviam sido deixados de lado. Em meio as incertezas trazidas pela pandemia em 2020, tomei a decisão de solicitar uma mudança de orientação para trabalhar somente com a professora Priscila, o que marcou oficialmente o início formal desta tese.

Desde o início da nova orientação, no final de 2020, deixei claro meu desejo de realizar um intercâmbio (doutorado sanduíche), uma experiência que já havia enriquecido minha formação na graduação. Com o apoio da professora Priscila, seguimos com esse plano e em paralelo precisávamos definir o tema da tese e a metodologia a ser adotada.

Inicialmente, meu plano era analisar os dados de estações meteorológicas do Estado de São Paulo, mas logo enfrentei dificuldades devido às falhas nos registros, que inviabilizaram análises em escalas temporais longas, comumente utilizadas na climatologia. Recebi sugestões de colegas da Espanha sobre o uso de pacotes do software R para preencher as lacunas, mas, devido ao isolamento e às falhas significativas em muitas estações do interior paulista, o procedimento mostrou-se inviável.

Enquanto lidava com essa frustração, a professora Priscila sugeriu que eu explorasse o trabalho do professor Vincent Dubreuil, na França, que possui anos de experiencia na temática do clima urbano. Essa sugestão me trouxe um novo entusiasmo, e logo estabelecemos contato.

Em pouco tempo o professor Vincent se tornou meu coorientador e, com o suporte dele, direcionei minha tese ao estudo do clima urbano em cidades de médio porte, escolhendo Indaiatuba (SP) como objeto de estudo.

Novamente, surgiram novos desafios. A necessidade de dados de campo tornou-se evidente, mas Indaiatuba contava apenas com uma estação meteorológica. Para suprir essa lacuna, seriam necessários sensores fixos ou transectos móveis, o que demandava recursos financeiros. Com muito esforço, especialmente por parte da professora Priscila, conseguimos financiamento para os sensores fixos, que foram instalados no final de 2021. Paralelamente, minha bolsa de doutorado sanduíche foi aprovada pelo Campus France, permitindo o início das atividades na França em setembro de 2022.

Com os dados de campo e a pesquisa em andamento, comecei a explorar de forma mais ampla as lacunas relacionadas à climatologia. Em paralelo, já vinha "alçando voos" em outras direções, como o ensino e a comunicação sobre mudanças climáticas. Nesse contexto, fui construindo uma coletânea de artigos para evidenciar problemáticas relacionadas à educação, comunicação e à prática científica na climatologia, demonstrando como essas lacunas geram implicações negativas que vão desde as escalas globais até as locais, impactando diretamente o avanço do conhecimento científico e sua disseminação para a sociedade.

Em função dos artigos desenvolvidos, a tese foi se estruturando em torno de um ponto em comum percebido em conversas e debates sobre clima – há uma escassez de dados meteorológicos que impede o desenvolvimento de diferentes frentes relacionadas a climatologia. Dessa forma, além do nosso objetivo principal, que era trabalhar o clima urbano em uma cidade paulista de médio porte, tivemos a percepção de que dados meteorológicos de qualidade são fundamentais para o avanço das pesquisas climáticas, sendo indispensáveis para a ciência (como claramente apresentado em alguns dos artigos presentes na tese), mas também para a educação e a comunicação das ciências do clima.

Além do que foi apresentado como sendo o ponto focal do meu doutoramento, outros projetos foram realizados ao longo desses cinco anos, que se mostraram intensos e repletos de aprendizados e descobertas. Com isso, esses anos de dedicação geraram, de forma direta e indireta, diversos trabalhos, que refletem a magnitude dessa jornada acadêmica e estão listados a seguir, como um testemunho do caminho percorrido. Somado a esses, estão os artigos diretamente atrelados à tese, os quais são apresentados no corpo desse trabalho.

Artigos (como primeira autora):

Zezzo, L.V.; Torres, G.A.L.; Pantano, A.P.; Coltri, P.P. Análise Climática como subsídios estatísticos para a discussão sobre mudanças climáticas e produção cafeeira: o estudo de caso de Campinas-SP. *Irriga*, 28, 190-209, 2023.

Zezzo, L.V.; Coltri, P.P.; De Miranda, M.J.; Junior, J. Z. Doenças infecciosas no contexto das mudanças climáticas e da vulnerabilidade socioambiental. *Revista Brasileira de Climatologia*, 28, 671-697, 2021.

Zezzo, L.V.; Oliveira, J.P. de.; Coltri, P. P. Clima em jogo: uma ferramenta pedagógica para aprendizagem de conceitos em Climatologia. *Revista Terrae Didática*, 16, 2020.

Capítulos de livro

Vieira Zezzo, L.; Pereira Coltri, P.; Dubreuil, V. Frequência e intensidade de ilhas de calor urbano em Indaiatuba (São Paulo). In: Margarete Cristiane de Costa Trindade Amorim; Vincent Dubreuil. (Org.). *Cidades, Clima e Vegetação: Modelagem e políticas ambientais públicas*. 1ed.: TotalBooks, 105-123, 2024.

Zezzo, L.V.; Oliveira, J.P. de.; Coltri, P.P. A importância dos jogos no ensino aprendizagem das Geociências: o jogo do clima e sua abordagem sobre climatologia. In: Luis Ricardo Fernandes da Costa. (Org.). *Estudos Teórico-Metodológicos nas Ciências Exatas, Tecnológicas e da Terra*. 1ed.Ponta Grossa: Atena Editora, 19-33, 2020

Trabalhos e resumos apresentados em congressos e anais

Zezzo, L.V.; Dubeuil, V.; Coltri, P.P. Modeling the urban thermal field in southeast Brazil: a case study in Indaiatuba. In: *37ème colloque annuel de l´Association Internationale de Climatologie*, Paris, 2024.

Zezzo, L.V.; Dubeuil, V.; Coltri, P.P. Urban heat islands monitoring in Indaiatuba (Brazil). In: *36ème colloque annuel de l´Association Internationale de Climatologie*, Bucareste, 2023.

Zezzo, L.V.; Coltri, P.P. Equívocos na educação em mudanças climáticas: um estudo exploratório no sudeste brasileiro. In: *Interfaces geociências e ensino: 50 anos de experiências no Brasil (1973-2023)*, Campinas, 2023.

Zezzo, L.V.; Coltri, P.P. O Desenvolvimento de Pesquisas em prol da Educação em Mudanças Climáticas. In: *Congresso Brasileiro de Profissionais da Geociências (II PROGEO)*, Campinas, 2022.

Zezzo, L.V.; Torres, G.A.L.; Pantano, A.P.; Coltri, P.P. Análise climática para Campinas: subsídios estatísticos para a discussão sobre mudanças climáticas. In: Simpósio em clima, água, energia e alimentos, Rio de Janeiro, 2021.

Zezzo, L.V.; Pacagnella, R.C.; Coltri, P.P. As doenças transmitidas pelo Aedes Aegypti e a influência da variabilidade climática: uma revisão sobre a metodologia aplicada. In: XIV *Simpósio Brasileiro de Climatologia Geográfica*, João Pessoa, 2021.

Zezzo, L.V.; Oliveira, J.P. de.; Coltri, P.P. Jogos no ensino da geografia: uma proposta para climatologia. In: *EnsionoGEO - VIII Simpósio Nacional de Ensino e História de Ciências da Terra*, Campinas, 2019.

Prêmios

- A melhor apresentação oral - *36ème colloque annuel de l´Association Internationale de Climatologie* - Bucareste, Romênia, 2023.
- O melhor trabalho apresentado - *XIV Simpósio Brasileiro de Climatologia Geográfica no Eixo 5: Clima e saúde* - Brasil, online, 2021.

Para ter acesso aos dados dessa tese, favor acessar e citar os dados depositados em: https://doi.org/10.25824/redu/RONEFN e https://doi.org/10.25824/redu/RMGPU1

CAPÍTULO 2 – INTRODUÇÃO

O tema das mudanças climáticas tem adquirido uma relevância crescente no cotidiano das pessoas, especialmente no que se refere ao desenvolvimento sustentável (Otto et al., 2019). Isso ocorre devido aos impactos profundos e multifacetados delas sobre a sociedade e nos recursos naturais, tornando o assunto uma prioridade para diversas áreas do conhecimento e da ação política (Molthan-Hill et al., 2019). Contudo, a complexidade desse fenômeno leva o público a frequentemente considerar as mudanças climáticas como um tema difícil de compreender. Nesse contexto, uma grande parte da população acessa informações sobre o assunto por meio da mídia (Areia et al., 2019), que desempenha um papel fundamental ao traduzir dados científicos para a sociedade, influenciando diretamente a percepção pública sobre o tema (Pasquaré & Oppizzi, 2012).

Embora a mídia tenha um papel crucial, vários desafios surgem em virtude da natureza técnica das comunicações científicas e das dificuldades enfrentadas pelos profissionais de comunicação ao tentar simplificar essas informações sem distorcê-las (Areia et al., 2019). Frequentemente, isso resulta em erros conceituais e no uso inadequado de terminologias, comprometendo a qualidade da informação disseminada (Somerville & Hassol, 2011).

Estudos mostram que a compreensão pública das mudanças climáticas é, muitas vezes, superficial ou equivocada, o que gera consequências que se estendem para diversos setores da sociedade (Busch et al., 2019; da Rosa, 2021). Assim, a educação se configura como uma ferramenta essencial para combater a carência de conhecimento científico, promovendo o pensamento crítico sobre o clima e capacitando a sociedade a discutir de forma coerente questões complexas que afetam diretamente o seu cotidiano (Zezzo & Coltri, 2023).

A alfabetização científica, portanto, emerge como um componente central para facilitar a compreensão dos fenômenos climáticos e suas inter-relações com os seres vivos e o meio ambiente (Wise, 2010). No entanto, pesquisas indicam a existência de lacunas significativas na educação sobre mudanças climáticas, especialmente no que diz respeito a erros conceituais e à interdisciplinaridade do tema (da Rosa, 2021). A complexidade do assunto desafia os educadores a integrar conteúdos de diversas áreas científicas de forma eficaz (Monroe et al., 2017; Hestness et al., 2014). Com isso, a dificuldade em tratar as mudanças climáticas de forma integrada reflete-se diretamente na formação de cidadãos aptos a compreender e enfrentar os desafios impostos por esse fenômeno global.

Neste cenário, os dados meteorológicos locais desempenham um papel fundamental na compreensão dos fenômenos climáticos em diferentes escalas (de Oliveira, 2009). Variáveis como temperatura, precipitação, velocidade do vento e umidade relativa são essenciais para a criação de modelos climáticos precisos, que auxiliam na previsão de eventos extremos e na identificação de tendências de longo prazo (IPCC, 2014).

No Hemisfério Sul, a escassez de infraestrutura e a distribuição desigual de estações meteorológicas comprometem a qualidade das análises climáticas (Sato et al., 2022), com impactos particularmente relevantes em países como o Brasil (Marengo & Bernasconi, 2015). Além disso, as áreas urbanas brasileiras enfrentam desafios significativos devido à falta de dados meteorológicos detalhados (Lohmann, 2013), o que dificulta tanto o monitoramento de fenômenos locais, como as Ilhas de Calor Urbano (ICU), quanto a formulação de políticas públicas eficazes para lidar com esse e outros fenômenos climáticos (Foissard et al., 2019; Amorim, 2020). Diante dessas limitações, o Brasil recorre predominantemente ao sensoriamento remoto como principal ferramenta para identificação e análise das ICU (Silva, 2020), embora a importância de dados de campo reais esteja amplamente comprovada (Vieira Zezzo et al., 2023).

A relevância de dados meteorológicos locais ultrapassa as fronteiras regionais, dado que sua integração em modelos climáticos globais aprimora previsões e embasa estratégias internacionais de mitigação e adaptação (Overpeck et al., 2011). Além disso, há uma preocupação adicional, já que a maioria dos estudos sobre ICU concentra-se em grandes centros urbanos (You et al., 2021) e em regiões de clima temperado (Kadhim-Abid et al., 2019), destacando a necessidade de ampliar essas pesquisas para áreas de clima tropical e subtropical (Roth, 2007). E essa questão é particularmente significativa porque os climas tropicais apresentam características distintas de ICU devido a fatores como maior radiação solar e diferentes padrões de vegetação e urbanização (Moreira et al., 2019; Zhao et al., 2014).

Os centros urbanos, que concentram a maior parte da população mundial, mantêm uma relação bidirecional com o clima, influenciando e sendo influenciados pelas condições meteorológicas locais (Voogt, 2007). Essa interação torna-se ainda mais crítica com o crescimento populacional e o desenvolvimento econômico, que intensificam os impactos das mudanças climáticas, especialmente sobre as populações mais vulneráveis (Grimmond, 2007; Foss & Ko, 2019). Entender essas dinâmicas é essencial para elaborar estratégias de mitigação e adaptação que promovam o desenvolvimento sustentável e fortaleçam a resiliência das cidades (Stewart, 2012).

A estreita relação entre clima e urbanização ressalta a importância de integrar dados meteorológicos locais a modelos globais, permitindo uma melhor compreensão dos fenômenos climáticos em diferentes escalas. Portanto, abordar a ciência do clima de forma eficaz exige esforços interdisciplinares que conectem dados locais a contextos globais, promovam a alfabetização científica e implementem estratégias educacionais robustas. O fortalecimento da infraestrutura de coleta de dados meteorológicos e a promoção de uma comunicação científica acessível são passos essenciais para superar os desafios impostos por esse tema complexo, contribuindo para um futuro mais responsável, sustentável e informado.

2.1 Hipótese

A compreensão de temas relacionados à climatologia, como as mudanças climáticas, é frequentemente desafiadora devido à sua complexidade. Nesse contexto, trabalhar o clima em escala local, por meio de dados meteorológicos de qualidade, pode ser uma abordagem eficiente para promover a ciência, a educação e a comunicação em clima.

2.2 Objetivo geral

Utilizar dados de estações meteorológicas para abordar temas de climatologia como ICU, de forma prática e acessível, conectando-o ao cotidiano de uma comunidade específica em escala local-regional, a fim de promover a educação e o engajamento quando da comunicação científica.

2.3 Objetivos específicos

- 1: Entender qual a influência da mídia na divulgação de notícias sobre mudanças climáticas no Brasil.

- 2: Analisar como vem ocorrendo a educação em mudanças climáticas no contexto brasileiro.

- 3: Observar quais os problemas relacionados ao ensino-aprendizagem de mudanças climáticas na região sudeste do Brasil.

- 4: Analisar as metodologias de análise de fenômenos climáticos (como ICU) existentes e a partir disso compreender o modo de avaliação coerente com as características de cada área de estudo.

- 5: Evidenciar a influência das ICU em Indaiatuba, a partir de dados de temperatura na região, facilitando a contextualização destes e a comunicação com a comunidade local.

- 6: Identificar e propor soluções para reduzir a lacuna de dados meteorológicos e climatológicos no Brasil.

Os objetivos específicos foram elaborados a partir do objetivo principal e são contemplados em diferentes artigos, conforme Figura 1.

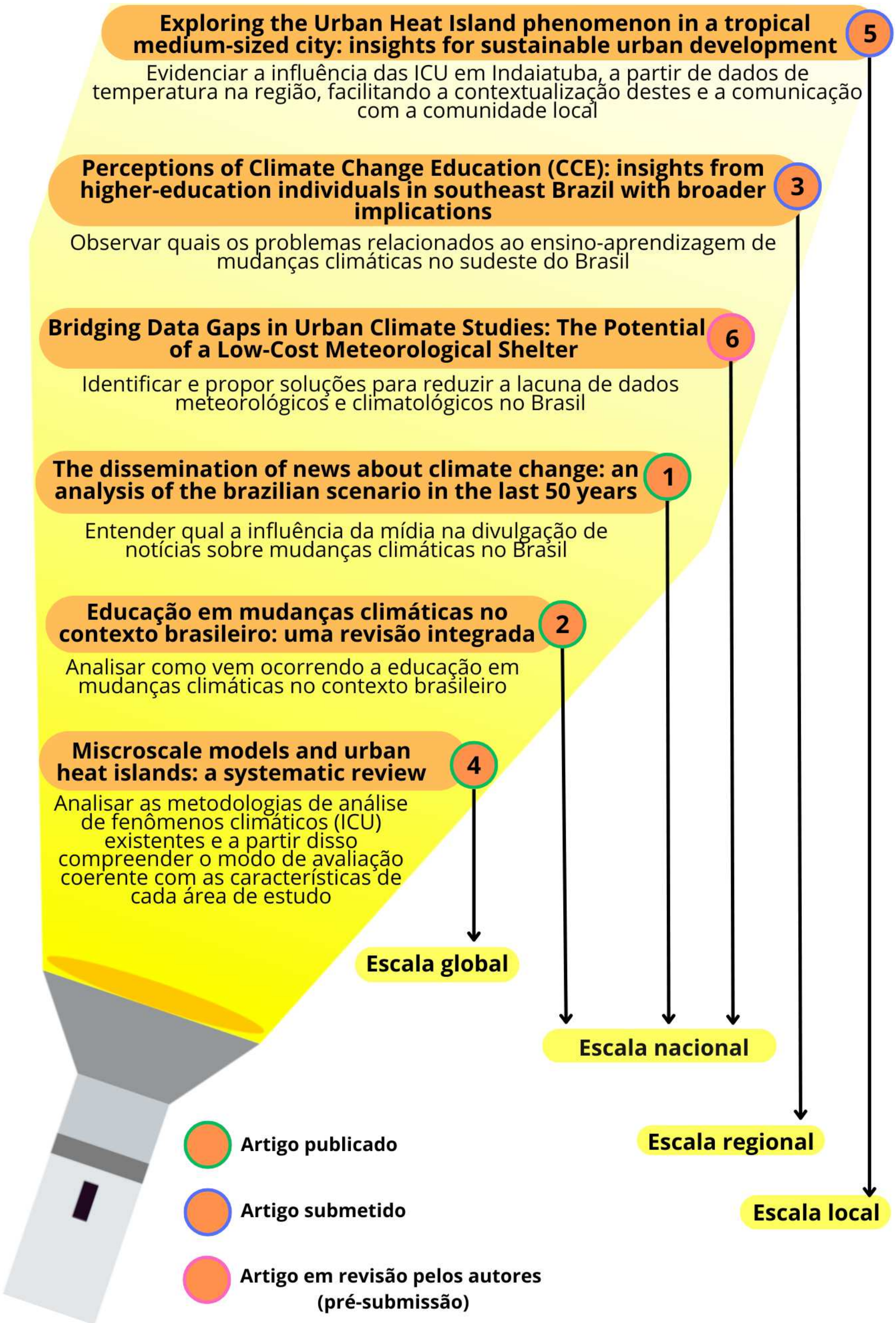


Figura 1: Descrição dos artigos publicados e submetidos que correspondem aos objetivos específicos descritos (com a numeração correspondente), compondo a tese.

2.4 Estrutura da tese

A presente tese foi organizada em diferentes capítulos, em que o primeiro faz uma apresentação geral da tese, demonstrando como o doutoramento teve início e se desenvolveu nos últimos 5 anos. Nesse capítulo é relevado o "fio condutor" dessa tese – o uso de dados meteorológicos para estudos do clima local, contemplando as influências sobre a ciência, educação e comunicação das ciências do clima. Além disso, são apresentadas outras produções científicas realizadas durante os anos de doutoramento.

Em seguida, é apresentado o segundo capítulo, que contempla a introdução e os objetivos da pesquisa, dando ênfase à hipótese e ao detalhamento dos objetivos específicos. Nesse capítulo, os contextos que permeiam a base dessa pesquisa são apresentados e reforçados. Nesse sentido, cada objetivo especifico dessa pesquisa culminou em um artigo cientifico que já foi publicado, está submetido ou sob revisão dos autores para posterior submissão.

O terceiro capítulo é referente ao primeiro artigo da série de artigos proposta para a tese. Este artigo apresenta uma revisão da bibliografia e aborda a influência da mídia na difusão e entendimento de conceitos relacionados às mudanças climáticas para a população brasileira, considerando um período de 50 anos. Nesse artigo é possível visualizar como as diferentes mídias possuem públicos específicos e maneiras próprias de comunicar. Além disso, nota-se a evolução quanto a divulgação de notícias sobre clima e meio ambiente na mídia. O artigo está escrito em inglês exatamente como foi publicado na Revista Caminhos da Geografia (revista Qualis A1) (10.14393/RCG249465663).

No quarto capítulo, consta um segundo artigo, que levanta a discussão sobre as dificuldades no ensino de mudanças climáticas no cenário brasileiro. A partir de uma revisão bibliográfica integrativa, evidenciou-se que há muitos problemas relacionados à educação em mudanças climáticas, que compreendem especialmente, a falta de preparo do professor em sala de aula para abordar um tema de grande complexidade, assim como a falta de materiais complementares que auxiliem o professor. Esse artigo também está exatamente como foi publicado na Revista *Terrae Didática* (revista do Programa de Pós-Graduação em Ensino e História em Ciências da Terra) (10.20396/td.v18i00.8671305).

O quinto capítulo contempla o artigo submetido à revista *Prospects* (https://link.springer.com/journal/11125) e que se encontra em processo de revisão por pares. Trata-se de um estudo de caso sobre educação em mudanças climáticas, realizado durante o período da pandemia e que, portanto, a metodologia de questionários se desenvolveu totalmente de forma online, através do *Google Forms*. Nesse artigo observamos com mais detalhe como se deu a educação em mudanças climáticas entre uma amostra seleta da sociedade, que abrange majoritariamente pessoas com graduação e pós graduação. A partir dos dados obtidos notamos forte interesse no tema, mas também falta de entendimento de alguns conceitos, o que é bastante problemático. Em razão dos resultados, inferimos algumas razões para termos observados esses dados em uma parcela da população na qual se esperava maior nível de conhecimento e entendimento de temas científicos.

O sexto capítulo retrata uma revisão sistemática da literatura sobre o uso de modelos em microescala na avaliação de ICU. Essa revisão foi pensada a partir da dificuldade de medições do fenômeno em campo e a pergunta cientifica do artigo foi: Quais as metodologias existentes na atualidade para mensurar ICU? Assim, essa revisão contou com a análise de 251 artigos científicos, culminando em 68 documentos que exemplificaram os principais modelos de microescala utilizados, mas enfatizaram, em contrapartida, a importância do uso de dados de campo em estudos do clima urbano. No que tange ao Brasil, discutiu-se no artigo como a falta de investimentos em centros de pesquisa e universidades dificulta o desenvolvimento de trabalhos de campo e, por conseguinte, análises do clima urbano. Este artigo também está escrito em inglês, da mesma forma como foi publicado na Revista *Environmental Monitoring and Assessment*, da Springer (10.1007/s10661-023-11906-2). Ressalta-se que esse artigo foi realizado em conjunto com o Prof. Dr. Vincent Dubreuil, da Universidade de Rennes 2, onde foi realizado um período de doutorado sanduíche. Nesse sentido, menciona-se que para a realização desse estágio doutoral houve a aprovação do projeto de pesquisa pelo Campus France e concessão da bolsa *France Excellence Eiffel*, concedida a alunos com excelência acadêmica.

Já no sétimo capítulo, consta outro artigo que está em processo de revisão por pares na revista *Environmental Monitoring and Assessment*. Trata-se de um artigo sobre a ocorrência e frequência das ICU em Indaiatuba (São Paulo - Brasil). Foram coletados dados de campo de temperatura durante o ano de 2022, a partir dos quais foi possível avaliar o desenvolvimento desse fenômeno no município. Notou-se a ocorrência de ICU especialmente durante a época seca, com destaque ao mês de Julho, mas também observaram-se ICU na época chuvosa, mas em menor frequência e intensidade. Os resultados relacionados ao uso e ocupação do solo confirmam que locais mais urbanizados apresentam maiores temperaturas mínimas, quando comparados com locais mais arborizados e/ou distantes do centro urbano, o qual é mais densamente construído.

O oitavo capítulo apresenta o artigo que será submetido à uma revista internacional e aborda a construção de um abrigo meteorológico de baixo custo. Nesse artigo, foi desenvolvido e validado um abrigo meteorológico de baixo custo, adequado para estudos de climatologia urbana no Brasil. Conforme explicitado, esse trabalho surgiu da necessidade de medir adequadamente o clima urbano, com recursos financeiros bastante restritos. O abrigo foi construído com materiais acessíveis e seguindo padrões da Organização Meteorológica Mundial (OMM), provando-se confiável e replicável, além de oferecer uma solução prática para instituições com recursos limitados. Este artigo se destaca pela contribuição quanto à democratização da coleta de dados climáticos, especialmente no que tange a fenômenos como as ICU, e sua adequação ao clima tropical.

O nono capítulo refere-se as discussões da tese, retomando os principais achados de cada artigo e interligando as descobertas cientificas. Nesse capítulo, a hipótese e os objetivos da pesquisa são retomados e discutidos, a partir dos quais pôde-se apresentar direcionamentos para pesquisas futuras. Na sequência, o décimo capítulo se refere as considerações finais da tese.

O décimo primeiro capítulo contempla as referências bibliográficas utilizadas ao longo da tese, mas a parte dos artigos. Por fim, o décimo segundo capítulo apresenta os anexos da tese, que se referem as autorizações das revistas em que os artigos foram publicados, para sua reprodução.

CAPÍTULO 3 – THE DISSEMINATION OF NEWS ABOUT CLIMATE CHANGE: AN ANALYSIS OF THE BRAZILIAN SCENARIO IN THE LAST 50 YEARS

3.1 Abstract

The understanding of scientific topics by society is considered complex and the different media play an important role when trying to transmit information. This study sought to contextualize how the communication of climate change occurred, considering the last 50 years and highlighting the Brazilian scenario, through an integrative literature review. Sixty-three articles were used, from which it became evident that the transmission of news by the media has always presented problems at different scales, having strong political influence and inclinations to the economic moment. The results also showed the high level of disinformation and misinformation, especially in digital media, worldwide. In Brazil, television remains the most used media, but in which little attention is perceived to scientific matters. Finally, the present research brings as a novelty to the state of the art, the indication of important questions to be answered and complemented in this area of study, such as the possibility of works to understand the public's relationship with the various media, with regard to the consumption, interpretation and appropriation of news.

3.2 Introduction

Climate change is frequently understood as a complex topic by the general public, and many people obtain information about it through the media (PAINTER; KRISTIANSEN; SCHÄFER, 2018; AREIA et al., 2019). Researches also show that there is a decline in the public that believe in climate change and the media may have a perceptual of responsibility for this panorama (SMITH, 2005).

Between the years 1970 and 2020, the climate issue has gained greater visibility in the media, as this topic encompasses socio-environmental and economic dimensions, generating greater interest. Intergovernmental Panel on Climate Change (IPCC) has also gained space and prominence in different media in recent years (BERGLEZ and AL-SAQAF, 2020).

Therefore, the media plays an important role in communicating critical information about climate change, affecting the public's perception of this issue (ASHLIN and LADLE, 2007; PASQUARÉ and OPPIZZI, 2012). Media can be recognized as one of the main sources of knowledge for the public (AREIA et al., 2019; CARVALHO, 2010).

The media acts like an agent of transformation, which can affect the social understanding of environmental problems (CARVALHO, 2010), explain and expose concepts, laws and diverse content, that can help the society take decisions based on this knowledge (AREIA et al., 2019).

It is important to emphasize that the mass media transit between scientific discourse, political discourse and the public sphere (MITTAL, 2012; IPING et al., 2019), playing a key role in risk perception (ALLAN; ADAM; CARTER, 2000), for example. In addition, they influence public opinion and the process of public policy formulation (MITTAL, 2012; GUARENGHI et al., 2018; PAINTER; KRISTIANSEN; SCHÄFER, 2018).

In this way, problems appear with the transmission of information, as the scientist is used to communicating in a certain format, with a specific level of detail and in a more technical language, which can be problematic for the understanding of the message (SOMERVILLE and HASSOL, 2011). At the same time, when the communication is not made by scientists, the journalistic media commonly confuses some climate concepts, not using adequate words or expressions to explain these concepts (SOMERVILLE and HASSOL, 2011; PASQUARÉ and OPPIZZI, 2012).

Several studies have introduced other problems around the concepts of climate change conveyed in the media, through different means of communication, such as newspapers, internet, movies or television (PASQUARÉ and OPPIZZI, 2012), which depend on different issues, such as economics and policy in each country (MANCINI, 2000). Likewise, Vu, Liu and Tran (2019) confirmed that the levels of development of each country, with regard to the political and social environment, have a significant influence on the media framing.

In addition to the above, the rise of the internet and, later, social media has profoundly changed the way the public, especially the younger ones, acquire and appropriate information, particularly in the scientific field (BRAINARD, 2015).

Considering the foregoing, the objective of the present work was to analyze the evolution of the communication of scientific themes, especially climate change, from an integrative review of the literature. For this, the last 50 years were considered as a temporal scale and the world scenario as a spatial scale, seeking to highlight the changes observed in the scenario of Brazilian scientific communication. Furthermore, we sought to highlight the media that publish environmental news, as well as the potential and problems associated with each one.

3.3 Material and methods

The present research was carried out from an integrative literature review, which enabled a broad approach to climate change and the communication of scientific issues, using data from the theoretical and empirical literature (SOUZA; da SILVA; CARVALHO, 2010).

The scheme (Figure 1) presented the methodological steps realized during the integrative literature review.

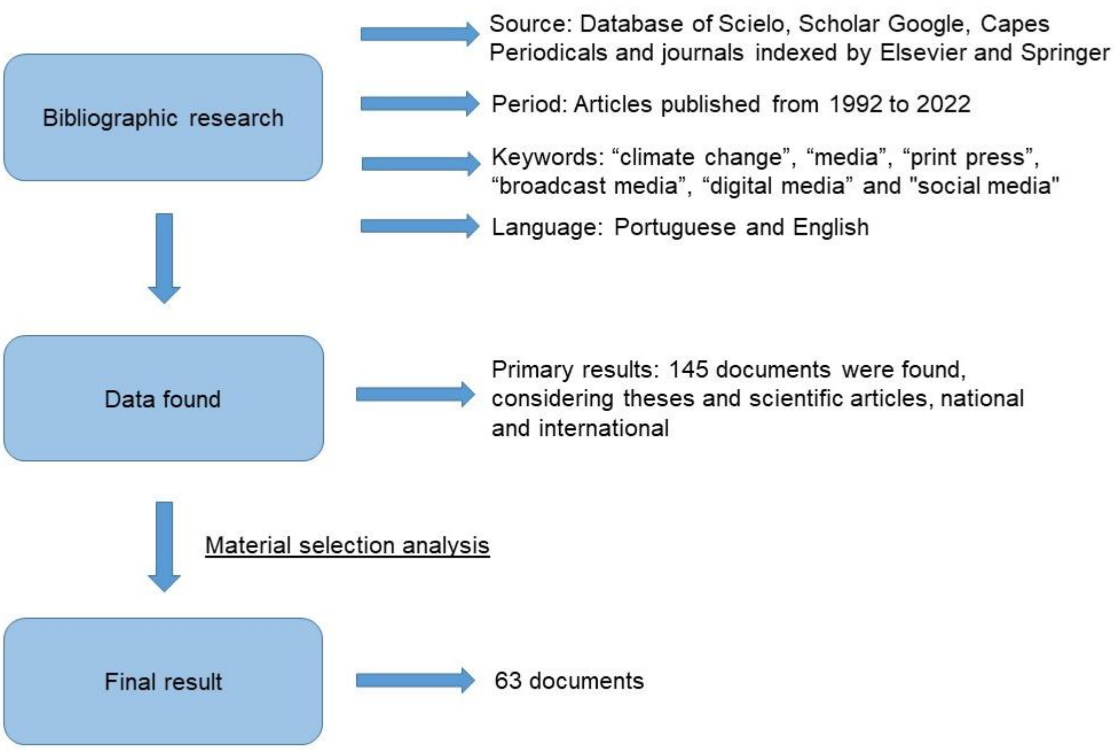


Figure 1: Methodological scheme applied to execute the integrative literature review. Source: Own Authorship.

The integrative review carried out in the study considered a period of 30 years in the search for academic documents, such as thesis and papers published from 1992 to 2022, providing a look at the evolution of the state of the art on the subject in the last 50 years.

The preceding documents were obtained from the database of Scielo, Scholar Google and Capes Periodicals, through the CAPES theses database, from postgraduate programs at Brazilian universities, as well as from journals indexed by Elsevier and Springer, allowing a survey of national and international research.

The investigation in the aforementioned databases was based on the selection of keywords, either jointly or separately, such as: “climate change”, “media”, “print media”, “broadcast media”, “digital media” and "social media", these terms were searched in Portuguese and English.

From this research, 145 documents were found, which underwent a thorough reading of their abstracts, methodology and conclusion, to meet the material selection criteria, shown in Figure 2, totaling a final volume of 63.

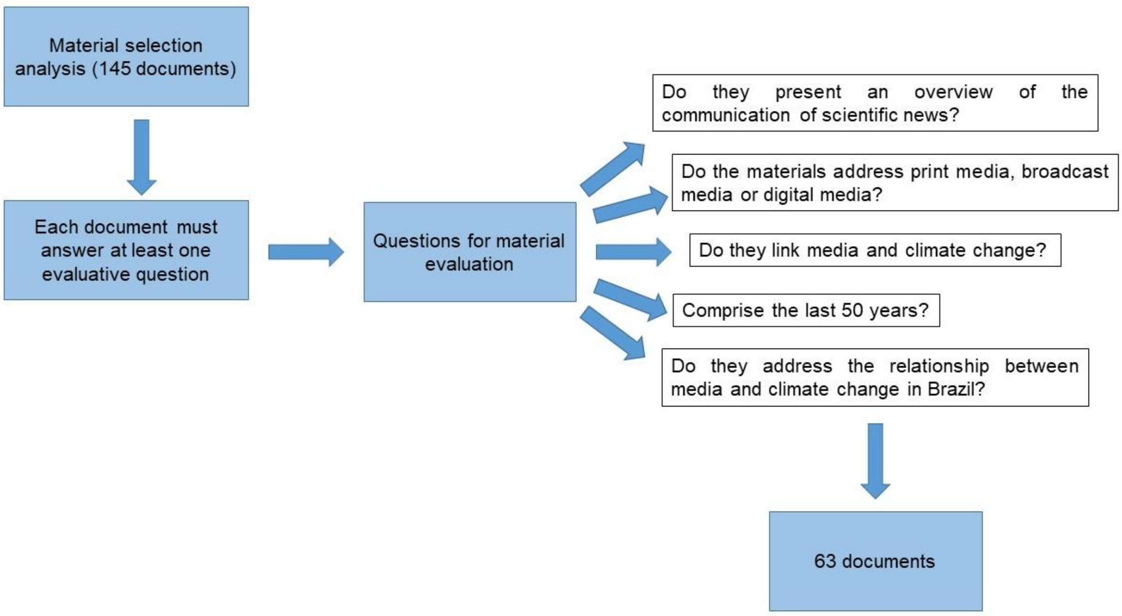


Figure 2: Considerations for the evaluation of previously found material and obtaining the materials used in the results of this article. Source: Own Authorship.

Through the integrative review, it was possible to answer specific questions related to the objective of the research, such as:

a) What have been the changes in the way of communicating scientific news about climate change in the last 50 years?

b) How scientific topics, such as climate change, were and are they publicized?

c) Are there problems with the dissemination of scientific news?

d) How can different media help to make the population aware of scientific issues?

Finally, to arrive at the results, the materials found were evaluated according to the media division of Ganapathy (2021), which considers print media, broadcast media and digital media.

3.4 Results and Discussions

63 documents were selected after a detailed evaluation of the materials found from the methodology described above. Some of the selected materials contemplated the theme in a broader way, while others approached a specific type of media. Thus, from the selected documents, it was possible to contemplate the objective of this research, discussing the questions presented in the methodology.

Then, a brief discussion of the different media is presented, as they gained space in social daily life, with regard to the dissemination of news about climate change and considering the division of Ganapathy (2021). Thus, to meet the proposed objective, as well as its specifications, the results were divided into two parts, in which the first makes a general approach to the types of media, while the second contextualizes the Brazilian scenario in the media, both relating to climate change.

The dissemination of news about climate change on media

The last 30 years were marked by the occurrence of conferences on climate change and the consequent increase in the number of publications on the topic, where scientific discourses gained greater prominence in the different media (DUNLAP and McCRIGHT, 2015; PAINTER et al., 2020).

Regarding climate scientists, from the 2000s onwards, there was a need to highlight events related to climate change, but mainly, to improve the way data were communicated to society (PAINTER et al., 2020).

The Intergovernmental Panel on Climate Change (IPCC) was, and still is, one of the first forms of communication in the technical-scientific field, as it informs policymakers about the global impacts caused by climate change (IPCC, 2021). The IPCC does not conduct scientific research, but presents the greatest scientific findings on the subject, providing reliable and relevant data (SOMERVILLE and HASSOL, 2011). The IPCC's first cycle of assessment reports began in 1990, highlighting the challenges and consequences of climate change at the global level and underlining the need for international cooperation. The IPCC is currently in its sixth reporting cycle, in 2022 (IPCC, 2021).

Given the importance of IPCC reports, one can also see the critical role of scientists in communicating their findings (SOMERVILLE and HASSOL, 2011). However, it is interesting to point out the difficulties encountered by the researchers, as the way they communicate is very different from the way the public is used to receiving the news. Scientists transmit their results in a technical way, in scientific journals, and the public, generally laymen to science, is not trained to understand them (SOMERVILLE and HASSOL, 2011). With this, the public often understands climate change only as an environmental issue, while it should be framed as a political and economic issue, which strongly interferes in societies and their development (SOMERVILLE and HASSOL, 2011). Therefore, it is necessary to improve the communication channel between the different sectors of society (NISBET and SCHEUFELE, 2009).

Given this scenario, the media appears as the main channel of communication between the different social sectors, as it is their role to present or evaluate information, disseminating it (JASNY; WAGGLE; FISHER, 2015; CARMICHAEL and BRULLE, 2016). The media is the most important source of information on various subjects for the public, including news about climate change (PASQUARÉ and OPPIZZI, 2012), this is because the teaching of this topic in school grades is recent in most countries or not yet official. Climate and environmental issues commonly appear in the media linked to visual appeals to mobilize the interest and engagement of the population, which ends up playing a different role in this process (NICHOLSON-COLE, 2005), by neglecting real images on the subject.

In this context, the role of the media in shaping public opinion on different social, political, economic and environmental issues is highlighted (SCHMIDT; IVANOVA; SCHÄFER, 2013). Latin American countries are considered some of the most vulnerable to climate change, facing multiple environmental problems (LOPÉZ et al., 2020), where the population receives information on these issues, mainly through the mass media (MERCADO, 2012).

It is understood that the media acts in the distribution of texts, images and sounds to a diverse audience through different media (McQUAIL, 2005). With this, the media presents itself as an agenda of production, reproduction and transformation, influencing the social construction of different issues (CARVALHO, 2010), including mediating the dissemination of information among different audiences, from the most lay to the most specialized, especially on scientific topics (AREIA et al., 2019).

Following the proposal by Ganapathy (2021), the media can be separated into three segments, namely: print media, which includes newspapers, magazines, books; broadcast media, which refers to radio, television and film, and digital media, which includes websites and the various social media platforms. At that point, an overview of the different types of media will be presented (according to Ganapathy, 2021), addressing the issues related to each one, as well as its importance.

Print Media

In print media, climate change is often portrayed as a controversy, as many newspapers present both sides of the issue as equally credible (SOMERVILLE and HASSOL, 2011), which can make the issue more confusing to the reader. In this sense, the lack of scientific journalism interferes negatively in the formulation of public policies (VU; LIU; TRAN 2019), generates a lack of coverage, less understanding on the part of the public that prefers the print media, in addition to promoting doubts about the theme and issues correlated (SOMERVILLE and HASSOL, 2011).

In addition, some framing made by journalists for the construction of news can influence the way the news is received by the public. In this case, Semetko and Valkenburg (2000) report the occurrence of five frames used by the media: conflict, (economic) consequences, responsibility, human interest and morality. In view of the above, it is observed that some of the journalistic coverage regarding climate change uses dramatization to attract public attention (PAQUARÉ and OPPIZZI, 2012).

In the big media (major magazines, newspapers, news) environmental news, especially those that include issues such as climate change and weather, compete with political, economic and social news, such as crimes and terrorism (KALHOEFER, 2017). As well as the different framings that the media can give about the news regarding climate change, the coverage and volume of information can also vary between countries, due to political and economic issues, for example.

In the United States of America, newspapers tend to report scientific uncertainties about the veracity of global warming and other climate issues, this discourse being dominant in some of the country's newspapers and, consequently, interfering in the way its citizens see climate issues (ZEHR, 2000). A study carried out in 2017 by Kalhoefer showed that, in the United States, about 1% of headlines are devoted to environmental issues. However, when the news appeals to an important local impact or even strong scenes of destruction, as in the case of extreme events, affecting families, for example, this information is boosted and replicated to the community (SHEPPARD et al., 2011).

Swedish journalism, according to the analysis of Olausson (2009), focuses on the framework of collective action, which is the most popular framework used by the print media in the country, which is reluctant to use uncertainty as the United States of America does. However, in developing countries, the dissemination of news about climate change can be even more complicated and in contrast to developed countries, as pointed out by Billett (2010) in his study on India, where environmental aspects are emphasized to the detriment of scientific data, promoting a nationalist and development-oriented position.

Regarding the print media, as well as all media, the use of images attaches great value to the news that accompanies it, being in itself a means of transmitting information and changing people's perception, inducing positive emotions and negative. It is noteworthy, therefore, that greater attention is needed to the use of images related to scientific topics, such as climate change, preferring real and motivating images that serve as an incentive to the public (NICHOLSON-COLE, 2005).

Broadcast media

Among the means of transmission, radio presents local, national and even international content, with a broad informative focus, including conversations with experts in various subjects, including scientists. Radio appears, therefore, as a means of great reach, capable of conditioning the opinion of the great mass on certain subjects.

According to Hamilton (2014), public radio stations in the US, specifically in New Hampshire, are strongly inclined to present their listeners with scientific data, persuading them to trust science and accept the scientific consensus on climate change. At the same time, it is noted that there is a local preference for public radio's due to the communicative style they have, which is, this source of information is preferred because of the scientific position it adopts.

The positioning of radio stations as to whether they are conservative or non-conservative also influences the news that will be disseminated and the way they will be disseminated through this means of communication. Comparisons between the content expressed by the conservative and non-conservative media regarding the framing of climate change present significant divergences (NISBET 2009; FELDMAN et al., 2012).

Television, as another strong means of mass communication, also presents different framings on news related to climate change, in which the news tends to follow the same logic as radio, having channels that are more conservative and others less conservative. Mention is made of the study by Feldman and colleagues (2012), in which the Fox News network appears to be quite conservative in denying the impacts of anthropogenic climate change, as well as its secondary effects, compared to other American cable television channels (FELDMAN et al., 2012).

Television news is, for many people, the only source of information, especially regarding environmental questions, demonstrating the power that this broadcast media has in terms of the possibility of raising public awareness of environmental issues (COOPER, 2011). With regard to films, especially those that depict the impacts of climate change, Manzo (2017) states that they are an important form of communication and that they provide an impetus for public engagement on concerns frequently raised in various scientific studies. Some widely broadcast films that had great television repercussions have already promoted many analyzes and debates regarding scientific dissemination and communication on climate change. This is because science communication material plays a notable role in conveying scientific messages to the public.

It is interesting to cite the Al Gore documentary, "An Inconvenient Truth" that portrays climate change, as Jacobsen (2011) indicates that there was an increase in the number of people who believe in global warming and its complications in the period in which the documentary was in exhibition, demonstrating that this type of communication can have a positive effect on climate awareness. According to Kjeldsen (2013) the images used in this documentary, in particular, were essential for the notion of the impacts arising from climate change, functioning as a strong argument on the subject.

As for films, the 2022 Oscar nominee, in multiple award categories, Don't Look Up (McKAY, 2021), highlights the different ways of communicating a catastrophic threat to the planet, the way politicians act, the influence of digital media and the strong disinformation and misinformation of society (DAVIS and LEWANDOWSKY, 2022). Disinformation is characterized by the manipulation of information, while misinformation is the dissemination of false or erroneous information, but without the author knowing that this information does not correspond to the true (GERBINA, 2021).

In this case, films known as Hollywood Science blockbusters or science fiction are a genre that arouses interest and has a large reach and audience (MANZO, 2007). However, some concerns arise about how accurate the scientific message disseminated through this genre is (KIRBY, 2014). Regarding communication on climate change, Sengupta (2013) points out some films as those that directly address science and those that do so indirectly.

Still with regard to films, documentaries appear as another aspect of cinematographic content that attract a more specific audience interested in particular causes, while blockbusters captivate a wider and sometimes less informed audience (MANZO, 2017).

In view of the above, it is essential to emphasize that some research indicates that both print and broadcast media are sometimes primary sources of information for the population, stressing again their important communicative role (SAMPEI and AOYAGI-USUAI, 2009).

Digital media

Historically, communication channels such as newspapers, radio and television were important mediators of climate discourse, influencing discussions about the connection between climate change and other events, deciding what would be discussed and in what way. However, the media landscape has changed radically with the emergence and growth of the internet and, therefore, social media. It all started in the 1990s, with the decline of publicity used in printed newspapers in many Western countries and the rupture in communication patterns caused by the internet. Faced with the situation, media organizations followed, which began their activities on digital platforms, but not as extensions of printed newspapers or television stations, but as their own websites or mobile applications (PAINTER; KRISTIANSEN; SCHÄFER, 2018).

Thus, with the advent of the internet, searches for information, including those of a scientific nature, began to be done through websites and other platforms, especially by the young audience, affecting traditional media, since the reach of the internet is incomparable (BRAINARD, 2015). Social media, in turn, appears as a consequence of digital media, standing out in the virtual environment, as it is a means in which it is possible to access news, comment and even engage in debates on different topics (ROXBURGH et al., 2019).

In this context, it should be clarified that the term social media encompasses several platforms, such as social networks, blogs and video and photo sharing sites, with strong emphasis on Facebook, Instagram and Twitter, which attract greater attention because they are used in political discussions and act as means of mobilization among young people (GANAPATHY, 2021). Twitter, in particular, has been standing out among social networks, as it allows its users to interact through short messages, generating around 500 million tweets daily (COSTOLO, 2012). This social network has become a source of observational data for social and natural scientists, given its potential for interaction between different people, who currently use it to post observations about everyday events (KIRILENKO; MOLODTSOVA; STEPCHENKOVA, 2015).

Given the above, digital media is seen as a potential way to improve the relationship between citizens and their representatives, bringing them closer (COLEMAN and BLUMLER, 2009). However, discussions on scientific topics, such as climate change, often occur through political, cultural or meteorological data, which intersect and generate controversy rather than promising discussions (GANAPATHY, 2021).

Among the characteristics of digital media, two are most striking and essential to influence the population and their actions, namely the possibility of expression and consumerism. In this sense, digital media allow the population to express their opinions on any subject and interact with other people, whether they have similar or contrary opinions. A second point, that of consumerism, refers to the possibility of people consuming different information, regardless of the veracity of the facts, and it may even be fake news spread by laypeople (GLADSTON and WING, 2019).

When it comes to digital media, and especially social media, the term "fake news" appears and gains relevance. This term is not new when it comes to the media, but its use has been frequent and is related to the concepts of disinformation and misinformation. This is because, with social media, fake news had a new reach and its dissemination became faster and more comprehensive (GERBINA, 2021). It is important to mention that "misinformation" can be defined as incorrect information, which was accidentally transmitted in the wrong way, while "disinformation" triggers an intention to bring false information to the public (SCHEUFELE and KRAUSE, 2019).

In general, and despite the negative points presented, digital media are seen as a valuable source of data that support the debate of current issues, where all individuals, regardless of their origin and culture, can freely share their opinions (LOUREIRO and ALLÓ, 2020), also contributing to the creation of political and social bonds and associations (HESS and MAKI, 2019).

A summary of the main data found on the types of media in the general analysis presented is illustrated (Figure 3).

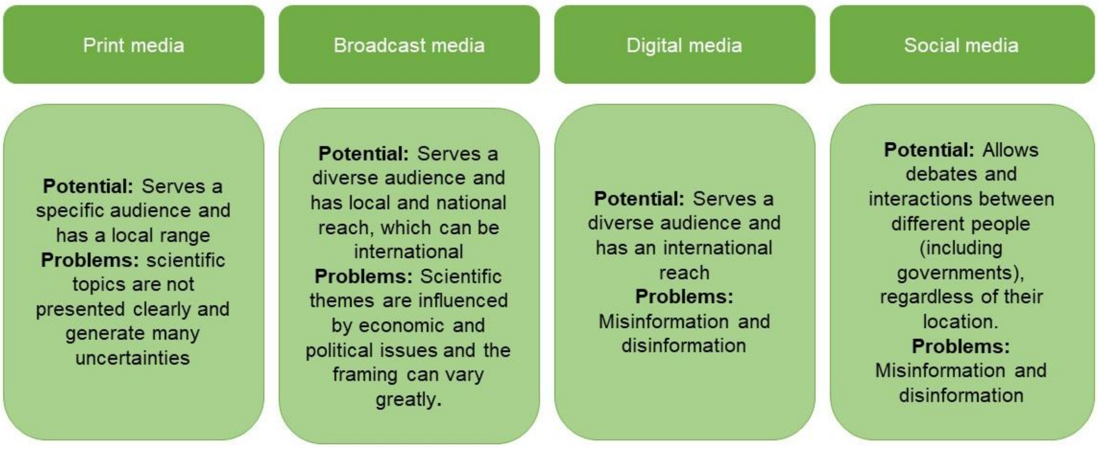


Figure 3: Summary of key results across print media, broadcast media, digital media and social media, highlighting potential of communication and associated problems. Source: Own Authorship.

The Brazilian scenario

Latin American countries are highly dependent on their natural resources and have historical social inequalities, reasons for which they can already be considered vulnerable in the face of climate change. In addition, specific issues in each country aggravate this situation. In Brazil, demographic pressure associated with unplanned urban sprawl are factors cited in the Brazilian Panel on Climate Change-PBMC (2013).

Considering exports, the issue of climate change gains even more importance in the national territory, and as a result, the press has been dedicating more space and time to the subject, especially at times when important reports and studies on the subject are made available, such as the IPCC, the World Bank, the IPEA, among others (COSTA BUENO, 2013; OLIVEIRA; CARNEIRO; VECCHIA, 2017; RODAS and DI GIULIO, 2017).

According to Gutierrez (2022), the Brazilian media remains focused on the consensus of economic development, ignoring the environmental debate for considering it alarmist rhetoric, contrary to the country's economic goals. The coverage of environmental issues by the Brazilian media began in the early 1970s, due to the international trend of monitoring and disseminating environmental and climate issues (CARVALHO and LOOSE, 2018).

Costa (2006) states that there was an intensification of journalistic coverage on environmental issues in the 1980s, with the attention given by the media to these issues being even more prominent at the end of this period, with the dissemination of satellite images demonstrating the fires in the Amazon (1987), as well as the promulgation of the new Brazilian Constitution (1988). At the same time, NGOs (Non-governmental organizations) began to gain more space in publications, especially on the international scene.

The 1990s maintained intense media coverage of environmental issues, with a high point during Rio-92 (1992) and the drought periods caused by El Niño, which culminated in large forest fires in Roraima (COSTA, 2006). From the 2000s onwards, different peaks were observed in which the media addressed environmental and climate issues more frequently, due to different events that unfolded in this period, among them the G8 Summit (2005), Hurricane Katrina (2005), the release of the film "An Inconvenient Truth" (2006) and the release of the 4th IPCC Assessment Report (2007) (GRUNDAMANN and SCOTT, 2012).

In view of the above, a timeline of the evolution of the media is presented (Figure 4), in Brazil and in the world, with emphasis on the dissemination of news about the environment in Brazil, according to studies by Miranda (2007), Costa (2006) and Painter, Kristiansen and Schäfer (2018).

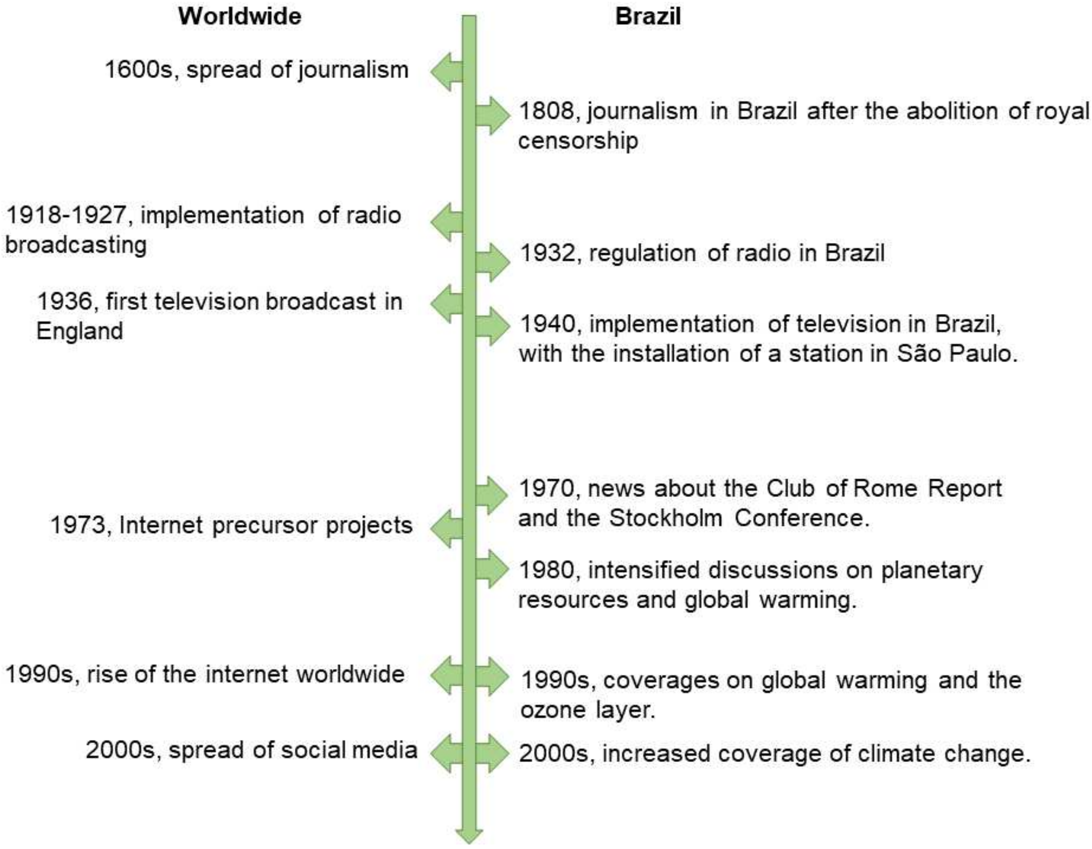


Figure 4: Timeline of the evolution of media throughout history, highlighting the Brazilian scenario and the dissemination of news about the environment in the Brazilian media. Source: Own Authorship.

Given the relevant role of the media, together with the expansion of the public debate on climate change, the last 20 years have been marked by the realization of different works in this field of study (OLIVEIRA; CARNEIRO; VECCHIA, 2017). According to Costa Bueno (2013 apud ALBUQUERQUE, 2012), the Brazilian media system focuses on television, where 77% of the population uses this means of communication daily as a source of information, thus being part of the country's culture. In second place is the internet, which is used by more than 50% of Brazilians daily to obtain information, a percentage that has been growing. Radio occupies the third place among the most used media by Brazilians, while newspapers have a much smaller circulation, representing only about 8% of the population, because this medium is intended for a small portion of society, considered elite (COSTA BUENO, 2013 apud ALBUQUERQUE, 2012).

Corroborating what has been pointed out, the study by Nunes (2009) analyzed the information on weather and climate published in the newspaper “O Estado de S. Paulo” (OESP) in 2008 on a daily basis, finding that OESP readers are mostly from the ruling classes (A, B and C) and that the themes and approaches of this journal are guided by their interests.

Considering the Brazilian TV programming, Ferreira (2009) evaluated some journalistic programs that deal with environmental themes, especially “Globo Repórter” and “Globo Ecologia”, as well as some films that focus on the same theme (such as “The day after tomorrow ” and “The inconvenient truth”), verifying that the media reproduces current capitalist precepts, so the coverage of environmental issues in these media is characterized by spectacularization, which aims to increase the audience and, therefore, favor the sponsored. Another study of the television media, among the few that exist, analysed the program “Fantástico” on TV Globo, noting that in this case, scientists were the most present sources of information, followed by government representatives, demonstrating the possibility of delving into environmental issues (SCALFI et al., 2013).

In general, the media, being dominantly linked to the current economic system, acts in the coverage of environmental issues in a shallow way (RODAS and Di GIULIO, 2017), emphasizing catastrophes (COSTA BUENO, 2013) in the information transmitted by the Brazilian media, postures that are adopted in the process of contemporary journalistic production regarding environmental journalism.

The study by Agência de Notícias dos Direitos da Infância (ANDI) identified that an insignificant number of journalistic materials dealt with basic environmental concepts and that less than 25% of the documents analyzed had scientific evidence to prove the problem at hand (COSTA BUENO, 2013).

The work of Rodas and Di Giulio (2017) regarding the dissemination of issues about climate change in the media, with regard to the newspaper “Folha de São Paulo”, between 2000 and 2014, confirmed a significant number of government sources, who associated the journalistic focus on political decisions related to climate change. In this same context, Oliveira (2011) infers that the Brazilian media are exclusively private, and this oligopoliticization of the media tends to have political implications due to the strong relations between corporate and political power in Brazil (FONSECA, 2010). Therefore, the media has deep political-economic relationships (FANTAZZINI, 2008).

Concerning the political issue, Costa Bueno (2013 apud ALBUQUERQUE, 2012) indicates that the Brazilian press has mainly a right-wing orientation. It should be noted, however, that the country has an alternative media with multiple initiatives for the production of independent information (OLIVEIRA, 2011).

Several studies indicate that media coverage of climate change in Brazil is mainly focused on international factors, with little emphasis on national inquiries, as a result, reports on the topic are dependent on international media (FIORAVANTI, 2007).

In view of the above, the media is not only a transmitter of messages, but also acts to foster beliefs, cultures and values, sometimes aiming to maintain the economic and political interests they represent (JUNIOR, 2014).

In this sense, the Brazilian media also has the potential to promote policies on climate change, where their implementation could contribute to mitigating the impacts of climate change (CARVALHO and LOOSE, 2018).

3.5 Final Considerations

The media were and are an important source of scientific information for society, constituting an essential tool for social development through the promotion of scientific knowledge and fostering the creation of environmental policies.

In this context, the last 30 years have been marked by rapid and strong changes in the media due to the emergence and expansion of the internet, as well as the consequent launch of social media in the 2000s. The way of communicating has become faster and more inclusive, allowing debates through social networks, between authorities and common people.

The news began to be transmitted in new ways and the relationship between society and media changed as each means of communication gained space in people's daily lives. Thus, print media, broadcast media and digital media have come to occupy a very particular place in society because of their characteristics, which concern them with different potentialities and problems.

The dissemination of scientific topics in turn, including climate change, demonstrated a pattern, which occurs in different countries and is reflected in the Brazilian scenario, where major environmental events, the launch of a new IPCC report, COP meetings or other climatic manifestations provide a greater volume of news. In this way, cycles are perceived, in which there are moments of greater and lesser dissemination of news about climate change, where scientific findings are directly linked to recent events, not being a directed transmission of academic data relevant to the public's knowledge.

It was therefore noted that the mode of dissemination of scientific topics, such as climate change, has been occurring in the same way throughout the described analysis period, with the difference that intense weather events are becoming more frequent and there are more meetings and ongoing climate agreements, generating greater media attention.

It should be noted that the dissemination of news related to climate change is more superficial and less explanatory in the print media, lacking clear and well-contextualized concepts, given the lack of more specialized scientific journalism.

It was noticed through the review that the vast majority of works on media and environmental issues, such as climate change, analyzed news and ways of communicating through print media. This fact seems a little controversial, considering that the Brazilian media system is centered on television as the main form of news dissemination.

The broadcast media, in turn, is characterized by the spectacularization or trivialization of scientific topics, even today, which generates an emotional and visual appeal, when on television, providing greater audience and more visibility. As a result, the reality of the scientific topic addressed ends up, sometimes, being distorted or generating some confusion for the public.

Despite the relevance of television in the Brazilian media scene, very few studies were found that analyzed the news published by this medium, representing an important gap in this theme. In addition, newspapers, television or radio channels have a political stance, which in most cases will interfere with the way scientific news is transmitted to the public, demonstrating the strong interference that political issues have on the dissemination of science topics.

When it comes to digital media, especially in social media, the issue of misinformation and disinformation are the most frequent problems, as they cause scientific doubts that go unanswered and are quickly disseminated, generating an endless cycle of uncertainties. In addition, there is little government control over this type of media and the dissemination of news, which brings more uncertainty about the development of this form of communication.

Since this media has been growing rapidly, with a high percentage of the Brazilian population using the internet to obtain information, research in this area should be implemented, in order to understand the profile of users, more specific problems (especially with regard to social media) and yet, ways to mitigate existing problems.

Despite all the problems presented, it is extremely important to emphasize the potential of each media, which involve different audiences, scope and dissemination speeds, acting as a tool in raising awareness of different scientific issues.

For this, trying to minimize the exposed problems, encouraging scientific journalism, generating less spectacularization of scientific topics and promoting the control of false information is the beginning, but not enough considering that these are not simple tasks. Even more important than what is proposed, is to enable the development of critical and scientific thinking by society.

At this point, education is focused, which does not necessarily need to be an education regarding the study of climate or climate change, but academic study, which in itself, allows the development of scientific skills, including critical thinking. Concurrently, the implementation of the theme in a transversal way in different journalistic subjects could also collaborate in the understanding of its relevance.

Moreover, to what has been mentioned, there are other interesting possibilities for studies on this topic, since carrying out practical work to understand the public's relationship with the various media (in terms of consumption, interpretation and appropriation of news) is important to know the extension of the problems and ways to minimize them, in addition to what is proposed here.

Understanding also the interference of education in the knowledge of climate concepts conveyed by the media and the social perception on the subject are shown as relevant and significant research considering that the climate is an essential factor in the development of different day-to-day activities.

In view of the above, the great novelty of this research was to contextualize how the communication of climate change has been occurring in the last 50 years, with emphasis on the Brazilian scenario, which allowed the unfolding of new questions and hypotheses.

Thus, the present study responded to the objective initially presented, as well as the subsequent questions, and also indicated possibilities for complementary studies to this area of study, which is still recent and underdeveloped with regard to the Brazilian context.

3.6 Acknowledgments

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for collaboration in carrying out this work.

3.7 References

ALLAN, S.; ADAM, B.; CARTER, C. Environmental risks and the media. **Routledge**, London and New York, 249p. 2000.

AREIA, N.P.; INTRIGLIOLO, D.; TAVARES, A.; MENDES, J.M.; SEQUEIRA, M.D. The role of media between expert and lay knowledge: A study of Iberian media coverage on climate change. **Science of the Total Environment**, v. 682, p. 291-300, 2019. DOI: https://doi.org/10.1016/j.scitotenv.2019.05.191

ASHLIN, A.; LADLE, R.J. Naturaldisasters' and newspapers: post-tsunami environmental discourse. **Environmental Hazards**, v. 7, p. 330–341, 2007. DOI: 10.1016/j.envhaz.2007.09.008

BRAINARD, C. The changing ecology of news and news organisations: implications for environmental news. In: Hansen, A., Cox, R. (Eds.). The Routledge Handbook of Environment and Communication. **Routledge**, London and New York, 454p. 2015.

BERGLEZ, P.; AL-SAQAF, W. Extreme weather and climate change: social media results, 2008–2017. **Environmental Hazards**, p. 382-399, 2020. DOI: https://doi.org/10.1080/17477891.2020.1829532

BIILLET. S. Dividing climate change: global warming in the Indian mass media. **Climatic Change**, v. 99, p. 1-16, 2010. DOI: https://doi.org/10.1007/s10584-009-9605-3

CARMICHAEL, J.T.; BRULLE, R.J. Elite cues, media coverage, and public concern: an integrated path analysis of public opinion on climate change, 2001–2013. **Environmental Politics**, v. 26, p. 232-252, 2016. DOI: http://dx.doi.org/10.1080/09644016.2016.1263433

CARVALHO, A. Media (ted) discourses and climate change: a focus on political subjectivity and (dis)engagement. **WIREs Climate Change**, v. 1, p. 172–179, 2010. DOI: https://doi.org/10.1002/wcc.13

CARVALHO, A.; LOOSE, E.B. Climate change in Brazilian media. In: Brevini, B., & Lewis, J. (Eds.). **Climate Change and the Media**, New York: Peter Lang, pp. 79-94, 2018. Available in:

<https://repositorium.sdum.uminho.pt/bitstream/1822/55759/1/2018_Carvalho_Loose_Climate-change-in-Brazilian-media-preprint.pdf> Accessed in: 30/04/2022.

COLEMAN, S.; BLUMLER, J.G. The Internet and Democratic Citizenship: Theory, Practice and Policy. **Information Communication and Society**, v. 13, p. 1230-1232, 2019. DOI: https://doi.org/10.1080/1369118X.2010.512637

COOPER, C.B. Media Literacy as a Key Strategy toward improving Public Acceptance of Climate Change Science. **BioScience**, v. 61, p. 231-237, 2011. DOI: https://doi.org/10.1525/bio.2011.61.3.8

COSTA BUENO, W. Imprensa e Mudanças Climáticas no Brasil: fontes hegemônicas e pouca atenção aos conceitos. **Razón y Palabra**, v. 17, p.48-64, 2013. Available in:

<https://www.revistarazonypalabra.org/index.php/ryp/article/view/308/344> Accessed in: 28/04/2022.

COSTA, L. M. O esverdeamento da imprensa. **Estudos em Jornalismo e Mídia**, v. 3, p. 41–54, 2006. Available in:

<https://periodicos.ufsc.br/index.php/jornalismo/article/ download/2289/2017> Accessed in: 30/04/2022.

COSTOLO, A. Internet Advertising Bureau's Engage Conference Speech, 2012. Available in: <http:// news.cnet.com/8301-1023_3-57541566-93/report-twitter-hits-half-a-billiontweets-a-day> Accessed in: 30/04/2022.

DAVIS, C.J.; LEWANDOWSKY, S. Thinking about climate change: look up and look around! **Thinking & Reasoning**, 2022. DOI: https://doi.org/10.1080/13546783.2022.2041095

DUNLAP, R. E.; McCRIGHT, A. M. Challenging climate change: the denial countermovement. In: DUNLAP, R.E.; BRULLE, J. (Eds.). **Climate change and society: sociological perspectives**. New York: Oxford University Press, 300332, 2015.

FANTAZZINI, O. **O poder da mídia e os caminhos para a democratização dos meios de comunicação**, 2012. Available in:

<http://www.apropucsp.org.br/revista/r25_r08.htm> Accessed in: 30/04/2022.

FELDMAN, L.; MIBACH, E.W.; ROSER-RENOUF, C.; LEISEROWITZ, A. Climate on cable: the nature and impact of global warming coverage on Fox News, CNN, and MSNBC. **The International Journal of Press/Politics**, v.17, p. 3–31, 2012. DOI: https://doi.org/10.1177/1940161211425410

FIORAVANTI, C. Climate change reporting in Brazil. **Presentation at workshop Carbonundrums: Making sense of climate change reporting around the world**. Oxford, UK. University of Oxford, 2007.

FONSECA, F. Mídia e poder: Elementos conceituais e empíricos para o desenvolvimento da democracia brasileira. **Texto para discussão 1509**. Brasília: Instituto de Pesquisa Econômica Aplicada, 2010. Available in:< http://repositorio.ipea.gov.br/bitstream/11058/2979/1/TD_1509.pdf > Accessed in: 01/05/2022.

GANAPATHY, D. Media and Climate Change: Making Sense of Press Narratives. **Routledge India**. 130p, 2021. DOI: 10.4324/9781003015673

GERBINA, T.V. Science Disinformation: On the Problem of Fake News. **Scientific and Technical Information Processing**, v. 48, p.290–298, 2021. DOI: https://doi.org/10.3103/S0147688221040092

GLADSTON, I.; WING, T. Social Media and Public Polarization over Climate Change in the United States. **Climate Institute**, 2019. Available in:

<https://climate.org/social-media-and-public-polarization-over-climate-change-in-the-united-states/> Accessed in: 28/04/2022.

GRUNDAMMAN, R.; SCOTT, M. Disputed climate science in the media: Do countries matter? **Public Understanding of Science**, v. 23, p.220-235, 2012. DOI: http://dx.doi.org/10.1177/0963662512467732

GUARENGHI, M.M., AZEVEDO, M.de A.; WALTER, A.; CAVALIERO, C.K.N. Barreiras na comunicação e alternativas para auxiliar a compreensão sobre as mudanças climáticas. **Holos**, v. 34, p. 123-134, 2018. DOI: https://doi.org/10.15628/holos.2018.5322

GUTIERREZ, E.P. Local climate change reporting in coastal cities: Selsey (UK), Santos (Brazil) and Broward County (USA). **Ámbitos-Revista Internacional de Comunicação**, v. 55, p. 73-96, 2022. DOI: http://dx.doi.org/10.12795/Ambitos.2022.i55.05

HAMILTON, L.C. Do you trust scientists about the environment? News media sources and politics affect New Hampshire resident views. **Regional Issue Brief No. 40**. Durham, NH: Carsey School of Public Policy, University of New Hampshire, 2014. Available in: <https://scholars.unh.edu/cgi/viewcontent.cgi?article=1213&context=carsey> Accessed in: 30/04/2022.

HESS, D.J.; MAKI, A. Climate change belief, sustainability education, and political values: Assessing the need for higher-education curriculum reform. **Journal of Cleaner Production**, v. 228, p. 1157-1166, 2019. DOI: https://doi.org/10.1016/j.jclepro.2019.04.291

IPCC - Intergovernmental Panel on Climate Change. Climate change 2021: The physical science basis. **Contribution of working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change**. Cambridge: Cambridge University Press, 2021.

IPING, A.; KISDTON-LATTARI, J.; SIMPSON-YOUNG, A.; DUNCAN, E.; McMANUS, P. (Re)presenting urban heat islands in Australian cities: A study of media reporting and implications for urban heat and climate change debates. **Urban Climate**, v. 27, p. 420-429, 2019. DOI: https://doi.org/10.1016/j.uclim.2018.12.014

JACOBSEN, G.D. The Al Gore effect: An inconvenient truth and voluntary carbon offsets. **Journal of Environmental Economics and Management**, v. 61, p. 67–78, 2011. DOI: https://doi.org/10.1016/j.jeem.2010.08.002

JASNY, L.; WAGGLE, J.; FISHER, D.R. An empirical examination of echo chambers in US climate policy networks. **Nature Climate Change**, v. 5, p. 782–786, 2015. DOI: https://doi.org/10.1038/nclimate2666

JUNIOR, L.N. A produção discursiva das mudanças climáticas. **Geografia em Questão**, v. 7, p. 50-64, 2014. DOI: https://doi.org/10.48075/geoq.v7i1.7955

KALHOEFER, K. (2017). **How broadcast networks covered climate change in 2016**. Available in: <https://www.mediamatters.org/donald-trump/how-broadcast-networks-covered-climate-change-2016> Accessed in: 01/05/2022.

KIRBY, D.A. Cinematic science: The public communication of science and technology in popular film. In: BUCCHI, M.; TRENCH, B. (Eds.). **Handbook of public communication of science and technology**. Routledge, New York, p. 41–56, 2014.

KIRILENKO, A. P.; MOLODTSOVA, T.; STEPCHENKOVA, S. O. People as sensors: Mass media and local temperature influence climate change discussion. **Global Environmental Change**, v. 30, p. 92–100, 2015. DOI: https://doi.org/10.1016/j.gloenvcha.2014.11.003

KJELDSEN, J. Formulas of Prize-Winning Press Photos. In: Van BELLE, H.; GILLAERTS, P.; Van GORP, B.; Van de MIEROOP, D.; RUTTEN, K. (Eds.). **Verbal and visual rhetoric in media world**, Leiden University Press, p. 465-489, 2013.

LOPÉZ, M.S.; SANTI, M.F.; MÜLLER, G.V.; GÓMEZ, A.A.; STAFFOLANI, C.; POMARES, L.A. Climate change communication by the local digital press in northeastern Argentina: An ethical analysis. **Science of the Total Environment**, v. 707, Article 135737, 2020. DOI: https://doi.org/10.1016/j.scitotenv.2019.135737

LOUREIRO, M.L.; ALLÓ, M. Sensing climate change and energy issues: Sentiment and emotion analysis with social media in the U.K. and Spain. **Energy Policy**, v. 143, Article 111490, 2020. DOI: https://doi.org/10.1016/j.enpol.2020.111490

MANZO, K. The usefulness of climate change films. **Geoforum**, v. 84, p. 88-94, 2017. DOI: http://dx.doi.org/10.1016/j.geoforum.2017.06.006

MANCINI, P. Political complexity and alternative models of journalism. In: CURRAN, J.; PARK, M.J. (Eds.), **De-Westernizing media Studies**. Routledge, New York, pp. 265–278, 2000.

McKAY, A. (Director). **Don't Look Up [Film]**. Hyperobject Industries, 2021.

McQUAIL, D. McQuail's Mass Communication Theory (6th Edition). London: **SAGE Publication Ltd**. 621p, 2005.

MERCADO, M. El análisis del tratamiento informativo del Cambio Climático. **Actas de las Jornadas Internacionales Medios de Comunicación y Cambio Climático**. Facultad de Comunicación de la Universidad de Sevilla 22 y 23 de noviembre de 2012, 2012. Available in:

<https://repositorioinstitucional.ceu.es/bitstream/10637/7795/1/El%20an%C3%A1lisis%20del%20tratamiento%20informativo%20del%20cambio%20clim%C3%A1tico.pdf> Accessed in: 01/05/2022.

MIRANDA, G.L. A história da evolução da mídia no Brasil e no mundo. **Trabalho de final de curso**. Centro Universitário de Brasília (UniCEUB), Faculdade de Ciências Sociais Aplicadas (FASA), Distrito Federal, Brasília, 2007.

MITTAL, R. Climate Change Coverage in Indian Print Media: A Discourse Analysis. **The International Journal of Climate Change: Impacts and Responses**, v. 3, p. 219-232, 2012. DOI: https://doi.org/10.18848/1835-7156/CGP/v03i02/37105

NISBET, M. C. Communicating climate change: why frames matter for public engagement. **Environment: Science and Policy for Sustainable Development**, v.51, p. 12–23, 2009. DOI: https://doi.org/10.3200/ENVT.51.2.12-23

NISBET, M.C.; SCHEUFELE, D.A. What's next for science communication? Promising directions and lingering distractions. **American Journal of Botany**, v. 96, p. 1767-1778, 2009. DOI: https://doi.org/10.3732/ajb.0900041

NICHOLSON-COLE, S. A. Representing climate change futures: a critique on the use of images for visual communication. **Computers, Environment and Urban Systems**, v. 29, p. 255–273, 2005. DOI: https://doi.org/10.1016/j.compenvurbsys.2004.05.002

NUNES, L.H. Media Communication of Extreme Events: A Case Study for Brazil. **European Conference on Severe Storms, 5th**. Landshut, Germany. 2p, 2009. Available in:<https://www.researchgate.net/publication/305699679_Media_communication_of_extreme_events_a_case_study_for_Brazil> Accessed in: 01/05/2022.

NUNES, L.H.; ZAMPARONI, C.A.G.P. A mídia em foco: Exemplos de desinformação climática. In: NUNES, L.H.; ZAMPARONI, C.A.G.P. (Eds.). **Multidimensão e territórios de risco. Coleção Digital Pombalina**. p.77-80, 2014. Available in: <https://www.researchgate.net/publication/305700082_A_Midia_em_Foco_Exemplos_de_Desinformacao_Climatica> Accessed in: 01/05/2022.

OLAUSSON, U. Global warming – global responsibility? Media frames of collective action and scientific certainty. **Public Underst. Sci**. v. 18, p. 421–436, 2009. DOI: https://doi.org/10.1177/0963662507081242

OLIVEIRA, D. Jornalismo alternativo: Um potencial para a radicalização da democracia. **Signo y Pensamiento**, v. 30, p.52–63, 2011. Available in: < http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-48232011000100004> Accessed in: 01/05/2022.

OLIVEIRA, M.J.; CARNEIRO, C.D.R.; VECCHIA, F.A.da Silva. Evolução (2004-2017) do interesse mundial pelas mudanças climáticas e aquecimento global: influência da ciência, mídia, política, economia e controvérsias. **Revista Científica ANAP Brasil**, v. 10, p. 93-120, 2017. DOI: https://doi.org/10.17271/19843240102020171667

PAINTER, J.; KRISTIANSEN, S.; SCHÄFER, M.S. How 'Digital-born' media cover climate change in comparison to legacy media: A case study of the COP 21 summit in Paris. **Global Environmental**, v. 48, p. 1-10, 2018. DOI: https://doi.org/10.1016/j.gloenvcha.2017.11.003

PAINTER, J.; OSAKA, S.; ETTINGER, J.; WALTON, P. Blaming climate change? How Indian mainstream media covered two extreme weather events in 2015. **Global Environmental Change**, v.63, Article 102119, 2020. DOI: https://doi.org/10.1016/j.gloenvcha.2020.102119

PASQUARÉ, F.A.; OPPIZZI, P. How do the media affect public perception of climate change and geohazards? An Italian case study. **Global and Planetary Change**, v. 90, p. 152-157, 2012. DOI: https://doi.org/10.1016/j.gloplacha.2011.05.010

PBMC—Painel Brasileiro de Mudanças Climáticas. **Contribuição do Grupo de Trabalho 2 ao Primeiro Relatório de Avaliação Nacional do Painel Brasileiro de Mudanças Climáticas**. Sumário Executivo do GT2, 2013. Available in:<http:// www.pbmc.coppe.ufrj.br/documentos/MCTI_PBMC_sumario_executivo_impactos_vulnerabilidades_e_adaptacao_WEB_3.pdf> Accessed in: 01/05/2022.

RODAS, C.de ARAÚJO.; Di GIULIO, G.M. Mídia brasileira e mudanças climáticas: uma análise sobre tendências da cobertura jornalística, abordagens e critérios de noticiabilidade. **Desenvolvimento e Meio Ambiente**, v. 40, p. 101-124, 2017. DOI: http://dx.doi.org/10.5380/dma.v40i0.49002

ROXBURGH, N.; GUAN, D.; SHIN, K.J.; RAND, W.; MANAGI, S.; LOVELACE, R.; MENG, J. Characterising climate change discourse on social media during extreme weather events. **Global Environmental Change**, v. 54, p. 50-60, 2019. DOI: https://doi.org/10.1016/j.gloenvcha.2018.11.004

SAMPEI, Y.; AOYAGI-USUI, M. Mass-media coverage, its influence on public awareness of climate-change issues, and implications for Japan's national campaign to reduce greenhouse gas emissions. **Glob. Environ. Change**, v. 19, p. 203–212, 2009. DOI: https://doi.org/10.1016/j.gloenvcha.2008.10.005

SCALFI, G.; MASSARANI, L.; RAMALHO, M.; AMORIM, L. Mudanças Climáticas em um programa brasileiro de infotainment: uma análise do "fantástico". **Razón y Palabra**, v. 84, 2013. Available in: <https://www.redalyc.org/pdf/1995/199528904006.pdf> Accessed in: 01/05/2022.

SCHEUFELE, D.; KRAUSE, N. M. Science audiences, misinformation, and fake news. **Proceedings of the National Academy of Sciences**, v. 116, p. 7662-7669, 2019. DOI: https://doi.org/10.1073/pnas.1805871115

SCHMIDT, A.; IVANOVA, A.; SCHÄFER, M. Media attention for climate change around the world: a comparative analysis of newspaper coverage in 27 countries. **Glob. Environ. Chang**, v. 23, p. 1233–1248, 2013. https://doi.org/10.1016/j.gloenvcha.2013.07.020

SHEPPARD, S.R.J.; SHAW, A.; FLANDERS, D.; BURCH, S.; WIEK, A.; CARMICHAEL, J.; ROBINSON, J.; COHEN, S. Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. **Futures**, v. 43, p. 400-412, 2011. DOI: https://doi.org/10.1016/j.futures.2011.01.009

SEMETKO, H.; VALKENBURG, P. Framing European politics: a content analysis of press and television news. **Journal of Communication**, v. 50, p. 93–110, 2000. DOI: https://doi.org/10.1111/j.1460-2466.2000.tb02843.x

SENGUPTA, M. A million dollar exit from the slum-world: Slumdog Millionaire's troubling formula for social justice. In: **The Slumdog Phenomenon: A Critical Anthology** (ed. Ajay Gehlawat). London: Anthem Press. p. 69–90, 2013.

SOMERVILLE, R.C.; HASSOL, S.J. Communicating the science of climate change. **Physics Today**, v. 64, p. 48-53, 2011. DOI: http://dx.doi.org/10.1063/PT.3.1296

SOUZA, M.T.; da SILVA, M.D.; CARVALHO, R. Revisão integrativa: o que é e como fazer. **Einstein**, v. 8, p. 102-106, 2010. DOI: https://doi.org/10.1590/S1679-45082010RW1134

VU, H.T.; LIU, Y.; TRAN, D.V. Nationalizing a global phenomenon: A study of how the press in 45 countries and territories portrays climate change. **Global Environmental Change**, v. 58, Article 101942, 2019. DOI: https://doi.org/10.1016/j.gloenvcha.2019.101942

ZEHR, S.C. Public representations of scientific uncertainty about global climate change. **Public Understanding of Science**, v. 9, p. 85–103, 2000. DOI: https://doi.org/10.1088/0963-6625/9/2/301

CAPÍTULO 4 – EDUCAÇÃO EM MUDANÇAS CLIMÁTICAS NO CONTEXTO BRASILEIRO: UMA REVISÃO INTEGRADA

4.1 Abstract

Climate change has become a topic of discussion in different areas of society, including education, where this topic is considered recent in the Brazilian context. Based on the above, an integrative review of the literature was realized to understand how research and the dissemination of knowledge about education on climate change in Brazil have been taking place. For this, Google Scholar and keywords in Portuguese were used, from which it was possible to find 25 articles that fit the guidelines established for this research. Among the results, 11 were theoretical and 14 practical articles, which showed a great concern with the students' understanding of the topic, given its complexity. In this sense, this research also showed that sometimes environmental education appears to be correlated with education on climate change, which can cause conceptual problems. It was also noted that there is a lack of studies on teacher training in climate change.

4.2 Resumo

Mudanças climáticas têm se tornado um tema de discussão em diferentes áreas da sociedade; em Educação, o tópico é considerado recente no contexto brasileiro. Este trabalho busca, a partir de uma revisão integrada da literatura, compreender como vem ocorrendo as pesquisas e a difusão de conhecimentos sobre a educação em mudanças climáticas no Brasil. Para isso, utilizou-se o Google Acadêmico, uma plataforma de livre acesso a pesquisadores e professores da rede básica de ensino, e palavras-chaves em português, a partir das quais foi possível encontrar 25 artigos que se encaixavam nas diretrizes estabelecidas para essa pesquisa. Dentre os resultados, 11 foram artigos teóricos e 14 práticos, os quais demonstraram uma grande preocupação com a compreensão do tema por parte dos estudantes, dada sua complexidade. Nesse sentido, esta pesquisa também evidenciou que algumas vezes a educação ambiental aparece correlata a educação em mudanças climáticas, o que pode ocasionar problemas conceituais. Notou-se também, que há carência de estudos sobre a formação de professores em mudanças climáticas.

4.3 Introdução

Nas últimas décadas, mudanças climáticas se tornaram tema central no debate público, principalmente sob a perspectiva do desenvolvimento sustentável (Otto et al. 2019). As consequências negativas sobre o planeta, seus habitantes e recursos, geram preocupação nas nações (Molthan-Hill et al. 2019). Adicionalmente, problemas estruturais da sociedade acabam por diferenciar a magnitude dos impactos, que passam a não ser igualmente percebidos por todos os grupos sociais (Van der Linden et al. 2015). Crianças e idosos que vivem na pobreza, por exemplo, estarão entre os mais vulneráveis, sofrendo mais fortemente os impactos provenientes da mudança do clima (Özdem et al. 2014).

De acordo com o sexto relatório do Painel Intergovernamental sobre Mudanças Climáticas (IPCC), os efeitos das mudanças climáticas serão sentidos por todas as sociedades, em maior ou menor grau, sendo minimizados em virtude das ações de mitigação e adaptação adotadas pelos governantes (IPCC, 2021). Adicionalmente ao exposto, os riscos descritos para as comunidades em todo o mundo tendem a crescer diante do rápido crescimento populacional e a urbanização sem planejamento dos grandes centros urbanos, que propiciam o aumento de condições inadequadas de vida. Estes fatores, associados às mudanças climáticas, trazem graves prejuízos à população (Foss & Ko, 2019).

Nesse contexto, aumentar a conscientização da população sobre os efeitos do clima extremo pode ajudar no desenvolvimento de ações de planejamento urbano, a partir de uma comunidade proativa e mais resiliente, haja visto o importante papel desenvolvido pelos cidadãos na tomada de decisões (Foss & Ko, 2019). Para tanto, há necessidade de educar, treinar e conscientizar o público sobre a relevância de sua participação e seu acesso à informação, no que tange as mudanças climáticas, como meio de mitigar a interferência que exercem sobre o sistema climático (McKenzie, 2021). Essa relação foi inicialmente reconhecida, internacionalmente, por meio da Convenção das Nações Unidas sobre Mudanças Climáticas em 1992 (UNFCCC, 1992).

Frente as evidencias cientificas sobre as mudanças climáticas e o consenso da comunidade global quanto à realização de ações de mitigação e adaptação para o enfrentamento dessa emergência climática (IPCC, 2021), muitos estudos ressaltam que a compreensão do público sobre o tema é rasa e muitas vezes distorcida, o que acarreta diversos problemas (Busch et al. 2019, Rosa, 2021). Além disso, o entendimento das questões climáticas pode variar em razão da localização geográfica, dados socioeconômicos, escolaridade e orientação política (Shealy et al. 2017), por isso a importância da educação em mudanças climáticas de forma interdisciplinar, permitindo a compreensão da complexidade de cenários possíveis.

4.3.1 A importância da Educação em Mudanças Climáticas

A alfabetização climática aparece como ponto chave para o processo de compreensão do público sobre a influência do clima sobre os seres vivos e vice-versa (Wise, 2010), sendo tema de destaque, fator que evidencia seu papel crítico no Programa de Ação Global para Educação para o Desenvolvimento Sustentável (UNESCO, 2020). A relevância da alfabetização sobre clima e mudanças climáticas é pontuada por formuladores de políticas educacionais, em âmbito nacional e internacional (Otto et al. 2019). Os conhecimentos e habilidades para saber como responder as mudanças climáticas, por intermédio do pensamento crítico e do desenvolvimento de abordagens sistêmicas, permitem a identificação de inter-relações de questões problema, sendo parte fundamental da alfabetização climática (Burandt & Barth, 2010).

Assim como o aumento dos debates e preocupações sobre mudanças climáticas nos últimos anos, o interesse na educação sobre o tema também cresceu, essencialmente porque é parte integrante da resolução do problema, bem como em função do financiamento de programas educacionais que tratam do assunto em diferentes perspectivas (Anderson, 2012). Monroe e colaboradores (2019) também salientam como causa do interesse educacional, a incorporação do tema no currículo educacional de muitos países, a percepção dos padrões climáticos incomuns e a aflição quanto aos efeitos climáticos sobre questões econômicas e sociais. Apesar disso, o investimento esperado na educação em mudanças climáticas não vem correspondendo ao seu estado de urgência, mesmo após o reconhecimento de sua importância, representada em nível internacional, pelo Artigo 12 do Acordo de Paris (Fahey, 2012), o qual incentiva as nações a "melhorarem a educação, o treinamento, a conscientização pública, a participação pública sobre mudanças climáticas e o acesso público à informação" (UNFCCC, 2015).

A educação em mudanças climáticas, aquém do assinalado quanto a alfabetização no assunto, consiste no processo de compreensão, adaptação e mitigação das mudanças climáticas, o qual é pautado pelas esferas da reflexão e do engajamento (UNESCO, 2014), ou seja, para além do entendimento da complexidade referente às mudanças climáticas, é preciso atuar em prol delas.

Os estudos sobre a educação em mudanças climáticas veem notabilizando, essencialmente, três áreas de estudo, de acordo com Wise (2010): a relação entre instrução e ativismo ambiental (1), equívocos em mudanças climáticas (2) e atividades práticas em sala de aula (3). Como pontuado por este autor, e corroborado por Busch et al., (2019) e Rosa (2021) os estudos voltados a compreender os equívocos evidenciam como a correta instrução sobre o assunto é fundamental e bastante desafiadora. Rosa (2021) demonstrou que muitas pessoas desenvolvem ideias erradas sobre a ciência do clima e os processos relacionados as mudanças climáticas, a qual interage com todos os sistemas humanos, devendo ser idealmente transmitida a partir de uma concepção interdisciplinar (Fortner, 2001) e formal, gerando um público alfabetizado sobre o assunto (Wise, 2010). Busch et al. (2019) também analisa a falta de conhecimento em ciência climática, demonstrando que equívocos são frequentes em diferentes públicos, não se limitando apenas aos alunos, mas se estendendo também aos professores.

Complementado a questão, Monroe et al. (2019) indicaram que os educadores carecem de novas habilidades para que possam contemplar a alfabetização em mudanças climáticas, sendo estas necessárias para que, na prática, possam, efetivamente, instruir os demais nessa temática.

4.3.2 O Ensino de Mudanças Climáticas no Brasil

Nos últimos anos, mais especificamente entre 2018 e 2022, o Brasil demonstrou pouca preocupação com as mudanças climáticas, embora tenha sido protagonista no passado de importantes políticas ambientais e ratificando acordos internacionais que reforçaram sua posição nos debates sobre a emergência ambiental e climática (Kiessling, 2018). Um dos acordos historicamente relevantes foi o Protocolo de Kyoto, criado em 1997 durante a 3º Conferência das Partes na Convenção das Nações Unidas sobre Mudanças Climáticas, com o intuito de reduzir as emissões de gases do efeito estufa (GEE) (Borges et al. 2021). O Brasil ratificou o Protocolo de Kyoto em 2002 por meio do Decreto Legislativo nº144 de 2002 (Brasil, 2002) e, posteriormente, instituiu a Política Nacional sobre Mudança do Clima (PNMC) (Brasil, 2009). A partir da PNMC ficaram definidas as estratégias e políticas relacionadas ao monitoramento e à implementação de estratégias de mitigação e adaptação às mudanças climáticas por meio do Ministério do Meio Ambiente (Borges et al. 2021).

O tratado internacional mais recente, no que concerne a questão climática, foi o Acordo de Paris (2015), que discutiu entre 195 países o estabelecimento de um compromisso para diminuir a emissão de GEE, entre outras ações, minimizando as consequências do aquecimento global. O Brasil concluiu sua ratificação em 2016, apresentando dentre muitos objetivos, a meta de diminuir até 2025, 37% das emissões de GEE (OCDE, 2022). Além disso, a Agenda 2030, com seus 17 Objetivos de Desenvolvimento Sustentável (ODS), propõe, dentre muitas coisas, o ODS 13 que ressalta a necessidade de uma "ação contra a mudança global do clima", pontuando ações urgentes para atuar contra as alterações climáticas e seus efeitos adversos. Cabe destacar dentre as metas do ODS 13, a meta 13.3, que destaca a relevância da educação e da conscientização sobre mitigação, adaptação e redução de impactos (UNESCO, 2017).

No que tange a legislação educacional brasileira, diferentes leis foram aprovadas para inserção do quesito ambiental, mas nenhuma direcionada ao ensino de mudanças climáticas. Atualmente são vigentes no Brasil, políticas públicas voltadas a Educação Ambiental como a Política Nacional de Educação Ambiental (BRASIL, 1999) e as Diretrizes Curriculares Nacionais para a Educação Ambiental (BRASIL, 2012). A educação em mudanças climáticas é um tema claramente novo no país, quando comparado a outros, como educação ambiental e educação para o desenvolvimento sustentável, que são mais frequentemente tratados no ensino formal e comentados pelo público em geral (Tibola da Rocha et al. 2020). Nesse contexto, Tibola da Rocha et al. (2020) mencionam que além da necessidade de incorporar a educação em mudanças climáticas ao currículo formal do ensino fundamental, é essencial que ocorram investimentos financeiros no processo de elaboração de materiais didáticos sobre o tema e na formação de professores, considerando que tais investimentos devem ser contínuos para propiciar o desenvolvimento educacional do país.

Para além dos investimentos financeiros destacados pro Tibola da Rocha et al (2020), as pesquisas de Monroe et al. (2019) ressaltam as dificuldades dos professores em se trabalhar a temática de modo dinâmico em sala de aula, bem como a deficiência de estratégias para desenvolver uma abordagem metodológica e o desenvolvimento da interdisciplinaridade, coerentes ao estudo das mudanças climáticas. O contexto dado por esses autores corrobora com o apresentado na Base Nacional Comum Curricular (BNCC), que apresenta as normas da Educação Básica brasileira e aparece como referência para a elaboração de currículos escolares em todo país (BNCC, 2018). Além disso, a BNCC coloca o ensino de Ciências frente ao letramento científico, que envolve a compreensão e interpretação do mundo, bem como sua transformação segundo os conhecimentos teóricos e informativos (BNCC, 2018).

Os dados mais recentes do IBGE (2019) demonstram que apesar das iniciativas educacionais sobre educação ambiental e mesmo quanto a educação em mudanças climáticas, é importante destacar que, no Brasil, ainda há problemas profundos quanto ao ensino, no que concerne o essencial, que é o acesso ao ensino de qualidade, pontuado pela Lei 9394/96.

Diante do apresentado, o objetivo geral desse trabalho foi analisar os trabalhos publicados sobre educação em mudanças climáticas no contexto brasileiro através de uma revisão integrativa da literatura. A partir dessa pesquisa foi possível compreender como o tema vem sendo trabalhado nas suas mais distintas possibilidades, evidenciando também, caminhos para pesquisas em outras vertentes do tema.

4.4 Materiais e métodos

A presente pesquisa desenvolveu-se sob a ótica de uma revisão integrativa da literatura, a qual parte de uma pergunta norteadora e baseia-se na busca de dados de forma ampla e diversificada, pautando-se na coleta de dados de modo objetivo e na discussão crítica dos mesmos (Souza et al. 2010). O esquema (Figura 1) contempla as etapas metodológicas realizadas durante a revisão integrativa da literatura e as considerações realizadas em cada uma.

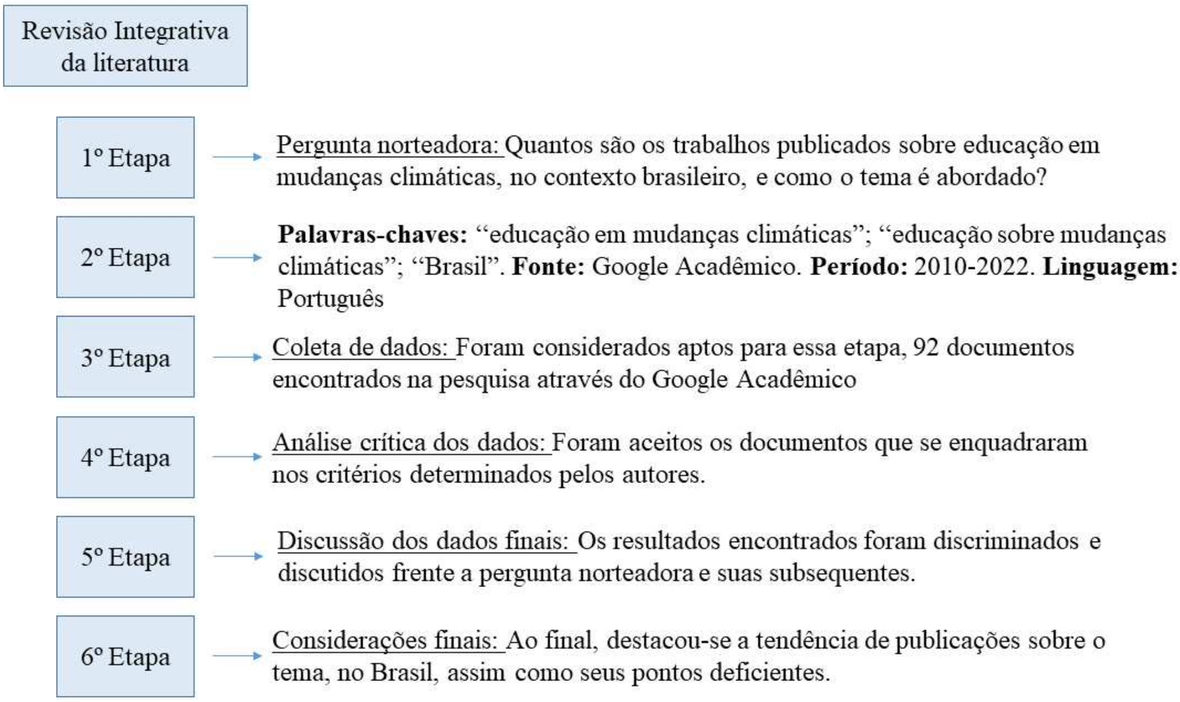


Figura 1. Indicação das etapas realizadas durante a revisão integrativa da literatura

A revisão integrativa realizada na pesquisa considerou todos os dados recuperados pela ferramenta Google Acadêmico a partir da busca de palavras-chaves em português, independente do período de publicação. Nesse sentido, ressalta-se que o Google Acadêmico foi utilizado como a plataforma de busca para o levantamento de informações na referida revisão integrativa dada sua abrangência e facilidade de acesso pelo público em geral, incluindo pesquisadores e professores de educação básica. Essa busca foi realizada no dia 21 de junho de 2022 e obteve 92 resultados.

Para compreender a diferença entre as publicações nacionais e internacionais sobre o tema, as mesmas palavras-chaves descritas anteriormente foram introduzidas no Google Acadêmico em inglês. Paralelamente a isso, os documentos em português foram analisados e divididos conforme o critério de seleção dos trabalhos, como pontuado na 4º etapa, que considerou unicamente artigos publicados em revistas com avaliação às cegas por pares. O detalhamento da 4ª etapa encontra-se na Figura 2

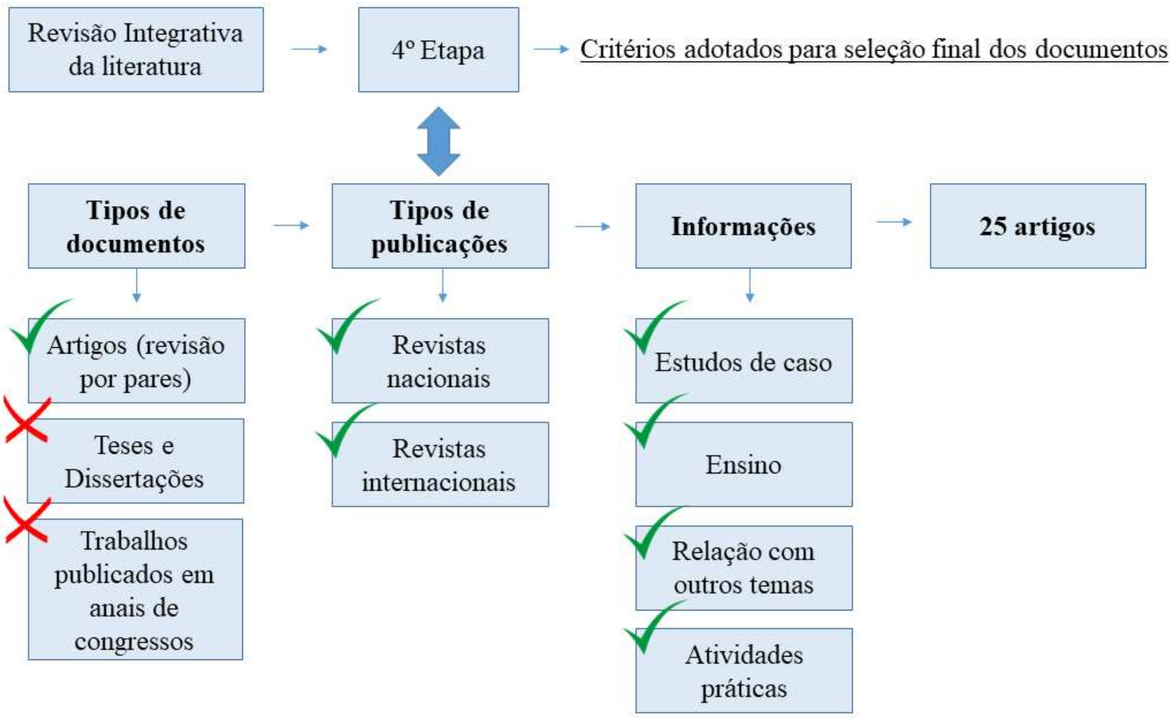


Figura 2. Descrição dos critérios adotados durante a análise e seleção dos documentos

A revisão possibilitou responder questões específicas relacionadas aos objetivos da pesquisa, como:

a) Qual a abordagem mais frequente?

b) Quais as características em comum desses artigos?

c) Quais abordagens não foram observadas nos artigos encontrados?

Dessa forma, as considerações finais sobre os resultados dessa revisão integrativa da literatura foram feitas, evidenciando as informações mais importantes encontradas, bem como questões problemáticas. Por fim, destacou-se os avanços no estado da arte e indicou-se novos caminhos para desenvolver a temática.

4.5 Resultados e Discussão

A partir da metodologia proposta, foram considerados 25 documentos após avaliação criteriosa, a qual foi realizada pela leitura de cada um dos 92 documentos encontrados inicialmente. Apesar dos resultados encontrados, foram substancialmente poucos aqueles que se encaixaram no critério de revisão integrativa adotado no presente estudo, culminando em um número consideravelmente pequeno de dados a serem analisados.

Em pesquisa no Google acadêmico com os termos em inglês, obteve-se uma quantidade significativamente maior de documentos, sendo aproximadamente 11 mil respostas na utilização do termo “climate change education” e cerca de 1500 respostas ao utilizar “climate change education” e “Brazil”, em conjunto, como palavras-chaves. Em ambos os casos, a busca foi realizada colocando os termos entre parênteses, assim como feito em português.

As publicações em português sobre o assunto são mais escassas do que aquelas feitas em língua inglesa e publicadas em revistas internacionais, o que sinaliza que esse é um tema de interesse mundial e que práticas realizadas aqui podem ser replicadas em outros locais e vice-versa, considerando-se as particularidades. Do lado da pesquisa, artigos publicados em inglês comumente são mais citados (Nassi-Calò, 2016), o que pode favorecer com que muitos autores brasileiros direcionem suas pesquisas a revistas internacionais e, consequentemente, que escrevam seus trabalhos em inglês. No entanto, esse resultado também sinaliza uma barreira aos professores de educação básica que utilizariam esses trabalhos como possíveis fontes. O fato de existirem poucos artigos na língua materna pode fazer com que o professor, nem sempre fluente em outra língua, recue diante de uma possível dificuldade de entendimento. Adicionalmente há o fato de que a grande maioria das revistas internacionais tem acesso restrito, havendo necessidade de parcerias entre as escolas e instituições de pesquisa, para, assim, conseguirem acessar alguns materiais.

De acordo com os trabalhos analisados e expostos anteriormente, há uma tendência crescente nas publicações que retratam a educação em mudanças climáticas, nas mais diferentes possibilidades. A Tabela 1 apresenta um quadro com as características dos artigos avaliados.

Tabela 1. Quadro resumo com dados dos artigos avaliados

Ano	Autores	Título	Foco do trabalho
2011	Jacobi et al.	Mudanças climáticas globais: a resposta da educação	Analisar e apresentar as políticas nacionais sobre mudanças climáticas e práticas educativas, da qual a Universidade de São

			Paulo foi parceira, abordando as respostas educativas frente ao fenômeno climático.
2015	Reis et al.	Complexidades inerentes ao tema “Mudanças Climáticas” desafios e perspectivas para o ensino de física	Destacar que a natureza complexa das mudanças climáticas favorece o surgimento das controvérsias, o que proporciona aos professores da Educação Básica possibilidades para o tratamento educativo diferenciado do tema
2016	Fernandes Silva et al.	A educação em mudanças climáticas: uma abordagem interdisciplinar	Abordagem de questões sobre os efeitos da aplicação de uma educação em mudanças climáticas de forma interdisciplinar.
2017	Lima	A crise climática, a onda conservadora e a educação ambiental: desafios e alternativas aos novos contextos.	Um ensaio sobre a policrise que marca as sociedades contemporâneas, como as que afetam o ambiente e a educação ambiental, mencionando-se a crise climática.
2017	Rumenos et al.	Significados atribuídos ao tema “Mudanças Climáticas” em Livros Didáticos de Ciências Naturais do Ensino Fundamental II Aprovados pelo PNLD de 2014	Identificar e analisar os significados atribuídos ao tema Mudanças Climáticas presentes nos livros didáticos de Ciências do ensino fundamental II, indicados pelo PNLD 2014.
2018	Rosa et al.	A importância da educação superior na percepção e compreensão de universitários do curso de educação física sobre as alterações climáticas	Avaliar qual a importância da inserção da temática das alterações climáticas no ambiente educacional, a fim de tornar a formação superior mais consciente e responsável na área da saúde e meio ambiente
2019	Yamada et al.	Assessment of the prototype of an educational game on climate change and its effects on marine and coastal ecosystems	Desenvolver o protótipo de um jogo educativo chamado “Apicum Game”, que aborda as mudanças climáticas e seus efeitos nos ecossistemas marinhos e costeiros, foi avaliado no presente estudo.
2019	Mesquita et al.	Percepções de universitários sobre as mudanças climáticas e seus impactos: estudo de caso no Distrito Federal	Compreender a percepção dos estudantes universitários sobre os impactos das mudanças climáticas.
2019	Cazetta et al.	Educação visual e mudanças climáticas: a invenção do aquecimento global	Verificar a emergência de três enunciados a partir da revisão bibliográfica: a globalização do processo de aquecimento; a dramatização das mudanças climáticas e de seus efeitos; e os riscos do aquecimento para diferentes populações.
2020	Freitas et al.	Explorando atividade de campo em ecossistemas amazônicos para discutir conceitos relacionados às mudanças climáticas globais	Desenvolvimento de uma atividade prática de campo que valorizasse questões do ecossistema amazônico e também ensinasse conceitos de mudanças climáticas.
2020	Oliveira e Souza	Mudanças climáticas na educação: um levantamento das práticas, ferramentas e tecnologias digitais	Apresentar um levantamento de práticas, ferramentas e tecnologias digitais usadas no ambiente educacional para abordar mudanças climáticas.
2020	Tibola da Rocha et al.	Climate change education in school: knowledge, behavior and attitude	Apresentar a experiência de inclusão do tema mudanças climáticas em uma escola pública brasileira através de um treinamento conduzido por professores.
2021b	Oliveira et al.	Educação ambiental e mudanças climáticas: análise do Programa Escolas Sustentáveis	Analisar as propostas pedagógicas desenvolvidas pelo Programa Escolas Sustentáveis, na perspectiva da Educação Ambiental e das Mudanças Climáticas em Teresina, Piauí.

2021	Silva et al.	O Conhecimento sobre Sismos e Mudanças Climáticas como Proposta Pedagógica: Estudo de Caso em uma escola Pública de Fortaleza/CE	Avaliar os resultados da aplicação de uma proposta pedagógica, baseada nos princípios norteadores da pedagogia libertadora, através da oferta de uma disciplina semestral com conteúdo sobre os sismos e sobre as mudanças climáticas para estudantes de uma escola pública em regime integral localizada em uma área de vulnerabilidade social em Fortaleza (Ceará)
2021	Liotti & Campos	Livros didáticos do Ensino médio e o conhecimento escolar sobre mudanças climáticas	Análise de como o conhecimento sobre Mudanças Climáticas abordado nos Livros Didáticos do Ensino Médio, pode contribuir para que os estudantes construam concepções científico-sociais, econômicas e políticas sobre este fenômeno
2021	Borges et al.	Estudo sobre as mudanças climáticas nos últimos anos da educação básica em Jaboticabal (SP)	Avaliar o conhecimento dos alunos dos últimos anos da educação básica, no município de Jaboticabal (São Paulo), sobre as mudanças climáticas.
2021	Barros e Pinheiro	Reflexões sobre a comunicação das mudanças climáticas e o cuidado ambiental: a visão de professores no contexto escolar	Compreender a visão que professores possuem sobre comunicação das mudanças climáticas nas escolas, investigando também, como seus contextos escolares abordam o tema e o cuidado ambiental com os estudantes.
2021	Consendey et al.	Um pouco de lagarto, restinga e mudanças climáticas: conversando sobre conservação ambiental com a educação básica	Investigação sobre a influência da crise climática e degradação ambiental na preservação de uma espécie de lagarto de restinga e a importância do fator social para a manutenção do ambiente.
2021	Faria et al.	Sequência Didática somo estratégia para o ensino sobre desafios socioambientais relacionados às Mudanças Climáticas	Apresentação de uma sequência didática para o ensino da temática socioambiental dentro do tema “Mudanças Climáticas” em consonância com a Base Nacional Comum Curricular (BNCC).
2021	Brandli et al.	Higher Education Institutions Facing Climate Change: The Brazilian Scenario	Apresenta como as mudanças climáticas têm sido tratadas em cada uma das principais dimensões da universidade, no contexto brasileiro: currículo, pesquisa, extensão e operações.
2021	Salvia e Brandli	Universities facing Climate Change and Sustainability – Chapter 4: Brazil	Expor como as mudanças climáticas são abordadas no Brasil, no que concerne o ensino universitário.
2021	Cidón et al.	A contribuição da Educação Ambiental para a Percepção Acerca do Consumo Sustentável	Investigar junto a graduandos de ensino superior, qual o grau de consciência ecológica desses indivíduos quanto as suas escolhas cotidianas.
2021a	Oliveira et al.	Alfabetização científica e Climatologia: proposta de um livro a partir dos princípios do Desenho Universal de Aprendizagem (DUA)	Desenvolvimento de um material didático a partir dos princípios da DUA, que incorpora questões sobre mudanças climáticas.
2021	Nuñez-Rodríguez	Educación para el cambio climático: ¿Por qué formar para afrontar la incertidumbre, vulnerabilidad y complejidad ambiental?	O objetivo deste ensaio é analisar os conceitos de incerteza, vulnerabilidade e complexidade ambiental nos cenários de alterações climáticas presentes e futuras e o papel essencial da escola na formação de cidadãos
2022	Buce	Educação sobre mudanças climáticas para o	Centrou-se no diagnóstico de necessidades para inserção de abordagem de Educação

		desenvolvimento sustentável no ensino de geografia no 2º ciclo do ensino secundário geral: caso da autarquia da Vila de Boane	sobre Mudanças Climáticas para o Desenvolvimento Sustentável (EMCDS), recomendada pela UNESCO

Dentre os documentos analisados, observam-se 11 artigos que focam em abordagens teóricas e 14 trabalhos que trazem enfoques práticos. Os artigos teóricos, de forma geral, ressaltam a relevância da educação em mudanças climáticas como ferramenta para possibilitar mais ações voltadas a sustentabilidade ambiental por parte das crianças e jovens. A interdisciplinaridade do tema foi frisada por Fernandes Silva et al. (2016), que destacaram a importância desse tipo de abordagem para melhor explicar os conceitos relacionados a temática. O estudo foi focado na sustentabilidade e o conceito foi relacionado ao contexto socioambiental das mudanças climáticas. Por fim, os autores discorrem como a educação em mudanças climáticas podem atuar positivamente no contexto socioambiental, seja pela geração de uma consciência climática e ambiental ou pelo simples reconhecimento dos conceitos climáticos pela sociedade.

Considerando o âmbito escolar, em seus anos iniciais de ensino, Núñez-Rodriguez (2021) buscou compreender como os conceitos de incerteza, vulnerabilidade e complexidade ambiental se relacionam às mudanças climáticas. Desse modo, o autor expôs como a vulnerabilidade educativa no que concerne as mudanças climáticas, pode ser uma ameaça direta e indireta aos alunos. Isso porque alterações no clima podem forçar, de forma direta, movimentos migratórios da população, promovendo, por conseguinte o abandono escolar e indiretamente, o aumento da pobreza em diferentes localidades. Esse mesmo autor, ao pontuar tais questões, coloca a educação em mudanças climáticas como ferramenta para mitigar a vulnerabilidade climática e ambiental, possibilitando que a escola e seus frequentadores possam se adaptar. Por fim, Núñez-Rodriguez (2021) ressaltam que a educação nessa temática tende a impulsionar políticas públicas no que tange a segurança alimentar, a saúde e a economia em regiões mais sensíveis.

O estudo de Brandli et al. (2021) teve ênfase em trabalhar a questão da educação superior frente as mudanças climáticas, no que tange o contexto brasileiro. Nesse caso, abordou-se o sistema de educação superior no Brasil, a forma como as mudanças climáticas são trabalhadas nesse nível educacional, a formulação dos currículos e a maneira de funcionamento do campus, de algumas universidades. Questões importantes foram mencionadas nesse estudo, como a relação direta que ocorre, no Brasil, entre educação em mudanças climáticas e educação ambiental, sendo essencial destacar que são temas complementares, mas que não funcionam como sinônimos. O papel central das universidades no desenvolvimento de pesquisas sobre mudanças climáticas, nas mais diversas áreas, bem como a função do professor e dos pesquisadores no meio universitário, também foi pontuado por esses autores. Por fim, Brandli et al. (2021), concluem que o sistema educacional brasileiro, no que se refere ao ensino-aprendizagem de mudanças climáticas, é parcialmente desenvolvido e bastante complexo, onde as ações dirigidas ao tema ainda são difusas e não seguem um direcionamento nacional, dependendo de cada instituição.

Desse modo, como não há uma regulamentação para formalizar a educação em mudanças climáticas, Salvia & Brandli (2021) analisaram como ações voltadas a educação climática vêm se desenvolvendo no âmbito de grandes universidades brasileiras, como a Universidade de São Paulo e a Universidade do Sul de Santa Catarina, e concluíram que geralmente as iniciativas em prol das mudanças climáticas surgem no ambiente acadêmico, a partir de pesquisas, projetos de extensão e ações incorporadas nos diferentes campus (Jacobi et al. 2011).

Oliveira & Souza (2020), por sua vez, realizaram um levantamento bibliográfico de dados sobre educação ambiental e educação em mudanças climáticas quanto a pergunta principal formulada por eles (Quais as práticas, ferramentas e tecnologias digitais usados nas abordagens educacionais voltadas para conscientização e entendimento das mudanças climáticas?). O trabalho desses autores indicou que a maioria dos estudos encontrados tratam da educação em mudanças climáticas, ainda que o tema de educação ambiental seja frequentemente vinculado ao tema do clima.

É interessante dizer que Oliveira & Souza (2020) verificaram estudos com uso de jogos, softwares, cursos de capitação e estudos de caso com a inclusão de questões climáticas no meio escolar. Dentre as conclusões do trabalho, Oliveira & Souza (2020) salientam a quantidade diminuta de estudos primários que relacionem mudanças climáticas a softwares educacionais, podendo ser essa, uma das lacunas a ser preenchida nessa temática. Nesse caso, o uso de softwares que abordem essa temática poderia facilitar a introdução do mesmo em diferentes disciplinas escolares.

Os artigos teóricos analisados não abordaram teorias educacionais clássicas, como Piaget ou Freire, mas focaram em tratar a educação em mudanças climáticas em diferentes vertentes do estado da arte, trazendo novas metodologias no que tange o levantamento bibliográfico (Oliveira & Souza, 2020), novas teorias educacionais (Núñez-Rodriguez, 2021) e também dados (Salvia & Brandli, 2021, Brandli et al. 2021) que podem complementar demais estudos, gerando avanços no estado da arte.

Ressalta-se aqui a comum relação entre ensino em mudanças climáticas e educação ambiental. O trabalho de Conjo et al. (2021), por exemplo, mencionou a questão das mudanças climáticas, mas de fato, o foco de seu estudo deu-se sobre a educação ambiental, demonstrando que por vezes essas duas temáticas podem se confundir, dificultando a compreensão dos conceitos que são exclusivos a cada um dos temas.

Analisando os artigos que trataram do tema sob uma perspectiva prática, foram identificadas duas principais vertentes: (i) aqueles estudos nos quais são desenvolvidos materiais sobre o tema a serem utilizados em sala de aula, e (ii) trabalhos que incluem a análise de materiais e/ou de práticas educativas junto aos alunos.

O estudo de Freitas et al. (2020), que objetivou desenvolver uma atividade prática de campo abordando o ecossistema amazônico e os conceitos de mudanças climáticas globais apresenta uma experiência prática educativa bastante relevante. Esses autores, inicialmente, realizaram um levantamento bibliográfico para contextualização e fundamentação teórica, que foi trabalhado junto a 17 alunos do Instituto Federal de Educação, Ciência e Tecnologia do Amazonas (IFAM) que participavam da disciplina de Ecologia da Amazônia. Após uma análise do conhecimento prévio dos participantes, por meio de um questionário, foi realizada a atividade prática de campo para demonstrar os conceitos de mudanças climáticas globais no que concerne os componentes da floresta, relacionado, ainda, temas como mitigação. Os resultados desse trabalho demonstraram que a realização de atividades práticas contextualizadas pode ser uma maneira efetiva para trabalhar a educação científica sobre mudanças climáticas, despertando nos alunos interesse na ciência e o desenvolvimento de habilidades.

Nesse mesmo sentido, Faria et al. (2021) elaboraram uma proposta para o ensino-aprendizagem de tópicos relacionados as mudanças climáticas considerando as prerrogativas da Base Nacional Comum Curricular (BNCC). O trabalho desses autores criou uma sequência didática em que o estudante se torna protagonista no processo de ensino-aprendizagem permitindo uma aprendizagem significativa. Todo o material utilizado por eles, foi disponibilizado para auxiliar o professor.

Seguindo essa tendência, o estudo de Oliveira et al. (2021a) apresentou a elaboração de um material de ensino-aprendizagem focado em clima e mudanças climáticas, adaptado a diferentes públicos ao conter elementos do Designer Universal da Aprendizagem (DUA). Tal material foi pensado para ser utilizado em formato de *e-book* e físico, como ferramenta de auxílio ao professor na sala de aula.

Yamada et al. (2019), também na abordagem do desenvolvimento de materiais educativos, desenvolveram um protótipo de um jogo que aborda questões sobre mudanças climáticas e seus efeitos nos ecossistemas marinhos e costeiros. Os testes desse protótipo foram realizados com alunos da rede particular de ensino. O estudo consistiu ainda na aplicação de um teste pré e pós jogo, para analisar se de alguma forma o jogo poderia ter influência no esclarecimento ou fixação de algum conteúdo. De acordo com esses autores, os questionários pós jogo demonstraram respostas mais assertivas, evidenciando que o jogo pode ser uma ferramenta de ensino-aprendizagem útil, também na temática de mudanças climáticas.

Dentre os demais estudos práticos encontrados, observou-se aqueles em que foram realizadas análises de material ou inquérito a um grupo de participantes. No primeiro caso, há o trabalho de Buce (2022) que fez um diagnóstico sobre os conteúdos associados às mudanças climáticas em documentos e livros utilizados na disciplina de Geografia do 2º Ano do Ensino Médio. Além disso, foram realizadas entrevistas com a comunidade sobre o tema, para compreender qual o entendimento desses sobre a temática. Diante do exposto, Buce (2022) evidenciou que uma parte dos entrevistados não consegue relacionar as ações humanas com as mudanças climáticas e ambientais. Destacam-se também, a constatação de que a comunidade precisa de uma intervenção no que concerne ao ensino sobre mudanças climáticas e que os professores enfrentam muitas dificuldades quanto ao ensino e aprendizagem dessa temática em sala de aula.

Cidón et al. (2021) realizaram um trabalho exploratório com estudantes de graduação que estudavam a temática da Educação Ambiental em uma universidade no Rio Grande do Sul. O questionário foi elaborado considerando a literatura sobre educação ambiental e consumo consciente, abordando em segundo plano as questões climáticas. Como resultado, esses autores notaram que há pouca compreensão sobre o tema e que o mesmo deveria ser aprimorado em sala de aula e exposto de forma mais prática do que teórica.

Com o intuito de conhecer a percepção de alunos da Universidade de Brasília sobre mudanças climáticas, Mesquita et al. (2019) construíram um questionário para ser aplicado aos estudantes universitários. Foram aplicados 1526 questionários, a partir dos quais os autores observaram a necessidade de incorporar mais conhecimentos ambientais e climáticos no meio acadêmico, haja visto que os alunos não puderam relacionar informações sobre a temática com questões de percepção e enfrentamento as mudanças do clima. Logo, a falta de percepção, pode, segundo esses mesmos autores, dificultar ações em prol de políticas públicas ligadas à mitigação e adaptação.

Tibola da Rocha et al. (2020), por sua vez, realizaram um estudo de caso com professores do ensino básico, de escolas públicas do Rio Grande do Sul, a fim de compreender como o tema das mudanças climáticas é incorporada por eles no ensino. Percebeu-se uma lacuna no conhecimento dos professores sobre mudanças climáticas, que culmina em uma dificuldade de ensino, alçada pela falta de investimento do governo na educação em mudanças climáticas.

Frente às análises realizadas no presente estudo, é possível verificar que os artigos que têm uma abordagem teórica aos temas relacionados ao ensino de mudanças climáticas buscam, de maneira geral, analisar a forma como a educação em mudanças climáticas vem sendo difundida no ensino básico (Reis et al. 2015, Fernandes Silva et al. 2016, Rumenos et al. 2017, Oliveira et al. 2021b, Núñez-Rodriguez, 2021) e no ensino superior (Jacobi et al. 2011, Brandli et al. 2021, Salvia & Brandli, 2021), as dificuldades de abordagem (Fernandes Silva et al. 2016, Oliveira & Souza, 2020), a singularidade da educação em mudanças climáticas (Oliveira et al. 2021b) e da educação ambiental (Conjo et al. 201), bem como a relação sociedade e mudanças climáticas (Lima, 2017, Cazetta et al. 2019).

Já os estudos com abordagens mais práticas, abordam majoritariamente, realização de atividades junto aos alunos (Rosa et al. 2018, Borges et al. 2021, Cidón et al. 2021), ou seja, o foco no processo de ensino-aprendizagem está nos estudantes (Silva et al. 2021, Faria et al. 2021, Liotti & Campos, 2021) e na maneira de abordar a questão com eles (Buce, 2022), utilizando-se de materiais didáticos diversificados (Rumenos et al. 2017, Yamada et al. 2019), inclusivos (Oliveira et al. 2021a) ou atividades práticas contextualizadas que facilitem a compreensão do tema (Freitas et al. 2020, Consendey et al. 2021). Entretanto, notou-se que é preciso diferentes investimentos no que concerne o ensino em mudanças climáticas (Busch et al. 2019), que não se concentram somente no aluno, mas também em todo o corpo docente e administrativo das escolas e universidades (Monroe et al. 2019, Siegner & Stapert, 2019).

As dificuldades do ensino em mudanças climáticas foram reconhecidas em diferentes trabalhos (Busch et al. 2019, Tibola da Rocha et al. 2020, Rosa, 2021) o que evidencia a importância de planos de ensino que envolvam o ambiente escolar e mesmo a comunidade, facilitando a contextualização do tema e a aproximação da sociedade ao assunto.

Também fora pontuado nos estudos avaliados, a função da BNCC (Faria et al. 2021) e dos programas de ensino em diferentes áreas e disciplinas, como documentos que direcionam o modo como cada conteúdo será desenvolvido em sala de aula junto com os estudantes.

4.6 Considerações finais

O presente trabalho buscou, a partir de uma revisão integrativa da literatura, compreender o estado da arte das pesquisas sobre a educação em mudanças climáticas no Brasil. Para isso, utilizou-se o Google Acadêmico, uma plataforma de livre acesso a pesquisadores e professores da rede básica de ensino. Priorizou-se trabalhos em português. Os resultados demonstram que os estudos práticos se sobressaem em quantidade, quando comparados com os estudos teóricos. A abordagem mais frequente, nos estudos práticos enfatiza a realização de sondagens com alunos, atividades práticas e o desenvolvimento de materiais de ensino-aprendizagem que podem ser utilizados em sala de aula. Já os estudos teóricos centram-se na revisão da literatura na busca da compreensão de como o ensino de mudanças climáticas vem avançando no ensino básico e superior, apontando os problemas e possibilidades nesse campo.

Analisando-se os artigos, conclui-se que a maioria deles insere o aluno como ator principal e o professor, em um papel de facilitador, conforme preconizado pela BNCC. No entanto, não se é enfatizada a lacuna na capacitação do professor para realizar tal tarefa. É importante também, sob um certo aspecto, se atentar ao papel do professor no processo da educação em mudanças climáticas no ensino básico e superior, uma vez que esse profissional precisa estar capacitado para abordar um tema abstrato, complexo e que exige saberes de diferentes áreas. Além disso, não foram observados estudos que abordassem a aptidão dos professores para lecionar sobre mudanças climáticas, no sentido de expor iniciativas para aprofundar o conhecimento do corpo docente no tema e dar maior segurança ao profissional em sala de aula. De modo geral, os estudos sobre educação em mudanças climáticas em português foram mais frequentes na esfera do ensino superior, enquanto a educação ambiental esteve mais presente na educação básica, mesmo porque esta última é parte do currículo e consta como política pública. Contudo, a falta de conhecimento prévio dos jovens dificulta a compreensão de alguns conceitos quando começam a trabalhar a temática das mudanças climáticas no ensino superior.

A partir da pesquisa foi possível compreender como o tema vem sendo trabalhado nas suas mais distintas possibilidades, evidenciando também, caminhos para pesquisas em outras vertentes do tema. Enfatizam-se estudos sobre a formação de profissionais de ensino em mudanças climáticas, desde o ensino básico, e de trabalhos voltados a projetos de extensão, haja visto as iniciativas em universidades públicas brasileiras e a possibilidade de levar conhecimento às comunidades próximas.

4.7 Agradecimentos

Os autores agradecem à Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pela colaboração na realização deste trabalho por meio da concessão de bolsa de doutorado.

4.8 Referências

Anderson, A. (2012). Climate Change Education for Mitigation and Adaptation. *Journal of Education for Sustainable Development*, *6*(2), 191-206. doi: 10.1177/0973408212475199.

Barros, H.C., & Pinheiro, J.Q. (2021). Reflexões sobre a comunicação das mudanças climáticas e o cuidado ambiental: a visão de professores no contexto escolar. *Educar em Revista*, Curitiba, *37*, e78098. doi: 10.1590/0104-4060.78098

Brasil. Ministério da Educação. (2018). *Base Nacional Comum Curricular.* Brasília: Secretaria da Educação Média e Tecnológica. 326p. URL: http://basenacionalcomum.mec.gov.br/images/BNCC_EI_EF_110518_versaofinal_site.pdf.Acesso 15.08.2022.

Borges, F. F., Bataghin, F. A., & Oliveira, T. V. (2021). Estudo sobre as mudanças climáticas nos últimos anos da educação básica em Jaboticabal (SP). *Revbea, Revista Brasileira de Educação Ambiental, 16*(4), 60-79. doi: https://doi.org/10.34024/revbea.2021.v16.11710

Brandli, L. L., Salvia, A. L., Mazutti, J., & Reginatto, G. (2021). Higher Education Institutions Facing Cli-mate Change: The Brazilian scenario. Transforming Universities for a Changing Climate. Working Paper Series, 5. URL: https://www.researchgate.net/publication/355485218_Higher_Education_institutions_facing_climate_change_the_Brazilian_scenario. Acesso 31.08.2022

Brasil. (2002). *Decreto Legislativo nº 144 de 2022*. "EMENTA: Aprova o texto do Protocolo de Quioto à Convenção-Quadro das Nações Unidas sobre Mudança do Clima, aberto a assinaturas na cidade de Quioto, Japão, em 14 de dezembro de 1997, por ocasião da Terceira Conferência das Partes da Convenção-Quadro das Nações Unidas sobre Mudança do Clima". URL: https://www2.camara.leg.br/legin/fed/decleg/2002/decretolegislativo-144-20-junho-2002-458772-norma-pl.html. Acesso: 10.08.2022.

Brasil. (1999). *Lei nº 9.795, de 27 de abril de 1999*. Dispõe sobre a educação ambiental, institui a Política Nacional de Educação Ambiental e dá outras providências. URL: http://www.planalto.gov.br/ccivil_03/leis/l9795.htm. Acesso: 20.08.2022.

Brasil. (2009). *Lei nº 12.187, de 29 de dezembro de 2009*. Institui a Política Nacional sobre Mudança do Clima - PNMC e dá outras providências. URL: http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l12187.htm. Acesso: 20.08.2022.

Buce, C.A. (2022). Educação sobre mudanças climáticas para o desenvolvimnto sustentável no ensino de geografia no 2º ciclo do ensino secundário geral: caso da autarquia da vila de boane. *Revbea-Revista Brasileira de Educação Ambiental*. *17*(4), 57-77. doi: 10.34024/revbea.2022.v17.13878

Burandt, S., & Barth, M. (2010). Learning settings to face climate change. *Journal of Cleaner Production, 18*(7), 659-665. doi: 10.1016/j.jclepro.2009.09.010.

Busch, K.C., Ardoin, N., Gruehn, D., & Stevenson, K. (2019). Exploring a theoretical model of climate change action for youth, *International Journal of Science Education*, *41*(17), 2389-2409. doi: 10.1080/09500693.2019.1680903

Cazetta, V., Viviani, L.M., & Antunes, D.M.M. (2019). Educação visual e mudanças climáticas: a invenção do aquecimento global. *Revista Pro-Posições*, *30*, e20170172. doi: 10.1590/1980-6248-2017-0172

Cidón, C. F., Schreiber, D., & Vecchietti, G. (2021). A contribuição da Educação Ambiental para a percepção acerca do consumo sustentável. *Ensino*, *22*(2), 137-145. doi: 10.17921/2447-8733.2021v22n2p137-145

Consendey, B., Militão, C., & Figueira M. (2021). Um pouco de lagarto, restinga e mudanças climáticas: conversando sobre conservação ambiental com a educação básica. *Ambiente e Educação, Revista de Educação Ambiental, 25*(3), 195-223. doi: 10.14295/ambeduc.v25i3.12285

Rosa, J. A. da. (2021). Comparing climate science misconceptions with worldview and cognitive reflection suggests poor understanding and motivated reasoning among undergraduates. *Journal of Geoscience Education*, *70*(4), 501-516. doi: 10.1080/10899995.2021.2006549.

Fahey, S.J. (2012). Curriculum change and climate change: Inside outside pressures in higher education. *Journal of Curriculum Studies*, *44*(5), 703-722. doi: 10.1080/00220272.2012.679011

Faria, D.R., Ramos, M.C., & Coltri, P.P. (2021). Sequência didática como estratégica para ensino sobre mudanças socioambientais relacionados às mudanças climáticas. *Terrae Didática*, *17*, 1-12, e021052. doi: 10.20396/td.v17i00.8667126

Fernandes Silva, C. M. L., Costa, F. A., & Borba, G. L. (2016). A educação em mudanças climáticas: uma abordagem interdisciplinar. *Holos, 32*(4), 176-188. doi: 10.15628/holos.2016.3950

Fortner, R. W. (2001). Climate change in schools: Where does it fit and how ready are we? *Canadian Journal of Environmental Education, 6,* p.18-31. URL: https://files.eric.ed.gov/fulltext/EJ661760.pdf. Acesso: 23.07.2022.

Foss, A.W., & Ko, Y. (2019). Barriers and opportunities for climate change education: The case of Dallas-Fort Worth in Texas. *The Journal of Environmental Education*. *50*(3), 145-159. doi: https://doi.org/10.1080/00958964.2019.1604479

Freitas, M.S., Marques, J.D.O., & Souza, A.J. (2020). Explorando atividade de campo em ecossistemas amazônicos para discutir conceitos relacionados às mudanças climáticas globais. *Experiências em Ensino de Ciências*, *15*(2), 477-500. URL: https://fisica.ufmt.br/eenciojs/index.php/eenci/article/view/736. Acesso: 23.07.2022.

IBGE. Instituto Brasileiro de Geografia e Estatística. (2019). Conheça o Brasil-Educação. *Governo Brasileiro*. URL: https://educa.ibge.gov.br/jovens/conheca-o-brasil/populacao/18317-educacao.html. Acesso: 20.08.2022.

IPCC. Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [V. P. Masson-Delmotte et al., (Eds.)]. Cambridge University Press. URL: https://www.ipcc.ch/report/ar6/wg1/. Acesso: 25.07.2022

Jacobi, P.R., Guerra, A.F., Sulaiman, S.N., & Nepomuceno, T. (2011). Mudanças climáticas globais: a resposta da educação. *Revista Brasileira de Educação*, *16*(46), 135-269. doi: 10.1590/S1413-24782011000100008

Kiessling, C.K. (2018). Brazil, Foreign Policy and Climate Change (1992-2005). *Contexto Internacional*, *40*(2), 387-408. doi: 10.1590/S0102-8529.2018400200004

Lima, G.F.C. (2017). A crise climática, a onda conservadora e a Educação Ambiental: desafios e alternativas aos novos contextos. *Revista Eletrônica do Mestrado em Educação Ambiental*. Edição Especial XVI Encontro Paraaense de Educação Ambiental, 40-54. doi: 10.14295/remea.v0i0.7141

Liotti, L.C., & Campos, M.A.T. (2021). Livros didáticos do ensino médio e o conhecimento escolar sobre mudanças climáticas. *Revbea-Revista Brasileira de Educação Ambiental*, *16*(2), 19-36. doi: 10.34024/revbea.2021.v16.11102

McKenzie, M. (2021). Climate change education and communication in global review: tracking progress through national submissions to the UNFCCC Secretariat. *Environmental Education Research*. *27*(5), 631-651. doi: 10.1080/13504622.2021.1903838

Mesquita, P.S., Braz, V.S., Morimura, M.M., & Bursztyn, M. (2019). Percepções de universitários sobre as mudanças climáticas e seus impactos: estudo de caso no Distrito Federal. *Ciência e Educação*, *25*(1), 181-198. doi: 10.1590/1516-731320190010012

Molthan-Hill, P., Worsfold, N. Nagy, G.J., Leal Filho, W., & Mifsud, M. (2019). Climate change education for universities: A conceptual framework from an international study. *Journal of Cleaner Production*, *226*, 1092-1101. doi: 10.1016/j.jclepro.2019.04.053

Monroe, M.C., Plate, R.R., Oxarart, A., Bowers, A., & Chaves, W.A. (2019). Identifying effective climate change education strategies: a systematic review of the research. *Environmental Education Research*, *25*, 791-812. doi: 10.1080/13504622.2017.1360842

Nassi-Calò, L. (2016). Como se relacionam pesquisadores e jornalistas no Brasil? SciELO em Perspectiva, São Paulo. URL: https://blog.scielo.org/blog/2016/08/17/como-se-relacionam-pesquisadores-e-jornalistas-no-brasil/#.Y1Uo13bMK3A. Acesso: 09.08.2022.

Nuñez-Rodríguez, J. (2021). Educación para el cambio climático: ¿Por qué formar para afrontar la incertidumbre, vulnerabilidad y complejidad ambiental?. *Revista Electrônica Educare*, *25*(2), 1-12. doi: 10.15359/ree.25-2.28

OCDE-Organização para a Cooperação e Desenvolvimento Econômico. (2022). *Estudos da OCDE sobre a política de conduta empresarial responsável (BRASIL)*. URL: https://mneguidelines.oecd.org/estudos-da-ocde-sobre-a-politica-de-conduta-empresarial-responsavel-brasil.pdf. Acesso: 13/09/2022

Oliveira, K.K.S., & de Souza, R.A.C. (2020). Mudanças climáticas na educação: um levantamento das práticas, ferramentas e tecnologias digitais. In: *Educação Ambiental e Cidadania: Pesquisa e Práticas Contemporâneas*, *1*, 296-314. doi: 10.37885/201102015

Oliveira, J.P., Zezzo, L.V., & Coltri, P.P. (2021a). Alfabetização científica e climatologia: proposta de um livro a partir dos princípios do Desenho Universal de Aprendizagem (DUA). Terrae Didática, v.17, e021019, p.1-13. DOI: 10.20396/td.v17i00.8664831.

Oliveira, N.C.R., Oliveira, F.C.S., & Carvalho, D.B. (2021b). Educação ambiental e mudanças climáticas: análise do Programa Escolas Sustentáveis. Ciência & Educação, v.27, e21068. DOI: https://doi.org/10.1590/1516-731320210068

Otto, D., Caeiro, S., Nicolau, P., Disterheft, A., Teixeira, A., Becker, S., Bollmann, A., & Sander, K. (2019). Can MOOCs empower people to critically think about climate change? A learning outcome based comparison of two MOOCs, Journal of Cleaner ProductioN. DOI: https://doi.org/10.1016/j.jclepro.2019.02.190

Özdem, Y., Dal, B., Öztürk, N., Sönmez, D., & Alper, U. (2014). What is that thing called climate change? An investigation into the understanding of climate change by seventh-grade students, International Research in Geographical and Environmental Education, v.23, n.4, p.294-313. DOI: https://doi.org/10.1080/10382046.2014.946323

Rosa, B.B.., Oliveira, L.R.M.C., Santos, D., Silva, R.B.V., Azeiteiro, U.M., & Andrade, M. (2018). A importância da educação superior na percepção e compreensão de universitários do curso de educação física sobre as alterações climáticas. Revbea-Revista Brasileira de Educação Ambiental, v. 13, n.3, p.209-232

Reis, D.A., Silva, L.F., & Figueiredo, N. (2015). Revista Ensaio, v.17, n.3, p.535-554. DOI: http://dx.doi.org/10.1590/1983-21172015170301

Rumenos, N.N., Silva, L.F., & Cavalari, R.M.F. (2017). Ensaio-Pesquisa em Educação em Ciências, v.19, e2793. DOI: http://dx.doi.org/10.1590/1983-21172017190113

Salvia, A., & Brandli, L. (2021). Chapter 4: Brazil. In: Universities facing Climate Change and Sustainability. McCowan, T., Filho, W.L., & Brandli, L. (Eds.).

Shealy, T., Godwin, A., & Gardner, H.M. (2017). Survey Development to Measure the Gap Between Student Awareness, Literacy and Action to Address Human Caused Climate Change. ASEE Annual Conference proceedings. Disponível em: https://par.nsf.gov/servlets/purl/10025991. Acessado em: 20/09/2022.

Siegner, A. & Stapert, N. (2019), Climate change education in the humanities classroom: a case study of the Lowell school curriculum pilot. Environmental Education Research, v.26, p. 1-21. DOI: https://doi.org/10.1080/13504622.2019.1607258.

Silva, E.M., Albuquerque, K.K.F., Alves, J.M.B., & Melo, F.C.B. (2021). Revista Brasileira de Meteorologia, v.36, n.3, p.529-537. DOI: http://dx.doi.org/10.1590/0102-77863630016

Souza, M.T., Silva, M.D.da., Carvalho, R. (2010). Revisão integrativa: o que é e como fazer. Einstein, v.8, n.1.

Tibola da Rocha, V., Brandli, L.L., & Kalil, R.M.L. (2020). Climate change education in school: knoledge, behavior and attitude. International Journal of Sustainability in Higher Education, v.21, n.4, p. 649-670. DOI: https://doi.org/10.1108/IJSHE-11-2019-0341

UNESCO-Organização das Nações Unidas para a Educação, a Ciência e a Cultura. (2020). "Educação para o Desenvolvimento Sustentável na Escola-Ação contra a mudança global do clima". Brasília, DF. Disponível em: https://unesdoc.unesco.org/ark:/48223/pf0000375083. Acessado em: 10/07/2022.

UNESCO-Organização das Nações Unidas para a Educação, a Ciência e a Cultura. (2017). "Educação para os Objetivos de Desenvolvimento Sustentável: objetivos de aprendizagem". Brasília, DF. Disponível em: https://unesdoc.unesco.org/ark:/48223/pf0000252197. Acessado em: 15/08/2022.

UNFCCC-United Nations Framework Convention on Climate Change. (1992). Disponível em: https://unfccc.int/resource/docs/convkp/conveng.pdf. Acessado em: 25/07/2022.

UNFCCC-United Nations Framework Convention on Climate Change. (2015). Disponível em: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement?gclid=CjwKCAjwzNOaBhAcEiwAD7Tb6GgTwU1rh9Pl-7FXmUvkSc9XmAcUcJfrQZZLhrJvBLTb1v94YEMdSBoCVGMQAvD_BwE. Acessado em: 25/07/2022.

Van der Linden, S.E., Maibach, A. (2015). Leiserowitz Improving public engagement with climate change. Perspectives on Psychological Science, v.10, n.6, p. 758-763. DOI: https://doi.org/10.1177/1745691615598516

Wise, S.B. (2010). Climate Change in the classroom: patterns, motivations, and barriers to instruction among Colorado Science teachers. *Journal of Geoscience Education, 58*(5), 297-309.

Yamada, F. M., Ribeiro, T., & Ghilardi-Lopes, N.P. (2019). Assessment of the prototype of an educational game on climate change and its effects on marine and coastal ecosystems. *Revista Brasileira de Informática na Educação, 27*(3), 01-31. doi: https://doi.org/10.5753/RBIE.2019.27.03.01

CAPÍTULO 5 – PERCEPTIONS OF CLIMATE CHANGE EDUCATION (CCE): INSIGHTS FROM HIGHER-EDUCATION INDIVIDUALS IN SOUTHEAST BRAZIL WITH BROADER IMPLICATIONS (Submetido)

5.1 Abstract

The issue of climate change is of critical and complex significance, affecting societies across the globe. Given its pivotal role in climate regulation, it is imperative that citizens in Brazil possess a comprehensive understanding of this subject matter. The objective of this study was to gain insight into the knowledge of climate change among highly educated individuals in Southeast Brazil, a region that is already distinguished by its high level of educational attainment. The study evaluated the participants' comprehension of climate change education (CCE), taking into account factors such as age, gender, level of education, interest in the subject, concerns, and misconceptions. The sample consisted of 1,111 participants, primarily young, educated individuals, predominantly women, with 89% having obtained a bachelor's or master's degree. Despite the sample's notable interest and concern regarding climate change, misconceptions were pervasive, raising concerns about the efficacy of the climate education they had received. These findings underscore gaps in climate change literacy, potentially linked to inadequate investment in education and teacher training. This study underscores the necessity for more comprehensive climate education in Brazil and highlights the importance of similar research at the national and global levels.

5.2 Introduction

The understanding of climate change has undergone significant evolution since its early conceptualizations in the 19th century. Joseph Fourier's 1824 hypothesis on Earth's atmospheric heat retention laid the groundwork for climate science (Weart 2008). Subsequent discoveries, such as John Tyndall's identification of carbon dioxide and water vapor as greenhouse gases in 1861 and Svante Arrhenius's 1895 calculations on the potential warming effects of CO_2 emissions, highlighted humanity's potential influence on the climate (Archer and Rahmstorf 2010). Despite these foundational insights, climate change remained a specialized scientific concern until the 20th century, when mounting empirical evidence and atmospheric data established it as a critical global issue (Weart 2008).

Today, the climate crisis is characterized by an unprecedented rate and scale of environmental change. Reports by the Intergovernmental Panel on Climate Change (IPCC 2021; IPCC 2022) emphasize the urgency of addressing greenhouse gas concentrations that have surpassed pre-industrial levels, leading to a global temperature rise nearing 1.5°C. These changes have accelerated biodiversity loss, threatening an estimated one million species (Nunez et al. 2019), and intensified risks to critical systems such as food security and water availability (Allan et al. 2013; IPCC 2022). Furthermore, the increased frequency of extreme weather events, such as hurricanes and droughts, underscores the cascading risks posed by global warming (Perera et al. 2020).

Education is widely recognized as a cornerstone for mitigating these challenges. The Paris Agreement explicitly emphasizes the role of education in fostering climate action and informed citizenship (Busch et al. 2019). Climate change education (CCE) equips individuals with knowledge and skills to address climate challenges, from adopting sustainable practices to shaping policy (Monroe et al. 2017). However, the field of CCE is relatively nascent, emerging primarily in the late 20th century in the UK and the USA, with persistent challenges in integrating climate science into global curricula (Nepraš et al. 2022).

CCE's interdisciplinary nature necessitates collaboration across fields such as environmental science, geography, and social studies, yet its integration remains inconsistent (Stephens et al., 2008). In Brazil, climate education is frequently confined to environmental or geographical contexts, which can narrow its scope and limit its impact (Conjo et al. 2021). Studies reveal that Brazilian textbooks often inadequately address the complexity of climate issues, and teaching quality heavily depends on individual educators' expertise and interests (Zezzo and Coltri 2022).

This study investigates the climate literacy of highly educated individuals in Southeast Brazil, a region distinguished by its advanced educational attainment. By examining their knowledge and misconceptions about climate change, it contributes to a broader understanding of barriers to effective climate literacy. While the study is rooted in a specific regional context, its findings hold global relevance, shedding light on universal challenges in integrating CCE into formal and informal educational systems.

Addressing these challenges is critical to fostering a globally informed citizenry capable of navigating and mitigating the multifaceted impacts of climate change.

5.3 Background

5.3.1 Misconceptions and Climate Change

Misconceptions about climate change are widespread and reflect a complex interplay of scientific, social, and psychological factors. These misunderstandings often serve as barriers to public engagement and effective policy-making. For instance, one of the most persistent misconceptions is the conflation of weather and climate. Cold weather events are frequently misinterpreted as evidence against global warming, despite the scientific consensus that short-term weather fluctuations do not negate long-term climate trends (Easterlin and Wehner 2009). Similarly, many individuals fail to grasp the anthropogenic drivers of climate change, instead attributing changes to natural climatic cycles or solar variability, which scientific evidence has shown to be insufficient to explain recent temperature trends (Lockwood and Frölich 2007).

Such misconceptions are amplified by systemic educational gaps and misinformation. The inconsistent integration of climate science into school curricula leaves students with an incomplete understanding of climate processes (UNESCO 2021). Moreover, misinformation campaigns—often propagated through digital platforms—undermine public understanding by promoting false narratives, such as claims that climate change is a hoax or that its impacts are exaggerated (Lewandowsky et al. 2019; van der Linden et al. 2017). These efforts exploit the inherent complexity of climate science, creating confusion even among educated individuals. Research indicates that while higher education is associated with better understanding, it does not guarantee literacy in climate systems or mitigation strategies, as the interdisciplinary nature of climate change often falls outside traditional academic silos (Schmidt et al. 2013).

Additionally, cognitive biases and psychological factors contribute to misconceptions. For instance, individuals are more likely to rely on personal experiences and immediate observations—such as local weather patterns—rather than abstract global data when forming beliefs about climate change (Weber and Stern 2011). This "availability heuristic" can reinforce erroneous perceptions, especially when misinformation aligns with pre-existing biases or ideologies.

5.3.2 The Importance of CCE

CCE is not merely about conveying scientific facts; it aims to foster critical thinking, empower behavioral change, and enhance resilience in the face of climate challenges (UNESCO, 2020). By promoting systems thinking, CCE enables individuals to understand the interconnectedness of climate processes and the socio-economic and environmental systems they influence (Monroe et al. 2017).

The critical role of education in climate action is recognized in global policy frameworks. The Paris Agreement explicitly underscores education as a vital component of climate resilience, highlighting the need to "enhance education, training, public awareness, public participation, and public access to information" (UNFCCC 2015). Similarly, UNESCO's Education for Sustainable Development (ESD) emphasizes embedding climate literacy into formal and informal educational settings to foster a globally informed and proactive citizenry (UNESCO 2020).

Despite these efforts, embedding CCE into educational systems remains fraught with challenges. Research shows that many curricula lack depth and fail to address the interdisciplinary and applied aspects of climate science (Reid 2019). Furthermore, teacher training programs often inadequately prepare educators to integrate climate science into their teaching, leaving them ill-equipped to navigate the complexity of climate issues or counteract misinformation (Nepraš et al. 2022). Cultural and political influences also shape how climate education is delivered, with some regions avoiding the topic altogether or framing it narrowly within local environmental issues (Monroe et al. 2017).

CCE in Brazil began to gain prominence in the late 2000s and early 2010s, driven by global discussions on sustainability and climate action, as well as Brazil's visibility in international climate negotiations. Before the implementation of the *Base Nacional Comum Curricular* (BNCC) in 2017, CCE was primarily subsumed under Environmental Education (EE), formalized through the *Política Nacional de Educação Ambiental* (PNEA) in 1999 (Zezzo and Coltri 2022). While the PNEA encouraged interdisciplinary approaches, it did not prioritize climate change as a distinct focus, and educational frameworks like the *Parâmetros Curriculares Nacionais* (PCN) and *Diretrizes Curriculares Nacionais* (DCN) provided only limited integration of the topic (UNESCO 2013). Consequently, CCE was sporadically addressed, often limited to natural science disciplines and overlooking its broader social, economic, and political dimensions.

Challenges such as inadequate teacher training, limited resources, conceptual errors in textbooks, and fragmented approaches further hindered the development of CCE (Zezzo and Coltri 2022). The increasing frequency of extreme weather events, deforestation in the Amazon, and Brazil's commitments to international agreements like the Paris Agreement (2015) underscored the urgency of climate education, yet efforts remained inconsistent and lacked systemic support.

The introduction of the BNCC marked some progress by including climate change within broader environmental education goals. However, this inclusion was often general and confined to specific disciplines, such as Natural Sciences and Geography, without a comprehensive, interdisciplinary framework. Critics have highlighted the absence of clear guidelines for integrating CCE into curricula, inadequate resources, and insufficient professional development for teachers (Souza 2022; Zezzo and Coltri 2022). Many educators remain unprepared to teach climate change in a meaningful, interdisciplinary way, while educational materials and extracurricular initiatives are still limited (Molthan-Hill et al. 2019; Tibola da Rocha et al. 2020).

These gaps emphasize the need for more targeted and structured policies to equip students with the knowledge and skills necessary to address climate challenges. As Brazil faces significant climate risks, fostering a scientifically literate population through improved climate education is essential for enabling informed action (Leal Filho and Hemstock 2019).

5.3.3 The Critical Role of CCE in Brazil and its implications

Educating Brazilian citizens about climate change is not merely an environmental endeavor but a strategic priority for safeguarding the nation's unique ecological, cultural, and economic legacy. Brazil's diverse biomes (encompassing two hotspots)—including the Amazon, Cerrado, Atlantic Forest, Pantanal, Pampas, and Caatinga—play critical roles in global carbon regulation, biodiversity preservation, and water cycles (de Figueiredo Machado et al. 2024). Their degradation, driven by deforestation, land-use changes, and climate pressures, poses serious risks both locally and globally (de Figueiredo Machado et al. 2024; Dionizio et al. 2020; Fearnside 2017; Sawyer 2008). Climate education can catalyze collective action to address these challenges and foster innovative solutions.

The Amazon, for instance, stores nearly 20 gigatons of soil organic carbon and harbors 10% of the world's known species. Its deforestation exacerbates global warming and threatens ecological balance (ILAJUC 2024). This storage capacity is vital for regulating atmospheric CO_2 levels, which directly influence global temperature. Forest degradation and deforestation, however, release stored carbon back into the atmosphere, turning these ecosystems into net carbon emitters rather than absorbers (Caballero et al. 2023; de Figueiredo Machado et al. 2024).

The Cerrado, known as the "water cradle of Brazil," feeds eight of the country's 12 major river basins, making it essential for agricultural productivity and freshwater availability (Agencia Brasil 2023; WWF 2024). However, its rapid conversion to farmland endangers these vital functions (Mongabay, 2018). Similarly, the Pantanal, one of the world's largest tropical wetlands, supports rich biodiversity and carbon storage but faces threats from land-use changes and wildfires (Junk et al. 2013). Other biomes, such as the Pampas and Caatinga, contribute to the country's agricultural potential and unique species diversity, but they are also increasingly vulnerable to desertification and overgrazing (Salazar et al. 2021; Roesch et al. 2009).

Local communities, including indigenous peoples, quilombolas, and smallholder farmers, depend on the climate balance provided by these biomes for their livelihoods (Climate and Land Use Alliance 2016). In this sense, climate disruptions threaten not only their subsistence but also Brazil's cultural and historical heritage.

Besides that, climate disturbances can exacerbate existing inequalities in urban centers, where marginalized groups often live in precarious conditions (The World Bank 2011). In cities, the most socio- and economically vulnerable people are disproportionately affected by the impacts of climate change, such as extreme heat, flooding and water scarcity (The World Bank 2011). Informal settlements, typically located in flood-prone or heat-intensified areas, face heightened risks due to insufficient infrastructure, lack of green spaces, and limited access to resources (WEFORUM 2023).

These vulnerabilities are further compounded by the spread of diseases. Habitat destruction and ecological imbalances have facilitated the emergence of new pathogens, while rising urban temperatures and poor sanitation in densely populated areas accelerate the proliferation of vector-borne illnesses like dengue and chikungunya (Nava et al. 2017; Tidman et al. 2021). Both rural and urban populations bear the brunt of these interlinked health and environmental crises, which deepen socio-economic disparities across Brazil (Zezzo et al. 2021).

Globally, Brazil's position as a major greenhouse gas emitter (de Figueiredo Machado et al. 2024), largely due to deforestation, underscores its responsibility in combating the climate crisis. Climate education equips citizens to understand their role in reducing emissions and advocating for sustainable practices (UNFCCC 2022), thereby enhancing Brazil's influence in international climate negotiations. It also fosters engagement in global initiatives to protect ecosystems of global significance.

For younger generations, climate education is particularly crucial (The World Bank 2024). By linking local challenges to global responsibilities, it prepares them to address the socio-environmental complexities of the future, fostering resilience and innovation. Ultimately, integrating climate education into national policies strengthens Brazil's ability to protect its biomes, support sustainable development, and lead global efforts in tackling the climate crisis.

5.4 Research Questions

This manuscript presents the findings of a research project exploring the knowledge of climate change among individuals with higher education in Southeast Brazil. It examines the variables that most influence their understanding and identifies the misconceptions held by this group. In addition, it considers the role of formal and informal education in shaping their knowledge. To gain a deeper understanding of the factors influencing their climate change knowledge and identify key predictors, the following research questions were posed:

(1) What is the level of knowledge and understanding about climate change among individuals with higher education in Southeast Brazil, and what common misconceptions exist?

(2) How do factors such as age, gender, and educational background influence the concerns and engagement of participants in climate-related discussions and actions?

(3) What are the challenges and gaps in CCE in Brazil, particularly regarding teacher training, educational content, and its impact on critical thinking and societal action?

5.5 Methodology

The methodology comprised two stages, as shown in Figure 1: preparation and application of the questionnaire based on the literature review (1); and, statistical treatment and analysis of results based on literature (2). Each step is described in detail in the sections below.

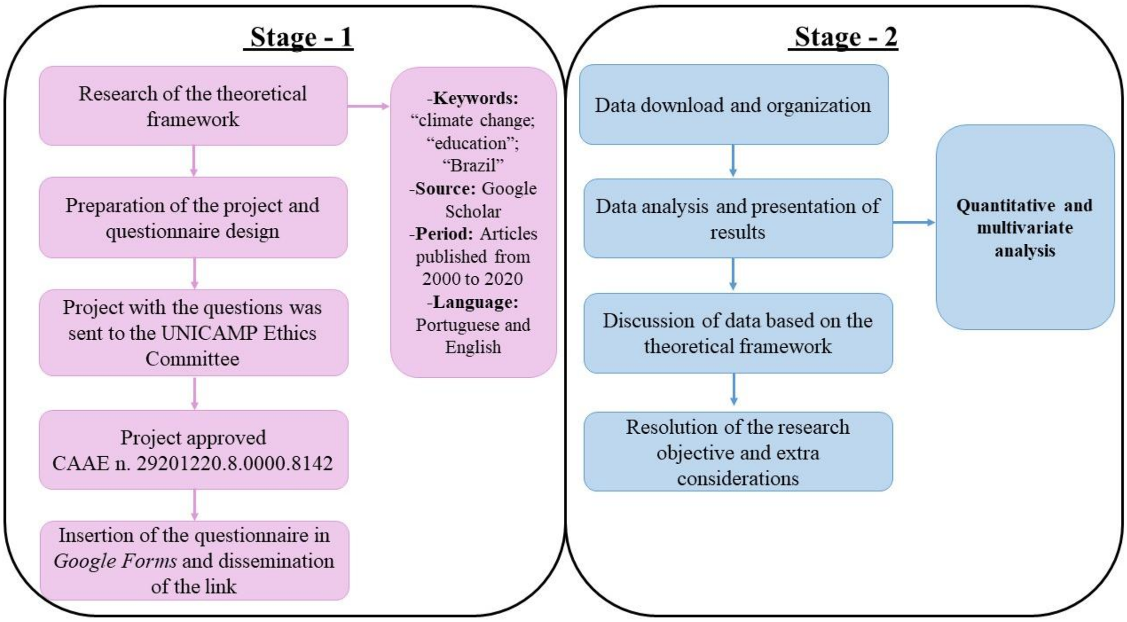


Figure 1: Illustrative diagram of the stages that comprise the methodology with their respective steps.

5.5.1 Preparation and Application of the Questionnaire

In the first stage, a comprehensive literature review was conducted to identify key themes, variables, and knowledge gaps relevant to CCE in both international and Brazilian contexts. The review focused specifically on the evolution of CCE in Brazil over the past two decades (2000–2020), analyzing how the field has developed and how the topic has been addressed in the country's academic discourse. This critical review allowed us to map the main concepts, skills, and challenges in CCE, such as: interdisciplinary teaching approaches, teacher training gaps, and the integration of CCE in national curricula. By understanding how researchers have positioned CCE in Brazil, we were able to frame our study within the broader educational and environmental landscape.

Based on the insights gathered from this literature review, we designed a structured questionnaire to assess academic professionals' understanding of and engagement with CCE in Southeast Brazil. The questionnaire was tailored to capture both qualitative and quantitative data, including closed-ended questions for statistical analysis and open-ended questions for deeper insights. Before dissemination, the questionnaire was submitted to and approved by the Ethics Committee of the State University of Campinas (UNICAMP), ensuring compliance with ethical research standards.

After receiving ethical approval, the questionnaire was hosted on Google Forms, an online survey platform, to facilitate data collection. To target our sample of academic professionals, we employed a multi-channel distribution strategy, disseminating the survey through personal networks, social media platforms of researchers, and institutional channels, including the Center for Meteorological and Climate Research Applied to Agriculture (CEPAGRI) and UNICAMP. This approach was designed to ensure that the majority of respondents would be individuals with advanced academic training, such as university students, professors, and researchers, thus providing a more homogeneous sample in terms of educational background.

The data collection period spanned from November 2020 to May 2021. During this time, the responses were regularly monitored and recorded. After the data collection phase concluded, we processed the results using both descriptive and inferential statistical techniques, applying the literature review as a theoretical framework for analysis (describe in 5.5.2 section). The qualitative responses were subjected to thematic analysis, providing additional insights that complemented the quantitative findings. These combined methods allowed for a more nuanced understanding of the current state of CCE in the region.

It is important to note that this method of questionnaire distribution was intentionally selected to reach a targeted academic audience, enabling us to gather insights from individuals deeply engaged with higher education and research. This sampling strategy ensured that the findings would reflect the perspectives of those most likely to influence CCE in academic settings.

5.5.2 Questionnaire Design

The questionnaire was carefully structured to achieve three main objectives, as illustrated in Figure 2: (1) to characterize the demographic profile of the participants, considering variables such as age, gender, and education level; (2) to assess the participants' prior exposure to CCE and evaluate their level of understanding on the subject; and (3) to gauge their level of concern and interest regarding climate change issues. These categories were essential to capture a comprehensive overview of the respondents' background and attitudes toward CCE.

A total of ten questions were developed based on a survey framework created by the United Nations Development Programme (UNDP) and the Ministry of Environment and Physical Planning of the Republic of Macedonia (2017). This established framework was chosen because of its effectiveness in assessing public perception of climate change and the level of public awareness on the topic. The adaptation of this survey allowed us to tailor it to the academic context of Southeast Brazil, ensuring relevance to the study's focus.

The questions combined both multiple-choice and Likert-scale formats to facilitate ease of response and ensure the collection of both quantitative and qualitative data. For instance, questions assessing the level of understanding of climate change ranged from basic concepts (e.g., knowledge of greenhouse gases) to more complex issues (e.g., familiarity with climate change mitigation strategies). Additionally, open-ended questions provided respondents with the opportunity to express their views on CCE, further enriching the dataset.

Given that the survey was conducted online, strict adherence to the General Data Protection Regulation (GDPR) was followed, ensuring proper data handling and safeguarding respondents' privacy. Although no personal identification data was collected, all respondents were fully informed of their rights and the nature of their participation through a consent form. This form explained the study's objectives, detailed the voluntary nature of participation, and outlined the requirements, including a minimum age of 18. Only those who provided explicit consent were able to proceed with the questionnaire.

This rigorous approach ensured both the ethical integrity of the study and the reliability of the data collected, while the structure of the questionnaire allowed for a clear and systematic analysis of the respondents' perspectives on CCE.

5.5.3 Statistical Treatment and Analysis of Results

The analysis of the collected data was carried out in two distinct stages to ensure both a broad understanding of individual responses and a deeper exploration of patterns within the data.

In the first stage, a general statistical evaluation was conducted. This involved analyzing the responses to each question separately, using quantitative methods to generate descriptive statistics. Percentages, mean values, and frequency distributions were calculated for each question, allowing for a clear understanding of the overall trends in the data. These descriptive statistics helped to identify commonalities and variations in the respondents' demographic characteristics, climate change awareness, and educational background.

In the second stage, we employed multivariate analysis to explore relationships between different variables and to identify potential respondent profiles. Specifically, we used techniques such as cross-tabulation and correlation analysis to assess how responses from different questions were interrelated. This multivariate approach provided insights into how factors such as age, education level, or gender might influence perceptions of CCE and climate-related concerns. By examining these relationships, we aimed to uncover patterns that could inform a more nuanced understanding of the respondent group's attitudes toward climate change.

To ensure the reliability of the statistical analysis, we performed data normalization, particularly when comparing responses across different scales or question types. This step was essential to prevent distortions and ensure that variations in the data accurately reflected differences in respondent profiles, rather than inconsistencies in measurement.

The processed data were then tabulated and visualized using various graphical methods, including bar charts, pie charts, and scatter plots. These visual tools were used to present the results in a clear and interpretable manner, making it easier to identify significant trends and relationships. The graphs provided a visual summary of the data, while the subsequent discussion focused on interpreting the results in light of the research objectives and the theoretical framework developed in the literature review.

This two-stage statistical analysis allowed for both a comprehensive overview of the data and a more detailed exploration of the underlying factors influencing CCE perceptions in the region.

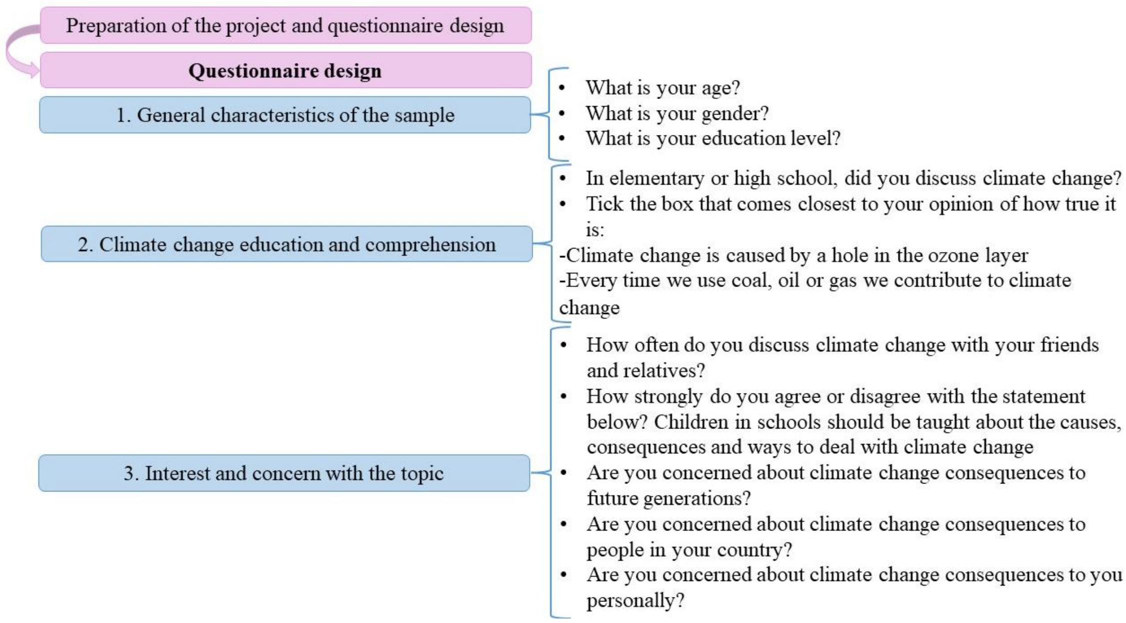


Figure 2: Presentation of the information designed for the questionnaire and the corresponding questions.

5.6 Results

The questionnaire yielded a total of 1,111 responses, providing a diverse sample for analysis. Notably, 33% of participants were aged between 21 and 30 years, followed by 22% in the 31 to 40 age group. In contrast, older age groups were underrepresented, with only 2% of respondents aged 71 to 80 years and 4% aged 18 to 20 years. This distribution indicates a robust representation of younger adults, suggesting that this demographic may be more engaged with climate change discussions.

Regarding gender, a significant majority (73%) of respondents identified as female, while 26% identified as male, and 1% chose not to disclose their gender. This gender distribution may reflect the demographics of the university communities surveyed, where women often demonstrate higher engagement in social and environmental issues.

However, the disproportionate representation calls for further exploration into the reasons behind this trend and its implications for climate change advocacy and education.

The educational background of the participants reflects a highly educated group, with nearly half (45%) holding postgraduate degrees and 44% having completed undergraduate studies. A smaller proportion reported secondary education (7%), technical qualifications (2%), or other forms of education (2%). This distribution highlights that the sample comprises individuals with some of the highest levels of formal education attainable in Brazil.

Given the age range of the respondents, their exposure to CCE likely occurred during their secondary schooling in the 1990s and 2000s or through their higher education from the 2000s onward. This timeline is critical for understanding the broader trends in CCE during their academic formation. Their learning would have been shaped by earlier frameworks such as the PCN and the PNEA, rather than the more recent BNCC, introduced in 2017.

In undergraduate and postgraduate contexts, climate change topics are generally absent from curricula, except in specialized environmental courses. This underscores the limited systemic integration of CCE during their academic journey and provides a key context for interpreting their knowledge and perspectives on the subject.

When examining interest in climate change discussions, 46% of respondents indicated they occasionally discuss climate change with friends or family, and 27% engage in these conversations frequently. Conversely, 24% reported rarely discussing the issue, while only 3% stated they never talk about climate change. These figures indicate a generally high level of engagement among participants, although a significant minority remains less involved, highlighting potential areas for targeted educational interventions.

Participants were also asked to recall any discussions about climate change during their primary or secondary education (Figure 3). Only 21% reported having specific classes on the topic, while 39% stated they had merely discussed it, and 27% indicated they had never addressed the subject in class. These questions aimed to evaluate the historical inclusion of CCE in formal education and its potential impact on participants' current engagement with the issue. The findings reveal a significant gap in the integration of CCE into past curricula, suggesting that many participants may have entered adulthood with a limited foundational understanding of climate change, potentially affecting their ability to comprehend and act on the issue today.

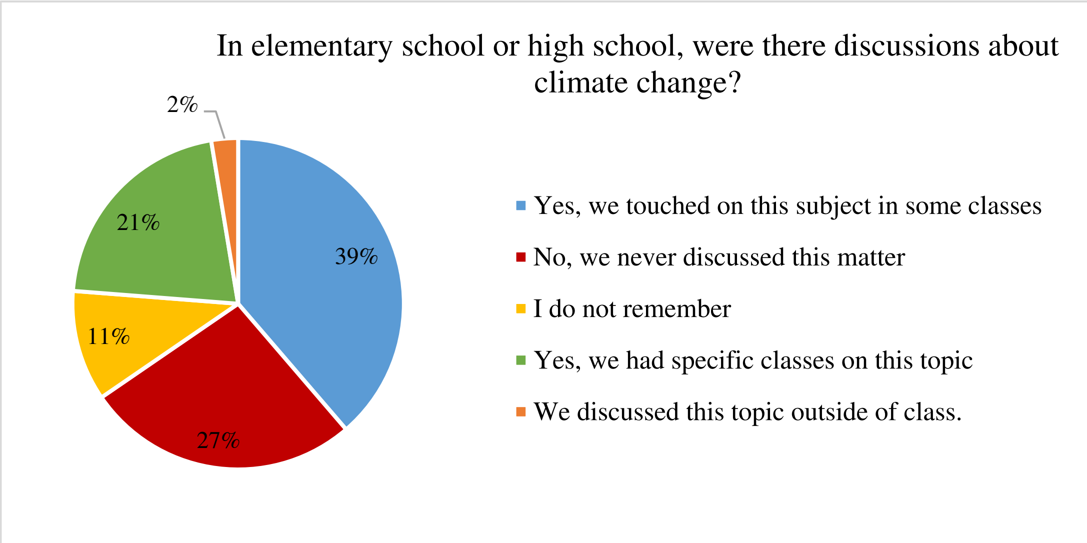


Figure 3: Percentage of participants who indicated having some type of contact with the issue of climate change in formal education.

To evaluate common misconceptions about climate change, participants were presented with two key statements: "Climate change is caused by a hole in the ozone layer" (Figure 4) and "Every time we use coal, oil, or gas, we contribute to climate change" (Figure 5). The first statement addresses a common misconception, with 47% of respondents saying it is probably true and 26% saying it is definitely true. Conversely, the second statement accurately reflects fossil fuel contributions to greenhouse gas emissions, with 65% affirming it as definitely true.

The questionnaire further explored attitudes towards integrating CCE into school curricula. A striking 93% of respondents strongly agreed with the statement: "Children in schools should be taught about the causes, consequences, and ways to combat climate change," reflecting a robust consensus on the necessity of early climate education as a means of fostering awareness and understanding among future generations. Only 2% of participants expressed disagreement, underscoring a collective commitment to enhancing CCE.

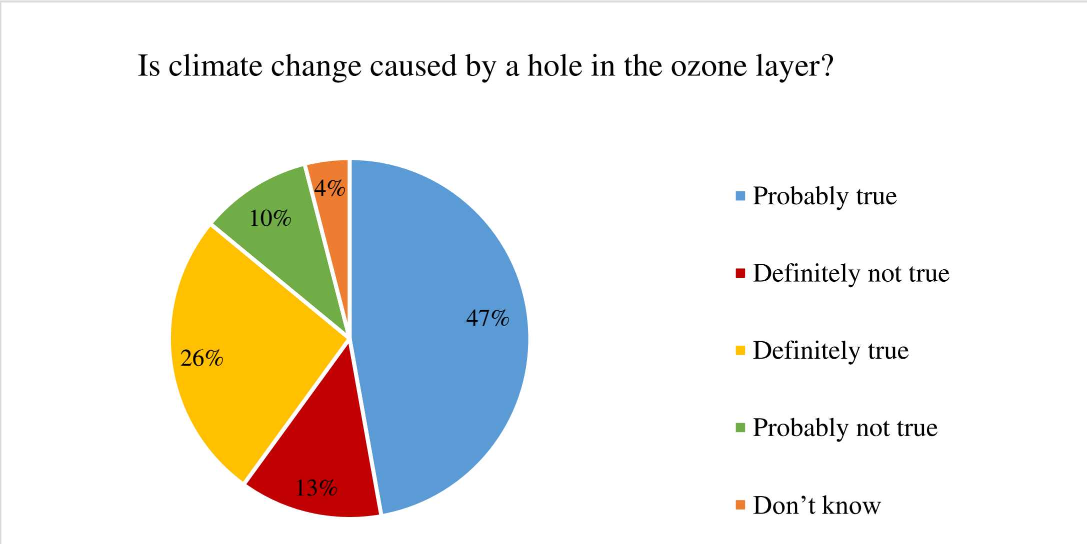


Figure 4: Indication of the percentage of participants who gave an opinion on the statement that climate change is caused by the hole in the ozone layer.

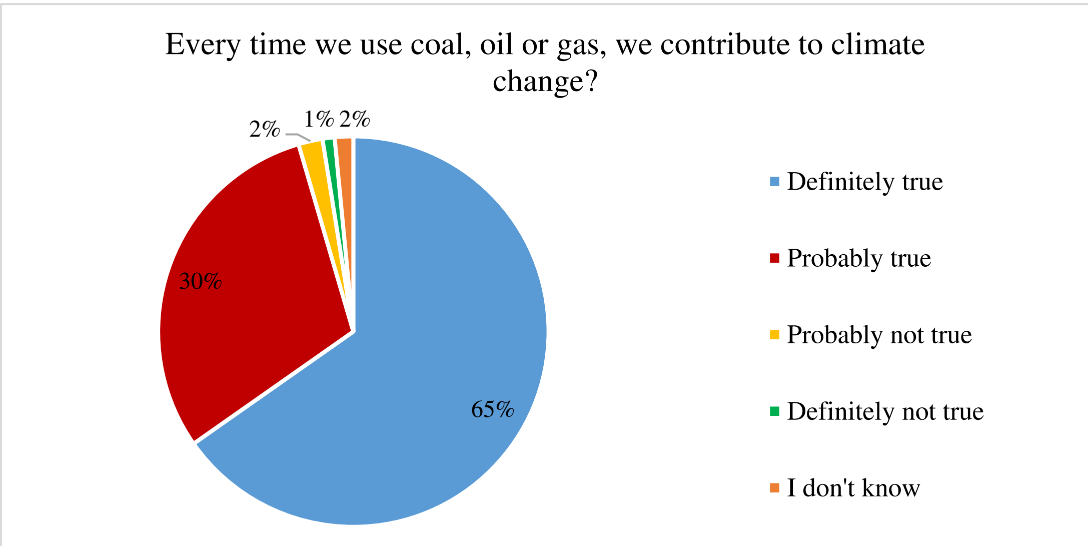


Figure 5: Survey participants' responses regarding the use of non-renewable fuels and the intensification of climate change.

The survey also assessed participants' concerns about the impacts of climate change across three levels: future generations, their country, and personal implications. A notable 80% of respondents expressed significant concern for future generations (Table 1), indicating a strong sense of responsibility and awareness of the long-term consequences of climate change. Furthermore, 65% of participants conveyed a high level of concern regarding climate change impacts in Brazil, while 54% expressed significant personal concern. These results suggest that while participants are generally aware of the broader societal implications of climate change, they also recognize its potential personal ramifications.

Collectively analyzing the responses revealed that younger age groups reported greater exposure to CCE, either through general classroom discussions or specific lessons (Figure 6). In contrast, participants aged 41-80 indicated a significant lack of discussions on this topic during their school years, which may contribute to the knowledge gaps identified in older cohorts. This generational disparity highlights the need for continuous and comprehensive climate education that addresses existing misconceptions and fosters critical thinking skills across all age groups.

Furthermore, an investigation into misconceptions regarding the relationship between the ozone layer and climate change showed that 80% of participants under 30 agreed with the erroneous statement, while 20% disagreed. This trend persisted in the 31-50 age group, where 70% affirmed the misconception. The persistence of such misunderstandings, despite exposure to CCE, raises concerns about the effectiveness of current educational strategies and emphasizes the necessity for curricula that challenge misconceptions directly.

Table 1: Percentage results for the questions about the concern about the impacts of climate change in different aspects.

Are you concerned about climate change consequences to…?	**Very concerned**	**Somewhat concerned**	**Not very concerned**	**Not at all concerned**
Future generations	80%	16%	3%	1%
People in your country	65%	30%	4%	1%
You personally	54%	35%	9%	2%

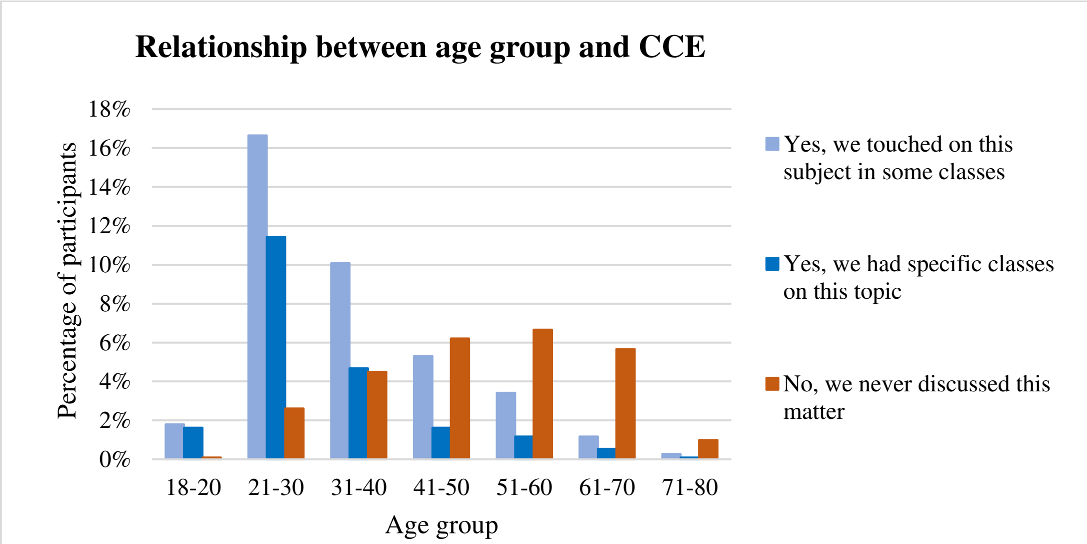


Figure 6: Relationship between the age group of the research participants and the education they had on climate change.

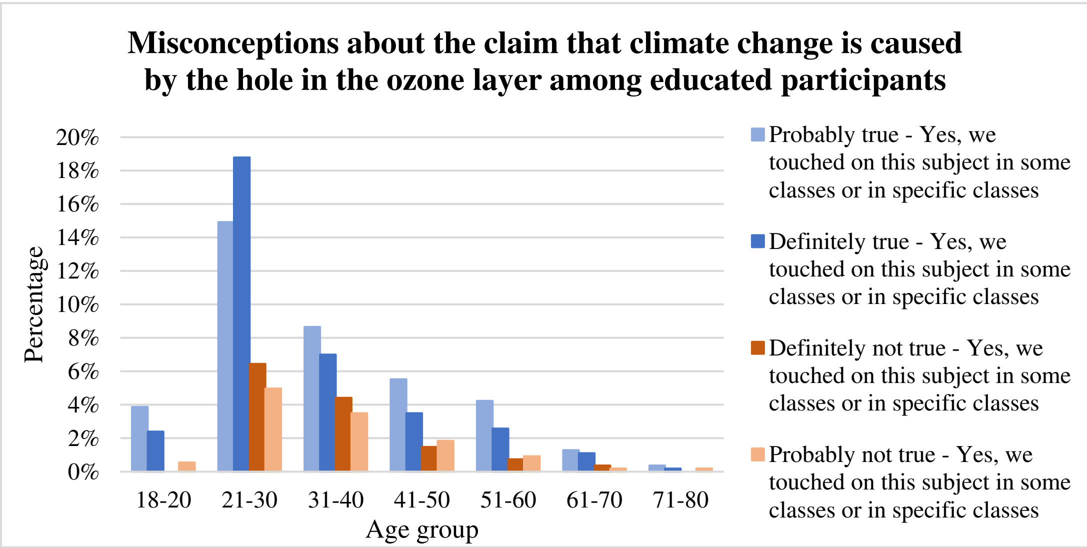


Figure 7: Relationship between participants who were educated on climate change and the misconception about environmental and climate issues.

Gender differences in beliefs about climate change were also notable. Among the 811 female respondents, 78% agreed with the misconception that climate change is caused by a hole in the ozone layer, compared to 58% of the 289 male participants. The larger number of female respondents complicates direct comparisons, but these findings warrant further exploration into the social and educational factors influencing gender-based differences in climate change perceptions.

Moreover, nearly unanimous support for incorporating CCE into formal curricula was evident, regardless of prior exposure to the subject (Figure 8). This strong collective recognition of the importance of addressing climate change within educational frameworks indicates a potential avenue for policy recommendations aimed at enhancing climate literacy across educational institutions.

Lastly, responses to questions concerning the impacts of climate change on participants' personal lives and their country demonstrated a consistent trend across demographic groups (Table 2). Even participants lacking formal education on climate change exhibited high levels of concern, suggesting a widespread awareness of the potential consequences of climate change.

In summary, while the results of this study provide a descriptive overview of participants' knowledge, attitudes, and concerns regarding climate change, they also highlight critical areas for future research and policy development. The identified misconceptions, varying levels of engagement, and strong support for educational integration all point to the need for targeted interventions that enhance climate literacy, address misconceptions, and prepare future generations to effectively tackle climate-related challenges.

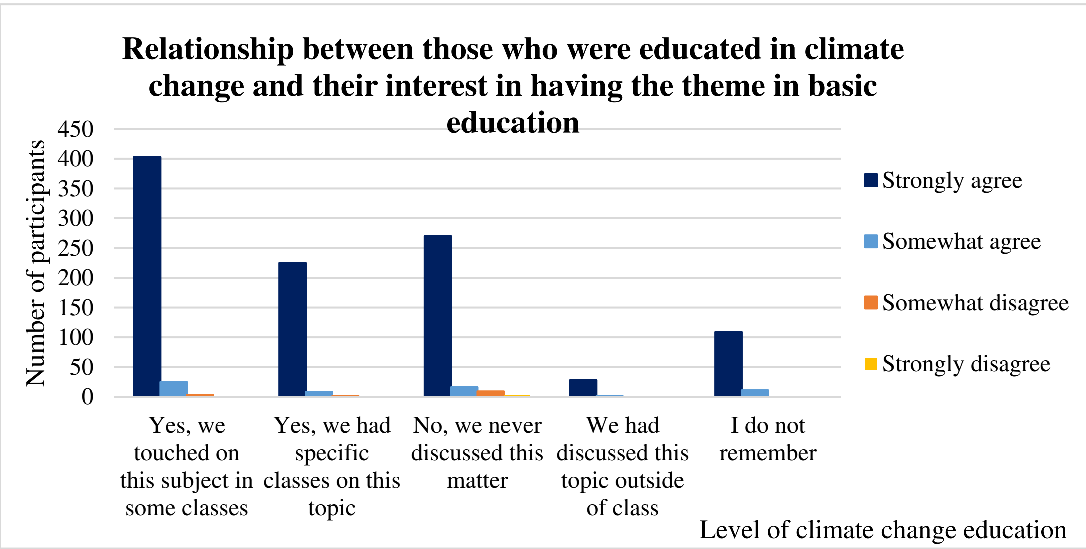


Figure 8: Relationship between the level of CCE and the public's interest in the formal teaching of this content in the school domain

Table 2: Indication of the level of concern about the impacts of climate change for future generations among the research participants, considering the scale of CCE of each one (data in percentage and absolute value).

Level of CCE among the participants and their concern with future generations	**Very concerned**	**Somewhat concerned**	**Not very concerned**	**Not at all concerned**
Yes, we touched on this subject in some classes	31 % (339)	7% (77)	1% (14)	0% (1)
Yes, we had specific classes on this topic	16% (182)	4% (43)	1% (9)	0% (0)
No, we never discussed this matter	22% (243)	4% (40)	1% (8)	1% (6)
We had discussed this topic outside of class	2% (27)	0% (1)	0% (1)	0% (0)
I do not remember	9% (95)	2% (21)	0% (3)	0% (1)

5.7 Discussions

The educational profile of our survey participants reveals significant differences from the broader Brazilian population. In our sample, 45% had completed postgraduate studies, and 44% had completed undergraduate studies. This suggests a relatively high level of education among participants, offering valuable insights into perceptions of climate change, as higher educational attainment typically correlates with a more sophisticated understanding of climate-related issues (McCright 2010; Leiserowitz et al. 2009). However, it is important to note that these findings may not fully represent the general Brazilian population, where lower educational levels are often linked to less awareness and concern about climate change. To enhance the representativeness of future studies, it would be beneficial to include participants from a wider range of educational backgrounds and socioeconomic statuses.

The majority of participants in this study (primarily aged between 21 and 30 years) were female, a trend consistent with existing research on gender differences in climate change concern (McCright 2010). Studies consistently show that women tend to express greater concern about climate change than men (Stevenson et al. 2016), a pattern also observed in this study. McCright (2010) notes that while women may sometimes underestimate their climate knowledge, they often have a clearer grasp of the issue's significance. This heightened concern among women may be attributed to greater awareness of the potential impacts of climate change on health, society, and the environment (Stevenson et al. 2016). The predominance of female participants in this study signals a growing recognition of the urgency of climate action among women and a higher likelihood of their engagement in studies of this nature.

Additionally, 73% of participants reported frequently or occasionally discussing climate change, underscoring the level of concern about the topic. Research suggests that such discussions—whether in informal settings with family and friends or in professional environments—are crucial for raising awareness and encouraging climate action (Stevenson et al. 2016). The more climate change is integrated into daily conversations, the more likely individuals are to take action, thus contributing to broader collective efforts.

Despite the high level of education among participants, misconceptions about climate change remain prevalent. For instance, a significant number of respondents incorrectly identified "a hole in the ozone layer" as the cause of climate change, a misconception also noted in other studies (Busch et al. 2019; da Rosa 2021). Monroe et al. (2017) argue that many students fail to understand the scientific basis of climate change, a gap exacerbated by inadequate teacher training and a lack of interdisciplinary approaches in climate education. CCE often focuses on the transmission of factual knowledge rather than fostering a deeper, more critical understanding of the issue (Monroe et al. 2017).

Educators, whether in formal or informal settings, face significant challenges in addressing such misconceptions. Erroneous ideas hinder the development of a society capable of critically engaging with climate issues. This challenge is compounded by the insufficient integration of CCE into school curricula, which often lacks the interdisciplinary depth needed to tackle climate change comprehensively (Chen 2011; Molthan-Hill et al. 2019; Tibola da Rocha et al. 2020). Our study's findings reinforce the need to address these misconceptions within educational settings, as even highly educated individuals struggled with basic climate concepts.

The relationship between misconceptions and participants' educational background and gender further highlights the complexity of climate literacy. Notably, 33% of graduate students and 30% of those with advanced degrees held misconceptions about climate change. This suggests that higher levels of formal education do not necessarily mitigate the persistence of misconceptions, pointing to a broader issue of scientific literacy that must be addressed through more effective climate education (da Rosa 2021).

Scientific literacy, including the ability to critically assess and respond to climate change, has been increasingly emphasized in global education policies (Otto et al. 2019). However, in Brazil, this remains poorly structured, with limited national guidance on how to teach climate change in schools (Souza 2022). Although climate change is occasionally mentioned in the BNCC, there is no clear directive on when or how to integrate it into primary and secondary education. This gap in the curriculum contributes to the continued spread of misconceptions and impedes the development of critical thinking about climate change (Zezzo and Coltri 2022).

To address these gaps, it is crucial to strengthen CCE across all educational levels, from primary to higher education. Key measures include improving teacher training, enhancing educational materials, and establishing a more structured curriculum. Investments in education and greater recognition of climate change as a fundamental subject are essential for fostering the scientific literacy required to drive global climate action (Tibola da Rocha et al. 2020; Zezzo et al. 2020).

Moreover, the study revealed that participants were more concerned about the impacts of climate change on future generations rather than on their own lives. This perception of climate change as a distant threat—a concern for future generations rather than an immediate crisis—aligns with findings from Wibeck (2014), which suggest that many people view climate change as a problem for governments to address, rather than an issue that also requires personal action and awareness. This sense of temporal and spatial distance may explain why many individuals still fail to prioritize climate action in their daily lives.

The limited investment and lack of clear educational policies on climate change in Brazil, despite international recognition of its urgency following the Paris Agreement (Fahey 2012), reflect a broader issue of neglect. There is an urgent need for more effective CCE policies that integrate climate change into formal education systems and focus on preparing young people to adapt to the realities of climate change (Leal Filho and Hemstock 2019; Zezzo et al. 2020).

This brief diagnostic analysis of CCE in Southeast Brazil confirms that, although climate change is a current issue, there are no clear guidelines for teaching the topic, and studies in this area remain scarce across the country (Zezzo and Coltri 2022). This lack of direction highlights a cycle of neglect in the fight against climate change, underscoring the critical role of scientific communication and education. This is particularly relevant in countries like Brazil, with vast territories and diverse characteristics, where targeted efforts in climate education are essential.

5.8 Conclusions

Brazil plays a pivotal role in global climate change mitigation and adaptation efforts, making it essential for both its government and citizens to comprehend the short, medium, and long-term impacts of climate change. However, the complexity of the issue presents substantial challenges to widespread understanding, particularly when misconceptions persist even among highly educated groups.

The study revealed that our sample, predominantly composed of young, educated women, demonstrated a strong awareness of climate change. Participants frequently engaged in discussions about climate change, indicating a high level of concern. Nevertheless, misconceptions about basic climate science—such as the erroneous belief that climate change is caused by a hole in the ozone layer—were prevalent, even within this well-educated demographic. This underscores the importance of refining CCE to foster a deeper, more accurate understanding of the phenomenon.

The persistence of misconceptions highlights the critical need for ongoing professional development for educators and the creation of comprehensive, interdisciplinary teaching materials that address climate change in a meaningful way. While Brazil has made some strides in integrating climate change into education, much remains to be done. The lack of structured national guidance on how to teach climate change at various educational levels, coupled with insufficient investment in teacher training, impedes the development of scientific literacy needed to address the climate crisis effectively.

Investments in education, especially at the foundational level, are urgently needed to equip educators with the tools necessary to engage students in critical climate discussions. Given Brazil's diverse demographic and regional disparities, these efforts must be tailored to local contexts while also ensuring national consistency in climate education. Furthermore, it is crucial to integrate climate change into both formal curricula and extracurricular activities, fostering a more comprehensive approach to education that empowers individuals to take personal action.

This study highlights the significant research potential regarding climate education in Brazil and underscores its relevance on the international stage. Similar studies conducted across the globe can provide invaluable insights into the systemic challenges and opportunities in cultivating scientifically literate, climate-conscious societies. Ultimately, addressing the gaps in climate education will be key to preparing future generations to face the realities of a changing climate.

5.9 References

Agencia Brasil (2023) Deforestation in Brazil's cerrado threatens water security countrywide. https://agenciabrasil.ebc.com.br/en/geral/noticia/2023-09/deforestation-brazils-cerrado-threatens-water-security-countrywide

Allan BJM, Domenici P, McCormick MI, Watson SA, Munday PL (2013) Elevated CO2 Affects Predator-Prey Interactions through Altered Performance. PLOS ONE 8(3): e58520. https://doi.org/10.1371/journal.pone.0058520

Archer D, Rahmstorf S (2009) The Climate Crisis: An Introductory Guide to Climate Change. Cambridge University Press. https://doi.org/10.1017/CBO9780511817144

Busch KC, Ardoin N, Gruehn D, Stevenson K (2019) Exploring a theoretical model of climate change action for youth. International Journal of Science Education 41(17): 2389-2409. https://doi.org/10.1080/09500693.2019.1680903

Caballero CB, Biggs TW, Vergopolan N, West TAP, Ruhoff A (2023) Transformation of Brazil's biomes: The dynamics and fate of agriculture and pasture expansion into native vegetation. Science of The Total Environment 896: 166323. https://doi.org/10.1016/j.scitotenv.2023.166323

Chen X (2011) Why Do People Misunderstand Climate Change? Heuristics, Mental Models and Ontological Assumptions. Climatic Change 108(1-2): 31-46. https://doi.org/10.1007/s10584-010-0013-5

Climate and Land Use Alliance (2016) Challenges and opportunities for conservation, agricultural production, and social inclusion in the Cerrado biome. Technical Annex: Traditional People and Communities, Biodiversity, Water and Climate Change. https://www.climateandlandusealliance.org/reports/cerrado/

Conjo MPF, Chichango DB, Tamele AJ, Simão EJ, et al (2021) Abordagens da educação ambiental e mudanças climáticas no ensino formal em Moçambique. Revista Ibero-Americana De Humanidades, Ciências E Educação 7(12): 140–157. https://doi.org/10.51891/rease.v7i12.3454

da Rosa JA (2021) Comparing climate science misconceptions with worldview and cognitive reflection suggests poor understanding and motivated reasoning among undergraduates. Journal of Geoscience Education 70(4): 501-516. https://doi.org/10.1080/10899995.2021.2006549

de Figueiredo Machado F, Terra MCNS, Rodrigues AF et al (2024) Beyond COP28: Brazil must act to tackle the global climate and biodiversity crisis. npj biodivers 3: 19. https://doi.org/10.1038/s44185-024-00051-9

Dionizio EA, Pimenta FM, Lima LB, Costa MH (2020) Carbon stocks and dynamics of different land uses on the Cerrado agricultural frontier. PLoS ONE 15(11): e0241637. https://doi.org/doi. org/10.1371/journal.pone.0241637

Easterling DR, Wehner MF (2009) Is the climate warming or cooling? Geophysical Research Letters 36: L08706. https://doi.org/10.1029/2009GL037810

Fahey SJ (2012) Curriculum change and climate change: Inside outside pressures in higher education. Journal of Curriculum Studies 44(5): 703-722. https://doi.org/10.1080/00220272.2012.679011

Fearnside P (2017) Deforestation of the Brazilian Amazon. Oxford Research Encyclopedia of Environmental Science. https://oxfordre.com/environmentalscience/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-102

ILAJUC. Instituto latino americano para justiça coletiva (2024) O papel dos biomas brasileiros no sequestro de Carbono. https://ilajuc.org/2024/06/11/o-papel-dos-biomas-brasileiros-no-sequestro-de-carbono/

IPCC. Intergovernmental Panel on Climate Change (2022) Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://www.ipcc.ch/report/ar6/wg2/

IPCC. Intergovernmental Panel on Climate Change (2021) Climate Change 2021: The Physical Science Basis. In: Masson-Delmotte VP, et al. (Eds.). Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Junk WJ, An S, Finlayson C, Gopal B (2013) Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. Aquatic Science 75: 151–167. https://link.springer.com/article/10.1007/s00027-012-0278-z

Leal Filho W, Hemstock SL (2019) Climate Change Education: An Overview of International Trends and the Need for Action. In: Leal Filho W, Hemstock S (eds.). Climate Change and the Role of Education. Change Management, Switzerland, 1-17. https://doi.org/10.1007/978-3-030-32898-6_1

Leiserowitz A, Maibach E, Roser-Renouf C, et al (2009) Climate change in the American mind. Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change Communication. www.climatechangecommunication.org/images/files/Climate_Change_in_the_American_Mind.pdf

Lewandowsky S, Cook J, Ecker UKH, Albarracín D, et al (2020) The Debunking Handbook. https://doi.org/10.17910/b7.1182

Lockwood M, Frölich C (2007) Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature. Proceedings of the Royal Society A 463: 2447-2460. https://doi.org/10.1098/rspa.2007.1880

McCright AM (2010) The effects of gender on climate change knowledge and concern in the American public. Population and Environment 32: 66-87. https://doi.org/10.1007/s11111-010-0113-1

Ministry of Environment and Physical Planning of the Republic of Macedonia (2017) Climate change perceptions and awareness level: an online survey of the citizens of the Republic of Macedonia. http://unfccc.org.mk/UNDP/SURVEY/files/CC%20UNDP%20survey%202016-2017%20final.pdf

Molthan-Hill P, Worsfold N, Nagy GJ, Leal Filho W, Mifsud M (2019) Climate change education for universities: A conceptual framework from an international study. Journal of Cleaner Production 226: 1092-1101. https://doi.org/10.1016/j.jclepro.2019.04.053

MONGABAY (2018) Cerrado: Agribusiness may be killing Brazil's 'birthplace of waters'. https://news.mongabay.com/2018/03/cerrado-agribusiness-may-be-killing-brazils-birthplace-of-waters/

Monroe MC, Plate RR, Oxarart A, Bowers A, Chaves WA (2017) Identifying effective climate change education strategies: A systematic review of the research. Environmental Education Research 25(6): 791-812. https://doi.org/10.1080/13504622.2017.1360842

Nava A, Shimabukuro JS, Chmura AA, Luz SLB (2017) The Impact of Global Environmental Changes on Infectious Disease Emergence with a Focus on Risks for Brazil, ILAR Journal 58(3): 393–400. https://doi.org/10.1093/ilar/ilx034

Nepraš K, Strejčková T, Kroufek R (2022) Climate change education in primary and lower secondary education: Systematic review results. Sustainability 14(22): 14913. https://doi.org/10.3390/su142214913

Nunez S, Arets E, Alkemade R, et al (2019) Assessing the impacts of climate change on biodiversity: is below 2°C enough?. Climatic Change 154: 351–365. https://doi.org/10.1007/s10584-019-02420-x

Otto D, Caeiro S, Nicolau P, Disterheft A, Teixeira A, Becker S, Bollmann A, Sander K (2019) Can MOOCs empower people to critically think about climate change? A learning outcome based comparison of two MOOCs. Journal of Cleaner Production 222; 12-21. https://doi.org/10.1016/j.jclepro.2019.02.190

Perera A, Mudannyaka S, Azamathulla H, Rathnayake U (2020) Recent climatic trends in Trinidad and Tobago, west indies. Asia-Pacific Journal of Science and Technology 25(2): 1-11. https://so01.tci-thaijo.org/index.php/APST/article/view/205343

Reid A (2019) Climate change education and research: possibilities and potentials versus problems and perils? Environmental Education Research 25(6): 767-790. https://doi.org/10.1080/13504622.2019.1664075

Roesch LFW, Vieira FCB, Pereira VA, Schünemann AL, Teixeira IF, Senna AJT, Stefenon VM (2009) The Brazilian Pampa: A fragile biome. Diversity 1: 182-198. https://doi.org/10.3390/d1020182

Salazar, AA, Arellano EC, Muñoz-Sáez A, Miranda MD, Oliveira da Silva F, et al (2021) Restoration and conservation of priority areas of Caatinga's Semi-Arid Forest remnants can support connectivity within an agricultural landscape. Land 10: 550. https://doi.org/10.3390/land10060550

Sawyer D (2008) Climate change, biofuels and eco-social impacts in the Brazilian Amazon and Cerrado. Phil. Trans. R. Soc. B 363: 1747–1752. https://doi.org/10.1098/rstb.2007.0030

Schmidt A, Ivanova A, Schäfer MS (2013) Media attention for climate change around the world: A comparative analysis of newspaper coverage in 27 countries. Global Environmental Change 23(5): 1233-1248. https://doi.org/10.1016/j.gloenvcha.2013.07.020

Souza LB (2022) A crise climática na escola: como a problemática das mudanças climáticas está sendo trabalhada em livros didáticos do Ensino Médio? Dissertation, Universidade Federal do Rio Grande do Sul.

Stephens JC, Wilson E.J, Peterson TR (2008) Socio-political evaluation of energy deployment (SPEED): An integrated research framework analyzing energy technology deployment. Technological Forecasting and Social Change 75: 1224 – 1246. https://doi.org/10.1016/j.techfore.2007.12.003

Stevenson KT, Peterson MN, Bondell HD (2016) The influence of personal beliefs, friends, and family in building climate change concern among adolescents. Environmental Education Research 25(6): 832-845. https://doi.org/10.1080/13504622.2016.1177712

The World Bank (2024) Choosing our future: Education for Climate Action. https://openknowledge.worldbank.org/server/api/core/bitstreams/9d1c318a-bcd3-49fa-b1c6-cc03e18d4670/content

The World Bank (2011) Climate Change, Disaster Risk, and the Urban Poor. https://documents1.worldbank.org/curated/en/669421468188348522/pdf/68358-v2-disaster-risk-urban-poor-final-Box393223B-PUBLIC.pdf

Tibola da Rocha V, Brandli LL, Kalil RML (2020) Climate change education in school: knowledge, behavior and attitude. International Journal of Sustainability in Higher Education 21(4): 649-670. https://doi.org/10.1108/IJSHE-11-2019-0341

Tidman R, Abela-Ridder B, de Castañeda RR (2021) The impact of climate change on neglected tropical diseases: a systematic review. Transactions of The Royal Society of Tropical Medicine and Hygiene 115(2):147–168. https://doi.org/10.1093/trstmh/traa192

UNFCCC. United Nations Framework Convention on Climate Change (2015) Adoption of the Paris Agreement. 21st Conference of the Parties. Paris: United Nations. https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf

UNFCCC. United Nations Framework Convention on Climate Change (2022) Momentum for Climate Education Continues to Build. https://unfccc.int/news/momentum-for-climate-education-continues-to-build

UNESCO. United Nations Educational, Scientific and Cultural Organization (2013) Climate change in the classroom: UNESCO course for secondary teachers on climate change education for sustainable development. https://unesdoc.unesco.org/ark:/48223/pf0000219752

UNESCO. United Nations Educational, Scientific and Cultural Organization (2020) Educação para o Desenvolvimento Sustentável na Escola-Ação contra a mudança global do clima. Brasília, DF. https://unesdoc.unesco.org/ark:/48223/pf0000375083. (accessed 12 January 2021).

UNESCO. United Nations Educational, Scientific and Cultural Organization (2021) UNESCO urges making environmental education a core curriculum component in all countries by 2025. https://en.unesco.org/news/unesco-urges-making-environmental-education-core-curriculum-component-all-countries-2025 van der Linden S, Maibach E, Leiserowitz A (2015) Improving Public Engagement With Climate Change: Five “Best Practice” Insights From Psychological Science. Perspectives on Psychological Science 10(6): 758-763. https://doi.org/10.1177/1745691615598516

Weart SR (2008) The discovery of global warming. Harvard University Press.

Weber EU, Stern PC (2011) Public understanding of climate change in the United States. American Psychologist 66(4): 315-328. https://doi.org/10.1037/a0023253

WEFORUM (2023) The climate crisis disproportionately hits the poor. How can we protect them? https://www.weforum.org/stories/2023/01/climate-crisis-poor-davos2023/

WWF (2024) Cerrado is the most devastated biome in Brazil, accounting by far for eight of the 12 main rivers that supply the country's water. https://www.wwf.org.br/?89766/Cerrado-is-the-most-devastated-biome-in-Brazil-accounting-by-far-for-eight-of-the-12-main-rivers-that-supply-the-countrys-water

Zezzo LV, Coltri PP (2022) Educação em mudanças climáticas no contexto brasileiro: uma revisão integrada. Terrae Didatica 18(00): e022039. https://doi.org/10.20396/td.v18i00.8671305

Zezzo LV, Coltri PP, de Miranda MJ, Júnior, JZ (2021) Doenças infecciosas no contexto das mudanças climáticas e da vulnerabilidade socioambiental. Revista Brasileira De Climatologia 28: 671-697. https://doi.org/10.5380/rbclima.v28i0.75500

Zezzo LV, Oliveira JP de, Coltri PP (2020) Clima em jogo: uma ferramenta pedagógica para aprendizagem de conceitos em Geociências, com ênfase na Climatologia. Terrae Didatica 16: e020003. https://doi.org/10.20396/td.v16i0.8656203

CAPÍTULO 6 – MISCROSCALE MODELS AND URBAN HEAT ISLANDS: A SYSTEMATIC REVIEW

6.1 Abstract

Urban climate analysis usually uses data from weather stations, mobile traverse, or satellite images. However, this methodology also has its limitations, since the series of data for climate monitoring can be scarce. Another option that has been earning attention in recent years is numeric models, which perform simulations in urban climate. Obtaining climate data is extremely important for climatology, as well as for related areas, such as urban planning, which uses this data to know how to best order the territory according to climate conditions and their projections. Our study aimed to carry out a literature review regarding urban heat island analysis methodologies, with emphasis on the use of models. We evaluated over 200 scientific documents and we used 68 in the results of this work, reporting different types of models. The results indicated that most of the works on urban climate use a more traditional methodological approach, with fieldwork, whereas studies with models have been carried out in a specific way, especially in cities in the northern hemisphere. Among the articles evaluated, the majority were published in Elsevier publisher journals, which have a more interdisciplinary approach. The most studied models were ENVI-met, SOLWEIG, PALM-4U, RayMan, and TEB. In this way, this work pointed out, unlike other works of review in urban climate methodologies, the difficulty in obtaining field data, emphasizing their importance, with regard to studies of urban heat islands and urban planning. We also conclude that the progress and development of the state of the art in numerical models are conditioned to scientific investment in the area.

6.2 Introduction

Urbanization led to changes in the physical environment of cities, due to economic development and increased population concentration. These modifications have contributed to urban climate change (Nakata and Souza 2013; Kim and Brown 2021), including problems related to heat stress, extreme events, floods, landslides, water scarcity, and air pollution (Nakata and Souza 2013). The high thermal mass emitted by concrete and asphalt roads, the low ventilation capacity due to tall buildings, and the combined effect of the heat released by vehicles and air conditioning equipment increase the temperature in urban areas (Akbari et al. 2016), and its effects are mainly noticed at night (Oke 1981). Additionally, the occurrence of extreme heat events further increases temperatures in regions that already feel the urban heat island (UHI) effect (Gaffin et al. 2012; Oleson et al. 2018).

The most common consequence of urbanization is the loss of vegetation cover, resulting in exposed soil surfaces or replaced by concrete areas, where surface temperatures tend to be higher due to the reduction of albedo (Ferreira and Duarte 2019; Nakata and Souza 2013). Then, UHI is a representative phenomenon of climate change in urban areas, mainly because it explains the increase in temperature in specific areas within cities (Porangaba et al. 2021; Moonen et al. 2012). The UHI also has a significant impact on people's health and the quality of life of urban populations (Nazarian et al. 2017), particularly during hot seasons and in extreme weather conditions (Foissard et al. 2019; Gong et al. 2012; O'Loughlin et al. 2012), what explains why this issue has been increasingly considered during urban planning (Liang et al. 2021).

In this context, the concern with the thermal comfort of the population in urban areas is evident (Porangaba et al. 2021), perceptible by the number of direct (field measurements) and indirect (theoretical research and numerical models) thermal assessment methods comfort based on the occurrence and intensity of UHI (Liu et al. 2020; Nazarian et al. 2017). The study of the UHI and its spatiotemporal patterns, dynamics and effects has been a constant concern for researchers and climatologists (Foissard et al. 2019) who seek to know the intensity and extent of the UHI, data that can help governments in planning centers urban areas (Jusuf et al. 2019). Traditionally, urban climate monitoring requires data from weather stations, satellite images and other data collected directly in the field (Liu et al. 2020; Gusson and Duarte 2016). However, the observational approach and the performance of field activities are limited since data series for monitoring the urban climate are usually scarce and flawed in some regions (Lam et al. 2021).

In the last two decades, numerical simulations have been incorporated into studies of urban climate change (Kwok and Ng 2021), with a focus on urban configuration regarding geometry (Nakata and Souza 2013), vegetation, shading devices, surface materials, and other factors related to the urban environment (Lai et al. 2019). However, this type of methodology also presents problems since some models are not open source and require different input parameters – such as air temperature, wind speed, humidity, and radiant temperature – to provide satisfactory data.

Regarding numerical models, Computational Fluid Dynamics (CFD) is considered an interesting tool capable of modeling the characteristics of the urban environment in detail (Kato 2018). It is implemented especially for microclimate assessment, as it has limitations regarding the mesoscale analysis (Mirzaei 2021). With the growing demand for CFD models, in recent years, several commercial free code software has been created, enabling their use by industries, researchers, and municipal authorities, for example. Some of the available CFD software are ENVI-met, IngridCloud, Designer Builder, RayMan, SOLWEIG, and Sky Helios (Mirzaei 2021).

Given the difficulties encountered in evaluating the UHI using direct and indirect methods, understanding the possibilities of each tool to develop methodologies that allow a more assertive assessment of the urban scenario is necessary (Silva and Torres 2021; Garuma 2017). Hence, this literature review enables a more comprehensive methodological approach by combining data from theoretical and empirical literature (Souza et al. 2010).

The main objective was to evaluate the methods used in UHI research and point out gaps in the literature by comparing and discussing numerical model studies. This article is intended for researchers, students and managers who need new alternatives for climate studies. With that, this work proves to be relevant by presenting the state of the art of microscale models and exemplifying the usefulness of these tools for different users. Analyzing microscale models allows for their improvement and highlights the importance of conducting predictive investigations, enabling urban planning and mitigating the effects of the UHI.

The following questions will be answered in our study by a literature review of around 200 manuscripts.

1. What are the methodologies in urban climate studies that use microscale numerical models? How is model data validated?

2. What are the most used numerical models and what are their advantages and disadvantages?

3. How to use numerical models for urban planning? What are the challenges?

Our article is structured as follows. Firstly, we expose a background about the models, then we present the methodology of the review including a brief description of how the data was validated. Afterwards, we show the results based on the questions mentioned above and discussed according to the current literature alongside a summary of other methods in the UHI analysis. Finally, we indicate gaps, limitations, and some considerations regarding the highlighted models.

6.3 Background

Decision makers, especially in large cities, play a fundamental role in the adoption of urban planning measures that enhance the quality of life of their citizens. On the European continent, for example, urbanization processes, that advanced rapidly, caused different problems such as soil sealing and modification of its quality. This happens because cities continue to expand and are recognized as a source of various problems, such as pollution and excessive consumption of resources and energy (Liang et al. 2021). It is important observe that approximately 54% of the world population lives in urban areas, and this figure could reach 66% by the year 2050, thus adding about 2.5 billion people to the population that already lives in urban areas (Data from the United Nations report). The same report indicates that there is an expected increase of 90% for areas of Asia and Africa, which are known to have little urban planning, leading to the emergence of several problems, mainly of a social and environmental nature (Jusuf et al. 2021).

Concurrently, the climatic impact is included, caused by the temperature difference between different areas of the city, due to anthropogenic sources of heat, different urban geometries, soil waterproofing, roughness, among others (*Akbari et al. 2016*). The thermal phenomenon of the UHI is directly intensified by the land use, demonstrating again the importance of urban planning (Nazarian et al. 2017). In this context, land use planning appears as an area related to the climate, which can influence it in different ways, and be influenced by it. (*Measham et al. 2011).* However, for politicians and decision makers to act in terms of urban planning, considering the episodes of UHI, it is essential to have knowledge about this climatic condition, its occurrence, extent and frequency in different urban centers.

The most used and more accurate among them is the collection of data from a meteorological station or by installing sensors on a mobile platform, the so-called mobile traverse (Oke et al. 2017), in the direct approach. Nevertheless, these methods have limitations, such as the use of data from fixed stations, limiting data obtention to specific locations (Jin et al. 2018). Installing new devices to cover a larger area can also be necessary, depending on the research objectives and its heterogeneity, what adds a significant expense to the research, being sometimes, an impediment to its continuity.

Furthermore, data obtention failures or even loss of data may occur, hindering data evaluation *(Lam et al. 2021; Dubreuil et al. 2020).* Although some studies on this subject are carried out in places with resources and support for data collection and analysis, in other places, studies lack financial resources (Kim et al. 2017) and greater support from universities, impeding the installation of sensors in more points (Salvati et al. 2019).

Mobile measurements have specific purposes and are based on determining a route and a period for its execution. This methodology, however, needs specific attention, as many factors - such as vehicle movement speed - can interfere with the quality of the data, which normally comprise only two variables, humidity and temperature (Makido et al. 2016).

Regarding indirect approaches, remote sensing is a methodology that has been widely used for UHI analysis, using data from satellites such as MODIS and LANDSAT (Weng et al. 2019) to extract information about its surface temperature (Zhou and Chen 2018). This method, however, has limitations such as image resolution and the occurrence of clouds (Stagakis et al. 2019). Typically, there is a need for high spatial resolution to reflect the urban elements of the study area, as distances of a few meters show significant changes in urban centers. The occurrence of clouds in the images makes it difficult and can even make it impossible to obtain quality data (Stagakis et al. 2019). In addition, satellite images allow mapping the surface UHI, which is different from the atmospheric UHI, a decisive factor depending on the objectives of the urban climate study (Parlow 2021).

Still in indirect approaches, numerical models have been gaining more space in scientific studies in recent years. Numerical models have been used with high performance to analyze UHIs, but also in areas beyond urban climate studies, such as the wind industry (Ayotte 2008; Albani and Ibrahim 2014; Blocken et al. 2015). Various models were developed to simulate temperature conditions in open areas, considering scales relevant to humans, ranging from neighborhoods to individual characteristics, such as the presence of a tree or building, for example (Silva et al. 2018).

The models have different specifications, such as spatial and temporal resolution, intensity, input requirements, types of output metrics, and calculations of atmospheric conditions (Crank et al. 2020). Furthermore, they differ in approach to representing the main flow equations and the energy balance on the urban surface. Some approaches only consider the radiation gradient and ignore the impact of fluid flow through the urban canyon, such as RayMan and TEB (Masson et al. 2020; Pigeon et al. 2008; Thorsson et al. 2007). Other models use large eddy simulation (LES) to understand the fluid flow around individual buildings and thus model the radiation gradient, such as the TUF-3D (Krayenhoff et al. 2007).

Urban climate studies widely use computational fluid dynamics (CFD) models at the microscale and numerical weather prediction (NWP) models at the mesoscale (Silva et al. 2018). Each type of model can help understand important issues of urban climate, like the CFD simulations (Toparlar et al. 2017), which respond well to issues such as heat island formation, pollutant dispersion mechanisms, and thermal comfort (Piroozmand et al. 2020). The CFD simulations are more costly, both in terms of time and consumption of computational resources, requiring less data than models like mesoscale models, for example, that require detailed information at the pedestrian level. (Chen et al. 2019).

The most recent CFD simulations use different approximations, with the Reynolds Averaged Navier-Stokes (RANS) equations and the large eddy simulation (LES) being the most common, differing by the way they model turbulence (Silva et al. 2018). In this context, note that numerical models that use Reynolds Averaged Navier-Stokes (RANS) equations show reasonable precision, but at a lower computational cost than LES (Mirzaei and Haghighat 2010). As for the approaches, RANS, FLUENT, OpenFOAM, and StarCCM + are the most sophisticated computational tools, requiring greater training by the user (Blocken et al. 2007; Botham-Myint et al. 2015; Chen et al. 2009). Other codes, such as ENVI-met and SOLWEIG, are more accessible by less experienced users (Elnabawi et al. 2015; Lindberg and Grimmond 2011; Samaali et al. 2007).

Microscale models are used to study atmospheric processes in smaller time and space scales of approximately 1km and 1 day (Foken 2008). Thus, individual elements in the urban canopy layer such as buildings and streets need to be incorporated (Maronga et al. 2015). Data input typically includes meteorological parameters at a single location and morphological data from the region under study, with multiple levels of detail (McRae et al. 2020). In this case, some authors (Maronga et al. 2015; Masson et al. 2020) emphasize that the level of detail of the simulation directly relates to the input data, that is, the level of detail of the data influences the final level of detail of the simulation.

In view of this, the high-resolution numerical simulations might reflect geographic and anthropogenic factors, such as relief and land use, allowing for greater calculation accuracy. Thus, numerical models have been developed from different approaches to represent the atmosphere in its different scales (Petersen et al. 1998).

6.4 Material and methods

The methodology was divided into two stages based on the PRISMA method (preferred reporting items for systematic reviews and meta-analyses) from Moher et al. (2009). The first stage refers to the choice of keywords to identify articles related to the topic of interest, while the second presents the forms of analysis and selection of documents for use in the literature review.

6.4.1 Search of peer reviewed documents

To identify the literature, some keywords and their combinations were used in this research, carried out only in English. Table 1 shows the main keyword defined, “urban climate”, and, from this, the other keywords included in the searches, such as “urban heat island”, “numerical model”, “geometry”, “urban planning, “characteristics” and others.

Table 1: Description of the methodological steps taken for the bibliographic survey

Keywords	K1: urban climate	K8: microscale models
	K2: urban heat island	K9: mesoscale models
	K3: thermal comfort	K10: CFD models
	K4: numerical models	K11: Envi-met
	K5: geometry	K12: RayMan
	K6: urban planning	K13: SOLWEIG
	K7: characteristics	K14: PALM-4

Combinations	C1: K1 and K2 **-** "urban climate" "urban heat island"
	C2: K1 and K2 and (K3 or K4 or K5) **-** "urban climate" "urban heat island" "thermal comfort"; "urban climate" "urban heat island" "numerical models"; "urban climate" "urban heat island" "geometry"

	C3: K2 and K4 and (K6 or K7) **-** "urban heat island" "numerical models" "urban planning"; "urban heat island" "numerical models" "characteristics"
	C4: K1 and K7 and (K8 or K10 or K11 or K12 or K13 or K14) - "urban climate" "characteristics" "microscale models"; "urban climate" "characteristics" "CDF models"; "urban climate" "characteristics" "Envi-met"; "urban climate" "characteristics" "RayMan"; "urban climate" "characteristics" "SOLWEIG"; "urban climate" "characteristics" "PALM-4"
	C5: K1 and K2 and K9 - "urban climate" "urban heat island" "mesoscale models"
	C6: K8 and K10 and (K11 or K12 or K13 or K14) - "microscale models" "CDF models" "Envi-met"; "microscale models" "CDF models" "RayMan"; "microscale models" "CDF models" "SOLWEIG"; "microscale models" "CDF models" "PALM-4"
	C7: K7 and K9 - "characteristics" "mesoscale models"
	C8: K4 and (K8 or K9) - "numerical models" "microscale models"; "numerical models" "mesoscale models"

**Table format adapted and modified from Kim and Brown (2021).*

The search for documents was focused from January 2014 to October 2021. Science Direct, Scopus, Google Scholar, and Web of Science were the sources of peer-reviewed articles, along editors such as Elsevier, Springer, Wiley, Francis & Taylor, and *Multidisciplinary Digital Publishing Institute* (MDPI). Some specific journals on climatology were also consulted directly, such as Journal of Climate, International Journal of Climatology, Climate, and PLOS Climate. The review studies were selected regardless of the publication date, whereas the empirical articles were limited to a 7-year interval, with the aim of presenting the most recent results in the area and drawing conclusions and lacks from them.

6.4.2 Analysis of documents and selection criteria

The initial dataset included 251 publications, but it was reduced to 151 after keyword and abstract reviewing. Then, each article was analyzed to determine whether the study was directly related to questions about UHIs and numerical models, which guide our study, leaving only 68 studies for review. Finally, each article was carefully read and analyzed. Figure1 shows a summary of the selection process and data. Thus, from the last analysis of the documents, the types of study, the concepts of UHIs related to each one, and the type of models used were identified.

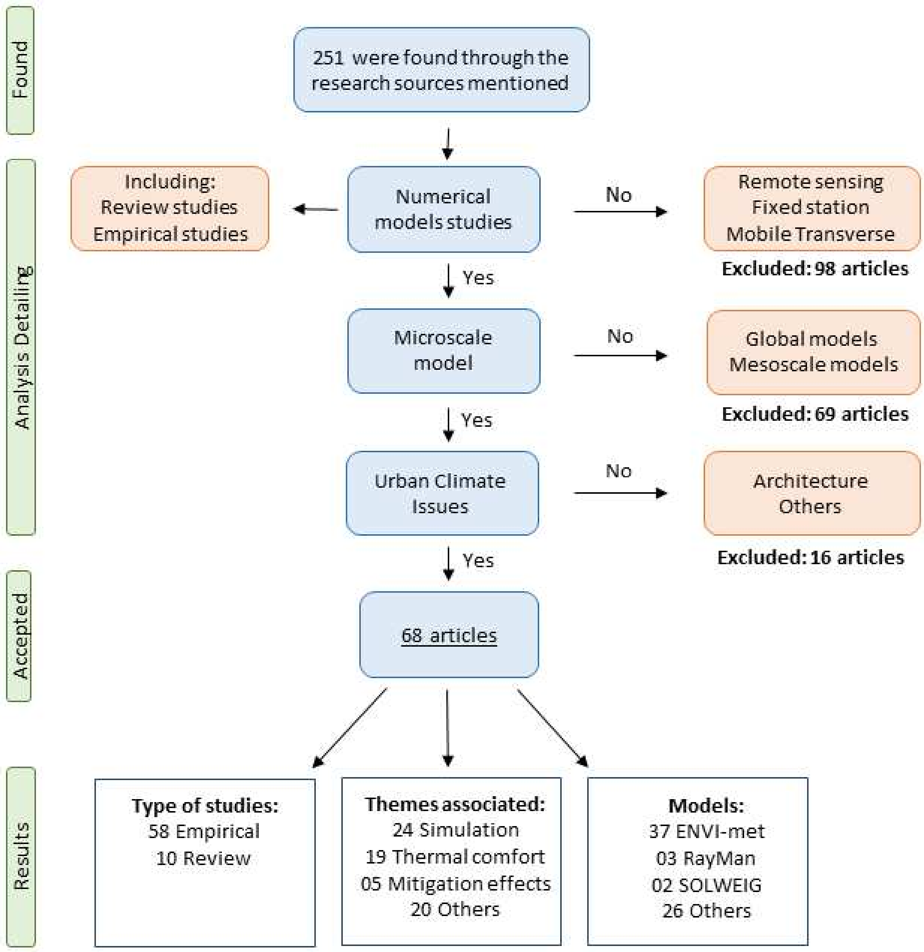


Figure 1: Selection process of peer reviewed documents flow and results.

6.5 Results

6.5.1 Analyzed studies

The literature review showed that 80% of the methodologies related to the UHI focus on remote sensing, fixed stations, and mobile field traverse, combined or not, being largely empirical studies at different scales. Mesoscale and microscale models guide the indirect method of analyzing the urban climate, with several studies, mainly mesoscale models, addressing issues such as air quality and analyzing the energy balance.

Due to most mesoscale studies, we also had a greater number of review articles with this focus. In short, the models for microscale analysis address issues related to thermal comfort, with emphasis on models such as ENVI-met, RayMan, PALM-4U, and TEB model, widely used with this focus (Figure 2). Other issues observed in the works conceived in the results of this research refer to urban planning, energy dynamics, sustainable themes, as well as simulations of new models, comparing them to the models mentioned above.

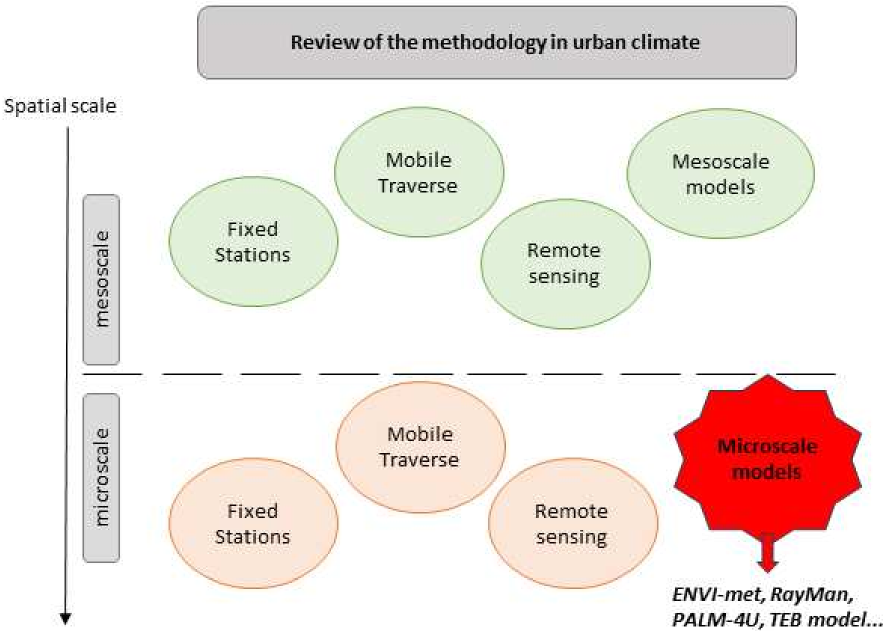


Figure 2: Scheme of methodologies found on UHI

Considering the focus of the research we selected 68 articles (published between 2014-2021), which we used for the discussions of this study (Figure 3). They are mainly practical studies analyzing microscale models, and some review studies. Journals indexed by Elsevier stand out, since a large percentage of the works were published in journals of that publisher, followed by Taylor & Francis, Wiley, Springer, and MDPI.

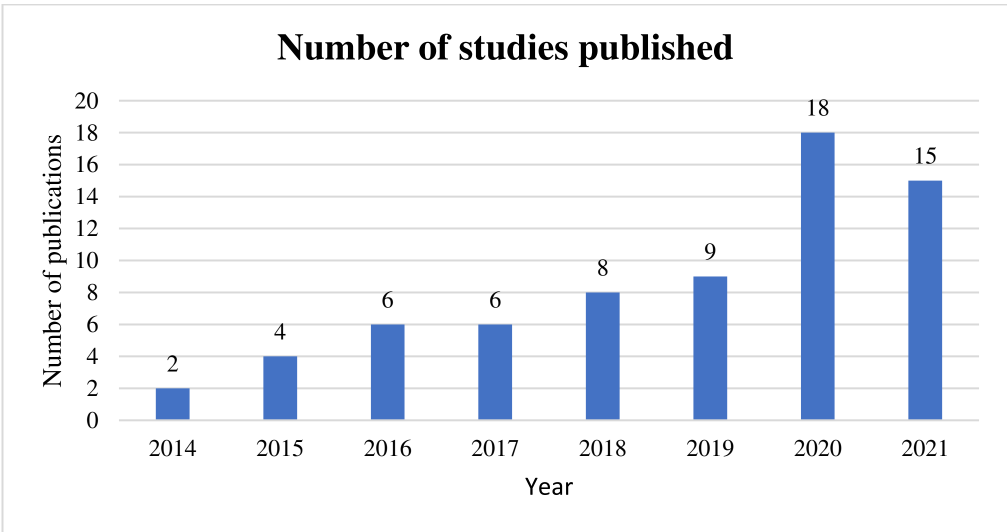


Figure 3: Graph showing the number of articles published on numerical models for urban studies, between 2014-2021 (n=68).

In this sense, the journal with the highest number of publications was the "Urban Climate" (12), followed by "Sustainable Cities and Society" (8), "Building and Environment" (7), and "Total Environmental Science" (7), representing about 50% of all periodicals found (Figure 4). The SCImago Journal Rank (SJR) for these journals ranged from 1.151 to 1.736 in 2021. Other journals that publish specific studies on climatology, such as Journal of Climate, International Journal of Climatology, Climate, and PLOS Climate, lacked studies that encompassed the keywords and their combinations, already mentioned in the methodology, for the desired period of analysis. Thus, most works that use models were found in journals that publish case studies and other works with an interdisciplinary approach.

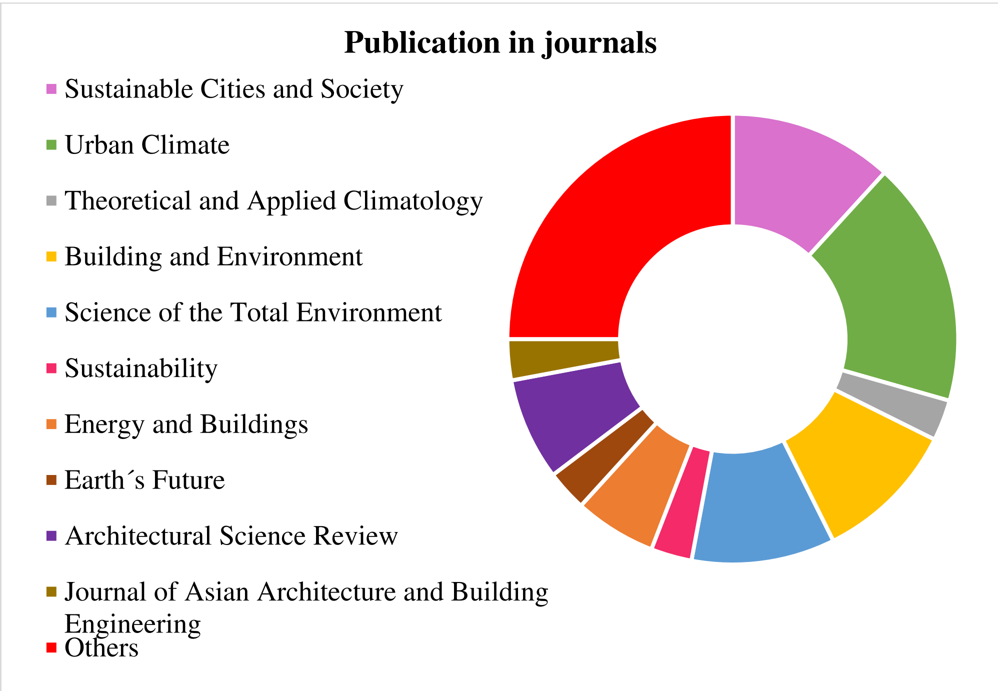


Figure 4: Works related to the analysis of urban microclimate in each journal.

Analyzing all selected documents, more than 14% were review works and lacked a geographically delimited study area, whereas others did not analyze numerical models of a specific area, but considered and evaluated the possible simulations in the models in focus instead. Considering the models that describe a study area to be modeled for the characterization of the microclimate, we noted that cities in Europe and Asia were predominantly chosen (Figure 5). The themes addressed in the studies, regardless of the type of work (review or practical), covered a range of topics based on the study of urban microclimate, such as thermal comfort, UHI, simulation and analysis of models, urban planning, health, and urban geometry, for example.

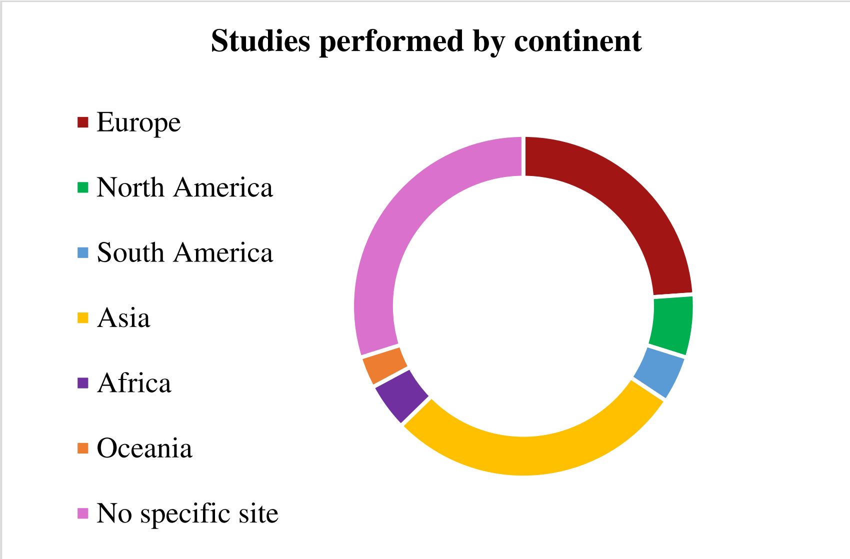


Figure 5: Placement of the study area described in each study, among the evaluated works.

Regarding microscale models, most works compiled for this assessment used the CFD. In many works, the analyzed type of CFD technology program was not determined, whereas some other works, described that, and they report the use of ENVI-met, *SOLWEIG*, PALM-4U, RayMan, SUEWS, and others (Table 2). The ENVI-met appeared in 55% of the evaluated works, being used alongside mesoscale models, in a study comparing the results of ENVI-met and another microscale model in the same area, or simply as a method for the main analysis of the urban microclimate.

Table 2: Description of the works and the described models, when applicable.

No	References	Models
1	Paas and Schneider, 2016	ENVI-met and Austal2000
2	Tsoka et al., 2018	ENVI-met
3	Crank et al., 2018	ENVI-met
4	Acero and Arrizabalaga, 2016	ENVI-met
5	McRae et al., 2020	WRF and ENVI-met
6	Javanroodi and Nik, 2020	CFD models
7	Othmer et al., 2020	ENVI-met (BIO-met)

8	Ambrosini et al., 2014	ENVI-met
9	Bande et al., 2019	UWG and ENVI-met
10	Acero et al., 2015	UC-Map (mesoscale) and ENVI-met
11	Salata et al., 2016	ENVI-met and BIO-met
12	Crank et al., 2020	RayMan and ENVI-met
13	Masson et al., 2020	UCM and ORM
14	Piroozmand et al., 2020	CFD models
15	San José et al., 2018	WRF-Chem model and MICROSYS-CFD model
16	Silva et al., 2018	CFD models
17	Chen et al., 2019	CFD models and mesoscale models
18	Hollósi et al., 2021	MUKLIMO_3 microscale model
19	Yu et al., 2021	single-layer (UCM) and multi-layer (BEP) urban canopy models
20	Miguel et al., 2021	CFD models
21	Lam et al., 2021	ENVI-met
22	Wong et al., 2021	WRF, UCM model, CFD model and Building energy model
23	Oliveira et al., 2021	Single-level model (LM) and linear-mixed model (LMM)
24	Ghaffarianhoseini et al., 2019	Envi-MET, IES-VE and RayMan
25	Jin et al., 2020	UDC model
26	Mirzaei, 2021	CFD models
27	Salata et al., 2017	ENVI-met
28	Sharmin et al., 2017	ENVI-met
29	Qaid et al., 2016	ENVI-met
30	Tsoka et al., 2017	ENVI-met
31	Chatterjee et al., 2019	ENVI-met
32	Muniz-Gäal et al., 2020	ENVI-met
33	Labdaoui et al., 2021	ENVI-met and Rayman
34	Berardi et al., 2020	WRF and ENVI-met
35	Marcel and Villot, 2021	UHI index
36	Kubilay et al., 2018	Rans k-Ɛ
37	Nice et al., 2018	VTUF-3D
38	Oswald et al., 2020	MUKLIMO_3 microscale model
39	Maggiotto et al., 2014	ADMS-TH and Envi-met
40	Roth and Lim, 2017	ENVI-met
41	Jihad and Tahiri, 2016	TEB model
42	Yin et al., 2019	ENVI-met
43	Chen et al., 2020	STEVE
44	Hamdi et al., 2020	No
45	Liu et al., 2020	urban canopy layer (UCL)
46	Steuri et al., 2020	PALM-4U
47	Liu et al., 2021	ENVI-met
48	Raymar et al., 2019	ENVI-met

49	Nazarian et al., 2018	OTC3D model
50	Coltri et al., 2019	ENVI-met
51	Wang et al., 2018	WRF-UCM
52	Sharma et al., 2021	GCM, WRF, ENVI-met and PALM-4U
53	Stewart et al., 2021	TUF-3D, BEP-Tree and WRF-BEP
54	Napoli et al., 2016	one-dimensional heat transfer model
55	Susca and Pomponi, 2020	WRF, ENVI-met, UCAR and UCM
56	Shinzato et al., 2019	ENVI-met
57	Dwivedi, 2019	ENVI-met
58	Guo et al., 2021	ENVI-met
59	Wang and Chang, 2020	SOLWEIG
60	Tan et al., 2021	ENVI-met
61	M'Saouri El Bat et al., 2020	Thermoradiative model
62	Liu et al., 2018	urban canopy model UDC
63	Shi et al., 2016	ENVI-met
64	Malys et al., 2015	SOLENE-microclimate
65	Ebrahimnejad et al., 2017	ENVI-met
66	Elnabawi et al., 2015	ENVI-met
67	Dai and Schnabel, 2014	ENVI-met and SOLWEIG
68	Swamy et al., 2017	ENVI-met

Given this scenario, ENVI-met is described as a Computational Fluid Dynamics (CFD) model (Crank et al. 2018), developed by Michael Bruse at Ruhr University of Bochum (Bruse and Fleer 1998), being freeware but not open source (Ambrosini et al. 2014). This program was launched in 1998 and since then, it has been one of the most used products for microclimate research (Tsoka et al. 2018), a fact confirmed in our study, which demonstrates that it is still the most widely used model in an urban climate 23 years after its launch.

In addition to the features presented by ENVI-met, another model often used in urban climate, with a focus on the microscale, is the RayMan. Out of the 68 works analyzed, 3 mentioned this model, being associated with the ENVI-met, to demonstrate a complementarity between them. The former simulates a complete set of atmospheric variables in grids, whereas the latter was developed specifically to model radiation flux densities and temperature (Crank et al. 2020).

ENVI-met (Bruse and Fleer 1998) and the RayMan (Matzarakis et al. 2010) are the most used models to assess thermal conditions at the microscale. The former simulates a complete set of atmospheric variables in grids, while the latter was developed specifically to model radiation flux densities and temperature (Labdaoui et al. 2021). Only one of the 68 works does not comment on any specific numerical model as it makes a general review of the modeling of cities in understanding the urban climate and its changes (Hamdi et al. 2020).

6.5.2 Validation of models

More than 90% of the works presented in Table 2 indicated some way to validate the output data obtained by the models used, with the exception of some works (Ambrosini et al., 2014; Chen et al., 2020; Marcel and Villot, 2021; Masson et al., 2020; Mirzaei, 2021; Lam et al., 2021; Yu et al., 2021). Validation of model data showed a pattern where field data and simulation data were statistically compared. For the correct functioning of the models portrayed here, it is necessary to introduce data from fields of some variables as input, so that the program generates new data as results.

The field data used refer mainly to data from station networks or even from fixed sensors installed in certain locations to obtain weather information. In this sense, the studies describe that in places without station networks, sensors were installed to cover the area and obtain atmospheric data, but without a detailed description of the density of points. The statistical procedure (Table 3) is the most important tool for investigating the goodness of fit and the accuracy of predicted or estimated data compared to measured data (Aboelkhair et al. 2019). Therefore, the works used different statistical methods with field data and simulation data.

Table 3: Statistical procedures used in the evaluated works and the percentage of studies that used them.

Statistical Procedures	***Percentage (%)***
Mean Bias Error (MBE)	38.30
Root Mean Square Error (RMSE)	57.45
Mean Average Error (MAE)	14.89
Pearson's correlation coefficient (R)	23.40
Coefficient of determination (R_2)	34.04
Coefficient of efficiency E	4.26
Index of agreement (d) or Willmott's index	14.89

Mean absolute deviation (MAD)	2.13
Mean absolute percentage error (MAPE)	2.13
Ray-tracing algorithm and geometric parameters	2.13
Mean Percentage Error (M%E)	2.13
Ratio of the root mean square error to observation standard deviation (RSR)	2.13
Nash–Sutcliffe coefficient	2.13
Mean Relative Error (MRE)	2.13
Mean Squared Error (MSE)	2.13

Among these indexes, some works used all procedures and others chose only two or three for comparing and discussing the results that justify the use of a certain model. In the evaluated works, 57.45% used the RMSE and 38.30% the MBE to demonstrate the similarity between the data obtained by the simulation and those acquired from the meteorological station. About this topic, the Root Mean Square Error (RMSE) represents the mean standard deviation of the model's prediction with respect to observation (Acero and Arrizabalaga 2016; Salata et al. 2016; Crank et al. 2020; Ghaffarianhoseini et al. 2019; Jin et al. 2020; Chen et al. 2020). The Mean Bias Error (MBE) is a measure of systematic error between predicted and observed values (Ghaffarianhoseini et al. 2019; Javanroodi and Nik 2020; Jin et al. 2020;). Arguably, statistical comparison was the safest way to highlight the possibilities and shortcomings of a simulation.

6.6 Discussions

Many articles also only emphasized the simulation of the models and its analysis (Yin et al. 2019; Chen et al. 2020), testing and analyzing recently developed models against models already recognized in the context of climate research (Paas and Schneider 2016; Acero and Arrizabalaga 2016; Javanroodi and Nik 2020; Ambrosini et al. 2014; Piroozmand et al. 2020; San José et al. 2018). From a general observation of the studies, with a methodological focus, they used different models, with the vast majority (90%) only related to the microscale. Few other works compiled different levels of spatial analysis for the study area or described them in their reviews (McRae et al. 2020; Bande et al. 2019; Acero et al. 2015; Masson et al. 2020; Hamdi et al. 2020; Wong et al. 2021).

According to the results obtained, it is noted that the microscale models are generally more expensive, as they present greater detail compared to the mesoscale models, which have a resolution of hundreds of meters. This makes it difficult to use microscale models and partly justifies the limited number of studies performed (Kwok and Ng 2021). However, two models studied stood out for being free and frequently present in the evaluated works, such as Envi-met and RayMan.

The characteristics of ENVI-met can explain its diffusion, as this software allows the generation of three-dimensional microclimatic models, which also simulate different interactions, such as surface-plant-air, in urban environments. In addition, the resolution is 0.5 meters and a few seconds, being based on the fundamental laws of fluid dynamics and thermodynamics (Bruse and Fleer 1998; Tsoka et al. 2018; Crank et al. 2018). ENVI-met also acts in the simulation of the dispersion of pollutants, allowing the analysis of numerous points, lines and areas that are sources of substances, frequent in the context of metropolises (Nikolova et al. 2011; Morakinyo and Lam 2016). It should be noted that the ENVI-met does not allow simulating the microclimate of entire cities, only isolated neighborhoods, due to the limited number of cells in the grid (Crank et al. 2018). This program can also be used to simulate the agricultural microclimate, showing good results for this type of environment and highlighting its versatility (Coltri et al. 2019).

On the other hand, RayMan is newer compared to ENVI-met, and its programming calculates radiation flux densities, long and short waves, TMRT, SVF and some thermal indices from meteorological data (Matzarakis et al. 2010). Input data required by the RayMan system include temperature, vapor pressure or relative humidity, cloud cover, latitude and longitude (Crank et al. 2020). In addition, when analyzing thermal comfort, the program allows you to include personal characteristics (height, weight, age, gender), information about clothing and activities, adapting the output data to a specific demographic group.

In this way, each software is designed to consider certain characteristics of the environment, when analyzing the microclimate, some emphasize urban geometry, while others prioritize other issues. In this sense, some authors (Acero et al. 2015; Jihad and Tahiri 2016; Roth and Lim 2017; Nazarian et al. 2018; Oliveira et al. 2021) addressed issues related to urban comfort, demonstrating the importance of analyzing the microclimate to understand ways to improve people's quality of life (Berardi et al. 2020) and promote health (Salata et al. 2016; Hollósi et al. 2021). Based on the theme of thermal comfort, some studies have incorporated issues related to urban planning (McRae et al. 2020; Othmer et al. 2020) and the use of models as an important governmental tool, facilitating the work of managers. Among the studies that used microscale models to work on urban planning issues, many of them also discussed the relationship between microclimate and urban geometry (Liu et al. 2020; Muniz-Gäal et al. 2020).

Most of the articles analyzed were published in 2020, with a notable increase in studies involving the use of numerical models to describe the urban microclimate relationships from January 2014 to October 2021, which is directly related to the advancement in the development of models and the improvement of those that already exist (Tsoka et al. 2018). Considering that, there has been an exponential increase in the number of works published on microscale models, it can be said that not only has there been an improvement in existing models, but also that there has been an important technological advance in the areas of informatics and climatology, which made this possible. It is interesting to point out that the improvement of models also leads to the development of a more rigorous methodology, which, together with relevant field data, culminates in more accurate results.

Models are commonly validated by calculating some indices, in which field data are compared with the output data of the chosen model, validating them or not. Different methodologies were observed, in which some works use more statistical indices to confirm or refute data validation (Coltri et al., 2019; Guo et al., 2021; M'Saouri El Bat et al., 2020; Napoli et al., 2016), while other studies did not perform data validation (Ambrosini et al., 2014; Chen et al., 2020; Marcel and Villot, 2021; Masson et al., 2020; Mirzaei, 2021; Lam et al., 2021; Yu et al., 2021) or used only one index to do it (Ghaffarianhoseini et al., 2019; Jin et al., 2020; Oliveira et al., 2021; Wong et al. , 2021). The lack of a methodological standard to validate data obtained from microscale models may be a gap to be filled with the development of the state of the art in this area. The determination of a data validation methodology would help new researchers who are not in the niche of climatology, as well as in the development of new programs.

The studies by Lam et al. (2021) and Huang et al. (2018), for example, were based on the use of direct and indirect methods, which used field data as a parameter to identify “hotspots”. Thus, these points of interest were used in simulations to model the area and understand its characteristics. The use of simulations in this sense is interesting for urban planning, when the intention is to modify or adapt certain regions of the city, where it is possible to understand the characteristics of these regions, in a specific way, from the collection of data and modeling software. Thus, it is observed that simulations can be used to identify the most appropriate heat mitigation strategies for each "hotspot" initially found. In addition, this type of study may include other issues such as urban geometry, a factor directly linked to planning issues.

Among the different adoptions of direct and indirect methods, and their joint use in urban climate research, the operation of models and field data should be encouraged in other cases. Models are a good alternative for situations where field data from sources such as fixed stations or mobile crossings, is lost. Nonetheless, some Latin American countries, such as Brazil, still have field measurement problems that may make the use of data in climate studies unfeasible. The present study shows a small number of research carried out in Africa, Oceania and South America, places with a predominantly tropical climate, indicating an inherent need for the development of simulation programs that are applicable in regions of the globe with different climatic characteristics (Crank et al. 2020). Roth (2007) reinforces the thesis that is necessary a software that considers the particularities of other environments is necessary when citing in his study that little research on climate phenomena is carried out in regions with tropical and subtropical climates.

Although the discussions are widespread, Brazil is emphasized given its importance in climate issues, as it contributes significantly to the stock of CO2, acting in climate control on a global scale (Junk et al., 2013). In Brazil, particularly, works related to climate emphasize remote sensing, since modeling satellite images is the most effective way to obtain meteorological information. Usually, field work is funded by large research agencies, which invest in installing sensors or crosses. Data from meteorological stations are little used because they are uncertain, scarce and flawed.

Finally, it is emphasized that users need to be clear about the objectives for which they are recreating a certain environment in the simulation and their objectives. The use of climate models in the study of urban climate makes urban planning possible, but also shows that there are challenges in their use. The models are an option in locations that do not have investment in the development of the standard methodology for urban climate analysis, but they can represent a complex challenge when these locations lack sufficient data to allow the validation of the final model data. More studies to understand the use of models are relevant, as they can help overcome the shortcomings of these models, improve their adaptation to different areas and climates, and thus expand their use. With regard especially to urban planning, numerical models are seen as one more possibility of use in the study of the climate of cities, mainly in the analysis of UHI, helping in the evaluation of the thermal comfort of the population and other important information for the planning, reinforcing the importance of investments in scientific research.

6.7 Conclusions

The review showed a significant number of works in urban climate carried out from field data regarding the use of data from meteorological stations, mobile traverse, and remote sensing, which may indicate that this is the preferred methodology by researchers for UHI determination-related topics.

Considering the focus of the research, the number of studies in the last five years is considerably smaller regarding the use of models in microclimate simulations. However, the growth of urban climate studies that used models to simulate the microclimate in cities, especially those located in the northern hemisphere – mostly in European cities – has increased in recent years, peaking in 2020 and reaching a close number in 2021, given the number of publications in the first 10 months of that year.

We perceived the low number of works carried out for countries in Latin America or Africa, which have different climatic and socioeconomic conditions in their territories, factors that recreate different urban scenarios. This may be associated with the scarcity of resources that researchers generally face in their countries with little investment. We also verify that some models (as EnviMet and RayMan) are more used than others depending on how easy they are to use and if they have a free operating system, allowing its widespread use for different audiences.

Our research confirmed that statistical analysis – such as the RMSE and the MBE, which require field data – is a means of validating simulations and new models. We understood that the use of models as an alternative for conducting research on the urban climate can be viable and very beneficial depending on the study area, or it can become a new challenge, even more complex than the delimitation of UHI.

The results strongly indicate that the use of numerical models requires a minimum of climate data obtained through meteorological stations or fixed sensors to provide input data and to validate the model. Without field data, most models cannot be initialized nor validated to prove if the model's data express well the reality of the study area. In this way, the models are shown as alternatives for capturing data on UHI that can collaborate for urban planning, helping governments to decide on the most sustainable alternatives for urban development, however, in some locations, the lack of reliable data, may prevent the use of templates.

Thus, the present work highlights, unlike other review studies on urban climate methodologies, the importance of field data and the difficulty encountered in some places to obtain them, a difficulty that permeates other spheres, such as territory planning. Therefore, it is noted a clear need for financial investments in climate and urban planning research, especially in developing countries, demonstrating how the different areas are correlated and self-infracted.

Lastly, we highlight a trend in the development of new software with an operating system similar to Envi-met or Rayman, which are popular among users. Considering the gaps exposed in this work, we envision the development of software that allows specialized characterization in tropical environments, helping to develop studies in these locations. Advances in the state of the art must be seen with the obtaining of new products, optimized, yet easy to handle and accessible to researchers and students.

6.8 Acknowledgements

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES), the Pro Rectory of the State University of Campinas (UNICAMP) and "Espaço da Escrita" for their collaboration in carrying out this work.

6.9 References

Aboelkhair, H., Morsy, M., El Afandi, G. (2019). Assessment of agroclimatology NASA POWER reanalysis datasets for temperature types and relative humidity at 2 m against ground observations over Egypt. *Advances in Space Research*, 64, 129–142. https://doi.org/10.1016/j.asr.2019.03.032

Acero, J.A., Arrizabalaga, J. (2016). Evaluating the performance of ENVI-met model in diurnal cycles for different meteorological conditions. *Theoretical and Applied Climatology*, 131, 455–469. https://doi.org/10.1007/s00704-016-1971-y

Acero, J.A, Kupski, S., Arrizabalaga, J., Katzschner, L. (2015). Urban climate multi-scale modelling in Bilbao (Spain): a review. *Procedia Engineering*, 115, 3-11. https://doi.org/10.1016/j.proeng.2015.07.348

El Bat, AM'S., Romani, Z., Bozonnet, E., Draoui, A. (2020). Integration of a practical model to assess the local urban interactions in building energy simulation with a street canyon. *Journal of Building Performance Simulation*, 13, 720-739. https://doi.org/10.1080/19401493.2020.1818829

Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A.L., Rossi, F., Santamouris, M., Synnef, A., Wong, N.H., Zinzi, M. (2016). Local climate change and urban heat island mitigation techniques – the state of the art. *Journal of Civil Engineering and Management*, 22, 1–16. https://doi.org/10.3846/13923730.2015.1111934

Albani, A., Ibrahim, M.Z. (2014). An Assessment of Wind Energy Potential for Selected Sites in Malaysia Using Feed-In Tariff Criteria. *Wind Engineering*, 38, 249-259. https://doi.org/10.1260/0309-524X.38.3.249

Ambrosini, D., Galli, G., Mancini, B., Nardi, I., Sfarra, S. (2014). Evaluating mitigation effects of urban Heat Islands in a historical small center with the ENVI-met climate model. *Sustainability*, 6, 7013-7029. https://doi.org/10.3390/su6107013

Ayotte, K.W. (2008). Computational modelling for wind energy assessment. *Journal of Wind Engineering and Industrial Aerodynamics,* 96, 1571-1590. https://doi.org/10.1016/j.jweia.2008.02.002

Bande, L., Afshari, A., Masri, D.A., Jha, M., Norford, L., Tsoupos, A., Marpu, P., Pasha, Y., Armstrong, P. (2019). Validation of UWG and ENVI-Met Models in an Abu Dhabi District, Based on Site Measurements. *Sustainability*, 11, 4378. https://doi.org/10.3390/su11164378

Berardi, U., Jandaghian, Z., Graham, J. (2020). Effects of greenery enhancements for the resilience to heat waves: A comparison of analysis performed through mesoscale (WRF) and microscale (Envi-met) modeling. *Science of the Total Environment*, 747, 141300. https://doi.org/10.1016/j.scitotenv.2020.141300

Blocken, B., Stathopoulos, T., Carmeliet, J. (2007). CFD simulation of the atmospheric boundary layer: wall function problems. *Atmospheric Environment*. 41, 238–252. https://doi.org/10.1016/j.atmosenv.2006.08.019

Blocken, B., van der Hout, A., Dekker, J., Weiler, O. (2015). CFD simulation of wind flow over natural complex terrain: Case study with validation by field measurements for Ria de Ferrol, Galicia, Spain. *Journal of Wind Engineering and Industrial Aerodynamics*, 147, 43-57. https://doi.org/10.1016/j.jweia.2015.09.007

Botham-Myint, D., Recktenwald, G.W., Sailor, D.J. (2015). Thermal footprint effect of rooftop urban cooling strategies. *Urban Climate*, 14, 268–277. https://doi.org/10.1016/j.uclim.2015.07.005

Bruse, M., Fleer, H. (1998). Simulating surface-plant-air interactions inside urban environments with a three-dimensional numerical model. *Environ. Model. Softw*. 13, 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5

Chatterjee, S., Khan, A., Dinda, A., Mithun, S., Khatun, R., Akbari, H., Kusaka, H., Mitra, C., Bhatti, S.S., Doan, Q.V., Wang, Y. (2019). Simulating micro-scale thermal interactions in different building environments for mitigating urban heat islands. *Science of the Total Environment*, 663, 610-631. https://doi.org/10.1016/j.scitotenv.2019.01.299

Chen, H., Ooka, R., Huang, H., Tsuchiya, T. (2009). Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation. *Building and Environment*, 44, 2290–2299. https://doi.org/10.1016/j.buildenv.2009.03.012

Chen, Y., Zhang, N., Zhu, Y. (2019). High-Resolution Simulations of the Urban Thermal Climate in Suzhou City, China. *Atmosphere*, 10, 118. https://doi.org/10.3390/atmos10030118

Chen, S., Zhang, W., Wong, N.H., Ignatius, M. (2020). Combining CityGML files and data-driven models for microclimate simulations in a tropical city. *Building and Environment*, 185, 107314. https://doi.org/10.1016/j.buildenv.2020.107314

Coltri, P.P., Pinto, H.S., Gonçalves, R.R.V., Zullo Junior, J., Dubreuil, V. (2019). Low levels of shade and climate change adaptation of Arabica coffee in southeastern Brazil. *Heliyon*, 5, e01263. https://doi.org/10.1016/j.heliyon.2019.e01263

Crank, P.J., Middel, A., Wagner, M., Hoots, D., Smith, M., Brazel, A. (2020). Validation of seasonal mean radiant temperature simulations in hot arid urban climates. *Science of The Total Environment*, 749, 141392. https://doi.org/10.1016/j.scitotenv.2020.141392

Crank, P.J., Sailor, D.J., Ban-Weiss, G., Taleghani, M. (2018). Evaluating the ENVI-met microscale model for suitability in analysis of targeted urban heat mitigation strategies. *Urban Climate*, 26, 188-197. https://doi.org/10.1016/j.uclim.2018.09.002

Dai, Q., Schnabel, M.A. (2014). Thermal comfort levels classified by aspect ratio and orientation for three zones of a street in Rotterdam. *Architectural Science Review*, 57, 286-294. https://doi.org/10.1080/00038628.2014.930016

Dubreuil, V., Foissard, X., Nabucet, J., Thomas, A., Quénol, H. (2020). Fréquence et intensité des îlots de chaleur à rennes: bilan de 16 années d'observations (2004-2019). *Climatologie*, 17, 6. https://doi.org/10.1051/climat/202017006

Dwivedi, A. (2019). Macro- and micro-level studies using Urban Heat Islands to simulate effects of greening, building materials and other mitigating factors in Mumbai city. *Architectural Science Review*, 62, 126-144. https://doi.org/10.1080/00038628.2019.1578193

Ebrahimnejad, R., Noori, O., Deihimfard, R. (2017). Mitigation potential of green structures on local urban microclimate using ENVI-met model. *International Journal of Urban Sustainable Development*, 9, 274-285. https://doi.org/10.1080/19463138.2017.1370424

Elnabawi, M.H., Hamza, N., Dudek, S. (2015). Numerical modelling evaluation for the microclimate of an outdoor urban form in Cairo, Egypt. *HBRC Journal*, 11, 246-251. https://doi.org/10.1016/j.hbrcj.2014.03.004

Ferreira, L.S., Duarte, D.H.S. (2019). Exploring the relationship between urban form, land surface temperature and vegetation indices in a subtropical megacity. *Urban Climate*, 27, 105–123. https://doi.org/10.1016/j.uclim.2018.11.002

Foissard, X., Dubreuil, V., Quenol, H. (2019). Defining scales of the land use effect to map the urban heat island in a mid-size European city: Rennes (France). *Urban Climate*, 29, 100490. https://doi.org/10.1016/j.uclim.2019.100490

Foken, T. (2008). *Micrometeorology*. Springer-Verlag, Berlin, 306 p.

Gaffin, S.R., Imhoff, M., Rosenzweig, C., Khanbilvardi, R., Pasqualini, A., Kong, A.Y.Y., Grillo, D., Freed, A., Hillel, D., Hartung, E. (2012). Bright is the new black-multi-year performance of high-albedo roofs in an urban climate. *Environmental Research Letters*, 7, 014029. https://doi.org/10.1088/1748-9326/7/1/014029

Garuma, G.F. (2017). Review of urban surface parameterizations for numerical climate models. *Urban Climate*, 24, 830-851. http://dx.doi.org/10.1016/j.uclim.2017.10.006

Ghaffarianhoseini, A., Berardi, U., Ghaffarianhoseini, A., Al-Obaidi, K. (2019). Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia. *Science of the Total Environment*, 666, 1327-1345. https://doi.org/10.1016/j.scitotenv.2019.01.284

Gong, P., Liang, S., Carlton, E.J., Jiang, Q., Wu, J., Wang, L., Remais, J.V. (2012). Urbanization and health in China. *Lancet*, 379, 843–52. https://doi.org/10.1016/S0140-6736(11)61878-3

Guo, S., Yang, F., Jiang, Z. (2021). Thermal environmental effects of vertical greening and building layout in open residential neighbourhood design: a case study in Shanghai. *Architectural Science Review*, 65, 72-88. https://doi.org/10.1080/00038628.2021.1916427

Gusson, C.S., Duarte, D.H. (2016). Effects of built density and urban morphology on urban microclimate-calibration of the model ENVI-met V4 for the subtropical Sao Paulo, Brazil. *Procedia Engineering*, 169, 2–10. https://doi.org/10.1016/j.proeng.2016.10.001

Hamdi, R., Kusaka, H., Doan, Q., Cal, P., He, H., Luo, G., Kuang, W., Caluwaerts, S., Duchêne, F., Schaeybroek, B.V., Termonia, P. (2020). The State-of-the-Art of Urban Climate Change Modeling and Observations. *Earth Systems and Environment*, 4, 631-646. https://doi.org/10.1007/s41748-020-00193-3

Hollósi, B., Zuvela-Aloise, M., Oswald, S., Kainz, A., Schöner, W. (2021). Applying urban climate model in prediction mode—evaluation of MUKLIMO_3 model performance for Austrian cities based on the summer period of 2019. *Theoretical and Applied Climatology*, 144, 1181–1204. https://doi.org/10.1007/s00704-021-03580-6

Huang, Y. et al. (2018). Impacts of species richness on productivity in a large-scale subtropical forest experiment. *Science*, 362, 80–83. https://doi.org/10.1126/science.aat6405

Javanroodi, K., Nik, V.M. (2020). Interactions between extreme climate and urban morphology: Investigating the evolution of extreme wind speeds from mesoscale to microscale. *Urban Climate*, 31, 100544. https://doi.org/10.1016/j.uclim.2019.100544

Jihad, A.S., Tahiri, M. (2016). Modeling the urban geometry influence on outdoor thermal comfort in the case of Moroccan microclimate. *Urban Climate*, 16, 25-42. https://doi.org/10.1016/j.uclim.2016.02.002

Jin, L., Pan, X., Liu, L., Liu, J., Gao, Y. (2020). Block-based local climate zone approach to urban climate maps using the UDC model. *Building and Environment*, 186, 107334. https://doi.org/10.1016/j.buildenv.2020.107334

Jin, K., Wang, F., Yu, Q., Gou, J., Liu, H. (2018). Varied degrees of urbanization effects on observed surface air temperature trends in China. *Climate Research*, 76, 131-143. https://doi.org/10.3354/cr01531

Junk, W.J. (2013). Current state of knowledge regarding South America wetlands and their future under global climate change. Aquatic Sciences, 75, 113-131. https://doi.org/10.1007/s00027-012-0253-8

Jusuf, S.K., Ignatius, M., Hien, W.N., Akbari, H. (2019). Editorial: Urban Heat Island (UHI) and its Mitigation through Urban Planning, Design and Landscaping. *Architectural Science Review*, 62(1), 1-2. https://doi.org/10.1080/00038628.2019.1548095

Kato, S. (2018). Review of airflow and transport analysis in building using CFD and network model. *Japan Architectural Review*, 1, 299–309. https://doi.org/10.1002/2475-8876.12051

Kim, M., Lee, K., Cho, G-H. (2017). Temporal and spatial variability of urban heat island by geographical location: a case study of Ulsan, Korea. *Building and Environment*, 126, 471–482. https://doi.org/10.1016/j.buildenv.2017.10.023

Kim, S.W., Brown, R.D. (2021). Urban heat island (UHI) intensity and magnitude estimations: A systematic literature review. *Science of the Total Environment*, 779, 146389. https://doi.org/10.1016/j.scitotenv.2021.146389

Krayenhoff, E.S., Voogt, J.A., Krayenhoff, E.S., Voogt, J.A. (2007). A microscale three-dimensional urban energy balance model for studying surface temperatures. *Boundary-Layer Meteorol*, 123, 433-461. https://doi.org/10.1007/s10546-006-9153-6

Kubilay, A., Derome, D., Carmeliet, J. (2018). Coupling of physical phenomena in urban microclimate: A model integrating air flow, wind-driven rain, radiation and transport in building materials. *Urban Climate*, 24, 398-418. https://doi.org/10.1016/j.uclim.2017.04.012

Kwok, Y.T., Ng, E. (2021). Trends, topics, and lessons learnt from real case studies using mesoscale atmospheric models for urban climate applications in 2000-2019. *Urban Climate*, 31, 100785. https://doi.org/10.1016/j.uclim.2021.100785

Labdaoui, K., Mazouz, S., Moeinaddini, M., Cools, M., Teller, J. (2021). The Street Walkability and Thermal Comfort Index (SWTC) assessment tool combining street design measurements and thermal comfort. *Science of the Total Environment*, 795, 148663. https://doi.org/10.1016/j.scitotenv.2021.148663

Lai, D., Liu, W., Gan, T., Liu, K., Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of the Total Environment*, 661, 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062

Lam, C.K.C., Lee, H., Yang, S., Park, S. (2021). A review on the significance and perspective of the numerical simulations of outdoor thermal environmental. *Sustainable Cities and Society*, 71, 102971. https://doi.org/10.1016/j.scs.2021.102971

Liang, X., Ji, X., Guo, N., Meng, L. (2021). Assessment of urban heat islands for land use based on urban planning: a case study in the main urban area of Xuzhou City, China. *Environmental Earth Sciences*, 80, 308. https://doi.org/10.1007/s12665-021-09588-5

Lindberg, F., Grimmond, C.S.B. (2011). Nature of vegetation and building morphology characteristics across a city: influence on shadow patterns and mean radiant temperatures in London. *Urban Ecosystems*, 4, 617–634. https://doi.org/10.1007/s11252-011-0184-5

Liu, Z., Cheng, W., Jim, C.Y., Morakinyo, T. E., Shi, Y., Ng, E. (2021). Heat mitigation benefits of urban green and blue infrastructures: A systematic review of modeling techniques, validation and scenario simulation in ENVI-met V4. *Building and Environment*, 200, 107939. https://doi.org/10.1016/j.buildenv.2021.107939

Liu, L., Lin, Y., Wang, D., Liu, J. (2018). Dynamic Spatial-temporal Evaluations of Urban Heat Islands and Thermal Comfort of a Complex Urban District Using an Urban Canopy Model. Journal of Asian *Architecture and Building Engineering*, 15, 627-634. https://doi.org/10.3130/jaabe.15.627

Liu, L., Liu, J., Ji, L., Liu, L., Gao, Y. (2020). Climate-conscious spatial morphology optimization strategy using a method combining local climate zone parameterization concept and urban capony layer model. *Building and Environment*, 185, 107301. https://doi.org/10.1016/j.buildenv.2020.107301

Maggiotto, G., Buccolieri, R., Santo, M.A., Leo, L.S., Di Sabatino, S. (2014). Validation of temperature-perturbation and CFD-based modelling for the prediction of the thermal urban environment: the Lecce (IT) case study. *Environmental Modelling and Software*, 60, 69-83. https://doi.org/10.1016/j.envsoft.2014.06.001

Makido, Y., Shandas, V., Ferwati, S., Sailor, D. (2016). Daytime Variation of Urban Heat Islands: The Case Study of Doha, Qatar. *Climate*. 4, 32. https://doi.org/10.3390/cli4020032

Malys, L., Musy, M., Inard, C. (2015). Microclimate and building energy consumption: study of different coupling methods. *Advances in Building Energy Research*, 9, 151-174. https://doi.org/10.1080/17512549.2015.1043643

Marcel, C., Villot, J. (2021). Urban Heat Island index based on a simplified micro scale model. *Urban Climate*, 39, 100922. https://doi.org/10.1016/j.uclim.2021.100922

Maronga, B., Gryschka, M., Heinze, R., Hoffmann, F., Kanani-Sühring, F., Keck, M., Ketelsen, K., Letzel, M.O., Sühring, M., Raasch, S. (2015). The Parallelized Large-Eddy Simulation Model (PALM) version 4.0 for atmospheric and oceanic flows: model formulation, recent developments, and future perspectives. *Geoscientific Model Development*, 8, 2515–2551. https://doi.org/10.5194/gmd-8-2515-2015

Masson, V., Heldens, W., Bocher, E., Bonhomme, M., Bucher, B., Burmeister, C., Munck, C., Esch, T., Hidalgo, J., Kanani-Sühring, F., Kwok, Y., Lemonsu, A., Lévy, J.P., Maronga, B., Pavlik, D., Petit, G., See, L., Schoetter, R., Tornay, N., Votsis, A., Zeidler, J. (2020). City-descriptive input data for urban climate models: Model requirements, data source and challenges. *Urban Climate*, 31, 100536. https://doi.org/10.1016/j.uclim.2019.100536

Matzarakis, A., Rutz, F., Mayer, H. (2010). Modeling radiation fluxes in simple and complex environments—basics of the RayMan model. *International Journal of Biometeorology*, 54, 131–139. https://doi.org/10.1007/s00484-009-0261-0

McRae, I., Freedman, F., Rivera, C., Li, X., Dou, J., Cruz, I., Ren, C., Dronova, I., Fraker, H., Bornstein, R. (2020). Integration of the WUDAPT, WRF, and ENVI-met models to simulate extreme daytime temperature mitigation strategies in San Jose, California. *Building and Environment*, 184, 107180. https://doi.org/10.1016/j.buildenv.2020.107180

Measham, T.G., Preston, B.L., Smith, T.F., Brook, C., Gorddard, R., Withycombe, G., Morrison, C. (2011). Adapting to climate change through local municipal planning: Barriers and challenges. *Mitigation and Adaptation Strategies for Global Change*. 16, 889–909. https://doi.org/10.1007/s11027-011-9301-2

Miguel, M., Hien, W.N., Marcel, I., Chung, H.D.J., Yueer, H., Zhonqi, Y., Ji-Yu, D., Raghavan, S.V., Son, N.N. (2021). A physically-based model of interactions between a building and its outdoor conditions at the urban microscale. *Energy and Buildings*, 237, 110788.https://doi.org/10.1016/j.enbuild.2021.110788

Mirzaei, P.A. (2021). CFD modeling of micro and urban climates: Problems to be solved in the new decade. *Sustainable Cities and Society*, 69, 102839. https://doi.org/10.1016/j.scs.2021.102839.

Mirzaei, P.A., Haghighat, F. (2010). Approaches to study Urban Heat Island – abilities and limitations. *Building and Environment*, 45, 2192–2201. https://doi.org/10.1016/j.buildenv.2010.04.001

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, *Annals of Internal Medicine*, 151, 264-269. https://doi.org/10.1136/bmj.b2535

Moonen, P., Defraeye, T., Dorer, V., Blocken, B., Carmeliet, J. (2012). Urban Physics: Effect of the micro-climate on comfort, health and energy demand. *Frontiers of Architectural Research*, 1, 197–228. https://doi.org/10.1016/j.foar.2012.05.002

Morakinyo, T., Lam, Y. (2016). Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort. *Building and Environment*, 103, 262–275. https://doi.org/10.1016/j.buildenv.2016.04.025

Muniz-Gäal, L.P., Pezzuto, C.C., Carvalho, M.F.H., Mota, L.T.M. (2020). Urban geometry and the microclimate of street canyons in tropical climate. *Building and Environment*, 169, 106547. https://doi.org/10.1016/j.buildenv.2019.106547

Nakata, C.M., Souza, L.C.L. (2013). Verification of the influence of urban geometry on the nocturnal heat island intensity. *Journal of Urban and Environmental Engineering*, 7, 286-292. https://doi.org/10.4090/juee.2013.v7n2.286292

Napoli, M., Massetti, L., Brandani, G., Petrall, M., Orlandini, S. (2016). Modeling Tree Shade Effect on Urban Ground Surface Temperature. *J Environ Qual*, 45, 146-56. https://doi.org/10.2134/jeq2015.02.0097

Nazarian, N., Fan, J., Sin, T., Norford, L., Kleissl, J. (2017). Predicting outdoor thermal comfort in urban environments: A 3D numerical model for standard effective temperature. *Urban Climate*, 20, 251-267. https://doi.org/10.1016/j.uclim.2017.04.011

Nazarian, N., Sin, T., Norford, L. (2018). Numerical modeling of outdoor thermal comfort in 3D. *Urban Climate*, 26, 212-230. https://doi.org/10.1016/j.uclim.2018.09.001

Nice, K.A., Coutts, A.M., Tapper, N.J. (2018). Development of the VTUF-3D v1.0 urban micro-climate model to support assessment of urban vegetation influences on human thermal comfort. *Urban Climate*, 24, 1052-1076. https://doi.org/10.1016/j.uclim.2017.12.008

Nikolova, I., Janssen, S., Vos, P., Vrancken, K., Mishra, V., Berghmans, P. (2011). Dispersion modelling of traffic induced ultrafine particles in a street canyon in Antwerp, Belgium and comparison with observations. *Science of the Total Environment*, 412–413, 336–343. https://doi.org/10.1016/j.scitotenv.2011.09.081

Oke, T.R. (1981). Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *Journal of Climatology*, 1, 237-254. https://doi.org/10.1002/joc.3370010304

Oke, T.R., Mills, G., Christen, A., Voogt, J.A. (2017). *Urban Climates*. Cambridge University Press. Cambridge.

Oleson, K.W., Anderson, G.B., Jones, B., McGinnis, S.A., Sanderson, B. (2018). Avoided climate impacts of urban and rural heat and cold waves over the U.S. using large climate model ensembles for RCP8.5 and RCP4.5. *Climate Change*, 146, 377–392. https://doi.org/10.1007/s10584-015-1504-1

Oliveira, A., Lopes, A., Correia, E., Niza, S., Soares, A. (2021). An urban climate-based empirical model to predict present and future patterns of the Urban Thermal Signal. *Science of the Total Environment*, 790, 147710. https://doi.org/10.1016/j.scitotenv.2021.147710

O'Loughlin, J., Witmer, F.D.W., Linke, A.M., Laing, A., Gettelman, A., Dudhia, J. (2012). Climate variability and conflict risk in East Africa, 1990–2009. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 18344–18349. https://doi.org/10.1073/pnas.1205130109

Oswald, A.M., Hollosi, B., Zuvela-Aloise, M., See, L., Guggenberger, S., Hafner, W., Prokop, G., Storch, A., Schieder, W. (2020). Using urban climate modelling and improved land use classifications to support climate change adaptation in urban environments: A case study for the city of Klagenfurt, Austria. *Urban Climate*, 31, 100582. https://doi.org/10.1016/j.uclim.2020.100582

Othmer, F.J., Schmitt, J.P., Greiving, S. (2020). Numerical modelling of the urban climate as an integrated part of environmental assessments. *Science of the Total Environment*, 731, 138774. https://doi.org/10.1016/j.scitotenv.2020.138774

Parlow, E. (2021). Regarding Some Pitfalls in Urban Heat Island Studies Using Remote Sensing Technology. *Remote Sensing*, 13, 3598. https://doi.org/10.3390/rs13183598

Pass, B., Schneider, C. (2016). A comparison of model performance between ENVI-met and Austal2000 for particulate matter. *Atmospheric Environment*, 145, 392-404. https://doi.org/10.1016/j.atmosenv.2016.09.031

Petersen, E.L., Mortensen, N.G., Landberg, L., Højstrup, J., Frank, H.P. (1998). Wind power meteorology. Part 1: climate and turbulence. *Wind Energy*, 1, 5–45. https://doi.org/10.1002/(SICI)1099-1824(199809)1:1<2::AID-WE15>3.0.CO;2-Y

Pigeon, G., Moscicki, A.M., Voogt, J.A., Masson, V. (2008). Simulation of fall and winter surface energy balance over a dense urban area using the TEB scheme. *Meteorology and Atmospheric Physics*, 102, 159–171. https://doi.org/10.1007/s00703-008-0320-9

Piroozmand, P., Mussetti, G., Allegrini, J., Mohammadi, M.H., Akrami, E., Carmeliet, J. (2020). Coupled CFD framework with mesoscale urban climate model: Application to microscale urban flows with weak synoptic forcing. *Journal of Wind Engineering and Industrial Aerodynamics*, 197, 104059. https://doi.org/10.1016/j.jweia.2019.104059

Porangaba, G.F.O., Teixeira, D.C.F., Amorim, M.C.C.T., da Silva, M.H.S., Dubreuil, V. (2021). Modeling the urban heat island at a winter event in Três Lagoas, Brazil. *Urban Climate*, 37, 100853. https://doi.org/10.1016/j.uclim.2021.100853

Qaid, A., Lamit, H.B., Ossen, D.R., Shahminan, R.N.R. (2016). Urban heat island and thermal comfort conditions at micro-climate scale in a tropical planned city. *Energy and Buildings*, 133, 577-595. https://doi.org/10.1016/j.enbuild.2016.10.006

Raymar, R., Zarghami, E., Bryant, M. (2019). Spatio-temporal planning of urban neighborhoods in the context of global climate change: Lessons for urban form design in Tehran, Iran. *Sustainable Cities and Society*, 51, 101554. https://doi.org/10.1016/j.scs.2019.101554

Roth, M. 2007. Review of urban climate research in (sub)tropical regions. International Journal of Climatology, 27, 1859–1873. https://doi.org/10.1002/joc.1591

Roth, M., Lim, V.H. (2017). Evaluation of canopy-layer air and mean radiant temperature simulations by a microclimate model over a tropical residential neighbourhood. *Building and Environment*, 112, 177-189. https://doi.org/10.1016/j.buildenv.2016.11.026

Salata, F., Golasi, I., Vollaro, R.L., Vollaro, A.L. (2016). Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustainable Cities and Society*, 26, 318-343. https://doi.org/10.1016/j.scs.2016.07.005

Salata, F., Golasi, I., Petitti, D., Vollaro, E.L., Coppi, M., Vollaro, A.L. (2017). Relating microclimate, human thermal comfort and health during heat waves: An analysis of heat island mitigation strategies through a case study in an urban outdoor environment. *Sustainable Cities and Society*, 30, 79-96. https://doi.org/10.1016/j.scs.2017.01.006

Salvati, A., Monti, P., Coch Roura, H., Cecere, C. (2019). Climatic performance of urban textures: analysis tools for a Mediterranean urban context. *Energy and Buildings*, 185, 162–179. https://doi.org/10.1016/j.enbuild.2018.12.024

Samaali, M., Courault, D., Bruse, M., Olioso, A., Occelli, R. (2007). Analysis of a 3D boundary layer model at local scale: validation on soybean surface radiative measurements. *Atmospheric Research*, 85, 183–198. https://doi.org/10.1016/j.atmosres.2006.12.005

San José, R., Pérez, J.L., Pérez, L., Barras, R.M.G. (2018). Effects of climate change on the health of citizens modelling urban weather and air pollution. *Energy*, 165, 53-62. https://doi.org/10.1016/j.energy.2018.09.088

Sharma, A., Wuebbles, D.J., Kotamarthi, R. (2021). The need for urban-resolving climate modeling across scales. *AGU Advances*, 2, e2020AV000271. https://doi.org/10.1029/2020AV000271

Sharmin, T., Steemers, K., Matzarakis, A. (2017). Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. *Sustainable Cities and Society*, 34, 293-308. https://doi.org/10.1016/j.scs.2017.07.006

Shi, Y., Ren, C., Zheng, Y., Ng, E. (2016). Mapping the urban microclimatic spatial distribution in a sub-tropical high-density urban environment. *Architectural Science Review*, 59, 370-384. https://doi.org/10.1080/00038628.2015.1105195

Shinzato, P., Simon, H., Duarte, D.H.S., Bruse, M. (2019). Calibration process and parametrization of tropical plants using ENVI-met V4 – Sao Paulo case study. *Architectural Science Review*, 62, 112-125. https://doi.org/10.1080/00038628.2018.1563522

Silva, A.F.G., Peña, A., Hahmann, A.N., Zaparoli, E.L. (2018). Evaluation of two microscale flow models through two wind climate generalization procedures using observations from seven masts at a complex site in Brazil. *Journal of Renewable and Sustainable Energy*, 10, 053306. https://doi.org/10.1063/1.5027692

Silva, A.G.L., Torres, M.C.A. (2021). Proposing an effective and inexpensive tool to detect urban surface temperature changes associated with urbanization processes in small cities. *Building and Environment*, 192, 107634. https://doi.org/10.1016/j.buildenv.2021.107634

Souza, L.C.L., Tente, C.M., Giunta, M.B., Nakata-Osaki, C.M. (2010). Fator de visão do céu e intensidade de ilhas de calor na escala do pedestre. *Ambiente Construído*, 10, 155–167. https://doi.org/10.1590/S1678-86212010000400011

Stagakis, S., Chrysoulakis, N., Spyridakis, N., Feigenwinter, C., Vogt, R. (2019). Eddy covariance measurements and source partitioning of CO2 emissions in an urban environment: application for Heraklion, Greece. *Atmospheric Environment*, 201, 278–292. https://doi.org/10.1016/j.atmosenv.2019.01.009

Steuri, B., Bender, S., Cortekar, J. (2020). Successful user-science interaction to co-develop the new urban climate model PALM-4U. *Urban Climate*, 32, 100630. https://doi.org/10.1016/j.uclim.2020.100630

Stewart, I.D., Krayenhoff, E.S., Voogt, J.A., Lachapelle, J.A., Allen, M.A., Broadbent, A.M. (2021). Time Evolution of the Surface Urban Heat Island. *Earth's Future*, 9, e2021EF002178. https://doi.org/10.1029/2021EF002178

Susca, T., Pomponi, F. (2020). Heat Island effects in urban life cycle assessment: Novel insights to include the effects of the urban heat island and UHI-mitigation measures in LCA for effective policy making. *Journal of Industrial Ecology*, 24, 410-423. https://doi.org/10.1111/jiec.12980

Swamy, G., Nagendra, S.M.S., Schlink, U. (2017). Urban heat island (UHI) influence on secondary pollutant formation in a tropical humid environment. *J Air Waste Manag Assoc*, 67, 1080-1091. https://doi.org/10.1080/10962247.2017.1325417

Tan, X., Liao, J., Bedra, K.B., Li, J. (2021). Evaluating the 3D cooling performances of different vegetation combinations in the urban area. *Journal of Asian Architecture and Building Engineering*, 21(3),1124-1136. https://doi.org/10.1080/13467581.2021.1903905

Thorsson, S., Honjo, T., Lindberg, F., Eliasson, I., Lim, E.M. (2007). Thermal comfort and outdoor activity in Japanese urban public spaces. *Environ Behav*, 39, 660–684. https://doi.org/10.1177/0013916506294937

Toparlar, Y., Blocken, B., Vos, P., van Heijst, G.J.F. (2015). CFD simulation and validation of urban microclimate: A case study for Bergpolder Zuid, Rotterdam. *Building and Environment*, 83, 79-90. https://doi.org/10.1016/j.buildenv.2014.08.004

Tsoka, S., Tsikaloudaki, K., Theodosiou, T. (2017). Urban space's morphology and microclimatic analysis: A study for a typical urban district in the Mediterranean city of Thessaloniki, Greece. *Energy and Buildings*, 156, 96-108. https://doi.org/10.1016/j.enbuild.2017.09.066

Tsoka, S., Tsikaloudaki, A., Theodosiou, T. (2018). Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. *Sustainable Cities and Society*, 43, 55-76. https://doi.org/10.1016/j.scs.2018.08.009

Wang, C., Chang, H. (2020). Hotspots, Heat Vulnerability and Urban Heat Islands: An Interdisciplinary Review of Research Methodologies. *Canadian Journal of Remote Sensing*, 46, 532-551. https://doi.org/10.1080/07038992.2020.1816815

Wang, C., Wang, Z., Yang, J. (2018). Cooling Effect of Urban Trees on the Built Environment of Contiguous United States. *Earth's Future*, 6, 1066-1081. https://doi.org/10.1029/2018EF000891

Weng, Q., Firozjaei, M.K., Sedighi, A., Kiavarz, M., Alavipanah, S.K. (2019). Statistical analysis of surface urban heat island intensity variations: A case study of Babol city, Iran. *GIScience & Remote Sensing,* 56, 576-604, https://doi.org/10.1080/15481603.2018.1548080

Wong, N.H., He, Y., Nguyen, N.S., Raghavan, S.V., Martin, M., Hii, D.J.C., Yun, Z., Deng, J. (2021). An integrated multiscale urban microclimate model for the urban thermal environment. *Urban Climate,* 35, 100730. https://doi.org/10.1016/j.uclim.2020.100730

Yin, S., Lang, W., Xiao, Y. (2019). The synergistic effect of street canyons and neighborhood layout design on pedestrian-level thermal comfort in hot-humid area of China. *Sustainable Cities and Society*, 49, 101571. https://doi.org/10.1016/j.scs.2019.101571

Yu, M., Chen, X., Yang, J., Miao, S. (2021). A new perspective on evaluating high-resolution urban climate simulation with urban canopy parameters. *Urban Climate*, 38, 100919. https://doi.org/10.1016/j.uclim.2021.100919

Zhou, X., Chen, H. (2018). Impact of urbanization-related land use land cover changes and urban morphology changes on the urban heat island phenomenon. *Science of the Total Environment*, 635, 1467–1476. https://doi.org/10.1016/j.scitotenv.2018.04.091

CAPÍTULO 7 – EXPLORING THE URBAN HEAT ISLAND PHENOMENON IN A TROPICAL MEDIUM-SIZED CITY: INSIGHTS FOR SUSTAINABLE URBAN DEVELOPMENT (Submetido)

7.1 Abstract

Urban Heat Islands (UHI) pose a significant challenge for tropical cities, especially as global temperatures continue to rise. Despite the prevalence of this problem, medium-sized cities in tropical regions remain underrepresented in UHI studies compared to large cities in temperate climates. This study aimed to characterize the UHI effect in a rapidly growing medium-sized city in a tropical region, which has experienced unplanned urban sprawl. Temperature data were collected using data loggers in ten distinct areas of the city (Willmott index d = 0.97). The results revealed a pronounced UHI effect, with higher intensities in the city center and lower intensities in areas with native vegetation. During the dry season, extreme UHI effects (>6°C) were observed 10% of the time, with strong UHI effects (4°C-6°C) present 50% of the month. In contrast, during the wet season, moderate UHI effects (4°C-6°C) were recorded only 15% of the time. A strong correlation was identified between land use, particularly vegetation cover, and UHI intensity. This study not only sheds light on the dynamics of UHI in this specific tropical city, but also offers relevant insights for other mid-sized cities in similar tropical contexts around the world. The findings provide valuable knowledge for the development of adaptation and mitigation strategies in urban planning, which can be applied globally to cities facing rapid urbanization in hot climates. Furthermore, this research contributes to the advancement of UHI analysis methodologies that can be replicated in tropical and temperate cities, building on previous studies conducted in Brazil and other regions of the world.

7.2 Introduction

As of 2018, more than half of the global population resides in urban areas, and this figure is projected to rise to 68% by 2050 (United Nations, 2018). This ongoing trend toward urbanization has led to significant changes in land use and cover, resulting in an increase in impermeable surfaces and a decrease in green spaces (Amorim, 2000; Amorim et al., 2009; Foissard et al., 2019). These changes, in turn, affect urban microclimates, altering energy balances and atmospheric compositions (Li and Heap, 2014; Ren, 2015;

Yu et al., 2019), with one of the most prominent consequences being the Urban Heat Island (UHI) effect.

The UHI effect, characterized by elevated temperatures in urban centers compared to surrounding rural areas (Oke et al., 2017), represents a global environmental challenge linked to rapid, often unplanned, urbanization (Santamouris et al., 2015; Yu et al., 2015). The negative impacts of UHI extend across various sectors, including public health, energy consumption, and urban infrastructure, and are especially detrimental to vulnerable populations (Bradford et al., 2015; McKenzie, 2015). Furthermore, climate change is exacerbating UHI intensity and frequency, making it a key issue for cities worldwide (Kim and Brown, 2021).

While much of the research on UHI has focused on large metropolitan areas in temperate regions (Kadhim-Abid et al., 2019; You et al., 2021), medium and small cities—especially those in tropical regions—remain underrepresented in the literature (Cardoso et al., 2017; Roth, 2007). This is particularly significant because tropical climates present distinct UHI characteristics due to factors such as higher solar radiation and different vegetation and urbanization patterns (Moreira et al., 2019; Zhao et al., 2014). Addressing this gap is crucial for creating effective mitigation and adaptation strategies, as medium-sized tropical cities are often undergoing rapid expansion without adequate urban planning, further intensifying UHI effects (Amorim, 2020).

Brazil, with its diverse climatic zones and high urbanization rates, serves as a critical context for UHI studies. However, research on UHI in Brazilian cities, particularly in medium-sized urban areas, is scarce. Previous studies have often been limited by insufficient data and inconsistent methodologies, making it difficult to generalize results or develop targeted urban management strategies (Amorim et al., 2017). Thus, there is a pressing need for comprehensive studies that address these gaps and provide insights into the dynamics of UHI in medium-sized cities in tropical climates.

In response to these challenges, this study aims to characterize the UHI effect in Indaiatuba, a rapidly growing medium-sized city in southeast Brazil, through the collection and analysis of temperature data from strategically placed sensors. By employing a statistically validated methodology that integrates land use and seasonal climate variations, this research contributes to the global understanding of UHI phenomena in under-studied tropical urban areas. Importantly, the study's methodology, which combines field-based temperature data with land-use analysis, is not only applicable to other Brazilian cities but also to similar urban contexts in tropical regions worldwide.

The findings from this study offer valuable insights for urban planners and policymakers, both locally and internationally, providing a framework for developing mitigation and adaptation strategies in medium-sized tropical cities. Moreover, this research advances UHI analysis methodologies by addressing gaps in data and applying a coherent, replicable approach that strengthens the global discourse on sustainable urban planning in the context of climate change.

7.3 Material and methods

7.3.1 Study area

The study was conducted in Indaiatuba, a municipality located in the southeast region of the State of São Paulo, Brazil (Fig. 1), which serves as a representative case of medium-sized tropical cities undergoing rapid urbanization. Like many cities worldwide that are experiencing accelerated population growth and urban expansion, Indaiatuba faces significant challenges related to urban heat islands (UHI), climate variability, and sustainable development. The city covers an area of 311.4 km², with an average elevation of 575 meters, and is situated at coordinates 23° 5' 18" S and 47° 13' 24" W.

Over the past 12 years, Indaiatuba's population has increased by over 75%, reaching 255,739 inhabitants as of the 2022 census (IBGE, 2022). This rapid growth mirrors global trends in urbanization, where medium-sized cities in tropical regions, in particular, are expanding without adequate planning to address the environmental consequences of such growth, including the exacerbation of UHI effects. The city's diverse economic base, which includes industrial, agricultural, and tourism sectors (Tecchio et al., 2011), further highlights the complexity of land use changes that contribute to urban heat dynamics.

Indaiatuba's combination of industrial activity, urban expansion, and tropical climate makes it an ideal location to study UHI effects and their implications for similar cities around the world that face comparable environmental and developmental challenges. By focusing on this city, the study aims to contribute to the broader understanding of how UHI phenomena manifest in medium-sized urban areas in tropical climates, providing insights applicable to urban management and climate adaptation strategies globally.

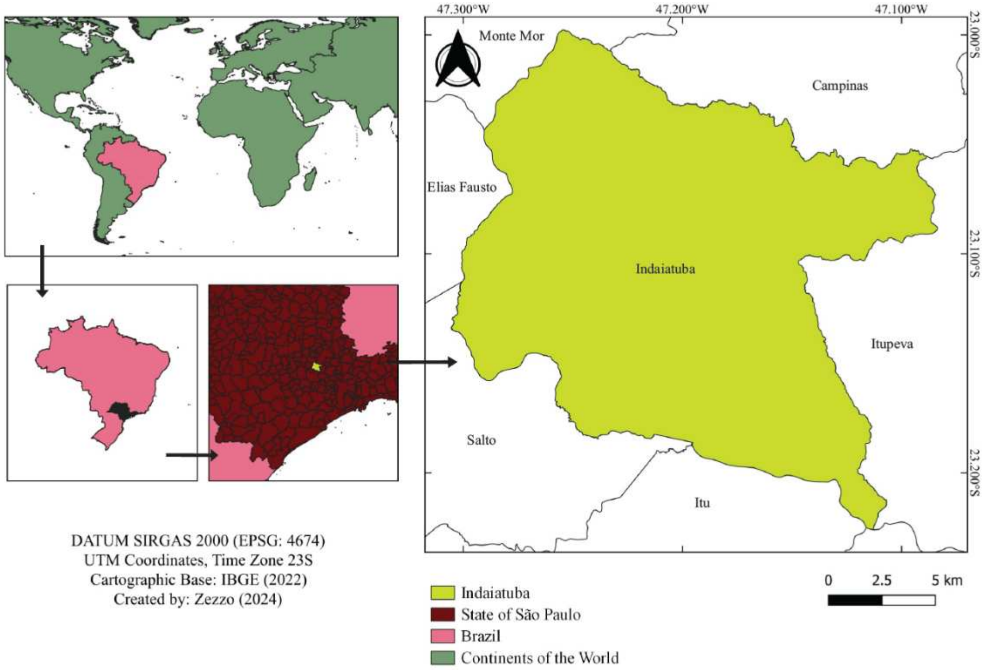


Fig. 1. Location of the municipality of Indaiatuba (study area) within the State of São Paulo, southeast of Brazil.

Indaiatuba's climate, classified under Köppen's system, is generally described as Cwa, tropical of altitude with dry winters (Dubreuil et al., 2017). The average annual temperature stands at 22.5ºC (Fig. 2), with February marking the warmest month (maximum temperature >25ºC), while July is the coldest (minimum temperature <15ºC) (CIIAGRO).

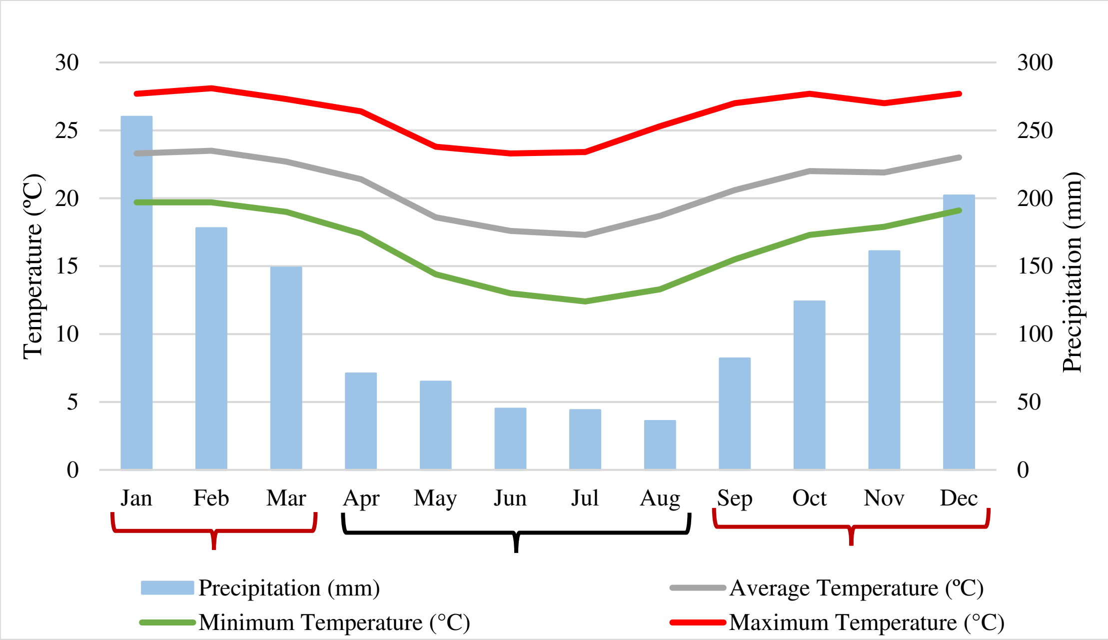


Fig.2. Presentation of data (from 2008 to 2021) about temperature and precipitation obtained at CIIAGRO automatic meteorological measurement station, located in the center of Indaiatuba. Identification of the dry season (black) and the rainy months (red).

Regarding precipitation, the yearly average is 1400mm (IAC, 2013). The winter months (late June, July, August, and September) are the driest, with an average precipitation of 40mm. Conversely, the summer months (late December, January, February, and March) are the wettest, experiencing an average rainfall of 260mm (CIIAGRO). In this context, some studies such as that by Castellano and Nunes (2017) showed that since 1970 extreme events have been increasingly frequent in Indaiatuba, with significant impacts resulting from heavy rains.

7.3.2 UHI Assessment: Multiscale Analysis and Data Collection

Studies have been conducted to assess the effects of UHI at three different scales: boundary UHI, canopy UHI, and surface UHI (Zhang et al., 2009). The first case is typically used to investigate mesoscale UHI, the second focuses on microscale UHI data, and in the last, UHI is measured at surface level (Deilami et al., 2018). For the study of the canopy UHI, for example, traditionally meteorological stations and other methods of collecting climate data are used directly in the study area (Gusson and Duarte, 2016; Liu et al., 2020).

Following the approaches mentioned previously, the UHI canopy methodology was chosen, with the installation of ten temperature sensors in the study area for the purposes of this research. Subsequently, the data collected from these devices was analyzed using statistical means, offering an accurate description of the municipality's local climatic conditions. The methodology was therefore implemented in three stages. Initially, the different areas of the municipality were evaluated and classified as urban or rural. This method was adapted from the work of Fialho (2009) to select the area for sensor installation (1). Secondly, a datalogger accuracy test was conducted (2). Finally, a general and refined analysis of the data was carried out (3). The third stage of the methodology involved the acquisition of sensor data, compilation, analysis and discussion of the information in comparison with official synoptic data. The three steps are described in detail below.

7.3.3 Land use and cover classification

An assessment of land use and coverage in areas of the municipality was carried out using Google Earth images, which were later visited and classified into urban and rural areas, adapting the research by Fialho (2009). Additionally, the Local Climate Zones (LCZ) classification given by Stewart and Oke (2012) was incorporated.

In the present study, the classification between rural and urban considered: the level of urban density and built area, the distance from the city center, the use (residential, industrial, commercial or mixed), the percentage of vegetation and the presence of tall trees (Table 1). The classification was, therefore, used to distinguish between sensors in rural and urban locations, with the decisive factor being the presence of vegetation with tall trees, plantations or exposed soil, as well as mixed areas. Hence, sensors 1, 2, 5, 9 and 10 were considered urban, while sensors 3, 4, 6, 7 and 8 were classified as rural (Table 1 and Fig. 3).

Table 1. Description of the points where the sensors are installed within Indaiatuba, considering the classification of land use and cover and evaluating the correspondence with the LCZ.

Spots	**Aerial view- 200m window**	**Description**	**Class and LCZ**	**Lat/long.**
1		Industrial expansion area on the edges of Indaiatuba, with some warehouses. Low urban development and low density of built area. Exposed soil and vegetation cover <10% within a radius of 200m. No tall trees. Altitude: 580m.	Rural - LCZ D -	23° 7'25.38"S 47°15'50.02"O
2		Area of urban expansion on the edges of the city, where the limit between a large green area (urban forest) can be seen. Medium urban development with low density and 1 or 2-story buildings. Vegetation coverage of 50% within a radius of 200m. Presence of tall trees. Altitude: 627m.	Rural - LCZ 3, A	23° 6'1.99"S 47°14'44.05"O
3		Area with simple brick and concrete buildings, often without finishing/undone. High urban development and high density of built area. Constructions with 1 or 2 floors. Mixed use, residential and services. Vegetation coverage <5% within a radius of 200 m. No tall trees. Altitude: 605m.	Urban - LCZ 3 -	23° 7'36.01"S 47°14'30.46"O
4		Industrial zone of the municipality, with a large concentration of companies and industries. High urban development and high density of built area. Vegetation coverage <5% within a radius of 200 m. No tall trees. Altitude: 583m.	Urban - LCZ 10	23° 8'22.08"S 47°13'56.98"O

5		Residential area with a predominance of large houses and green areas, with the presence of farms. Interspersing built and open areas. Vegetation coverage of 20% within a radius of 200m. Presence of tall trees. Altitude: 641m.	Rural - LCZ 6	23° 3'28.29"S 47°13'22.16"O
6		Commercial area (center of Indaiatuba), with stores, warehouses and bus station. Intense movement of people and vehicles. High urban development with high density of built area and buildings from 1 to 3 floors. Vegetation coverage equal to or less than 5% within a radius of 200m. No tall trees. Altitude: 582 m.	Urban - LCZ 3	23° 5'14.71"S 47°12'35.01"O
7		Area with simple brick and concrete buildings. High urban development and high density of built area. Constructions with 1 or 2 floors. Mixed use, mostly residential, but with some services. Vegetation coverage around 5% within a radius of 200m. No tall trees. Altitude: 619m.	Urban - LCZ 3	23° 6'27.77"S 47°13'13.47"O
8		Residential area with a predominance of concrete houses, with 1 or 2 floors. High urban development and medium density. Mixed use, residential and services. Little vegetation, around 5% within a radius of 200 meters. No tall trees. Altitude: 628m.	Urban - LCZ 3	23° 4'55.74"S 47°12'6.84"O

9		Residential and commercial expansion zone (mixed use) on the edges of the city. Medium urban development and medium density of built area. Planting areas and exposed soil. Vegetation cover 10% within a radius of 200m. No tall trees. Altitude: 606m.	Rural - LCZ 3, D	23° 6'6.22"S 47°10'57.01"O
10		Residential area with high standard condominiums on the edges of the city. Medium urban development with low density and 1 or 2-story buildings. Average vegetation coverage of 20% within a radius of 200m. Presence of tall trees. Altitude: 660m.	Rural - LCZ 3 and 6	23° 3'44.50"S 47°10'19.17"O

7.3.4 Datalogger accuracy test

In this study, the term 'sensor' refers to the combination of a datalogger and a meteorological shelter. The dataloggers utilized in this research are of the Instrutherm brand, specifically the HT-900 model. They have the capacity to store up to 32,000 readings in their memory and can be programmed to record data with intervals ranging from 10 seconds to 18 hours. These devices are capable of measuring temperatures within the range of -30ºC to 60ºC, with an average battery lifespan of 12 months, which can be replaced when needed. The meteorological shelters were constructed by ourselves based on the methodologies outlined in the works of Freitas (2018) and Júnior et al. (2016).

In July 2021, prior to the installation of the sensors in their designated locations, a calibration test was conducted using the dataloggers to assess their accuracy. This was done by setting up a datalogger in close proximity to the automatic meteorological station at the Center for Meteorological and Climate Research Applied to Agriculture (CEPAGRI-UNICAMP). The CEPAGRI meteorological station serve as reference for this study region, with meteorological data since 1989. After a week of data collection, the readings recorded by the datalogger were compared to the data provided by the CEPAGRI automatic station. In this context, we employed the agreement index (d) from Willmott (1981), which is defined by the equation (1):

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_1)^2}{\sum_{i=1}^{n}(|P_i - O| + |O_i - O|)^2} \quad (1)$$

The value of "d" ranges from 0 to 1, where a higher value, close to 1, indicates a stronger agreement between the compared datasets. The test result for temperature for this study yielded a value of 0.977, confirming the reliability of the datalogger in capturing temperature data. Consequently, each datalogger was programmed and strategically placed (Fig. 3), recording data at 10-minute intervals over the course of 2022.

In the subsequent phase, all devices were monitored every four months to retrieve the stored data. These data were accessed using software, available in both CSV and PDF formats, and afterwards organized and analyzed using basic statistical methods, including trend measures, maximum, minimum and average values.

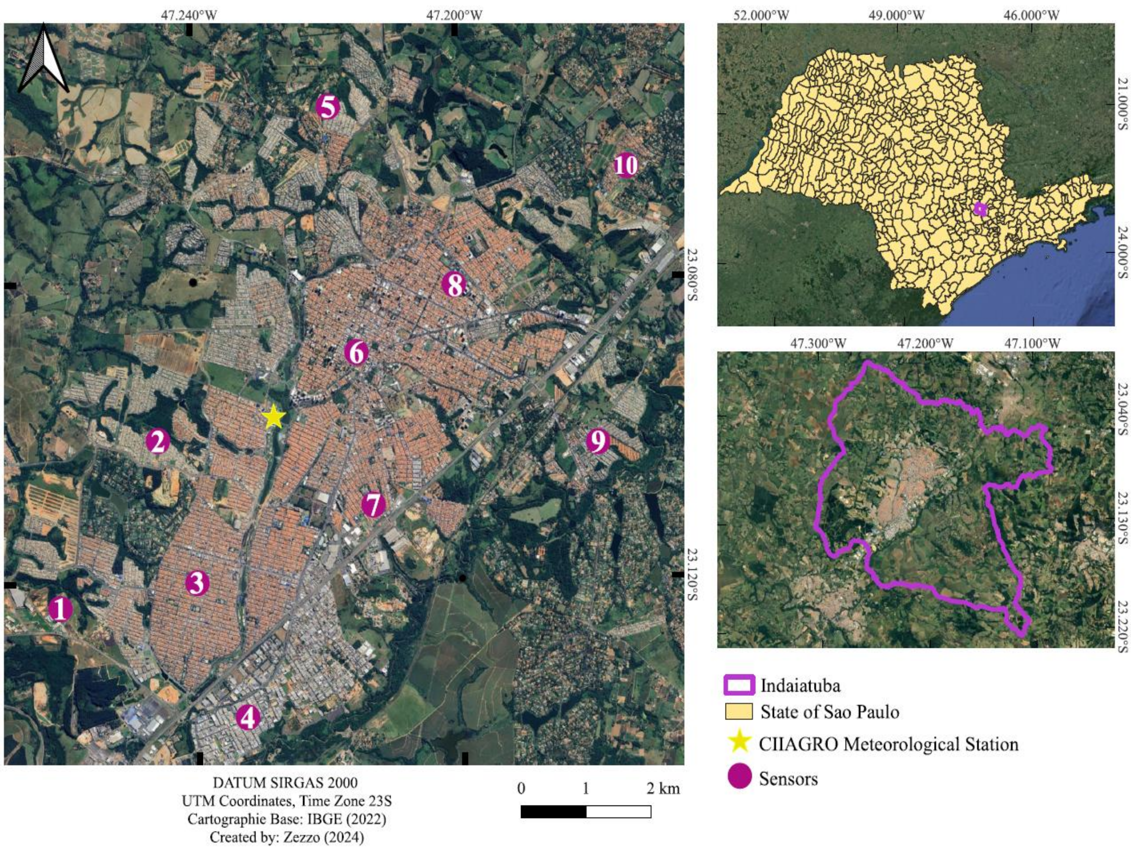


Fig. 3. Location of sensors installed in the municipality for temperature measurement.

7.3.5 General and refined analysis of the data

The data were analyzed based on a hierarchy, starting with annual data and ending with hourly data, which allowed us to verify the behavior of the UHI throughout the day, observing the magnitude and frequency. The Fig. 4 explains how the results were analyzed in this work.

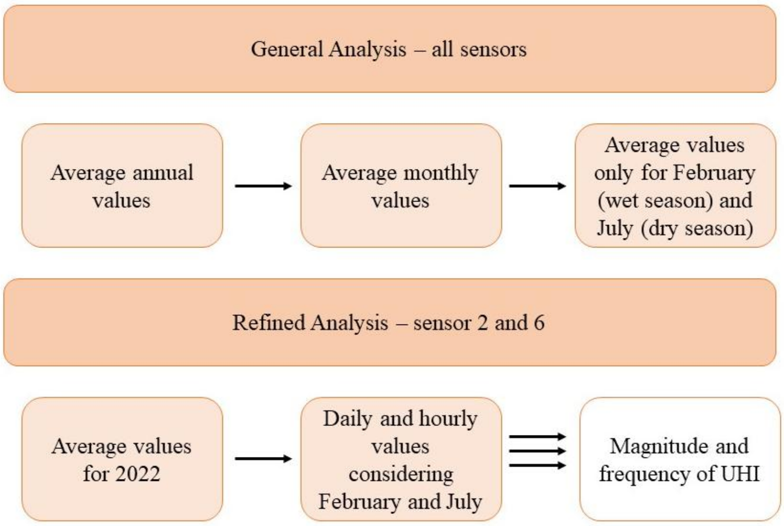


Fig. 4. Demonstration of the data analyzes developed to present the results, delimiting them between general and refined analysis.

The UHI analysis focuses on the analysis of minimum temperatures during the dry months (Amorim, 2020), considering for this study the month of July 2022, in addition to this, we compared data from wet months, in this case, February 2022. Besides that, the most significant disparities in minimum temperatures between urban and rural sensors were identified in sensors 2 and 6. Hence, for our comprehensive UHI evaluation, we utilized these specific sensors to illustrate the impact of UHI in the study area.

With the aim of understanding more precisely what led to the formation of UHI, influencing its intensity and frequency during the study period, we conducted a simultaneous compilation and analysis of synoptic information alongside our results database to perform the refined analysis. In this case, we made a comparison with data from the automatic meteorological station of the Integrated Center for Agrometeorological Information (CIIAGRO), a network of stations managed by the Campinas Agronomic Institute (IAC), covering temperature, precipitation and daily relative humidity. Additionally, we referred to the Meteorological Information Service (OGIMET) website for insights into wind direction and cloud cover. Moreover, we consulted synoptic charts provided by the Brazilian Navy for information on atmospheric pressure and atmospheric systems.

All detailed information about atmospheric conditions at the time of UHI formation is important for refined data analysis, as it also helps to explain the frequency and magnitude of this phenomenon in the study area.

Regarding magnitude analysis, García's (1996) classification was used, which indicates that a very strong UHI magnitude is one in which the temperature difference between a point in an urban area and another in a rural area is equal to or greater than 6ºC. The same author mentions that an UHI with temperatures between 4ºC and 6ºC can be considered as high magnitude, variations between 2ºC and 4ºC are considered medium magnitude UHI and variations from 0ºC to 2ºC are low magnitude UHI.

7.4 Results

7.4.1 General Analysis

Table 2 provides an overview of the average minimum temperatures recorded in 2022, both on an annual and monthly basis. The focus was primarily on presenting data related to minimum values, as the UHI is assessed through the disparity in minimum temperatures between urban and rural sensors (Foissard et al., 2019).

Table 2: Minimum average values for 2022 and for each month.

Sensors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
January	20.4	19.9	21.0	21.0	20.4	21.1	21.1	21.1	20.7	20.3
February	20.3	**19.0**	20.8	20.6	20.4	**21.2**	20.9	21.1	20.6	20.4
March	21.2	20.5	**21.9**	21.8	21.1	**21.9**	21.8	21.8	21.4	21.0
April	18.5	16.7	19.0	18.7	18.7	19.5	19.2	19.4	18.6	18.6
May	14.0	12.1	14.9	14.4	14.4	15.2	15.0	15.1	14.2	14.3
June	**13.4**	**12.0**	14.4	13.9	14.1	15.0	14.6	14.8	13.6	14.1
July	13.8	**12.2**	15.6	14.9	15.0	**16.3**	15.9	15.8	14.3	15.1
August	13.0	12.4	14.8	14.5	14.2	15.1	14.8	15.0	14.1	14.4
September	14.5	14.2	15.5	15.3	15.1	15.7	15.5	15.6	15.2	15.0
October	17.2	16.7	18.6	18.5	18.2	18.9	18.8	18.9	18.4	18.1
November	15.6	15.2	17.3	17.2	17.0	17.7	17.5	17.8	17.2	16.8
December	20.3	19.9	21.0	21.0	20.3	20.8	20.8	20.9	20.5	20.2
Annual minimum average	16.8	**15.9**	17.9	17.7	17.4	**18.2**	**18.0**	**18.1**	17.4	17.4

Sensor 6 showed the highest annual minimum temperature at 18.2ºC, followed closely by sensors 8 at 18.1ºC, and sensor 7 at 18ºC (black color). Conversely, sensor 2 displayed the lowest average minimum temperature for the same year, registering at 15.9ºC (purple color). Therefore, sensors 2 and 6 emerged as the most distinct in terms of annual values. Examining the monthly data, it was noted that the highest minimum temperatures were observed in March, peaking at 21.9ºC in sensors 6 and 3 (red color). The lowest minimums were recorded in June, with 12ºC for sensor 2 and 13.4ºC for sensor 1 (green color).

For the month of February, selected to represent the wet season, sensor 6 reported the highest minimum temperature at 21.2ºC, while sensor 2 registered the lowest value at 19.0ºC (blue color). In contrast, July is exampling the dry season, and showed sensor 6 with the highest average temperature for the month (16.3ºC) and sensor 2 with the lowest average minimum (12.2ºC) (orange color).

Fig. 5 depicts the daily variation in the average minimum temperature for the months of February and July, considering the 10 fixed sensors installed in the study area. It is possible to observe a consistent pattern in temperature trends, with smaller fluctuations in the wet period (February). On the other hand, the dry month (July) illustrates more pronounced fluctuations between sensors, particularly emphasizing the disparities between sensors 2 and 6, further accentuating the contrast in minimum temperatures between them.

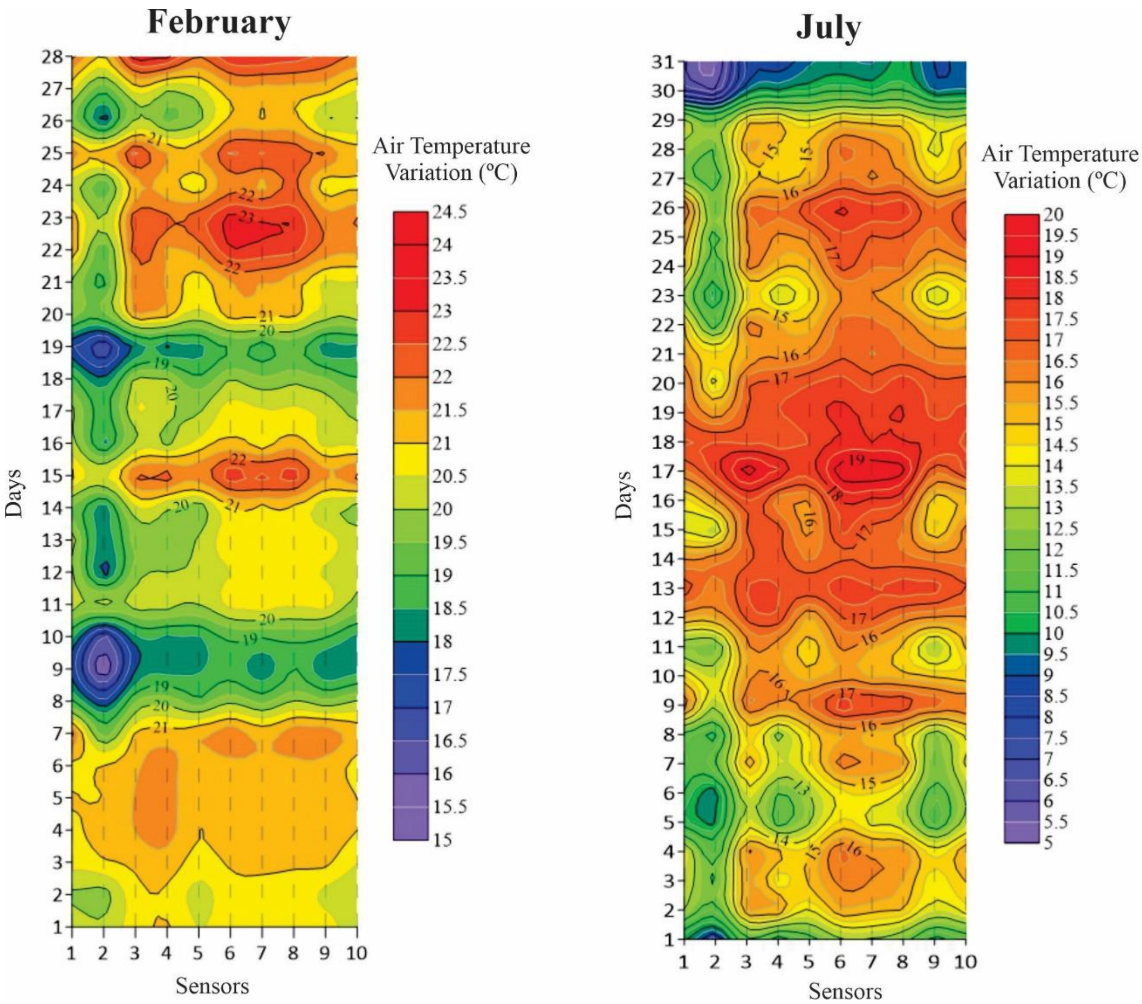


Fig. 5. Spatio-temporal variation of minimum temperatures in the months of February and July 2022, considering the 10 fixed sensors present in Indaiatuba.

7.4.2 Refined Analysis

7.4.2.1 Average monthly temperature

Regarding the average maximum and minimum temperatures obtained (Fig. 6), there is a smaller oscillation between the maximum temperatures during the year with sensors 2 and 6 (1.10ºC), while the minimum temperatures differ more between these sensors (4.43ºC). The highest maximum and minimum temperatures were observed in March 2022, and then in February 2022. Alternatively, the lowest minimum temperatures were observed in May, June and July of this year (dry season).

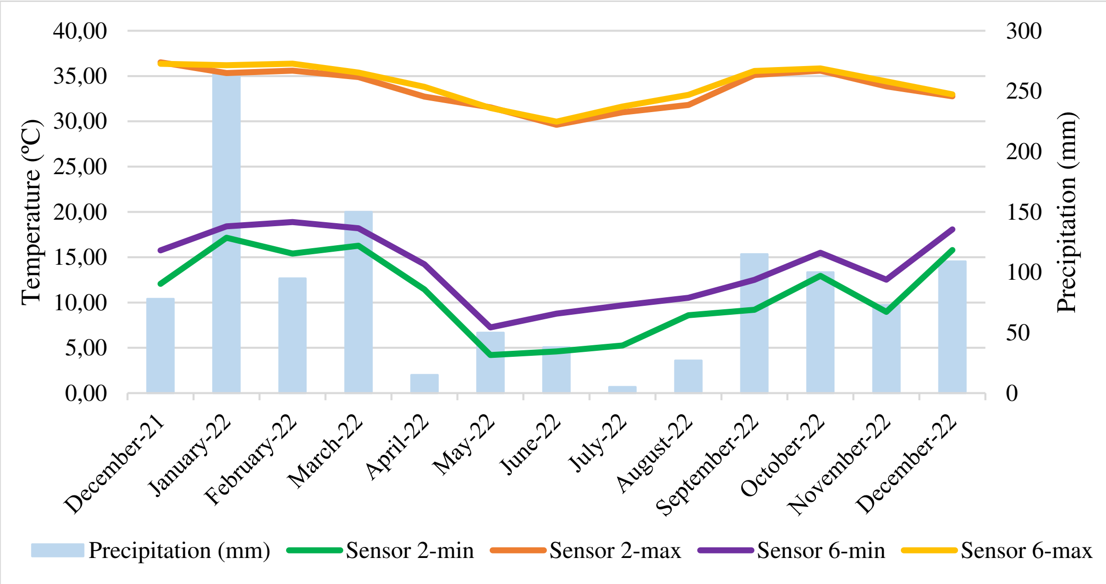


Fig. 6. Average Maximum and minimum temperatures for the study period, considering rural (2) and urban (6) sensors, with the presentation of precipitation values.

July recorded the lowest rainfall of the entire study period (6.47 mm) where the expected average was 44 mm according to CIIAGRO data, being much lower than expected for the month. January had the highest rainfall (271.29 mm), above the average of 260mm, as well as March, which recorded 151.88 mm when the average is 149mm. The month of February had 93.98 mm of rain, below the expected value for the period, which would be around 178mm.

7.4.2.2 Magnitude and frequency of the UHI

A comparison of the minimum temperature readings from sensors 2 and 6 in the months of February and July 2022, respectively, revealed that the two sensors exhibited different variations in minimum temperature. The UHI between the two sensors was particularly pronounced in February 2022 (4.1ºC), while in May, July and August of the same year, the magnitude of the UHI was found to be very strong (6ºC, 6.7ºC and 6.2ºC, respectively). In the remaining months of 2022, UHI were also identified in the study area, especially between sensors 2 and 6, but also in sensors in other zones. However, no UHI was identified with very strong magnitude, except in July, with the others being mostly of medium magnitude. Fig. 7 and Fig. 8 illustrate the temperature differences between February 2022 and July 2022 with respect to sensors 2 and 6, in accordance with Garcia's (1996) classification of the magnitude of the UHI.

In consideration of the climatological data from Indaiatuba (Fig. 2), the average temperature for the month was consistent with the historical average, remaining elevated (between 20 and 35ºC) throughout the month. However, the volume of rainfall was significantly below the normal range for the month of February, which is 179 mm in 13 days, while the average is 93.9 mm in nine days. In this context, the greatest precipitation occurred at the beginning of the month, resulting in a decline in relative humidity from the second week onwards. The minimum relative humidity was 20% and the average was close to 50% for the majority of the month.

Based on the analysis of synoptic charts and information from OGIMET for February, only two atmospheric systems were identified in the study area, namely the cold fronts occurring in two different periods, still at the beginning of the month (February 1st, 2nd and 7th) and the South Atlantic Convergence Zone (ZCAS) (between the 8th and 11th, as well as February 16th and 22nd). The cold fronts come from the southern region of Brazil, bringing cold and humid winds to the area, generating rain in contact with the tropical air mass present in the place, while ZCAS act bringing humidity from the Amazon region as well as heat. The higher concentration of humidity at the beginning of the month explains the greater occurrence of islands of freshness over the days (Figure 7), as well as smaller magnitudes of UHI.

In brief, Fig. 7 demonstrates that in the wet months, as February, the UHI rarely reach a very strong magnitude (red color), being normally weak, with a temperature of up to 2ºC (green color), while the freshness islands are more frequent and extend into the nocturnal period (blue color). Furthermore, there is no longer a pattern in the distribution of the strongest UHI, showing that there is little oscillation between the minimum temperatures of sensors 2 and 6 throughout the day.

Days	Hours 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Daily Average	Precipitation (mm)
1	-0.02	0.02	0.13	0.03	0.12	0.20	0.15	0.20	0.15	-0.02	-0.20	0.73	0.68	-0.03	-0.20	0.07	0.22	0.02	0.38	0.45	0.87	0.80	1.12	1.52	0.34	20.83
2	1.23	1.30	1.12	0.95	1.00	0.73	0.37	0.22	0.08	0.43	0.03	-0.03	-0.23	-0.02	-0.02	-0.15	-0.03	-0.88	-0.72	-0.38	-0.12	-0.02	-0.03	0.03	0.27	18.29
3	-0.22	-0.17	0.03	0.22	0.08	0.08	0.12	0.05	-0.02	-0.10	0.55	0.27	0.03	0.27	0.37	-0.60	-0.37	0.22	0.57	2.17	2.43	0.70	0.58	0.07	0.41	3
4	0.12	0.27	0.40	0.47	0.05	0.23	0.33	0.40	0.27	0.03	0.12	-0.07	0.20	0.32	0.57	0.67	1.08	0.68	0.58	1.22	1.63	0.73	0.17	0.65	0.60	16
5	0.52	0.60	0.53	0.57	0.37	0.50	0.25	0.43	0.33	-0.23	0.28	-0.02	0.07	0.12	-0.40	0.60	0.48	1.20	1.35	0.92	0.52	0.57	0.35	0.53	0.62	8.13
6	0.45	0.32	0.23	0.33	0.30	0.23	0.23	0.05	0.12	-0.05	0.13	0.20	0.42	-0.12	0.03	0.58	0.90	0.95	0.82	1.58	2.22	1.62	1.40	1.17	0.80	6
7	1.17	0.97	0.43	0.18	0.12	0.70	1.28	1.13	0.57	0.48	-0.27	-0.50	0.67	0.55	0.92	0.73	0.68	0.22	0.32	0.12	0.27	0.33	1.88	2.93	0.92	0.25
8	2.93	2.25	2.10	2.12	1.98	2.23	2.40	2.87	0.98	0.97	1.32	1.33	1.28	0.07	0.02	-0.08	1.13	0.58	0.58	0.48	0.28	0.03	0.02	-0.20	1.43	0
9	-0.20	0.63	2.50	2.73	3.10	3.63	3.48	4.05	1.25	0.97	0.92	0.75	0.93	1.75	1.62	1.07	1.90	1.10	0.58	0.25	0.43	0.53	0.78	0.97	1.79	0
10	0.23	0.28	2.12	3.08	3.37	1.50	1.32	1.65	0.73	0.45	1.22	0.98	1.32	0.92	1.27	1.42	1.22	0.27	0.48	0.30	0.30	0.42	0.43	0.20	1.42	0
11	0.03	0.00	-0.05	-0.13	0.50	0.40	0.38	0.20	-0.20	0.70	0.55	0.73	0.78	0.52	0.07	0.52	0.75	0.88	0.45	0.38	0.43	0.40	0.50	0.32	0.80	0
12	0.35	0.48	1.18	2.48	2.87	2.92	3.42	1.48	1.08	1.32	1.20	0.83	0.60	1.28	2.12	1.22	0.07	0.97	0.47	0.43	0.20	0.13	0.40	0.60	1.60	0
13	0.25	0.82	0.80	0.73	1.55	2.50	2.92	1.33	1.00	-0.10	0.48	0.20	-0.25	0.20	0.60	0.95	1.58	1.28	0.67	3.00	5.13	1.45	0.68	0.60	1.66	0
14	0.43	0.40	0.40	0.57	1.08	2.55	2.88	3.07	0.78	-0.20	0.42	0.08	-0.68	-0.35	0.85	1.37	1.27	1.40	2.42	5.02	5.62	1.12	0.38	-0.03	1.79	0
15	0.28	0.27	0.33	0.52	0.90	2.33	2.38	1.08	0.82	1.38	1.32	0.47	0.43	0.68	2.70	1.47	1.35	0.98	0.83	0.43	0.43	0.50	0.32	0.48	1.51	0
16	1.23	0.33	1.33	0.10	0.92	2.52	2.97	3.20	1.33	1.28	0.62	0.78	0.47	-1.18	-0.93	0.98	1.15	0.17	0.15	0.30	0.20	0.25	0.45	0.37	1.40	0
17	0.30	1.00	2.22	2.67	1.40	0.92	0.65	0.82	0.05	-0.07	0.30	-0.08	0.12	0.77	-0.10	-0.70	-0.85	0.73	0.63	0.63	0.65	0.88	1.75	2.33	1.36	0
18	2.47	1.62	1.03	0.50	0.75	1.27	2.03	1.47	1.20	1.58	0.75	0.52	0.65	-0.13	-0.08	0.23	1.88	1.23	0.52	0.33	0.23	0.25	0.47	1.55	1.61	19.05
19	1.45	2.55	2.68	2.70	2.55	1.83	2.67	2.82	0.75	-0.07	-0.03	0.38	-0.38	0.05	0.92	1.50	1.38	2.35	3.47	1.92	0.23	0.50	0.07	0.17	2.06	0
20	0.23	0.58	2.10	2.12	1.55	1.85	1.93	1.95	0.87	-0.17	-0.78	-0.02	0.13	-0.67	-0.17	2.02	2.23	1.60	2.28	4.40	2.43	0.05	0.38	1.45	1.93	0
21	0.52	1.75	1.48	1.97	2.78	2.75	2.82	2.60	0.13	-0.22	-0.12	0.87	0.08	-0.58	0.27	1.67	2.43	1.67	2.32	5.35	4.05	0.93	0.80	0.62	2.32	0
22	0.42	0.53	1.60	2.85	3.80	4.12	4.13	4.42	0.92	-0.18	0.03	0.17	0.12	-0.27	0.70	1.63	1.43	0.48	0.77	0.82	0.38	0.28	0.60	0.97	2.11	0
23	1.70	2.32	2.63	3.40	3.38	3.28	3.30	2.42	0.27	-0.28	0.00	-0.07	-0.45	-1.00	0.22	1.38	2.47	1.13	1.00	1.73	1.82	2.02	1.27	1.50	2.34	0
24	1.08	1.52	2.33	2.70	2.88	3.08	2.97	3.10	3.10	1.70	1.45	1.02	0.92	0.97	1.07	1.60	1.53	0.95	0.67	0.08	0.20	0.37	0.72	0.27	2.41	2
25	0.20	0.15	0.30	0.43	1.72	1.33	0.88	0.97	1.08	1.08	0.98	0.67	1.05	0.28	1.03	-0.08	0.98	0.90	0.72	0.32	0.37	0.28	0.10	1.43	1.69	0
26	1.63	0.48	0.35	1.27	2.22	3.25	3.57	2.87	0.97	0.50	0.95	0.45	0.25	-0.37	1.08	1.28	1.20	0.53	0.13	-0.05	0.40	0.47	0.35	0.75	2.02	0
27	0.82	0.70	0.52	0.15	0.47	0.90	2.37	3.30	1.02	-0.18	0.05	-0.03	-0.37	-1.23	0.55	1.88	2.10	1.48	2.05	3.13	0.72	0.25	0.27	1.50	1.98	0
28	1.40	0.87	0.52	0.35	0.13	1.15	2.12	2.62	0.38	-0.27	0.17	0.20	0.13	0.37	0.73	1.33	1.53	1.52	2.90	5.10	6.13	5.90	5.37	3.12	2.87	0
Houly Average	0.76	0.86	1.19	1.38	1.62	1.90	2.11	2.03	1.00	0.72	0.81	0.79	0.76	0.59	1.06	1.40	1.68	1.47	1.60	2.08	2.05	1.51	1.54	1.72	1.36	

ΔT (°C) = (U-R) <0°C 0 - 2°C 2.1 °C - 4°C 4.1°C - 6°C >6°C

Fig. 7. Intensity and hourly evolution of the UHI in Indaiatuba during the month of February 2022.

The month of July shows more marked differences in magnitude (Figure 8), which are explained by the atmospheric conditions in that period. In this context, July 2022 indicated more peculiarities, since the average temperature for the month is 17.1 ºC and CIIAGRO data indicated that the average for the month in 2022 was mostly higher than 20ºC. Precipitation also indicated anomalies, as the historical average indicates about 44mm of rain and the compiled volume in 2022 found only 6.47mm.

Due to less precipitation, the average relative humidity followed the same trend and remained low throughout the month, with an average of 50% and minimums below 20%. In this case, on rainy days, the minimum relative humidity increased significantly. Analyzing the synoptic charts, the atmospheric systems identified for that period were cold fronts and high-pressure areas, in which the first one brings more humidity to the region (concentrated in the middle of this month) and the second one generates periods of more heat and drought. Thus, the atmospheric characteristics agree with the observed temperature magnitudes for that month, explaining the occurrence of days with very strong magnitude (>6ºC) at the beginning and end of the month, with a less hot period in the middle of July.

Analyzing the data in Fig. 8, the UHI are more intense between 6 pm and 10 am (indicated in the Figure 8 with yellow, orange and red colors), normally ranging from medium to very strong UHI magnitude, while during the day, the UHI are classified as low magnitude (green color).

Days	Hours																								Daily Average	Precipitation (mm)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
1	5.00	4.72	4.47	4.23	4.15	4.50	4.77	5.23	6.17	3.32	1.87	1.03	0.12	-0.43	-0.08	0.07	0.43	2.48	5.82	6.43	5.98	2.00	1.20	0.63	3.09	0
2	0.35	0.27	1.92	3.18	3.42	3.40	3.63	4.65	4.67	1.85	1.35	0.58	-0.17	-0.23	-0.05	0.10	1.17	3.30	4.95	5.48	5.08	4.07	3.52	2.92	2.48	0
3	3.97	4.57	4.65	4.17	4.37	4.18	4.23	4.60	6.48	3.30	1.40	0.20	-0.08	0.02	0.52	1.02	0.63	2.08	5.50	6.28	5.98	5.05	2.53	2.13	3.24	0
4	1.15	0.72	2.43	4.65	5.65	5.43	5.37	5.75	6.32	2.85	1.23	0.27	-0.38	-0.22	0.38	0.35	0.62	2.63	6.03	6.68	5.92	5.67	5.48	5.40	3.35	0
5	4.92	4.72	4.63	4.52	4.35	4.12	4.90	5.33	5.87	4.28	1.33	0.17	-0.22	-0.62	-0.22	0.15	0.80	2.88	5.28	7.25	6.70	5.78	5.68	5.25	3.66	0
6	5.32	5.45	5.47	4.95	4.68	4.67	4.87	5.43	5.40	2.87	0.95	0.15	-0.03	0.52	0.38	0.55	0.92	3.52	5.82	5.40	4.75	4.25	3.92	4.10	3.51	0
7	4.98	5.25	6.18	4.28	2.95	1.83	1.48	1.43	1.15	1.12	0.45	-0.05	0.03	-0.27	0.22	0.17	0.73	3.12	6.05	6.52	5.85	5.20	2.77	4.10	2.73	0
8	4.62	2.95	4.88	5.05	4.65	5.02	4.85	5.67	6.57	2.35	1.13	0.17	0.20	0.97	0.32	0.35	0.30	0.93	0.40	0.67	0.98	1.93	3.13	4.32	2.60	0
9	5.80	6.68	6.35	4.92	4.65	5.02	4.77	4.73	2.22	1.17	0.27	-0.20	-0.25	-0.32	-0.28	-0.07	0.03	2.68	5.78	6.42	5.98	3.92	5.35	5.47	3.38	0
10	2.67	0.50	0.38	0.48	1.38	0.90	0.77	2.72	1.75	1.10	0.43	-0.17	-0.58	-0.53	0.03	0.12	0.43	1.08	3.38	5.18	4.97	4.57	2.50	1.30	1.47	0
11	1.43	2.68	2.43	3.83	3.73	2.92	3.35	4.40	3.47	1.15	0.33	-0.08	-0.18	-0.42	-0.12	0.23	0.42	1.07	2.33	2.63	3.10	3.78	1.48	1.38	1.89	0
12	1.02	1.43	1.42	1.43	1.45	0.73	0.83	0.57	0.72	0.60	0.13	0.12	-0.23	-0.28	0.00	0.92	0.82	1.78	3.62	4.30	4.12	3.40	1.40	0.52	1.28	0
13	0.28	0.25	0.10	0.52	0.95	1.38	0.82	0.68	0.63	-0.02	0.47	0.47	0.60	0.70	0.35	0.32	0.05	1.17	0.87	0.50	0.47	0.72	2.10	1.52	0.66	0.50
14	0.13	0.07	0.10	0.15	0.07	0.45	0.42	0.35	0.95	0.90	0.47	-0.22	-0.48	-0.30	-0.12	-0.23	0.30	1.47	4.42	5.45	5.17	5.07	2.62	2.25	1.23	0.63
15	4.22	5.22	4.88	4.23	3.13	4.37	4.73	4.57	4.23	1.65	0.70	0.10	-0.30	-0.13	-0.05	0.45	0.72	2.65	4.98	5.25	5.45	3.53	3.10	3.38	2.96	0.76
16	2.75	3.65	3.98	3.60	1.67	0.92	0.97	2.70	1.63	0.33	0.25	0.08	0.28	0.13	0.22	0.13	0.38	1.20	2.95	4.48	4.93	3.83	1.63	1.27	1.83	0
17	1.02	0.92	0.78	1.05	1.63	1.47	0.95	1.83	2.25	1.60	0.52	0.15	-0.83	-0.15	0.45	0.63	1.27	2.07	2.60	0.92	0.65	0.13	0.03	0.18	0.92	0
18	0.10	0.30	0.23	0.05	0.05	0.02	0.30	0.97	1.43	0.98	0.82	0.50	0.65	0.40	0.60	0.88	0.58	0.58	0.97	0.80	0.55	0.40	0.35	0.03	0.52	0
19	-0.05	0.03	0.13	0.15	0.58	2.37	3.00	2.12	1.45	0.88	-0.17	-0.18	-0.45	-0.28	0.52	0.83	0.83	1.85	4.62	2.02	0.85	0.65	0.40	0.30	0.94	0
20	0.42	0.42	0.72	0.58	0.93	2.40	3.90	5.05	5.23	2.88	0.73	0.23	0.33	0.47	0.33	0.28	0.60	0.67	0.50	0.37	0.67	2.55	1.18	0.07	1.31	0
21	0.02	0.23	0.22	0.55	0.40	0.43	1.28	1.05	1.42	1.30	0.33	-0.20	-0.58	-0.47	-0.12	0.95	0.80	2.62	5.45	6.18	5.75	5.32	5.02	5.10	1.79	0
22	3.82	1.37	1.50	4.48	5.60	5.30	5.30	6.25	5.55	1.62	1.12	0.10	0.62	0.22	0.47	0.25	0.33	2.28	6.28	7.08	6.50	5.00	3.30	5.73	3.34	0
23	6.38	6.28	6.20	6.10	5.92	5.65	6.00	6.65	6.23	2.65	0.72	-0.12	0.02	0.27	0.87	0.30	0.38	1.90	5.52	6.50	6.07	5.93	6.12	6.50	4.13	0
24	6.53	4.68	2.58	1.50	1.18	3.27	5.95	6.72	6.52	1.87	0.97	0.22	0.92	1.42	0.63	1.42	0.80	2.52	5.33	6.35	5.18	3.07	4.90	4.00	3.27	0
25	5.12	5.12	2.03	2.18	6.43	6.63	5.93	6.72	6.83	2.58	0.80	-0.27	-0.17	0.90	0.92	1.58	1.10	1.85	5.25	4.93	0.90	0.88	3.30	4.92	3.19	0
26	4.73	5.17	5.53	5.58	6.85	7.05	7.12	7.32	5.88	1.62	1.15	-0.10	-0.50	0.03	1.28	0.67	0.83	1.65	0.52	0.40	0.45	0.45	0.30	0.92	2.70	0
27	1.27	2.23	3.72	4.40	4.38	4.48	4.97	5.47	5.12	1.90	0.42	-0.03	-0.60	-0.28	0.63	0.57	1.00	1.63	4.25	5.82	5.68	5.22	5.00	4.95	3.01	0
28	4.93	5.12	4.00	3.97	4.13	4.45	4.78	4.85	3.17	0.80	0.10	-0.48	-0.38	-0.27	0.22	0.35	0.57	1.45	3.55	5.35	6.17	5.93	5.33	6.00	3.09	0
29	6.27	4.67	2.20	2.23	3.42	2.95	1.70	1.20	1.18	0.43	1.03	0.85	0.88	0.72	0.58	1.48	0.85	1.22	1.90	2.97	2.53	2.90	3.12	2.95	2.09	0
30	3.53	3.88	3.98	4.20	4.55	4.67	5.02	5.90	5.97	2.42	1.57	1.12	1.00	1.55	1.60	1.55	0.77	0.70	1.03	2.17	3.63	4.13	4.48	1.90	2.97	5
31	2.92	4.02	3.80	3.68	4.28	4.55	4.42	5.77	4.82	1.77	1.02	0.60	0.48	0.92	0.58	1.58	1.52	1.87	4.50	6.00	6.02	5.48	5.13	4.93	3.36	0
Houly Average	3.02	2.99	2.97	3.09	3.33	3.48	3.70	4.21	4.07	2.00	1.09	0.53	0.40	0.56	0.81	1.06	1.19	2.40	4.36	4.90	4.63	4.15	3.73	3.70	2.45	

ΔT (°C) = (U-R) <0°C 0 - 2°C 2.1 °C - 4°C 4.1°C - 6°C >6°C

Fig. 8. Intensity and hourly evolution of the UHI in Indaiatuba during the month of July 2022.

Furthermore, Fig. 9 illustrates the frequency of low (0-2 ºC), medium (2.1 – 4 ºC), strong (4.1-6 ºC) and very strong (>6ºC) UHI, as well as freshness islands (<0ºC) in 2022, regarding the minimum temperature difference of sensors 2 and 6. In general, low intensity UHI (45%) were more frequently observed, followed by medium (33%) and strong (17%) intensity UHI. Freshness islands represented 3% of frequency for the analysis period, while very strong UHI corresponded to 1%.

In the rainy months, such as January and March, low and medium intensity islands stood out, as well as freshness islands. In December, low, medium and strong intensity UHI were more frequently observed, along with the presence of freshness islands. February, which was characterized as a hot month, showed low, medium and strong intensity UHI, despite the lack of rainfall in 2022.

In the months of May, June, July and August, which are typically dry, there were no instances of freshness islands, and medium and strong UHI intensities were more frequent, with very strong UHI magnitudes also being observed. This was particularly evident in the months of May, July and August. July was identified as the month in which very intense UHI were observed most frequently, corresponding to 10% of the UHI identified in that month.

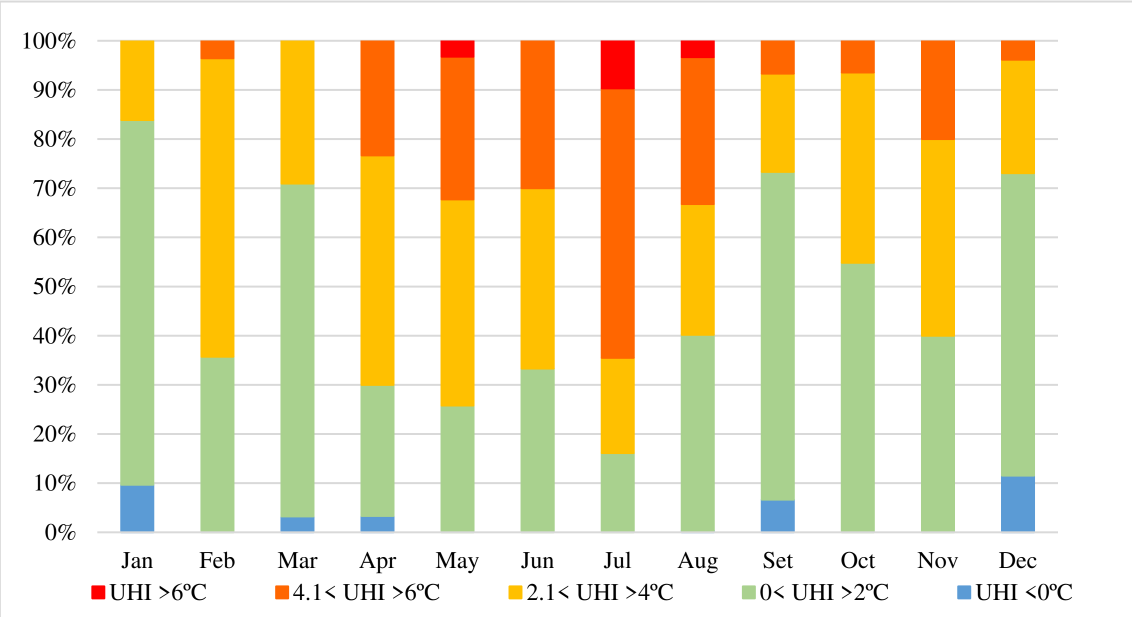


Fig. 9. Monthly frequencies of UHI intensities in Indaiatuba for 2022.

7.5 Discussion

The results presented on the UHI pattern in Indaiatuba corroborate the findings of Amorim and Dubreuil (2017). This pattern is characterized by higher temperatures in the central areas of the municipality, in contrast to lower temperatures observed in the surrounding regions. However, it is important to note that this UHI distribution characteristic cannot be applied universally in our study area, but tends to be characteristic of medium-sized cities. This deviation is attributed to the intrinsic heterogeneity of the municipality and the lack of well-structured urban planning, leading to the use of inappropriate materials in certain locations (Dorigon and Amorim, 2019, Stewart and Oke, 2012).

Regarding minimum temperature values, a less pronounced pattern was observed in February (a month characterized by heat and precipitation) compared to July (a month marked by colder and drier conditions). Differences between sensors were most prominent in July. However, a discernible pattern emerges in both months, with some sensors consistently recording higher temperatures than others. Notably, sensor 6 (urban) stands out for recording the highest minimum temperatures, while sensor 2 (rural) consistently displays the lowest minimum temperatures. Similar data patterns were identified in studies carried out in cities of similar size in southeastern Brazil (Amorim, 2020), which also have a tropical climate. This highlights the critical role that land use plays in influencing surface-level temperatures (Amorim et al., 2021; Cardoso et al., 2017), as well as the impact of climate seasonality (Nayak et al., 2023).

In this context, the main sources of heat release refer to impermeable surfaces, such as asphalt and concrete floors commonly used in urban centers for different purposes (parking lots, commercial and residential structures) as observed in sensor 6 of this study. On the other hand, surfaces covered with vegetation act as heat dispersers, indicating lower temperatures (Ferrari et al., 2020; Nuruzzaman, 2015), as observed in sensor 2.

Given the aforementioned, it is essential to note that sensor 6 is positioned within the city's commercial hub, characterized by a high density of buildings, paved streets, and a substantial volume of pedestrian traffic year-round. In this location, any type of vegetation is rare or non-existent, increasing the air temperature and favoring the formation of UHI. In contrast, sensor 2 is far from the urban center, yet still undergoing urbanization due to the construction of condominiums and upscale residences. The important factor to be highlighted is that sensor 2 is close to a dense forest area, which may have generated a balance in the local thermal gradient. Although in an urbanized area, sensor 2 is the only one located close to an area with a high proportion of dense vegetation (with tall trees), facilitating the occurrence of islands of freshness (Amorim, 2020; Mendonça, 1994), which contributes to a decrease in air temperature (Nuruzzaman, 2015).

In relation to other aspects, the UHI were more intense at night, a fact that agrees with what was reported in the work of Amorim et al. (2021), in which these authors also indicated that this was the period to better characterize them. This occurs because during the day, solar radiation is absorbed by impermeable surfaces and exposed soil, while during the night, heat is released, causing an increase in air temperature in more built-up areas, producing higher temperatures in central areas compared to rural areas (Arshad et al., 2021). According to Yukihiro and collaborators (2006), the air temperature at night can be up to three times higher than the air temperature during the day, due to heat release processes in urbanized areas. In addition to the detection of UHI in Indaiatuba, islands of freshness (Amorim, 2000; Mendonça, 1994) were also noted during the day, which occurs when the air temperature difference between urban and rural areas is less than zero, which is more frequent in wet months, such as February.

In terms of magnitude and frequency, we observed lower-intensity of UHI in January, which corresponds to the wet season. This contrast is noticeable when compared to July. The difference arises from the fact that January typically experiences more cloud cover and a higher occurrence of ZCAS, leading to atmospheric instability and inhibiting UHI formation (Teixeira, 2015). Meanwhile, the dry weather observed in July, the lower occurrence of atmospheric systems (generating atmospheric stability), lower cloudiness and high minimum temperatures provided an ideal scenario for the formation of UHI (Teixeira, 2015). Thus, seasonal climate conditions (Nayak et al., 2023) presented during the days and in different seasons, together with the characteristics of land use and cover (Amorim et al., 2021; Foissard et al., 2019) directly influenced the occurrence and frequency of UHI in medium-size cities with tropical climate.

Based on the observed data, the application of a methodology that uses field data stood out, adapted from the work of Amorim (2020) and well consolidated for use in medium-sized cities around the world (Foissard et al., 2019). The replicability of this study and the quality of the data obtained are demonstrated, allowing the understanding and management of UHI. Finally, the need for mitigation and adaptation measures for the well-being of the local population is inferred, especially in areas with the highest occurrence and magnitude of UHI. Then, considering the work of Spyrou et al. (2023), it is understood that there are some sets of actions to mitigate and adapt cities to UHI. These authors cited urban design and planning (1), the non-sealing of soil and the maintenance of green areas (2), in addition to the appropriate use of construction materials (3). Among the possibilities highlighted and proven to be important in the management of UHI in urban areas, it is understood that the study area can more easily incorporate the introduction of vegetation in the areas most heavily impacted by UHI (presented in this research) and maintain green areas on the edges of the municipality, also avoiding soil sealing.

7.6 Conclusions

This research successfully identified and characterized the occurrence and magnitude of Urban Heat Island (UHI) effects in a medium-sized city with a tropical climate, pinpointing areas where UHI developed with greater intensity. The study suggested that land use, land cover, and seasonal climate variations are key drivers of UHI formation in tropical regions. Vegetation, in particular, played a significant role in mitigating UHI intensity, reinforcing its critical importance in urban planning.

The temperature data showed that the city center consistently recorded the highest minimum temperatures, particularly during the dry season, with UHI magnitudes reaching strong to very strong levels, especially at night. These findings align with global observations of UHIs, which tend to be more intense in densely built environments with limited vegetation. While UHI intensity was lower during the rainy season, the discomfort experienced by the population in tropical cities during the hotter months remains a significant challenge, as average temperatures often exceed 30°C.

Importantly, this study contributes to the broader understanding of how UHI manifests in medium-sized tropical cities, a category often underrepresented in UHI research compared to larger metropolitan areas. The findings are not only relevant for Indaiatuba but also for other rapidly growing cities worldwide that face similar challenges of unplanned urban expansion and climate impacts. The patterns observed in this study regarding the influence of vegetation and seasonal climate conditions offer valuable insights for urban planners and policymakers globally, as they design strategies to mitigate UHI and improve thermal comfort.

In conclusion, the results underscore the need for the implementation of targeted mitigation and adaptation measures to enhance the quality of life in tropical urban environments. These measures, including increased vegetation, green infrastructure, and climate-responsive urban planning, are critical to addressing the UHI phenomenon. The methodology developed in this study provides a robust framework that can be applied to other cities, both in Brazil and globally, advancing the state of the art in UHI analysis.

By providing practical recommendations for decision-makers in Indaiatuba and beyond, this research contributes to the global discourse on urban climate resilience. It highlights the importance of integrating UHI mitigation strategies into broader urban planning efforts, particularly in tropical regions, where climate conditions exacerbate the challenges posed by rapid urbanization.

7.7 References

Amorim, M. C. C. T. (2000). O clima urbano de Presidente Prudente. In: Tese. *Faculdade de Filosofia, Letras e Ciências Humanas*, Universidade de São Paulo, São Paulo, Brasil. https://www.teses.usp.br/teses/disponiveis/8/8135/tde-26122022-144828/pt-br.php

Amorim, M.C.C.T. (2020). Daily evolution of urban heat islands in a Brazilian tropical continental climate during dry and rainy periods. *Urban Climate*, **34**, 100715. https://doi.org/10.1016/j.uclim.2020.100715

Amorim, M.C.C.T., Dubreuil, V. (2017). Intensity of Urban Heat Islands in Tropical and Temperate Climates. *Climate*, **5**, 91. https://doi.org/10.3390/cli5040091

Amorim, M. C. C. T., Dubreuil, V., Quenol, H., Sant'anna Neto, J. L. (2009). Características das ilhas de calor em cidades de porte médio: exemplos de Presidente Prudente (Brasil) e Rennes (França). *Confins*, **7**, 1-16. https://doi.org/10.4000/confins.6070

Amorim, M.C.C.T., Dubreuil, V., Amorim, A.T. (2021). Day and night surface and atmospheric heat islands in a continental and temperate tropical environment. Urban *Climate*, **38**, 100918. https://doi.org/10.1016/j.uclim.2021.100918

Arshad, M., Khedher, K.M., Eid, E.M., Aina, Y.A. (2021). Evaluation of the urban heat island over Abha-Khamis Mushait tourist resort due to rapid urbanization in Asir, Saudi Arabia. *Urban Climate*, **36**, 100772. https://doi.org/10.1016/j.uclim.2021.100772

Bradford, K., Abrahams, L., Hegglin, M., Klima, K. (2015). A heat vulnerability index and Adaptation solutions for Pittsburgh, Pennsylvania. *Environ. Sci. Technol*, **49**, 11303-11311. https://pubs.acs.org/doi/10.1021/acs.est.5b03127

Cardoso, L.M.G. (2017). Estudo do Microclima urbano a partir de plataformas de coleta de dados (PCD's) da fachada sudeste de salvador. In: Dissertação. *Faculdade de Engenharia Civil. Universidade Federal da Bahia*, Bahia, Brasil. https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.jsf?popup=true&id_trabalho=5954004

Castellano, M.S., Nunes, L.H. (2017). Imóveis invadidos pela água oriundos de chuvas extremas na Região Metropolitana de Campinas (SP). In: *XVII Simpósio Brasileiro de Geografia Física Aplicada*. Os Desafios da Geografia Física na Fronteira do Conhecimento. **1**, 1445-1456. https://doi.org/10.20396/sbgfa.v1i2017.2053

CIIAGRO - Centro Integrado de Informações Agrometeorológicas. http://www.ciiagro.sp.gov.br/ (accessed 10 March 2023).

Deilami, K., Kamruzzaman, M., Liu, Y., (2018). Urban heat island effect: a systematic review of spatio-temporal factors, data, methods, and mitigation measures. *International Journal of Applied Earth Observation and Geoinformation*, **67**, 30–42. https://doi.org/10.1016/j.jag.2017.12.009

Dorigon, L.P., Amorim, M.C.C.T. (2019). Spatial modeling of an urban Brazilian heat island in a tropical. *Urban Climate*, **28**, 100461. https://doi.org/10.1016/j.uclim.2019.100461

Dubreuil, V., Foissard, X., Nabucet, J., Thomas, A., Quenol, H. (2020). Fréquence et intensité des îlots de chaleur à rennes : bilan de 16 années d'observations (2004-2019). *Climatologie*, **17**, 1-17. https://doi.org/10.1051/climat/202017006

Dubreuil V., Fante, K., Planchon, O., Sant'anna Neto, J.L. (2017). Les types de climats annuels au Brésil: une application de la classification de Köppen de 1961 a 2015. *EchoGéo*, **41**,1-27. https://doi.org/10.4000/echogeo.15017

Ferrari, A., Kubilay, A., Derome, D., Carmeliet, J. (2020). The use of permeable and reflective pavements as a potential strategy for urban heat island mitigation. *Urban Climate*, **31**, 100534. https://doi.org/10.1016/j.uclim.2019.100534

Fialho, E.S. (2009). Ilha de calor em cidade de pequeno porte: Caso de Viçosa, na Zona da Mata Mineira. In: Tese. *Instituto de Geografia*. Universidade de São Paulo, São Paulo, Brasil. https://www.teses.usp.br/teses/disponiveis/8/8135/tde-22022010-154045/publico/EDSON_SOARES_FIALHO.pdf (accessed 15 October 2023).

Foissard, X., Dubreuil, V., Quénol, H. (2019). Defining scales of the land use effect to map the urban heat island in a mid-size European city: Rennes (France). *Urban Climate*, **29**, 100490. https://doi.org/10.1016/j.uclim.2019.100490

Freitas, M. (2018). Caracterização de sensores e abrigos meteorológicos de baixo custo. In: Trabalho de conclusão do Curso. Instituto de Física. Universidade Federal do

Rio Grande do Sul, Rio Grande do Sul, Brasil. https://lume.ufrgs.br/handle/10183/180974 (accessed 2 March 2023).

García, F.F. (1996). Manual de climatologia aplicada: clima, medio ambiente y planificación. *Editorial síntesis*, S.A, Madrid.

Gusson, C. S., & Duarte, D. H. (2016). Effects of built density and urban morphology on urban microclimate-calibration of the model ENVI-met V4 for the subtropical Sao Paulo, Brazil. *Procedia Engineering*, **169**, 2–10. https://doi.org/10.1016/j.proeng.2016.10.001

He, B.J. (2019). Towards the next generation of green buildings for urban heat island mitigation: zero UHI impact building. *Sustainable Cities and Society*, **50**, 101647. https://doi.org/10.1016/j.scs.2019.101647

IAC - Instituto Agronômico de Campinas. (2013). Polo turístico do circuito das frutas do Estado de São Paulo: fisiografia e clima. https://www.iac.sp.gov.br/publicacoes/arquivos/iacbt213.pdf (accessed 22 March 2023).

IBGE – Instituto Brasileiro de Geografia e Estatística. *Censo 2022*. https://cidades.ibge.gov.br/brasil/sp/indaiatuba/panorama (accessed 10 March 2023).

Júnior, M.O.V., de Moura Santos, F.M., Ribeiro, K.F.A., Nogueira, M.C.J.A., Nogueira, J.S. (2016). Análise da relação entre abrigos meteorológicos alternativos para pontos fixos e o comportamento de variáveis termo-higrométricas. *Revista Brasileira de Climatologia*, **18**, 157-179. http://dx.doi.org/10.5380/abclima.v18i0.45146

Kadhim-abid, A.L., Ichim, P., Atanasiu, G.M. (2019). Seasonal occurrence of heat island phenomenon in the urban built environment. *Environmental Engineering and Management Journal*, **18**, 417-424. https://doi.org/10.1016/j.uclim.2023.101547

Kim, S. W., Brown, R. D. (2021). Urban heat island (UHI) intensity and magnitude estimations: A systematic literature review. *Science of the Total Environment*, **779**, 146389. https://doi.org/10.1016/j.scitotenv.2021.146389

Li, J., Heap, A.D. (2014). Spatial interpolation methods applied in the environmental sciences: a review. *Environmental Modelling & Software*, **53**, 173–189. https://doi.org/10.1016/j.envsoft.2013.12.008

Liu, J., Liu, Y., Yang, L., Liu, T., Zhang, C., Dong, H. (2020). Climatic and seasonal suitability of phase change materials coupled with night ventilation for office buildings in Western China. *Renewable Energy*, **147**, 356-373. https://doi.org/10.1016/j.renene.2019.08.069

McKenzie, L. (2015). Hotter cities: climate change and planning for resilient, healthy urban environments. In: Barton, H., Thompson, S., Burgess, S., Grant, M. (eds.), *The Routledge Handbook of Planning for Health and Well-Being: Shaping a Sustainable and Healthy Future*, Routledge, 1st Edition, pp.1-17.

Mendonça, F.A. (1994). O clima e o planejamento urbano de cidades de porte médio e pequeno: Proposição metodológica para estudo e sua aplicação à cidade de Londrina/PR. In: Tese. *Faculdade de Filosofia, Letras e Ciências Humanas, Universidade de São Paulo*, São Paulo. https://pos.fflch.usp.br/node/42832 (accessed 15 March 2023).

Moreira, J., Amorim, M.C.C.T., Fernández García, F. (2019). Análisis de la intensidad y evolución horaria de las islas de calor y seca en ambiente tropical, Brasil. *Revista de Geografia e Ordenamento do Território*, **1**, 151–178. http://dx.doi.org/10.17127/got/2019.17.007

Nayak, S., Vinod, A., Prasad, A.K. (2023). Spatial Characteristics and Temporal Trend of Urban Heat Island Effect over Major Cities in India Using Long-Term Space-Based MODIS Land Surface Temperature Observations (2000–2023). *Applied Science,* **2**, 13323. https://doi.org/10.3390/app132413323

Nuruzzaman, M. (2015). Urban heat island: causes, effects, and mitigation measures-a review. *International Journal of Environmental Monitoring and Analysis*, **3**, 67–73. https://doi.org/10.11648/j.ijema.20150302.15

OGIMET–Serviço de Informações Meteorológicas. https://www.ogimet.com/gsynop.phtml (accessed 20 March 2023).

Oke, T.R. (1989). The micrometeorology of the urban forest. Philosophical Transactions of the Royal Society of London. *Series B: Biological Sciences*, **324**, 335-349. https://doi.org/10.1098/rstb.1989.0051

Oke, T.R., Mills, G., Christen, A., Voogt, J.A. (2017). Urban Climates. *Cambridge University Press*, Cambridge.

Ren, G.Y. (2015). Urbanization as a major driver of urban climate change. *Advances in Climate Change Research*, **6**, 1-6. https://doi.org/10.1016/j.accre.2015.08.003

Roth, M. (2007). Review of urban climate research in (sub)tropical regions. International *Journal of Climatology*, **27**, 1859–1873. https://doi.org/10.1002/joc.1591

Santamouris, M., Cartalis, C., Synnefa, A., Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings - a review. *Energy and Buildings*, **98**, 119–124.

https://doi.org/10.1016/j.enbuild.2014.09.052

Spyrou, G., Ioannou, B., Souliotis, M., Savvides, A.L., Fokaides, P.A. (2023). The Adaptability of Cities to Climate Change: Evidence from Cities' Redesign towards Mitigating the UHI Effect. *Sustainability*, **15**, 6133.

https://doi.org/10.3390/su15076133

Stewart, I. D., Oke, T. R. (2012). Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society*, **93**, 1879–1900. https://doi.org/10.1175/bams-d-11-00019.1

Tecchio, M.A., Neto, J.E.B., Barbosa, W., Tucci, M.L.S. (2011). Evolution and perspective of the temperate fruit crops in São Paulo state, Brazil. *Revista Brasileira de Frutic. Volume Especial*, 150-157. https://doi.org/10.1590/S0100-29452011000500018

Teixeira, D.F. (2015). O clima urbano de Rancharia (SP). In: Dissertação. Instituto de Geografia. *Universidade Estadual Paulista*. Presidente Prudente, São Paulo, Brasil. https://acervodigital.unesp.br/handle/11449/132057 (accessed 12 March 2023).

United Nations. (2018). *The world's cities in 2018—Data booklet. Department of Economic and Social Affairs*, Population Division.

Willmott, C.J. (1981). On the validation of models. *Physical Geography*, **2**(2), 184-194. https://doi.org/10.1080/02723646.1981.10642213

Wu, J. (2010) Urban sustainability: an inevitable goal of landscape research. *Landscape Ecology*, **25**, 1–4. https://doi.org/10.1007/s10980-009-9444-7

You, M., Lai, R., Lin, J., Zhu, Z. (2021). Quantitative Analysis of a Spatial Distribution and Driving Factors of the Urban Heat Island Effect: A Case Study of Fuzhou

Central Area, China. *Int. J. Environ. Res. Public Health*, **18**, 13088. https://doi.org/10.3390/ijerph182413088

Yu, ZW., Guo, QH., Sun, RH. (2015). Impact of urban cooling effect based on landscape scale: a review. *Chinese Journal of Applied Ecology*, **26**, 636–642

Yu, Z., Yao, Y., Yang, G., Wang, X., Vejre, H. (2019). Spatiotemporal patterns and characteristics of remotely sensed region heat islands during the rapid urbanization (1995–2015) of Southern China. *Science of the Total Environment*, **674**, 242-254. https://doi.org/10.1016/j.scitotenv.2019.04.088

Yukihiro, K., Yutaka, G., Hiroaki, K., Keisuke, H. (2006). Impacts of city-block-scale countermeasures against urban heat-island phenomena upon a building's energy-consumption for air-conditioning. *Applied Energy*, **83**, 649-668. https://doi.org/10.1016/j.apenergy.2005.06.001

Zhang, P., Imhoff, M.L., Wolfe, R.E., Bounoua, L. (2010). Characterizing urban heat islands of global settlements using MODIS and nighttime lights products. *Canadian Journal of Remote Sensing*, **36**, 185–196. https://doi.org/10.5589/m10-039

Zhang, Y., Odeh, I.O.A., Han, C. (2009). Bi-temporal characterization of land surface temperature in relation to impervious surface area, NDVI and NDBI, using a sub-pixel image analysis. *International Journal of Applied Earth Observation and Geoinformation*, **11**, 256–264. https://doi.org/10.1016/j.jag.2009.03.001

Zhao, L., Lee, X., Smith, R.B., Oleson, K. (2014). Strong contributions of local background climate to urban heat islands. *Nature*, **511**, 216–219.

https://doi.org/10.1038/s41598-018-25296-w

CAPÍTULO 8 – BRIDGING DATA GAPS IN URBAN CLIMATE STUDIES: THE POTENTIAL OF A LOW-COST METEOROLOGICAL SHELTER (Sob revisão pelos autores)

8.1 Abstract

Global climate change and rapid urbanization are reshaping urban ecosystems, intensifying phenomena such as urban heat islands (UHI) and exacerbating challenges related to air quality, water availability, and public health. The replacement of natural surfaces with built infrastructure alters local climate patterns, while global warming increases the frequency of extreme events, such as heat waves and intense rainfall, heightening urban vulnerability. Understanding urban microclimates is essential for sustainable planning and the implementation of effective adaptation and mitigation strategies. However, obtaining reliable meteorological data remains a significant challenge, especially in developing countries, where long-term monitoring networks are scarce due to financial constraints and infrastructure limitations for maintaining weather stations. In response to this scenario, this study aimed to develop and validate a low-cost meteorological shelter for climate studies in Brazil, with a focus on urban climatology. Constructed with affordable materials and in compliance with World Meteorological Organization (WMO) standards, the shelter was tested in the field throughout 2022. The results demonstrated its reliability in measuring temperature at a local scale. Its low cost and ease of replication make it a viable alternative for institutions with limited resources, democratizing climate data collection. Beyond its application in UHI studies, expanding monitoring networks with this shelter can benefit various areas of applied climatology, such as agroclimatic studies, hydrometeorological modeling, and the prediction of environmental impacts. Its durability in tropical climates further reinforces its relevance. Future improvements are suggested to enhance its efficiency and sustainability.

8.2 Introduction

Global climate change and rapid urban growth have significantly transformed urban ecosystems, presenting complex challenges for climate study and management in cities (Angel et al., 2010; Seto et al., 2012; United Nations, 2012). Urbanization, characterized by the replacement of natural surfaces with built infrastructure, alters local climate patterns (Amorim, 2020), intensifying phenomena such as urban heat islands (UHI) and impacting air quality, water resource availability, and public health (Oke, 1982;

Stewart & Oke, 2012). These changes are exacerbated by climate change, which increases the frequency and intensity of extreme weather events such as heatwaves, heavy rainfall, and prolonged droughts, heightening urban vulnerability (IPCC, 2021). In this context, understanding urban microclimates and their impacts is crucial for developing effective public policies and implementing adaptation and mitigation strategies (Grimmond et al., 2010; Vieira Zezzo et al., 2024).

The interaction between urbanization and climate change is particularly evident in the formation of UHI, where urban temperatures can be up to 10°C higher than those in surrounding rural areas (Chapman et al., 2017; Santamouris, 2015). This phenomenon is driven by the high concentration of impermeable surfaces, such as asphalt and concrete, which absorb and retain heat, alongside the reduction of vegetation cover and the emission of pollutants from vehicles and industries (Akbari et al., 2016; Gohain et al., 2023). Additionally, air pollution, exacerbated by human activities, interacts with climate patterns, increasing public health risks such as respiratory and cardiovascular diseases (Lichtblau et al., 2024; WHO, 2018). These factors underscore the urgent need for detailed and continuous climate monitoring to provide reliable data for future scenario modeling and the implementation of sustainable urban planning measures (Lemonsu et al., 2015; Murakami et al., 2016).

Studies investigating the effects of urban heat islands (UHI) typically focus on three distinct scales: boundary UHI, canopy UHI, and surface UHI (Zhang et al., 2009). Boundary UHI occurs in the atmospheric layer above urban surfaces and explores how urbanization affects heat distribution at the mesoscale (Voogt & Oke, 2003). This scale is examined using advanced technologies such as weather stations, radars, and balloon-borne sensors, which generate vertical temperature profiles and insights into urban heat flux (Kim & Brown, 2021). Additionally, satellite-based remote sensing enhances these analyses by providing large-scale temperature observations (Kim & Brown, 2021).

Canopy UHI refers to microclimate dynamics within the urban canopy, where interactions between buildings, vegetation, and streets significantly influence temperature patterns (Peng et al., 2022). This scale is studied through temperature sensors positioned at various heights, as well as remote sensing technologies that estimate surface temperature variations and assess the cooling effects of vegetation (Peng et al., 2022). Surface UHI is the most visible manifestation of the urban heat island effect, referring to temperature differences at the Earth's surface between urban and rural areas. This scale is analyzed using land surface temperature (LST) data from the Landsat satellite, which provides extensive spatial and temporal coverage (Peng et al., 2022; Zhou et al., 2011). Complementary ground-based sensors, such as infrared thermometers, offer real-time localized temperature data, enabling high-resolution urban heat mapping (Zhou et al., 2011).

Among these scales, Canopy UHI studies present unique challenges, as they require the direct collection of climate data—such as temperature and humidity—using instruments deployed at fixed or mobile locations (Kousis et al., 2022). Ensuring consistent and reliable climate data, particularly from fixed locations, remains a significant hurdle, especially in the Global South (Karlsson & Srebotnjak, 2007; Pasgaard & Strange, 2013; Rojas et al., 2014; Rojas & Postigo, 2025; Zuniga, 2016). In these regions, meteorological monitoring infrastructure is often insufficient or inadequate, limiting the availability of high-quality urban climate data and hindering long-term climatological analyses (Domonkos et al., 2022).

Addressing climate study in countries with diverse climatic and regional conditions necessitates tailored strategies, particularly where financial constraints pose additional challenges to scientific research (Vieira Zezzo et al., 2023). In Brazil, for instance, the scarcity of meteorological stations in urban areas (Medeiros et al., 2019) and the high costs associated with acquiring and maintaining standard equipment (Muller et al., 2013) hinder researchers and policymakers from effectively addressing urban climate challenges (Marengo & Bernasconi, 2015). Furthermore, the location of existing stations, often distant from urban centers or in non-representative areas, results in significant data gaps, impairing the accuracy of climate analyses (Hamdi et al., 2020). Compounding these challenges, research funding disparities in Brazil exacerbate the issue, with the majority of state investment concentrated in the Southeast, particularly in São Paulo (Silva, 2023). Due to local economic activity, prestigious universities, and higher public funding, the state accounted for over 70% of national research and development expenditures between 2017 and 2022 (Silva, 2023).

In light of this scenario, the development of accessible and innovative climate monitoring solutions is essential. Low-cost meteorological shelters, constructed using readily available materials and simplified techniques, have emerged as a viable alternative for democratizing climate data collection and expanding the spatial coverage of measurements (Rojas et al., 2014).

Within this framework, the central hypothesis of this study is that a low-cost meteorological shelter, developed using accessible materials and simplified methods, can provide reliable measurements comparable to those obtained with standard commercial shelters. This solution has the potential to facilitate detailed studies of urban climate, particularly in regions with limited infrastructure, making it a valuable tool for climate research. The proposal is justified by the urgent need for precise and accessible climate measurements, which not only advance scientific knowledge but also contribute to addressing urban climate challenges in an inclusive and sustainable manner.

The need for accessible and reliable climate data collection methods is particularly evident in urban climatology research, where financial and infrastructural constraints often limit long-term monitoring efforts. This study was motivated by challenges encountered during UHI analysis in Indaiatuba, São Paulo, within a collaborative doctoral research project between the Institute of Geosciences at the State University of Campinas (UNICAMP) and Université Rennes 2. The limitations observed in existing monitoring networks reinforced the importance of developing adaptable, cost-effective solutions for urban climate studies, contributing to broader efforts to democratize meteorological data acquisition in developing regions.

8.3 Objectives

The present study aimed to describe the process of development, implementation, and validation of a low-cost meteorological shelter designed to meet the specific needs of urban climate research. Also, to achieve this general objective, the following specific objectives were established to guide the research stages:

1. Describe the materials and methods used in the construction of the meteorological shelter;
2. Evaluate and compare the performance of the developed shelter with commercially available models;
3. Demonstrate the applicability of the shelter in urban climate studies, highlighting its effectiveness and feasibility for scientific research.

8.4 Methodology

The methodology was divided into three stages, corresponding to the specific objectives (as shown in Figure 1):

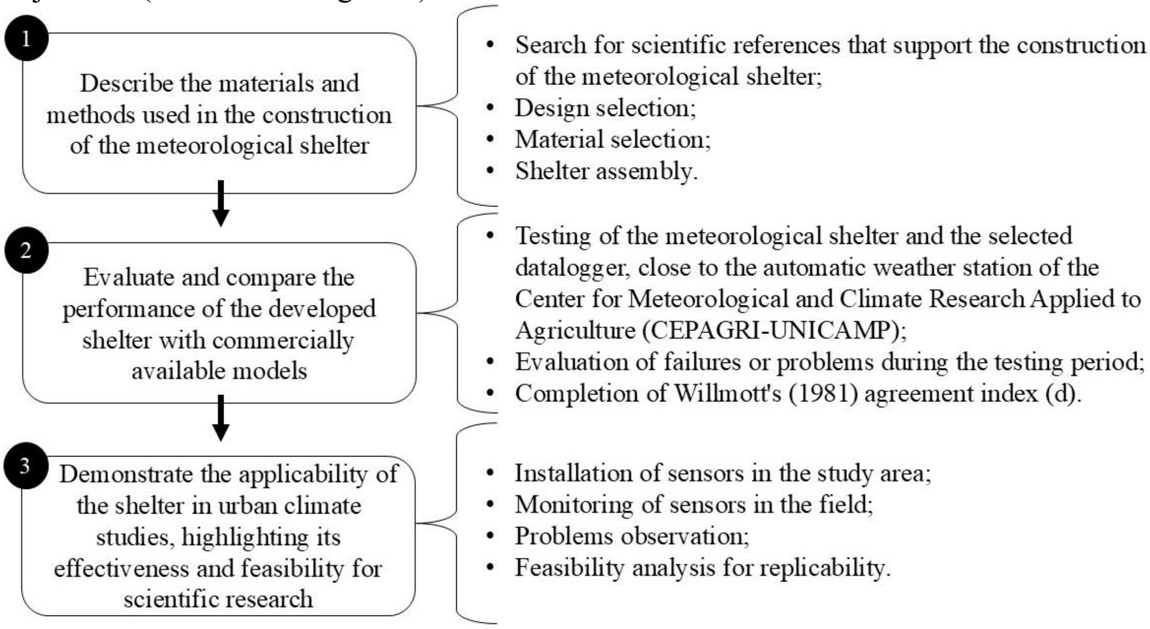


Figure 1: Presentation of the methodological steps taken to achieve the main objective of the research

8.4.1 Methods from Stage 1:

The initial literature review was conducted using Google Scholar, as illustrated in Figure 2.

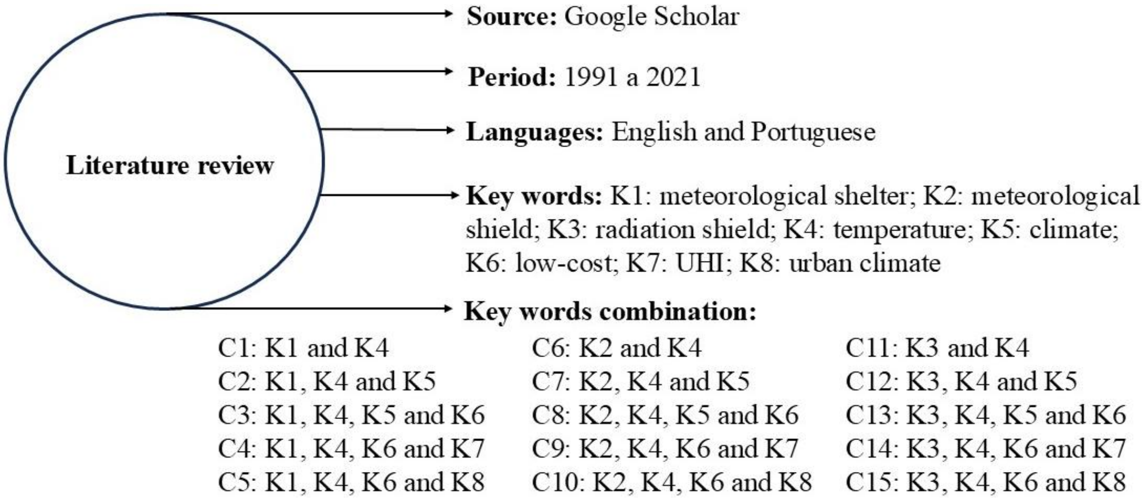


Figure 2: Description of the method used for literature review

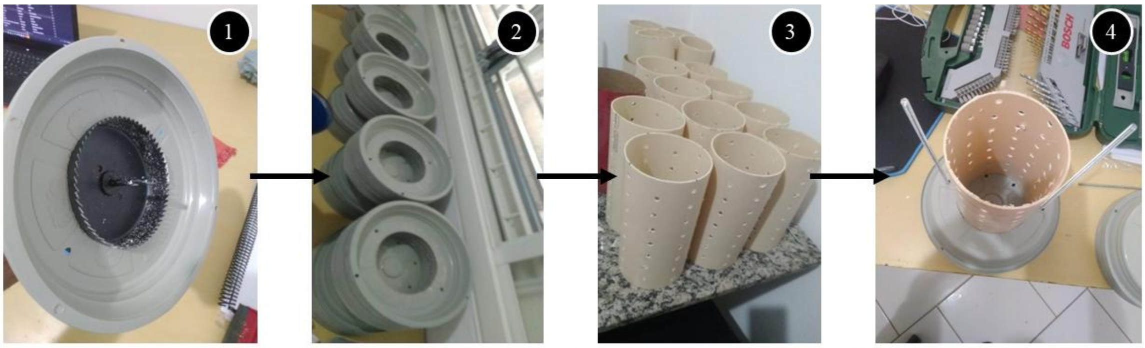
During the literature review, we analyzed scientific documents focusing on two key aspects: the materials used in meteorological shelters and their practical application in field studies.

Based on insights from this review, students from the Center for Applied Meteorological and Climate Research in Agriculture, from University of Campinas (CEPAGRI-UNICAMP) constructed the meteorological shelters, ensuring alignment with the best practices identified in the literature.

The construction utilized accessible and cost-effective materials, including pine slats, polypropylene (PP) plastic, and polyvinyl chloride (PVC), which were used to support the sensor and form the shelter walls, respectively (Figure 3).

To comply with World Meteorological Organization (WMO, 2018) standards, white paint was applied to the shelters' surfaces, reducing heat absorption and ensuring more accurate temperature measurements (Figure 4).

The selection of materials prioritized cost efficiency and durability, taking into account Brazil’s climate conditions, which include high humidity and extreme high temperatures. The list of materials used is presented as supplementary material for this research. The construction process followed standardized methods, utilizing basic tools such as drills and widely available accessories. This approach was designed to facilitate replication by schools, universities, and research institutions, even those with limited financial resources.



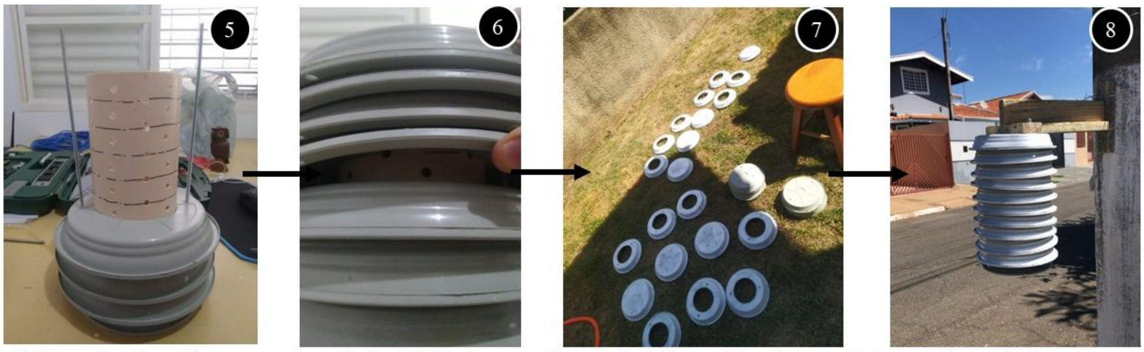
1. Approximately 10 plastic plates were used for each meteorological shelter. These plates, commonly used as plant supports, are available at gardening and construction material stores.

2. Eight out of the ten plates were drilled at the center and at two parallel points on their ends to facilitate assembly and stability.

3. Each sensor incorporated a 75mm PVC pipe, approximately 30cm in length, with multiple perforations to ensure proper air circulation.

4. The structure was assembled by placing a base plate, which was drilled only at two specific parallel points, allowing the insertion of two threaded steel rods measuring 5mm x 30cm, securing the entire setup.

Figure 3: Details of the construction process of weather shelters (part 1)



5. Once the first plate was secured, the PVC pipe was inserted, followed by the remaining perforated plates being stacked in sequence.

6. The plates were spaced 2 cm apart, ensuring proper ventilation and heat dissipation.

7. After the pre-assembly was completed, all plates were removed and spray-painted white to reduce heat absorption and comply with meteorological standards.

8. Once the material had dried, the meteorological shelter was fully assembled. Nuts were fastened at both ends of the threaded bars to secure the plates and stabilize the structure. Finally, the datalogger was inserted through the bottom of the shelter, fitting into the PVC pipe space.

Figure 4: Details of the construction process of weather shelters (part 2)

8.4.2 Methods from Stage 2:

A sensor unit, consisting of a meteorological shelter and a datalogger, was installed near the automatic weather station at CEPAGRI-UNICAMP. This weather station has served as a reference for the study region, continuously collecting meteorological data since 1989.

To assess data reliability, the Willmott (1981) agreement index (d) was applied, as defined in Equation (1).

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_1)^2}{\sum_{i=1}^{n}\left(|P_i - \overline{O}| + |O_i - \overline{O}|\right)^2} \quad (1)$$

Where:

P_1: Predicted value at observation i.

O_i: Observed value at observation i.

$\overline{O}$: Mean of the observed values.

n: Number of observations.

$|P_i - \overline{O}|$: Absolute deviation of the predicted value from the mean of observed values.

$|O_i - \overline{O}|$: Absolute deviation of the observed value from the mean of observed values.

The index ranges from 0 to 1, with values closer to 1 indicating a higher degree of agreement between the compared datasets.

8.4.3 Methods from Stage 3:

Following this validation, the sensors were deployed in a tropical medium-sized city. They were installed on electricity poles belonging to São Paulo Power and Light Company (*Companhia Paulista de Força e Luz - CPFL Energia)*, at a height of approximately three meters. The deployment took place in December 2021, and the sensors remained in the field until December 2022.

8.5 Results

The results will be presented according to the methodological sequence, detailing the findings from each stage of the study.

8.5.1 Results from Stage 1:

During the literature review on low-cost meteorological shelters, 80 articles were identified by the reading of title and abstract. Among them, only 25 were considered for full reading, especially the methodology, as they address the use of low-cost fixed sensors. However, only 9 addressed low-cost meteorological shelters, of these all mentioned the materials used in shelter construction, but just 7 underwent field testing, demonstrating their applicability in urban climate studies and followed the WMO standards.

Notably, there were few studies focusing on the Global South (xx papers identified), with Júnior et al. (2016) and Freitas (2018) standing out. These studies not only detailed the materials used in shelter construction but also included field tests, making them fundamental references for this research.

Each meteorological shelter (Figure 5) was built at a cost of 300 reais, updated to 2025 values (approximately 50 euros, considering an exchange rate of 1 EUR = 6 BRL). The Instrutherm HT-900 datalogger, used in this study, currently costs 465 reais (77.5 euros). Thus, the total cost of each sensor unit amounted to 127.50 euros.

On the other hand, a standard meteorological shelter sold in a specialized store costs around 1200 reais (which would represent around 200 euros, when converted to

1EUR = 6BRL). This shows the considerable difference in the amount invested to obtain a standard shelter compared to a low-cost shelter.

It is also important to highlight that the meteorological shelter was easy to assemble, requiring one month to construct the ten shelters. An additional month was dedicated to testing and installing the sensors in the study area, ensuring their proper functionality before deployment.

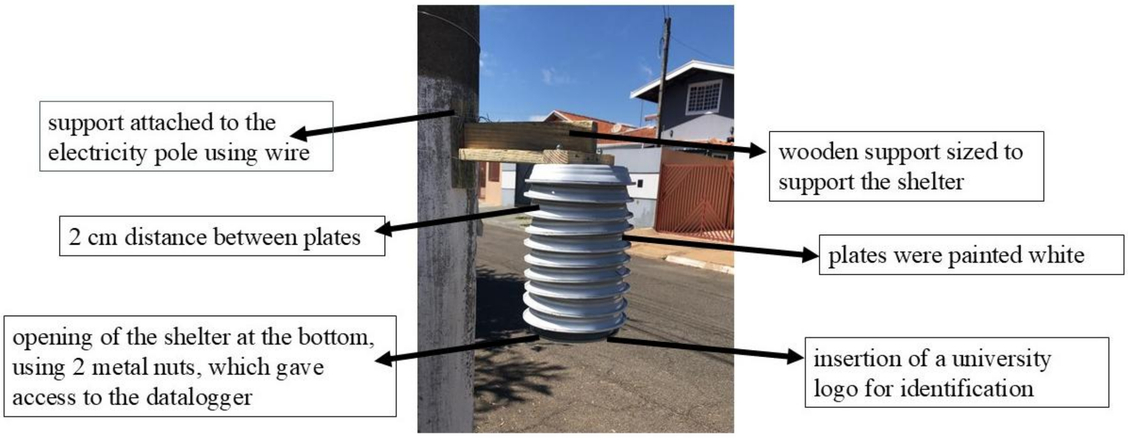


Figure 5: Finished weather shelter with description of important components that characterize it as a quality product, following WMO standards

8.5.2 Results from Stage 2:

The meteorological shelter installed near the automatic weather station at the Center for Meteorological and Climate Research Applied to Agriculture (CEPAGRI-UNICAMP) remained fully operational throughout the testing period, with no reported issues.

During this time, the datalogger recorded temperature measurements every 10 minute. A comparative analysis between the automatic weather station and the datalogger readings was conducted using Willmott's (1981) agreement index (d), which yielded a value of 0.977. This result confirms both the reliability of the datalogger and the effectiveness of the meteorological shelter in accurately capturing temperature data.

8.5.3 Results from Stage 3:

Given the promising results observed in Stage 2, the sensors were deployed in the study area, where they remained operational for one year, recording temperature and humidity data every 10 minutes.

Over the analysis period, a total of 52,560 data points were collected, with downloads performed every four months. This interval was chosen to prevent data loss, as the datalogger's memory holds approximately 20,000 measurements, and to allow for regular assessments of potential structural issues with the shelter or technical malfunctions in the datalogger.

The collected data have been deposited in a public repository (Zezzo et al., 2025a), and part of the findings were recently published, highlighting the effects of the urban heat island (UHI) in the study area (Zezzo et al., 2025b).

Notably, no operational issues were reported during the monitoring period, confirming that low-cost weather shelters can serve as a reliable option for urban climate studies. Their minimal material requirements, ease of assembly, and simple installation enhance their replicability, making them a valuable tool for expanding climate monitoring efforts, particularly in resource-limited settings.

8.6 Discussions

A comprehensive literature review conducted for this study identified a significant gap in academic research on affordable climate measurement methods. Most existing studies focus on the use of low-cost display devices (LCDs) (Gluber et al., 2021; Meyer, 2021), including wireless sensor networks and Arduino-based systems for environmental monitoring (Antonini et al., 2020; Hubbart, 2011; Khandelwal & Mohit Singhal, 2021). Additionally, some research explores mobile monitoring systems, such as urban transects and vehicle-mounted devices, to assess UHIs (Lima & Galvani, 2020). However, there is a notable lack of peer-reviewed studies specifically addressing the development of affordable and efficient weather shelters for long-term climate monitoring. This gap underscores the need for further research to support the establishment of cost-effective and reliable meteorological networks, particularly in resource-limited settings.

Notably, the most comprehensive studies on the development of climate shelters have been conducted by Brazilian researchers and published in national journals (Armani & Galvani, 2006) or as undergraduate theses without peer review (Júnior et al., 2016; Freitas, 2018). A significant portion of the existing literature builds upon the foundational work of Armani and Galvani (2006), who developed a low-cost weather shelter inspired by the 410031-Plate Gill Radiation Shield model. Their study included a qualitative assessment of recorded data to identify discrepancies, ultimately concluding that the shelter functioned as a passive ventilation system, particularly suitable for remote locations and forest microclimate environments.

These findings underscore the need for more rigorous, peer-reviewed, and internationally disseminated academic publications to bridge this knowledge gap and support researchers facing financial constraints in establishing climate monitoring networks on a global scale. Within this context, the collection of long-term climate data (Domonkos et al., 2022) in developing countries is hindered by substantial structural and financial challenges (Vieira Zezzo et al., 2023). The lack of adequate infrastructure and limited funding for climate monitoring (Muller et al., 2013) result in fragmented and outdated measurement networks (Marengo & Bernasconi, 2015). In contrast, developed nations benefit from extensive, technologically advanced networks that are well-integrated with climate services. This stark disparity in meteorological data accessibility restricts environmental management capabilities and impairs the implementation of effective climate adaptation policies in more vulnerable regions.

The collection and analysis of climate data play a crucial role in mitigating the effects of UHIs (Chapman et al., 2017; Santamouris, 2015). A comprehensive understanding of local climate dynamics enables public authorities to implement effective adaptation strategies, such as expanding green spaces, integrating reflective materials in urban infrastructure, and designing ventilation corridors (Lemonsu et al., 2015; Murakami et al., 2016). Consequently, meteorological data are fundamental for sustainable urban planning and the formulation of climate adaptation strategies.

Developing affordable and easily replicable meteorological shelters is essential to democratizing access to climate data (Rojas et al., 2014). Low-cost solutions facilitate the expansion of climate monitoring networks in regions that would otherwise lack access to such data (Muller et al., 2013). Compared to advanced and expensive meteorological technologies, these solutions offer a viable alternative for research institutions, local governments, and communities that rely on accurate data for informed decision-making. Open access to meteorological data can benefit various sectors of society by fostering the development of more inclusive and participatory climate policies. Furthermore, democratizing data access can encourage collaboration among academic institutions, government agencies, and civil society organizations, ultimately enhancing climate resilience across multiple scales (Rojas et al., 2014).

Despite the potential of low-cost solutions, significant barriers persist in expanding meteorological monitoring networks. Financial and logistical constraints hinder the deployment of sensors in remote or inaccessible regions (Marengo & Bernasconi, 2015). Additionally, the lack of adequate training and the need for regular maintenance may compromise both the quality and continuity of climate measurements (Hamdi et al., 2020).

Scientific collaboration and international partnerships are critical in addressing these challenges by facilitating the exchange of technologies, data, and methodologies. Cooperative initiatives between universities, research institutes, and government organizations can support the expansion of climate monitoring networks, ensuring broader accessibility to high-quality meteorological data for researchers, policymakers, and local communities.

8.7 Final considerations

The low-cost meteorological shelter developed in this study demonstrates a significant positive impact on urban climate research, providing an accessible and effective tool for climate monitoring. Its cost-effectiveness and ease of assembly make it particularly valuable in regions with limited infrastructure, where the availability of reliable meteorological data is often restricted.

Beyond its scientific contributions, this shelter model offers great potential for collaboration with educational institutions, enabling schools and universities to incorporate hands-on meteorological monitoring. Such partnerships can broaden access to climate data, enhance scientific literacy, and inspire new generations of researchers and environmental scientists.

Ultimately, this study highlights how simplicity and efficiency can be effectively combined to address key challenges in climate research. The low-cost meteorological shelter stands as a practical and scalable innovation, capable of supporting both scientific advancement and the democratization of knowledge. By integrating science, education, and society, this initiative fosters greater awareness and action in response to climate change, reinforcing the importance of community-driven research and sustainable technological solutions.

8.8 Referências

Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A. L., Rossi, F., ... & Zinzi, M. (2016). Local climate change and urban heat island mitigation techniques – The state of the art. *Journal of Civil Engineering and Management, 22*(1), 1-16. https://doi.org/10.3846/13923730.2015.1111934

Amorim, M. C. C. T. (2020). Daily evolution of urban heat islands in a Brazilian tropical continental climate during dry and rainy periods. *Urban Climate, 34*, 100715. https://doi.org/10.1016/j.uclim.2020.100715

Amorim, M. C. C. T., & Dubreuil, V. (2017). Intensity of urban heat islands in tropical and temperate climates. *Climate, 5*, 91. https://doi.org/10.3390/cli5040091

Angel, S., Parent, J., Civco, D. L., Blei, A., & Potere, D. (2010). The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Progress in Planning, 75*, 53–107. https://doi.org/10.1016/j.progress.2011.04.001

Antonini, A., Bini, L., Rafanelli, G., et al. (2020). Implementation of a low-cost weather station developed in design-based learning framework. In *2020 IEEE International Conference on Sensing, Communication and Networking (SECON Workshops)*. https://doi.org/10.1109/SECONWorkshops50264.2020.9149776

Armani, G., & Galvani, E. (2006). Avaliação do desempenho de um abrigo meteorológico de baixo custo. *Revista Brasileira de Agrometeorologia, 14*(1), 116–122. Available at: https://www.researchgate.net/profile/Gustavo-Armani/publication/257054410_Performance%27s_evaluation_of_a_low_cost_meteorological_shield/links/00463524438cdaf6a3000000/Performances-evaluation-of-a-low-cost-meteorological-shield.pdf

Chapman, S., Watson, J. E. M., Salazar, A., et al. (2017). The impact of urbanization and climate change on urban temperatures: A systematic review. *Landscape Ecology, 32*, 1921–1935. https://doi.org/10.1007/s10980-017-0561-4

Cheung, H. K., Levermore, G. J., & Watkins, R. (2010). A low cost, easily fabricated radiation shield for temperature measurements to monitor dry bulb air temperature in built-up urban areas. *Building Services Engineering Research and Technology, 31*(4), 371–380. https://doi.org/10.1177/0143624410376565

Domonkos, P., Tóth, R. & Nyitrai, L. (2022) *Climate observations: data quality control and time series homogenization*. Amsterdam, Netherlands: Elsevier, p. 302.

Freitas, M. (2018). *Caracterização de sensores e abrigos meteorológicos de baixo custo* (Trabalho de Conclusão de Curso, Instituto de Física, Universidade Federal do Rio Grande do Sul). https://lume.ufrgs.br/handle/10183/180974

Gohain, K. J., Goswami, A., Mohammad, P., et al. (2023). Modelling relationship between land use land cover changes, land surface temperature and urban heat island in

Indore city of central India. *Theoretical and Applied Climatology, 151*, 1981–2000. https://doi.org/10.1007/s00704-023-04371-x

Grimmond, S., Roth, M., Oke, T. R., Au, Y. C., Best, M., Betts, R., ... & Voogt, J. (2010). Climate and more sustainable cities: Climate information for improved planning and management of cities (Producers/Capabilities Perspective). *Procedia Environmental Sciences, 1*, 247-274. https://doi.org/10.1016/j.proenv.2010.09.016

Gubler, M., Christen, A., Remund, J., & Brönnimann, S. (2021). Evaluation and application of a low-cost measurement network to study intra-urban temperature differences during summer 2018 in Bern, Switzerland. *Urban Climate, 37*, 100817. https://doi.org/10.1016/j.uclim.2021.100817

Hamdi, R., Kusaka, H., Doan, Q. V., et al. (2020). The state-of-the-art of urban climate change modeling and observations. *Earth Systems and Environment, 4*, 631–646. https://doi.org/10.1007/s41748-020-00193-3

Holden, Z. A., Klene, A. E., Keefe, R. F., & Moisen, G. G. (2013). Design and evaluation of an inexpensive radiation shield for monitoring surface air temperatures. *Agricultural and Forest Meteorology, 180*, 281–286. https://doi.org/10.1016/j.agrformet.2013.06.011

Hubbard, K. G., Lin, X., & Baker, C. B. (2001). Air temperature comparison between the MMTS and the USCRN temperature systems. *Journal of Atmospheric and Oceanic Technology, 18*(3), 329–340. https://journals.ametsoc.org/view/journals/atot/21/10/1520-0426_2004_021_1590_atcbtm_2_0_co_2.pdf

Hubbart, J. A. (2011). An inexpensive alternative solar radiation shield for ambient air temperature micro-sensors. *Journal of Natural & Environmental Sciences, 2*(2), 9–14. Available at: https://www.researchgate.net/profile/Jason-Hubbart/publication/266075427_An_Inexpensive_Alternative_Solar_Radiation_Shield_for_Ambient_Air_Temperature_Micro-Sensors/links/54a2e57e0cf256bf8bb0dcf0/An-Inexpensive-Alternative-Solar-Radiation-Shield-for-Ambient-Air-Temperature-Micro-Sensors.pdf

Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Júnior, M. O. V., de Moura Santos, F. M., Ribeiro, K. F. A., Nogueira, M. C. J. A., & Nogueira, J. S. (2016). Análise da relação entre abrigos meteorológicos alternativos para pontos fixos e o comportamento de variáveis termo-higrométricas. *Revista Brasileira de Climatologia, 18*, 157–179. http://dx.doi.org/10.5380/abclima.v18i0.45146

Karlsson, S., Srebotnjak, T., & Gonzales, P. (2007). Understanding the North–South knowledge divide and its implications for policy: A quantitative analysis of the generation of scientific knowledge in the environmental sciences. *Environmental Science & Policy, 10*(7-8), 668–684. https://doi.org/10.1016/j.envsci.2007.04.001

Khandelwal, D. D., & Singhal, M. (2021). Developing a low-cost weather monitoring system for data-sparse regions of the Himalayas. *Weather, 76*(2). https://doi.org/10.1002/wea.3647

Kousis, I., Manni, M., & Pisello, A. L. (2022). Environmental mobile monitoring of urban microclimates: A review. *Renewable and Sustainable Energy Reviews, 169*, 112847. https://doi.org/10.1016/j.rser.2022.112847

Lemonsu, A., Viguié, V., Daniel, M., & Masson, V. (2015). Vulnerability to heat waves: Impact of urban expansion scenarios on urban heat island and heat stress in Paris (France). *Urban Climate, 14*, 586-605. https://doi.org/10.1016/j.uclim.2015.10.007

Lichtblau, M., Reimann, L., & Piccari, L. (2024). Pulmonary vascular disease, environmental pollution, and climate change. *Pulmonary Circulation, 14*(2), e12394. https://doi.org/10.1002/pul2.12394

Lima, T. L., & Galvani, E. (2020). Avaliação da ilha de calor urbana na zona norte de São Paulo: Estudo de caso do bairro Jardim Peri. *Revista Brasileira de Climatologia, 26*. https://doi.org/10.5380/abclima.v26i0.69933

Lin, X., Hubbard, K. G., & Meyer, G. E. (2001). Airflow characteristics of commonly used temperature radiation shields. *Journal of Atmospheric and Oceanic Technology, 18*(3), 329–340. https://doi.org/10.1175/1520-0426(2001)018

Marengo, J. A., & Bernasconi, M. (2015). Regional differences in aridity/drought conditions over Northeast Brazil: Present state and future projections. *Climatic Change, 129*(1–2), 103–115. https://doi.org/10.1007/s10584-014-1310-1

Medeiros, S. E. L., Abrahão, R., da Silva, L. P., et al. (2019). Comparison between observed and estimated data to assess air temperature variability and trends in the Sertão Paraibano mesoregion (Brazil). *Environmental Monitoring and Assessment, 191*, 63. https://doi.org/10.1007/s10661-019-7207-8

Middleton, W. E. K. (1969). *Invention of the meteorological instruments*. Johns Hopkins Press.

Muller, C., Chapman, L., Grimmond, C. S. B., Young, D., & Cai, X. (2013). Sensors and the city: A review of urban meteorological networks. *International Journal of Climatology, 33*(7), 1585–1600. https://doi.org/10.1002/joc.3678

Murakami, D., Peters, G. W., Yamagata, Y., & Matsui, T. (2016). Participatory sensing data tweets for micro-urban real-time resiliency monitoring and risk management. *IEEE Access, 4*, 347–372. https://doi.org/10.1109/ACCESS.2016.2516918

National Weather Service. (n.d.). *Weather education*. NOAA. Retrieved [insert retrieval date], from https://www.weather.gov/rah/edu2

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society, 108*(455), 1-24. https://doi.org/10.1002/qj.49710845502

Pasgaard, M., & Strange, N. (2013). A quantitative analysis of the causes of the global climate change research distribution. *Global Environmental Change, 23*(6), 1684–1693. https://doi.org/10.1016/j.gloenvcha.2013.08.013

Peterson, T. C., Vose, R. S., & Schmoyer, R. L. (1998). Global Historical Climatology Network (GHCN) quality control of monthly temperature data. *International Journal of Climatology, 18*(11), 1169–1179. https://doi.org/10.1002/(SICI)1097-0088(199809)18:11<1169::AID-JOC309>3.0.CO;2-U

Rojas, J., Gilete, S. D., & Mazon, J. (2014). Development of a low-cost weather station to measure in situ essential climate variables. *Journal of Earth Science and Engineering, 4*(8), 455–463. Available at: http://hdl.handle.net/2117/26929

Rucavado Rojas, D., & Postigo, J. C. (2025). The cycle of underrepresentation: Structural and institutional factors limiting the representation of Global South authors and knowledge in the IPCC. *Climatic Change, 178*, 19. https://doi.org/10.1007/s10584-025-03857-z

Santamouris, M. (2015). Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. *Science of the Total Environment, 512-513*, 582-598. https://doi.org/10.1016/j.scitotenv.2015.01.060

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083-16088. https://doi.org/10.1073/pnas.1211658109

Silva, L. D. A. (2023). *Políticas públicas municipais em ciência, tecnologia e inovação e o futuro das cidades* (Dissertação de Mestrado, Universidade Estadual do Rio de Janeiro, Faculdade de Direito). Available at: https://www.bdtd.uerj.br:8443/handle/1/19658

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society, 93*(12), 1879-1900. https://doi.org/10.1175/BAMS-D-11-00019.1

United Nations. (2012). *World urbanization prospects: The 2011 revision*. United Nations. Retrieved from http://esa.un.org/unpd/wup/index.htm

Vieira Zezzo, L., Pereira Coltri, P., & Dubreuil, V. (2023). Microscale models and urban heat island studies: A systematic review. *Environmental Monitoring and Assessment, 195*, 1284. https://doi.org/10.1007/s10661-023-11906-2

Vieira Zezzo, L., Pereira Coltri, P., & Dubreuil, V. (2024). Frequência e intensidade de ilhas de calor urbano em Indaiatuba (São Paulo). In M. C. C. T. Amorim & V. Dubreuil (Eds.), *Cidades, clima e vegetação: Modelagem e políticas ambientais públicas* (pp. 105-123). TotalBooks.

Willmott, C. J. (1981). On the validation of models. *Physical Geography, 2*(2), 184–194. https://doi.org/10.1080/02723646.1981.10642213

World Health Organization. (2018). *Ambient (outdoor) air pollution*. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Meteorological Organization (WMO). (2018). *Guide to meteorological instruments and methods of observation* (WMO-No. 8). Geneva: WMO.

World Meteorological Organization. (2018). *Guide to instruments and methods of observation*. https://community.wmo.int/en/activity-areas/imop/wmo-no_8

Yang, J., An, Q., Liu, Q., Tan, M., & Jiang, L. (2024). Development of a radiation shield for atmospheric temperature measurement system. *Measurement, 229*, 114399. https://doi.org/10.1016/j.measurement.2024.114399

Zezzo, L. V., Coltri, P. P., & Dubreuil, V. (2025). *Dados de temperatura e umidade de Indaiatuba - Ano 2022* (v1). Repositório de Dados de Pesquisa da Unicamp. https://doi.org/10.25824/redu/RMGPU1

Zezzo, L. V., Coltri, P. P., & Dubreuil, V. (2025). Exploring the urban heat island phenomenon in a tropical medium-sized city: Insights for sustainable urban development.

Environmental Monitoring and Assessment, 197, 445. https://doi.org/10.1007/s10661-025-13890-1

Zuniga, P. (2016). *Innovation system in development: The case of Peru* (UNU-MERIT Working Paper No. 2016-058). United Nations University - Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT). Available at: https://unu-merit.nl/publications/wppdf/2016/wp2016-058.pdf

CAPÍTULO 9 – DISCUSSÕES DA TESE

Neste capítulo, buscou-se realizar uma análise detalhada de cada um dos artigos apresentados, relacionando-os diretamente aos objetivos específicos desta tese, e, por conseguinte, ao objetivo geral proposto. Através dessa discussão, pretende-se avaliar como os resultados obtidos em cada estudo contribuem para a comprovação ou refutação da hipótese levantada. Cada artigo será analisado não apenas sob a ótica dos dados e resultados que ele apresenta, mas também em termos de sua aplicação prática e implicações quanto ao uso de dados meteorológicos reais, considerando ainda a escala de trabalho e a dimensão do estudo.

Desse modo, as discussões aqui apresentadas visam integrar as diferentes abordagens dos artigos, proporcionando uma visão mais abrangente e coerente dos achados científicos desta pesquisa. Com isso, espera-se não apenas reforçar os postos-chave da tese, mas também identificar possíveis lacunas ou limitações nos dados, contribuindo para um entendimento mais profundo dos processos investigados.

9.1 Análise dos objetivos específicos

Tabela 1: Análise da coletânea de artigos em função dos objetivos específicos apresentados

Objetivos	Artigo relacionado	Escala do trabalho	Dimensão	Relação com o uso de dados meteorológicos
Entender qual a influência da mídia na divulgação de notícias sobre mudanças climáticas no Brasil.	The dissemination of news about climate change: an analysis of the Brazilian scenario in the last 50 years	Nacional	Comunicação	A integração de dados meteorológicos locais na mídia pode aumentar a credibilidade das notícias climáticas, pois o público confia mais em informações conectadas à sua realidade (Edelman, 2023). Por exemplo, um jornal local que mostre o aumento das temperaturas em áreas urbanas densas com dados reais pode gerar debates e ações práticas. Além disso, é fundamental capacitar jornalistas para interpretar e comunicar dados científicos com precisão e clareza, evitando ambiguidades (Caldas & Macedo, 1999). A colaboração entre cientistas, meteorologistas e jornalistas pode melhorar a comunicação científica (Pinto & Carvalho, 2011), promovendo a alfabetização científica e o engajamento social.

Analisar como vem ocorrendo a educação em mudanças climáticas no contexto brasileiro.	Educação em mudanças climáticas no contexto brasileiro: uma revisão integrada	Nacional	Educação	Os dados meteorológicos têm um papel interdisciplinar no ensino (Grasso et al., 2017), sendo aplicados não apenas em geografia (Maia, 2018) ou ciências naturais, mas também em matemática, física e química. Como Wise (2010) destaca, a alfabetização científica deve envolver várias disciplinas para promover uma compreensão completa dos fenômenos climáticos. Além disso, conectar esses dados ao ensino pode aumentar o engajamento comunitário, pois os estudantes, ao entenderem os impactos locais dos fenômenos climáticos, se tornam mais envolvidos na temática (Grasso et al., 2017), fortalecendo a resiliência e a cultura de sustentabilidade a longo prazo.

Observar quais os problemas relacionados ao ensino-aprendizagem de mudanças climáticas na região sudeste do Brasil.	Perceptions of Climate Change Education (CCE): insights from higher-education individuals in southeast Brazil with broader implications	Regional	Educação	A falta de dados meteorológicos reais contribui para falácias, como a crença equivocada de que o aquecimento global é causado por um buraco na camada de ozônio (Monroe et al., 2017). A ausência de uma compreensão concreta e mensurável dos impactos climáticos locais e regionais leva a uma percepção distorcida do fenômeno. A escassez de infraestrutura para coleta de dados climáticos impede o desenvolvimento de uma base empírica sólida (Gonçalves et al., 2021), essencial para corrigir essas falácias e promover uma compreensão mais precisa. A falta de educação climática adequada e dados meteorológicos locais destaca a necessidade urgente de investimentos quanto: a melhoria da formação educacional sobre mudanças climáticas, com maior capacitação de professores (Zezzo & Coltri, 2023) e a integração de dados reais nos currículos escolares (Grasso et al., 2017); e a expansão da infraestrutura de coleta de dados climáticos em áreas urbanas e rurais (Santos et al., 2019).

Analisar as metodologias de análise de fenômenos climáticos (como ICU) existentes e a partir disso compreender o modo de avaliação coerente com as características de cada área de estudo.	Microscale models and urban heat islands: a systematic review	Global	Ciência do clima	A revisão sistemática apresentada nesta tese revelou que os modelos de microescala, embora eficazes na simulação de fenômenos climáticos urbanos, dependem fortemente de dados de campo para validação e aprimoramento. No Brasil, a falta de investimento em infraestrutura para coleta de dados e a escassez de centros de pesquisa especializados limitam a aplicação desses modelos em larga escala (Vieira Zezzo et al., 2023). Essa realidade dificulta a utilização de modelos precisos para entender as dinâmicas climáticas locais (IPCC, 2014) e compromete a base de dados para políticas públicas eficazes, afetando negativamente as estratégias de adaptação e mitigação (Stewart, 2012).

Identificar e propor soluções para reduzir a lacuna de dados meteorológicos e climatológicos no Brasil.	Desenvolvimento de um abrigo meteorológico de baixo custo para pesquisas em clima urbano no Brasil	Nacional	Ciência do clima	Os abrigos desenvolvidos, feitos com materiais simples e acessíveis, são adequados para estudos de climatologia urbana, proporcionando medições precisas das variáveis climáticas (Oke, 2004; Chapman et al., 2017). A adaptação dessas tecnologias simples pode representar um marco na produção de dados locais confiáveis, essenciais para entender as variações climáticas regionais (Overem et al., 2013). Além de expandir a rede de coleta de dados meteorológicos, esses dispositivos incentivam a participação de instituições locais, como escolas e universidades, que podem atuar como centros de monitoramento e análise (Arienzo et al., 2021). Capacitar essas instituições promove a inclusão da comunidade no processo científico, estimulando o engajamento público nas questões climáticas. Isso gera dados robustos e localizados, criando uma base sólida para políticas públicas que atendam às necessidades reais das populações e fortaleçam a resiliência climática local (Mahajan et al., 2020).

Evidenciar a influência das ICU no município de Indaiatuba, a partir de dados anuais de temperatura na região, facilitando a contextualização destes e a comunicação com a comunidade local.	Exploring the Urban Heat Island phenomenon in a tropical medium-sized city: insights for sustainable urban development	Local	Ciência do clima	Dados meteorológicos locais mostram como a urbanização afeta a temperatura, prejudicando o bem-estar da população (Chapman et al., 2017; Oke, 2004). Integrar esses dados em campanhas educacionais poderia facilitar o entendimento da ciência do clima ao relacioná-la a um fenômeno local (Arienzo et al., 2021). Além disso, a coleta e análise de dados meteorológicos locais orientam políticas públicas eficazes e empoderam os cidadãos a participar ativamente na mitigação e adaptação aos impactos climáticos, promovendo resiliência (Overem et al., 2013).

9.2 Análise do objetivo geral da tese

O objetivo geral da tese foi utilizar dados meteorológicos para abordar temas de climatologia, como ICU, de forma prática e acessível, conectando-os ao cotidiano de uma comunidade específica em uma escala local-regional, a fim de promover maior compreensão e engajamento nas questões de comunicação científica. A ciência do clima possui muitas camadas, que se desdobram em diferentes dimensões, tendo sido difícil desvincular a essa ciência, temáticas como da comunicação e educação. No entanto, tal objetivo foi amplamente alcançado por meio dos artigos elaborados, a dizer: "Exploring the Urban Heat Island phenomenon in a tropical medium-sized city: insights for sustainable urban development" (1), Desenvolvimento de um abrigo meteorológico de baixo custo para pesquisas em clima urbano no Brasil" (2) e "Microscale models and urban heat islands: a systematic review" (3).

Dessa forma, a partir desses artigos demonstrou-se a relevância dos dados meteorológicos locais para a compreensão de fenômeno climático, destacando as principais metodologias atuais para análise de ICU e a importância de dados reais. Além disso, a pesquisa conectou esses dados ao contexto local de uma cidade de médio porte do sudeste brasileiro, contextualizando uma questão climática que possui múltipla relevância no âmbito social e econômico. Esse estudo se mostra como uma forte contribuição para a construção de uma sociedade consciente e resiliente quanto aos fenômenos climáticos que tendem a se intensificar em função das mudanças climáticas, ao destacar diversas lacunas no que tange outras dimensões do assunto.

9.3 Hipótese: comprovada ou refutada

A hipótese pode ser parcialmente aceita. A revisão e os dados apresentados sugerem que, de fato, trabalhar com dados meteorológicos locais de qualidade facilita a compreensão de fenômenos climáticos, tornando-os mais tangíveis e acessíveis para o público. Isso pode, consequentemente, promover a educação científica e a comunicação sobre as mudanças climáticas de forma mais eficaz, já que as pessoas podem perceber como fenômenos climáticos afetam diretamente sua realidade local. Contudo, nenhuma pesquisa direta atrelando o uso de dados meteorológicos à educação e à comunicação foi realizada na presente tese, o que nos impede de aceitar a hipótese por completo.

9.4 Limitações do estudo e sugestões para trabalhos futuros

Ao longo deste capítulo, foi possível observar como os objetivos específicos se alinham com os resultados de cada estudo, esclarecendo a relação entre eles e consolidando as bases para a conclusão do trabalho. Além disso, buscou-se estabelecer a conexão de cada tema apresentado nos artigos aqui compilados com o uso de dados meteorológicos de qualidade. Como já mencionado no início desse trabalho, o uso de dados meteorológicos representou uma limitação direta para a presente tese, dificultando a execução de algumas pesquisas, mas também impulsionando o desenvolvimento de alternativas criativas para superar os obstáculos encontrados.

Com base no exposto, sugere-se a ampliação das pesquisas realizadas para a elaboração dessa tese, especialmente no que tange a educação e a comunicação, dando ênfase ao uso de dados meteorológicos.

CAPÍTULO 10 – CONSIDERAÇÕES FINAIS

O tema das mudanças climáticas, com sua complexidade multifacetada, consolida-se como uma prioridade no cenário global, demandando abordagens científicas, educacionais e comunicativas integradas. Simultaneamente, temas da climatologia também exigem esforços interdisciplinares que conectem dados locais a contextos globais, enquanto promovem a alfabetização científica e estratégias robustas na educação. Fortalecer a infraestrutura de coleta de dados meteorológicos e fomentar a comunicação científica são passos fundamentais para superar os desafios impostos por esse tema complexo, promovendo um futuro mais sustentável e informado.

Esta pesquisa, ao explorar a relação entre comunicação, educação e a ciência do clima em múltiplas escalas, contribuiu significativamente para o entendimento da climatologia nessas dimensões, elucidando possibilidades para a alfabetização científica e para a implementação de estratégias educacionais mais eficazes.

Isso é especialmente importante em um país como o Brasil, onde as desigualdades no acesso à informação e a falta de recursos para a coleta de dados detalhados são desafios persistentes. O fortalecimento da infraestrutura de coleta de dados meteorológicos e a ampliação do acesso à educação climática são passos essenciais para capacitar a sociedade a enfrentar os desafios impostos pelas mudanças do clima, avançando na construção de um futuro mais justo e resiliente.

REFERÊNCIAS

AMORIM, M. C. C. T. Daily evolution of urban heat islands in a Brazilian tropical continental climate during dry and rainy periods. *Urban Climate*, v. 34, 100715, 2020.

AREIA, N. P.; INTRIGLIOLO, D.; TAVARES, A.; MENDES, J. M.; SEQUEIRA, M. D. The role of media between expert and lay knowledge: A study of Iberian media coverage on climate change. *Science of the Total Environment*, v. 682, p. 291–300, 2019.

ARIENZO, M. M.; COLLINS, M.; JENNINGS, K. S. Enhancing engagement of citizen scientists to monitor precipitation phase. *Frontiers in Earth Science*, v. 9, e617594, 2021.

BUSCH, K. C.; ARDOIN, N.; GRUEHN, D.; STEVENSON, K. Exploring a theoretical model of climate change action for youth. *International Journal of Science Education*, v. 41, n. 17, p. 2389–2409, 2019.

CALDAS, C.; MACEDO, M. A formação de jornalistas científicos no Brasil. *Revista Pesquisa FAPESP*, [s.l.], 1999. Disponível em: https://revistapesquisa.fapesp.br/a-formacao-de-jornalistas-cientificos-no-brasil/. Acesso em: 13 dez. 2024.

CHAPMAN, L.; BELL, C.; BELL, S. Can the crowdsourcing data paradigm take atmospheric science to a new level? A case study of the Urban Heat Island of London quantified using Netatmo weather stations. *International Journal of Climatology*, v. 37, n. 9, p. 3597–3605, 2017.

DA ROSA, J. A. Comparing climate science misconceptions with worldview and cognitive reflection suggests poor understanding and motivated reasoning among undergraduates. *Journal of Geoscience Education*, v. 70, n. 4, p. 501–516, 2021.

DE OLIVEIRA, A. G. A importância dos dados das variáveis climáticas nas pesquisas em geografia: um estudo de caso empregando a precipitação pluviométrica. *Caminhos de Geografia Uberlândia*, v. 10, n. 32, p. 9–21, 2009.

EDELMAN. *Edelman Trust Barometer: Relatório Especial – Confiança e as Mudanças Climáticas.* [S.l.]: Edelman, 2023. Disponível em: https://www.edelman.com.br/sites/g/files/aatuss291/files/2024-02/2023%20Edelman%20Trust%20Barometer%20Relat%C3%B3rio%20Especial%20-

%20Confian%C3%A7a%20e%20as%20Mudan%C3%A7as%20Clim%C3%A1ticas.pdf Acesso em: 13 dez. 2024.

FOISSARD, X.; DUBREUIL, V.; QUÉNOL, H. Defining scales of the land use effect to map the urban heat island in a mid-size European city: Rennes (France). *Urban Climate*, v. 29, 100490, 2019.

FOSS, A. W.; KO, Y. Barriers and opportunities for climate change education: The case of Dallas-Fort Worth in Texas. *The Journal of Environmental Education*, v. 50, n. 3, p. 145–159, 2019.

GONÇALVES, S. T. N.; JUNIOR, F. C. V.; SAKAMOTO, M. S.; SILVEIRA, C. S.; MARTINS, E. S. P. R. M. Índices e metodologias de monitoramento de secas: uma revisão. *Revista Brasileira de Meteorologia*, v. 36, n. 3, p. 495–511, 2021.

GRASSO, V.; BARTOLINI, G.; BENEDETTI, R.; BETTI, G.; CAPECCHI, V.; GOZZINI, B.; MAGNO, R.; ORLANDI, A.; ROVAI, L.; TEI, C.; TORRIGIANI, T.; ZABINI, F. Engaging students and teachers in meteorology and atmospheric sciences: the LaMMA activities. *Advances in Science and Research*, v. 14, p. 109–114, 2017.

GRIMMOND, S. U. E. Urbanization and global environmental change: local effects of urban warming. *The Geographical Journal*, v. 173, n. 1, p. 83–88, 2007.

HETNESSS, E.; MCDONALD, R. C.; BRESLYN, W.; MCGINNIS, J. R.; MOUZA, C. Science teacher professional development in climate change education informed by the Next Generation Science Standards. *Journal of Geoscience Education*, v. 62, p. 319–329, 2014.

IPCC. Climate change 2014 synthesis report summary chapter for policymakers. *IPCC*, 31, 2014.

KADHIM-ABID, A. L.; ICHIM, P.; ATANASIU, G. M. Seasonal occurrence of heat island phenomenon in the urban built environment. *Environmental Engineering and Management Journal*, v. 18, n. 2, p. 417–424, 2019.

LOHMANN, M. Análise dos alagamentos no município de Curitiba entre os anos de 2005 a 2010. *Ciência Geográfica*, v. 16, p. 135–149, 2013.

MAIA, D. C. Imagens de satélite meteorológico nas aulas de geografia: uma possibilidade didática. In: MAIA, D. C. (org.). *Climatologia escolar: saberes e práticas* [online]. São Paulo: Editora Unesp, 2018. p. 49–64. DOI: 10.7476/9788595462830.0003

MAHAJAN, S.; KUMAR, P.; PINTO, J. A.; RICCETTI, A.; SCHAAF, K.; CAMPRODON, G.; SMÁRI, V.; PASSANI, A.; FORINO, G. A citizen science approach for enhancing public understanding of air pollution. *Sustainable Cities and Society*, v. 52, 101800, 2020.

MARENGO, J. A.; BERNASCONI, M. Regional differences in aridity/drought conditions over Northeast Brazil: present state and future projections. *Climatic Change*, v. 129, n. 1–2, p. 103–115, 2015.

MONROE, M. C.; PLATE, R. R.; OXARART, A.; BOWERS, A.; CHAVES, W. A. Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, v. 25, n. 6, p. 791–812, 2017.

MOLTHAN-HILL, P.; WORSFOLD, N.; NAGY, G. J.; LEAL FILHO, W.; MIFSUD, M. Climate change education for universities: A conceptual framework from an international study. *Journal of Cleaner Production*, v. 226, p. 1092–1101, 2019.

MOREIRA, J.; AMORIM, M. C. C. T.; FERNÁNDEZ GARCÍA, F. Análisis de la intensidad y evolución horaria de las islas de calor y seca en ambiente tropical, Brasil. *Revista de Geografia e Ordenamento do Território*, v. 1, p. 151–178, 2019.

OKE, T. R. Initial guidance to obtain representative meteorological observations at urban sites. *Instruments and Observing Methods Report* No. 81, WMO/TD No. 1250, 2004.

OTTO, D.; CAEIRO, S.; NICOLAU, P.; DISTERHEFT, A.; TEIXEIRA, A.; BECKER, S.; BOLLMANN, A.; SANDER, K. Can MOOCs empower people to critically think about climate change? A learning outcome-based comparison of two MOOCs. *Journal of Cleaner Production*, v. 222, p. 12–21, 2019.

OVERPECK, J.; MEEHL, G. A.; BONY, S.; EASTERLING, D. R. Climate data challenges in the 21st century. *Science*, v. 331, n. 6018, p. 700–702, 2011.

OVEREM, A. et al. Crowdsourcing urban air temperatures from smartphone battery temperatures. *Geophysical Research Letters*, v. 40, n. 15, p. 4081–4085, 2013.

PASQUARÉ, F. A.; OPPIZZI, P. How do the media affect public perception of climate change and geohazards? An Italian case study. *Global and Planetary Change*, v. 90, p. 152–157, 2012.

PINTO, S.; CARVALHO, A. Cientistas, jornalistas e profissionais de comunicação: agentes na comunicação de ciência e tecnologia. *Observatorio (OBS*) *Journal*, v. 5, n. 3, 2011.

ROTH, M. Review of urban climate research in (sub)tropical regions. *International Journal of Climatology*, v. 27, p. 1859–1873, 2007.

SATO, K.; INOUE, J.; YAMAZAKI, A.; TOMIKAWA, Y.; SATO, K. Reduced error and uncertainty in analysis and forecasting in the Southern Hemisphere through assimilation of PANSY radar observations from Syowa Station: A midlatitude extreme cyclone case. *Quarterly Journal of the Royal Meteorological Society*, v. 148, p. 748, 2022.

SANTOS, R. C.; COSTA, K. F.; LOVATTO, J.; DA SILVA, L. A. M.; DO NASCIMENTOS, M. A.; SANCHES, A. C. Avaliação ambiental com informações climáticas mensuradas no local e dados disponíveis na rede. In: XLVIII Congresso Brasileiro de Engenharia Agrícola, Campinas, São Paulo, 2019. [Anais…]. s.l.: s.n.

SILVA, F. D. A. Ilha de calor urbana: diagnóstico como ferramenta de gestão ambiental urbana para a cidade de Coari (AM). 2020. 110 f. Dissertação (Mestrado em Engenharia de Produção) – Universidade Federal do Amazonas, Manaus, 2020.

SOMERVILLE, R. C.; HASSOL, S. J. Communicating the science of climate change. *Physics Today*, v. 64, p. 48–53, 2011.

STEWART, I. D.; OKE, T. R. Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, v. 93, p. 1879–1900, 2012.

VIEIRA ZEZZO, L.; PEREIRA COLTRI, P.; DUBREUIL, V. Microscale models and urban heat island studies: a systematic review. *Environmental Monitoring and Assessment*, v. 195, 1284, 2023.

VOOGT, J. A. How cities alter weather and climate. In: STRAHLER, A.; STRAHLER, A. (eds.). *Physical geography—science and systems of human environment.* 2. ed. New Delhi: Wiley, 2007.

WISE, S. B. Climate change in the classroom: patterns, motivations, and barriers to instruction among Colorado Science teachers. *Journal of Geoscience Education*, v. 58, n. 5, p. 297–309, 2010.

YOU, M.; LAI, R.; LIN, J.; ZHU, Z. Quantitative analysis of a spatial distribution and driving factors of the urban heat island effect: A case study of Fuzhou Central Area, China. *International Journal of Environmental Research and Public Health*, v. 18, 13088, 2021.

ZEZZO, L. V.; COLTRI, P. P. The dissemination of news about climate change: an analysis of the brazilian scenario in the last 50 years. *Revista Caminhos de Geografia*, v. 24, n. 94, p. 1–16, 2023.

ZHAO, L.; LEE, X.; SMITH, R. B.; OLESON, K. Strong contributions of local background climate to urban heat islands. *Nature*, v. 511, p. 216–219, 2014. DOI: 10.1038/s41598-018-25296-w

ANEXOS

- ## CAMINHOS DE GEOGRAFIA

Revista Caminhos de Geografia <caminhosdegeografia@ig.ufu.br>
para mim

sex., 6 de dez. de 2024, 09:55

Prezada Larissa,

Os autores que publicam na Revista Caminhos de Geografia mantêm os direitos autorais da publicação conforme a licença Creative Commons CC BY-NC-ND 4.0. De acordo com essa licença, os autores tem o direito de compartilhar o artigo em qualquer suporte ou formato, desde que seja dado o devido crédito à revista, que o artigo não sofra nenhuma modificação do seu conteúdo e que não seja utilizado para fins comerciais. Maiores detalhes estão disponíveis em: http://creativecommons.org/licenses/by-nc-nd/4.0/.

Assim, uma vez que a inserção do artigo como parte da tese atenda esses requisitos, os autores poderão realizá-la.

Desejamos sucesso na conclusão do seu doutoramento.

Qualquer dúvida, estamos à disposição.

Atenciosamente,

Equipe Editorial da Revista Caminhos de Geografia

- ## ENVIRONMENT MONITORING AND ASSESSMENT

Springer Nature Submissions<rheycel.monsanto@springernature.com>
To: You

Wed 11/20/2024 7:55 AM

Flagged

Dear Prof. Vieira Zezzo,

Manuscript Title: Exploring the Urban Heat Island Phenomenon in a Tropical Medium-Sized City: Insights for Sustainable Urban Development
Manuscript ID: d2ca7140-d363-410f-b82b-70d008936123 v2.0

Technical Check of your submission has now taken place. As a result, we need you to address the following points before your manuscript can progress any further:

1. Some Author Names provided in the submission system are not provided in the manuscript (Larissa Vieira Zezzo, Priscila Pereira Coltri, Vincent Dubreuil, Guilherme Almussa Leite Torres, Margarete Cristiane de Costa Trindade Amorim). Please make sure the information in the manuscript and in the submission system is identical, including the order in which authors are mentioned.
2. Please provide a Funding Declaration in the manuscript. If there was no Funding, please state so.
3. Kindly provide all of the author(s) email address, affiliation, country and city information in the title page of your manuscript.

Your paper has been placed back in the menu of the submitting author. We hope to receive your revised manuscript within 2 days from the receipt of this email. To access it, please use the following link, making sure you log in with the same email address you registered with:
https://submission.springernature.com/submission/f7d37595-feed-4d33-9d46-5d73caae991c

(Press/Click on the above link to be automatically sent to the web page.)

Please make the requested amendments carefully, before selecting the Submit manuscript button on the Review page. Do not change anything else in your manuscript.

Meanwhile, if you have any questions, please feel free to contact me.

Best regards,
Rheycel Monsanto
Editorial Support at Environmental Monitoring and Assessment

- **REVISTA *TERRAE DIDATICA***

Declaramos, a quem interessar possa, que a autora Larissa Vieira Zezzo, doutoranda no Instituto de Geociências da Universidade Estadual de Campinas (Unicamp), publicou em *Terræ Didatica* o seguinte Artigo:

Zezzo, L. V., Oliveira, J. P. de, & Coltri, P. P. (2020). Clima em jogo: uma ferramenta pedagógica para aprendizagem de conceitos em Geociências, com ênfase na Climatologia. *Terrae Didatica*, *16*(Publ. Contínua), e020003. doi: https://doi.org/10.20396/td.v16i0.8656203.

Os autores que publicam na revista *Terræ Didatica* preservam seus direiros autorais, nos termos da licença Creative Commons CC BY 4.0. De acordo com a licença, os autores têm o direito de compartilhar o trabalho em qualquer suporte ou formato, desde que seja dado o devido crédito à revista e que o artigo não sofra qualquer modificação em seu conteúdo.

Assim, se a inserção do artigo atender a esses requisitos, a autora poderá fazer uso do documento como parte da tese. Desejamos sucesso na conclusão do doutoramento.

Para os devidos fins, firmamos a presente.

gov.br Documento assinado digitalmente
CELSO DAL RE CARNEIRO
Data: 20/01/2025 10:49:09-0300
Verifique em https://validar.iti.gov.br

Prof. Dr. Celso Dal Ré Carneiro
Revista *Terræ Didatica*
IG-Unicamp
Editor-Chefe
E-mails: cedrec@unicamp.br, terraed@unicamp.br