FUTURE CLIMATE SCENARIOS FOR THE CUIABÁ RIVER VALLEY METROPOLITAN REGION: AN URBANIZATION PROCESS ANALYSIS

CENÁRIOS CLIMÁTICOS FUTUROS PARA A REGIÃO METROPOLITANA DO VALE DO RIO CUIABÁ: UMA ANÁLISE DO PROCESSO DE URBANIZAÇÃO

ESCENARIOS CLIMÁTICOS FUTUROS PARA LA REGIÓN METROPOLITANA DEL VALLE DEL RÍO CUIABÁ: UN ANÁLISIS DEL PROCESO DE URBANIZACIÓN

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ABSTRACT
This study analyzes the impacts of climate change in the Metropolitan Region of the Cuiabá River Valley (RMVRC) projecting future maximum temperature trends in response to ongoing urbanization. With a population of over one million people and a semi-humid tropical climate, the region faces a worrying scenario, where projections indicate a significant increase in temperature, which could reach up to 10 °C by the end of the century. The research uses data from the CNRM-ESM2-1 climate model, coupled with the SSP370 scenario obtained by the WorldClim platform, analyzing the evolution of maximum temperatures in the periods 2021-2040, 2041-2060, 2061-2080, 2081-2100. The results indicate that the urbanized areas of Baixada Cuiabana are likely to experience more intense warming, with average annual maximum temperatures reaching up to 38 °C by 2100. Furthermore, the analysis of the percentage increase relative to historical climate data shows that transitional months are projected to experience significant drying and warming, further exacerbating local climatic vulnerabilities These findings underscore the urgent need for targeted urban planning policies and integrated adaptation and mitigation strategies to reduce the impacts of climate change, protect the environment, and guarantee the quality of life for the population.

KEYWORDS
Urban heating, Sustainable planning, Climate emergency, Climate change, Baixada Cuiabana.

RESUMO
Este estudo analisa os impactos das mudanças climáticas na Região Metropolitana do Vale do Rio Cuiabá (RMVRC) projetando tendências futuras de temperaturas máximas em resposta à urbanização em curso. Com uma população de mais de um milhão de habitantes e um clima tropical semiúmido, a região enfrenta um cenário preocupante, onde as projeções indicam um aumento significativo da temperatura, que pode chegar a até 10 °C até o final do século. A pesquisa utiliza dados do modelo climático CNRM-ESM2-1, acoplados ao cenário SSP370 obtidos pela plataforma WorldClim, analisando a evolução das temperaturas máximas nos períodos 2021-2040, 2041-2060, 2061-2080, 2081-2100. Os resultados indicam que as áreas urbanizadas da Baixada Cuiabana provavelmente sofrerão um aquecimento mais intenso, com temperaturas máximas médias anuais atingindo até 38 °C até 2100. Além disso, a análise do aumento percentual em relação aos dados climáticos históricos mostra que os meses de transição devem apresentar seca e aquecimento significativos, exacerbando ainda mais as vulnerabilidades climáticas locais. Essas descobertas

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ressaltam a necessidade urgente de políticas de planejamento urbano direcionadas e estratégias integradas de adaptação e mitigação para reduzir os impactos das mudanças climáticas, proteger o meio ambiente e garantir a qualidade de vida da população.

PALAVRAS-CHAVE

Aquecimento urbano, Planejamento sustentável, Emergência climática, Mudanças climáticas, Baixada Cuiabana.

RESUMEN

Este estudio analiza los impactos del cambio climático en la Región Metropolitana del Valle del Río Cuiabá (RMVRC) y proyecta las tendencias futuras de las temperaturas máximas en respuesta a la urbanización en curso. Con una población de más de un millón de personas y un clima tropical semihúmedo, la región se enfrenta a un escenario preocupante, donde las proyecciones indican un aumento significativo de la temperatura, que podría alcanzar hasta 10 °C para finales de siglo. La investigación utiliza datos del modelo climático CNRM-ESM2-1, acoplados al escenario SSP370 obtenido por la plataforma WorldClim, analizando la evolución de las temperaturas máximas en los períodos 2021-2040, 2041-2060, 2061-2080 y 2081-2100. Los resultados indican que las áreas urbanizadas de Baixada Cuiabana probablemente experimenten un calentamiento más intenso, con temperaturas máximas anuales promedio que alcancen hasta 38 °C para 2100. Además, el análisis del aumento porcentual en relación con los datos climáticos históricos muestra que se proyecta que los meses de transición experimenten un secado y calentamiento significativos, lo que exacerbará aún más las vulnerabilidades climáticas locales. Estos hallazgos subrayan la necesidad urgente de políticas de planificación urbana específicas y estrategias integradas de adaptación y mitigación para reducir los impactos del cambio climático, proteger el medio ambiente y garantizar la calidad de vida de la población.

PALABRAS CLAVE

Calefacción urbana, Planificación sostenible, Emergencia climática, Cambio climático, Baixada Cuiabana.

1. INTRODUCTION

The ongoing urbanization of natural environments has changed local climate patterns and intensified the impacts of global climate change, becoming increasingly present in scientific discussions (Vélez-Nicolás et al., 2022; Yang et al., 2019). Extreme weather events, including droughts, heat waves, floods and inundations, whose frequency and intensity have increased, trigger a cascading effect on several sectors (Britto and Pessoa, 2023; Rosso et al., 2023). These phenomena are directly related to environmental degradation and changes in climate patterns, largely driven by human activities.

Urbanization is closely linked to economic and social development, but rapid urban growth, especially in low- and middle-income countries, poses significant challenges. The Global Urbanization Prospects Report (UN, 2018) highlights current and future trends in global urbanization. In 2018, 55% of the global population lived in urban areas, totaling 4.2 billion people, while 3.4 billion lived in rural areas. Urbanization has been increasing rapidly since 1950; in that year, only 30% of the world's population was urban. It is projected that by 2050, 68% of the world's population will be urban. Urbanization is expected to increase in all regions. These impacts will be particularly acute in places where urbanization is progressing rapidly without adequate planning and infrastructure to support growth, resulting in the expansion of cities and putting pressure on essential services such as water, energy, housing, mobility, urban ecosystems, public health, well-being and quality of life in cities.

In view of this, understanding changes in local climate patterns in future scenarios is essential to achieving sustainable development through integrated public policies that improve the lives of urban and rural residents. Espindola and Ribeiro (2020) analyzed master plans of Brazilian municipalities and found that, although documents prepared after 2015 mention climate mitigation and adaptation strategies, few consider local climate particularities. This scenario shows that climate change is still underestimated in municipal planning, compromising the ability of cities to effectively deal with extreme events.

This scenario is not restricted to Brazil. Araos et al. (2016) conducted a global survey on the incorporation of climate adaptation into urban planning and the implementation of adaptive measures. Analyzing 401 cities with more than one million inhabitants, they found that only 73 cities (18%) had some type of planning for adaptive policies, and only 61 (15%) had implemented concrete measures. These data highlight a significant gap in the integration of adaptive strategies, indicating that most cities are still not sufficiently prepared to face the impacts of climate change.

Although future climate projections involve uncertainties, recent years have already shown a significant increase in water stress, with water scarcity impacting several regions of the world. This essential resource plays a fundamental role in food production and human well-being (Moss et al., 2010; Vélez-Nicolás et al., 2022). Furthermore, Gasparrini et al. (2017) warn of the high risk of mortality associated with rising average temperatures, especially in hot climate regions such as Brazil. In densely populated urban areas with low vegetation cover, heat retention is more intense, aggravating the heat island phenomenon. This effect is due to the predominant use of materials with low reflectance, which absorb and retain heat, raising surface temperatures and intensifying the warming of the urban environment (Carvalho et al., 2017).

Li and Bou-Zeid (2013) observed that heat waves have become more frequent, intense and long-lasting, aggravated by air pollution resulting from traffic and industrial activity. In this context, the Sustainable Development Goals (SDGs), established by the United Nations (2015), reinforce the importance of planning sustainable cities and communities, with emphasis on SDG 11. Anticipating future challenges is essential for implementing effective solutions in the short, medium and long term, promoting urban resilience and sustainability.

In general, climate change has an impact on the urban environment, making adaptation and mitigation strategies essential to reduce its effects. The Intergovernmental Panel on Climate Change (IPCC) proposes several adaptation and mitigation possibilities applicable to different local contexts (Core Writing Team, Pachauri and Meyer, 2014). For adaptation strategies to be truly effective, it is essential that they consider the particularities of each city, integrating socioeconomic, environmental and infrastructural factors. Mitigating the adverse effects of climate change strengthens the capacity of cities to respond to future challenges, promoting urban resilience.

Thus, global climate models, developed in the 1960s, emerge as mathematical tools capable of simulating the dynamics of the interaction between the atmosphere, biosphere, cryosphere, ocean and land surface, allowing the prediction of future scenarios of climate variables. The application of these models in urban studies has become essential to assess the impacts of climate change on the expansion of cities and guide urban planning strategies (IPCC, 2021). Research indicates that future climate scenarios influence the distribution and intensity of extreme events, such as floods and heat waves, increasing vulnerabilities in densely populated areas (Nobre et al., 2010). Therefore, understanding these projections is crucial for the development of more resilient cities adapted to emerging climate challenges.

To assess future climate change scenarios, global databases have been widely used as references in climate studies, as demonstrated in the research by Karger et al. (2020) and Title and Bemmerls (2018). Among these databases, WorldClim stands out as the most cited collection, being regularly updated and widely used in climate modeling (Noce, Caporaso and Santini, 2020).

Among global climate models (GCMs), CNRM-ESM2-1, developed by the Centre National de Recherches Météorologiques (CNRM), stands out for its ability to represent atmospheric and oceanic processes under different global warming scenarios. Its application in tropical regions is especially relevant, as the model simulates precipitation patterns, climate variability and atmospheric circulation with greater precision, factors essential for assessing the impacts of climate change in areas vulnerable to extreme events, such as droughts and floods (Séférian et al., 2019).

Coupled with climate models are Shared Socioeconomic Pathways (SSPs), a set of five narratives that represent different trajectories of socioeconomic development and their challenges for climate change mitigation and adaptation (O'Neill et al., 2014; Kriegler et al., 2014). SSPs describe alternative scenarios that include: sustainable development (SSP1) (Van Vuuren et al., 2017), an intermediate pattern of development (SSP2) (Fricko et al., 2017), regional fragmentation and socioeconomic instability (SSP3) (Fujimori et al., 2017), rising inequality between and within regions (SSP4) (Calvin et al., 2017), and fossil fuel-driven economic development (SSP5) (Kriegler et al., 2014). These scenarios are essential for assessing the potential impacts of climate change and guiding adaptation and mitigation policies in different global contexts.

In this context, this study aims to analyze the projections of future climate scenarios for the Metropolitan Region of the Cuiabá River Valley, using the CNRM-ESM2-1 climate model under the SSP370 socioeconomic pathway. The research seeks to understand the impacts of climate change in the region and highlight the urgency of effective public policies to mitigate extreme climate events. In addition, this study proposes a balance between human demands and the preservation of the natural environment, contributing to the improvement of the quality of life and well-being of the local population.

2. METHODOLOGY

2.1. Location and Description of the Study Region

This study analyzed projections of future climate change in the state of Mato Grosso, focusing on the municipalities that make up the Cuiabá River Valley Metropolitan Region (RMVRC). The RMVRC covers the cities of Cuiabá, Várzea Grande, Acorizal, Chapada dos Guimarães, Nossa Senhora do Livramento, Santo Antônio de Leverger and Campo Verde, which was included in the region in 2024 (ALMT, 2024) (Figure 1).

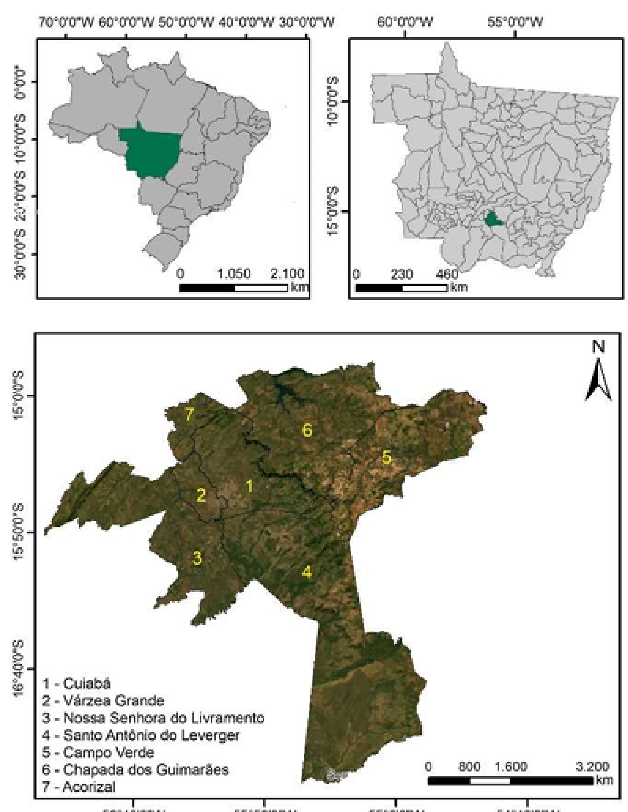

Figure 1: Location of municipalities within the Cuiabá River Valley Metropolitan Region (RMVRC) in the state of Mato Grosso, Brazil.
Source: The authors, 2025.

The RMVRC has a population of over 1 million inhabitants and an approximate territorial area of 68,022.1 km² (IBGE, 2024), distributed as per Table 1.

Munici-pality	Population	Population Density (hab/km²)	Altitude (m)
Acorizal	5.014	5,89	170
Campo Verde	44.585	9,35	736
Chapada dos Guimarães	18.990	2,88	798
Cuiabá	650.877	150,41	165
Nossa Senhora do Livramento	12.940	2,34	232
Santo Antônio do Leverger	15.246	1,61	141
Várzea Grande	300.078	414,31	190

Table 1: Population, demographic density and altitude of the municipalities of RMVRC, Mato Grosso.
Source: The Authors, 2024.

According to the Köppen climate classification (Beck et al., 2018), the region analyzed in the study has a semi-humid tropical climate (Aw), characterized by two well-defined seasons: a rainy season (November to April) and a dry season (May to September), corresponding to summer and winter, respectively.

2.2. Projection of future scenarios

In this study, future temperature projections were evaluated for the period 2021 to 2100, classified by time slices: 2021–2040, 2041–2060, 2061–2080 and 2081–2100. The data were obtained from the WorldClim database - version 2, from the coupled climate model CNRM-ESM2-1, part of phase 6 of the Coupled Model Intercomparison Project (CMIP6). The study considered the Shared Socio-Economic Pathway (SSP) 370, with a radiative forcing of 7.0 W/m² and a spatial resolution of 30 seconds (~1 km²).

The dataset was pre-processed using ArcGIS software, and the study area was clipped to the RMVRC boundaries. Then, the monthly values of maximum air temperature were extracted, calculating the final average for each period of analysis. The results were represented in four comparative maps, allowing visualization of the spatial variation of temperature over the different time intervals. The flowchart of the steps is presented in Figure 2.

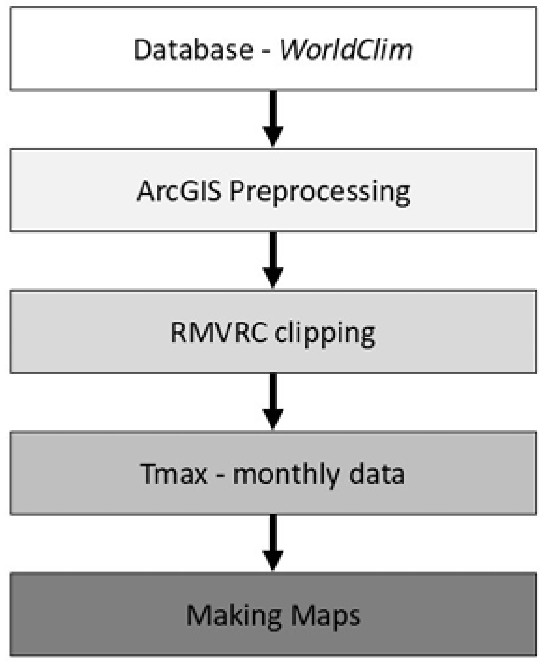

Figure 2: Flowchart of simulation of future scenarios.
Source: The authors, 2025.

A box plot graph was generated to analyze the percentage increase in maximum temperature over time. The comparison considered historical climate data (1970-2000), obtained through the WorldClim platform, and monthly maximum temperature projections for the period 2021 to 2100. This approach allowed us to identify seasonal variations in temperature rise, highlighting warming trends and possible climate impacts on the RMVRC.

3. RESULTS AND DISCUSSION

Figure 3 presents the thermal maps of average annual maximum temperature projected by the analyzed climate model, considering the periods 2021–2040, 2041–2060, 2061–2080 and 2081–2100 in the municipalities of the RMVRC. The analysis of the evolution of the maximum temperature over these intervals indicated a significant warming trend, with an estimated increase of around 10 °C between the initial period (2021–2040) and the final period (2081–2100) (Figure 3).

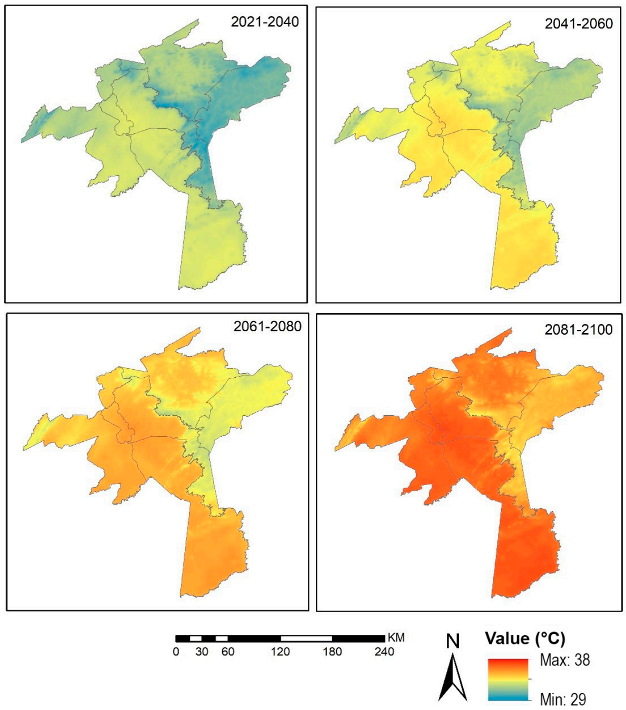

Figure 3: Average annual maximum temperature (°C) estimated by the CNRM-ESM2-1 SSP 370 model in the periods 2021–2040/2041–2060/2061–2080/2081–2100 in the Cuiabá River Valley Metropolitan Region (RMVRC) in the state of Mato Grosso, Brazil.
Source: The authors, 2024.

In the period 2021-2040, greens and blues predominate, indicating more moderate maximum temperatures, around 29 °C. In the period 2041-2060, a gradual increase is observed, with a greater presence of areas in yellow tones, signaling the intensification of urban warming. In the period 2061-2080, the trend of thermal elevation becomes more expressive, with large areas in orange tones, representing temperatures around 35 °C. Finally, in the period 2081-2100, there is a predominance of red tones, indicating that maximum temperatures may reach approximately 38 °C.

Topography and elevation play a fundamental role in the thermal behavior of a region, influencing the spatial distribution of air temperature. Studies such as those by Pepin et al. (2015) and Li et al. (2019) demonstrate that higher altitude areas tend to have lower temperatures due to the decrease in atmospheric pressure and air density, which reduce the capacity to retain heat. In addition, variations in relief can affect local patterns of atmospheric circulation, condensation, and cloud cover, modulating ambient temperature and humidity. In the RMVRC, cities located in the upper eastern portion, such as Chapada dos Guimarães and Campo Verde, show a more moderate temperature increase compared to the region called "Baixada Cuiabana", which includes the municipalities of Cuiabá, Várzea Grande, Santo Antônio do Leverger, Nossa Senhora do Livramento, and Acorizal, where projected warming is intense. However, even with less intense temperature variations, according to Vieira et al. (2024) precipitation and air temperature data already show that Campo Verde faces significant water challenges.

Furthermore, accelerated urbanization, one of the main factors responsible for local climate change, occurs more intensely in cities with consolidated infrastructure and greater regional connectivity (Sarzynski et al., 2006). This process contributes to the formation of a radial gradient of warming around the Cuiabá-Várzea Grande urban agglomeration, where urban expansion intensifies heat retention and alters local climate patterns.

Among the municipalities of the RMVRC, the case of Santo Antônio do Leverger stands out, located in the southern portion of the region, which has shown significant warming over the analyzed periods. This increase is directly related to the urban expansion of Cuiabá, which boosted the growth and densification of the neighboring municipality. The projected overall increase in maximum temperature for the region analyzed, considering all months of the year, is around 12% to 14% (Figure 4).

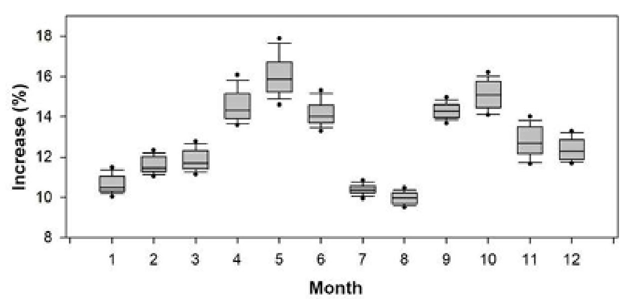

Figure 4: Monthly increase (%) in average maximum temperature in the Cuiabá River Valley Metropolitan Region (RMVRC) in the state of Mato Grosso, Brazil.
Source: The authors, 2024.

Despite the general increase in temperature, the months with the highest precipitation intensity (November to March) show relatively less warming, with percentages ranging from 10 to 12%. However, even in these periods, the projected increase remains significant. This behavior can be explained by the role of precipitation in heat redistribution, as reported by Trenberth, Fasullo and Kiehl (2009), who, when analyzing the global energy balance, observed that precipitation contributes to thermal dissipation, promoting a temporary reduction in local temperature.

However, the months of climatic transition, such as May and October, show more significant increases, around 17 to 18%, as shown in Figure 4. These months are considered transition periods between the hot-rainy and hot-dry seasons (Maitelli, 1994). This behavior corroborates those found by Alves (2022), who states that the hot-dry period will be extended, with the conversion of the transition months into periods of greater water scarcity.

4. CONCLUSION

In conclusion, the results of this study reveal an alarming scenario of warming in the Metropolitan Region of the Cuiabá River Valley (RMVRC) in the coming decades. Projections indicate that, between 2021 and 2100, the maximum temperature could increase by up to 10°C, with spatial variations influenced by the topography and the degree of urbanization of the region.

The Baixada Cuiabana, which includes Cuiabá and Várzea Grande, tends to face more intense warming, amplified by the rapid process of urban growth and the expansion of interconnected urban areas. The closer the area is to the central urbanized areas, the greater the temperature increase will be, reinforcing the impact of the urban heat island phenomenon.

Given this context, it is urgent to think of strategies to mitigate the impacts of this warming. Cuiabá is the capital of Mato Grosso, known nationally as one of the hottest cities in Brazil. Therefore, understanding the effects of climate change in the RMVRC will be essential for the development of effective public policies, capable of containing the advances of global warming and ensuring the improvement of the population's quality of life.

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NSS: project administration, resources, Writing – review & editing, conceptualization
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FFGP: conceptualization, formal analysis, Investigation, methodology, visualization,
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AFOS: investigation, methodology, formal analysis, and writing – original draft.

DCJP: conceptualization, formal analysis, methodology, and writing – original draft.

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