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Research paper

Water vulnerability and environmental impacts in the State of Mato Grosso

Vulnerabilidade Hídrica e Impactos Ambientais no Estado de Mato Grosso

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ABSTRACT: In recent decades, Brazilian tropical regions have experienced a significant reduction in the water surface area, driven by environmental and anthropogenic factors, and the state of Mato Grosso is no exception, as it hosts three biomes (Cerrado, Pantanal, and Amazon). Concerned about climate change and its effects on geo-hydrology, this study aimed to diagnose the water surface in the municipalities of the state of Mato Grosso. We used the AdaptaBrasil and MapBiomas platforms to identify the most vulnerable areas to geo-hydrological disasters and drought. The analysis showed that the geo-hydrological vulnerability index for the state is high (0.69), with 56% of the municipalities at high risk. On the other hand, the drought vulnerability index was low, with an average of 0.26, and 61% of the municipalities were at low risk of drought. Although drought vulnerability is relatively low compared to geo-hydrological vulnerability, significant challenges persist, especially in municipalities with unregulated population growth and inadequate water resource management. Municipalities such as Colniza, Cotriguaçu, and Serra Nova Dourada are highly vulnerable to geo-hydrological conditions, while Várzea Grande, Nova Guarita, and Cuiabá are vulnerable to drought. This study emphasizes the urgent need to implement conservation measures and sustainable water resource management, including the restoration of degraded areas and the protection of remaining forests. Additionally, it is suggested that integrating state policies with federal initiatives could strengthen the state's resilience to climate change.

Keywords: climate change, geo-hydrology, drought, tropical environment.

RESUMO: *Nas últimas décadas as regiões tropicais brasileiras têm apresentado uma redução significativa na superfície hídrica, impulsionada por fatores ambientais e antrópicos, e no estado de Mato Grosso esta situação não é diferente, visto que este estado abriga três biomas (Cerrado, Pantanal e Amazônia). Preocupados com as mudanças climáticas e seus efeitos na geo-hidrologia, este trabalho teve como objetivo realizar um diagnóstico dos municípios do estado de Mato Grosso no que se refere à superfície hídrica. Utilizamos as plataformas AdaptaBrasil e MapBiomas para identificar as áreas mais vulneráveis a desastres geo-hidrológicos e à seca. A análise mostrou que o índice de vulnerabilidade geo-hidrológica é alto para o estado (0,69) com 56% dos municípios em alto risco. Já o índice de vulnerabilidade à seca se mostrou baixo, com uma média de 0,26, com 61% dos municípios com baixo risco à seca. Apesar da vulnerabilidade à seca ser relativamente baixa em comparação com a vulnerabilidade geo-hidrológica, desafios significativos persistem, especialmente em municípios com crescimento populacional desordenado e gestão inadequada dos recursos hídricos. Municípios como Colniza, Cotriguaçu e Serra Nova Dourada são altamente vulneráveis às condições geo-hidrológicas, enquanto Várzea Grande, Nova Guarita e Cuiabá são vulneráveis à seca. Este trabalho enfatiza a necessidade urgente de implementar medidas de conservação e gestão sustentável dos recursos hídricos, incluindo a restauração de áreas degradadas e a proteção das florestas remanescentes. Além disso, sugere-se que a integração de políticas estaduais com iniciativas federais possa fortalecer a resiliência do estado diante das mudanças climáticas.*

Palavras-chave*: mudanças climáticas, geo-hidrologia, seca, ambiente tropical.*

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INTRODUCTION

Tropical regions, including the state of Mato Grosso in Brazil, have faced a significant reduction in water surface area over the past few decades. This phenomenon can be attributed to several environmental factors that directly affect water resources, such as global climate change, intensive land use for agricultural activities, accelerated deforestation, and alterations in precipitation patterns (Marengo *et al*., 2020; Ikeda-Castrillon *et al*., 2022). With continued anthropogenic pressure and climate change, a comprehensive understanding of these factors and their interactions is essential for developing effective water resource conservation and management strategies in the region (Malhi *et al*., 2008).

Climate change has significantly altered the hydrological regime in several parts of the world, including Brazil. Projections indicate that rising global temperatures and climate variability are associated with changes in precipitation, intensifying both dry and flood periods (IPCC, 2014). In the context of Mato Grosso, these climate changes have led to a notable reduction in the water surface, affecting aquatic biodiversity, agriculture, and the water supply for the population (Marengo *et al*., 2021; Lázaro; *et al*., 2020).

In addition to climate change, land use plays a crucial role in the dynamics of water resources. The conversion of native forests to pasture and crop areas has been one of the principal causes of changes in the hydrological cycle in the Amazon and other tropical regions. Studies show that this change in land use alters evapotranspiration and surface runoff, leading to a decrease in the available water surface (Davidson *et al*., 2012). In Mato Grosso, deforestation associated with agricultural expansion has contributed significantly to the reduction of water surface areas, with direct implications for freshwater availability (Silvério *et al*., 2015). These authors highlight that deforestation is a crucial factor that negatively impacts water resources. Removing native vegetation reduces the land's ability to retain water and affects the regional hydrological cycle, increasing the frequency and intensity of drought events. Furthermore, vegetation plays an essential role in maintaining the local microclimate and regulating water flows, meaning that its loss can have long-lasting and potentially irreversible consequences for the water resources in the region.

Given these challenges, the need to implement conservative measures and integrated management of water resources is evident, especially considering the condition of ecological, social, and economic transition in Mato Grosso. Strategies that include the restoration of degraded areas, the protection of remaining forests, and the sustainable management of land use are fundamental to mitigate the negative effects of environmental changes on the water surface in Mato Grosso. Thus, this work aims to identify the municipalities in Mato Grosso with the greatest geo-hydrological and drought vulnerabilities, to promote the direction and establishment of public policies for the region.

METHODOLOGICAL PROCEDURES

The vulnerability analysis of municipalities in Mato Grosso used the AdaptaBrasil platform (https://adaptabrasil.mcti.gov.br/), which was developed by the Ministry of Science, Technology, and Innovation (MCTI), to assess the vulnerability of Brazilian municipalities to natural disasters and climate change. The platform integrates several socioeconomic, environmental, and risk exposure indicators, providing a comprehensive and detailed assessment of the resilience of municipalities.

The AdaptaBrasil platform presents specific indicators that measure vulnerability to

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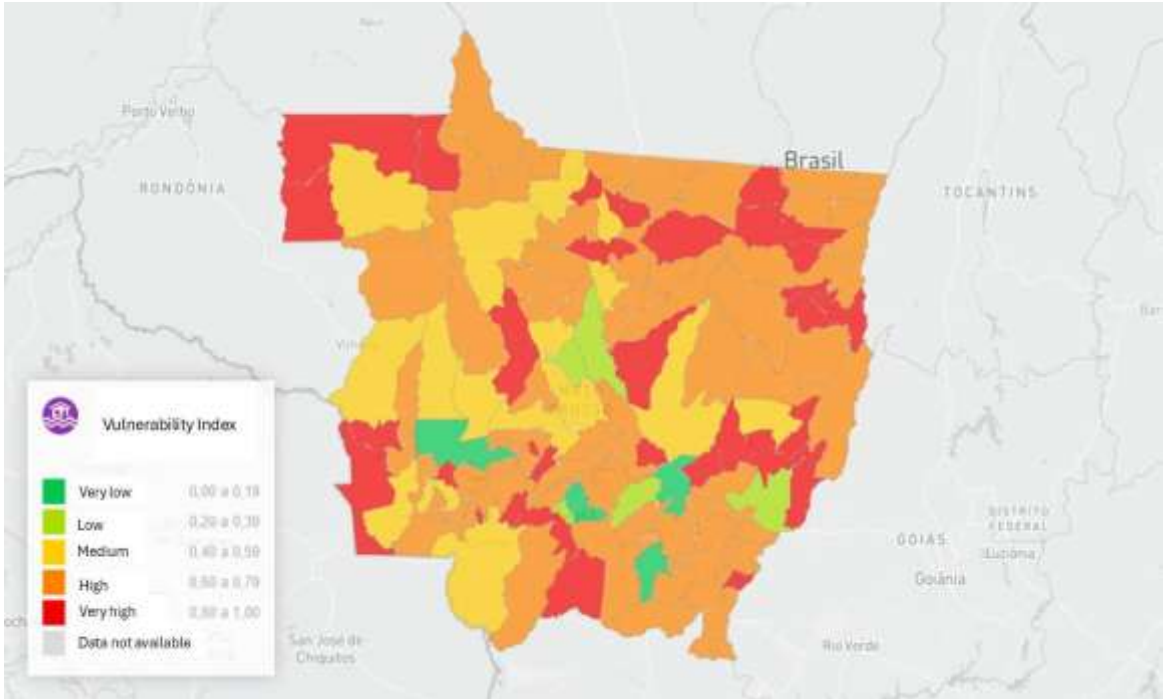
geo-hydrological disasters, including socioeconomic indicators - Human Development Index (HDI), per capita income and urbanization rate -, environmental indicators, forest cover, land use and occurrence of natural disasters (such as floods and landslides), and infrastructure indicators, such as health infrastructure, basic sanitation and access to public services. Through these indicators, the platform offers a vulnerability index that varies from 0 to 1, with values closer to 1 indicating higher vulnerability. The vulnerability rating has five categories: Very Low, Low, Medium, High, and Very High. Water surface data were obtained from the MapBiomas platform (https://plataforma.brasil.mapbiomas.org/agua) and compared over decades (1985-2022).

The analysis was conducted based on data from the two platforms to diagnose municipalities in Mato Grosso that are susceptible, in addition to the tendency to reduce the water surface. The analyses used Excel © software (Microsoft Corporation) and Python © language (Python Software Foundation) with the libraries Pandas (The pandas development team) and Matplotlib (Hunter, 2007) to plot the results.

RESULTS AND DISCUSSIONS

Mato Grosso has significant diversity in the vulnerability indices of its municipalities, reflecting the socioeconomic, environmental, and infrastructure variations throughout the territory. The indexes, calculated from the combination of these factors, provide a measure of the susceptibility of municipalities to natural disasters, especially those related to geo-hydrological events, such as floods and landslides (**Figure 1**). The average geo-hydrological vulnerability index for Mato Grosso is approximately 0.689. In general, 56.74% of the state's municipalities are categorized as high risk, 4.82% as very high risk, 3.55% as low risk, and 2.84% as very low risk.

Figure 1. Geo-hydrological vulnerability of municipalities in Mato Grosso



Source: https://sistema.adaptabrasil.mcti.gov.br/, 2024.

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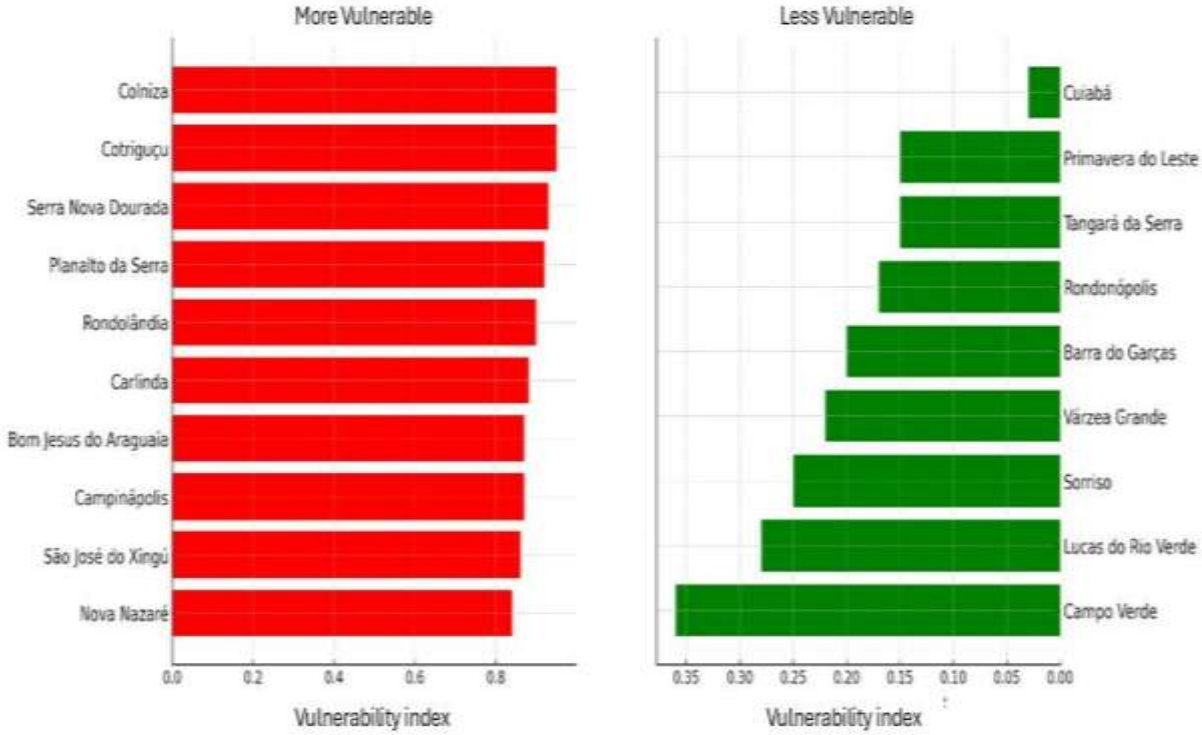
The analysis of the municipalities of Mato Grosso demonstrated an important contrast in vulnerability indices, highlighting the municipalities most and least exposed to geo-hydrological disasters (**Figure 2**). In this case, the most vulnerable municipalities are predominantly located in regions with socioeconomic and environmental challenges. Among the ten most vulnerable, the following stand out: Colniza, Cotriguçu, Serra Nova Dourada, Planalto da Serra, and Rondolândia. These municipalities have vulnerability rates above 0.90 and are classified as having a "Very High" risk. Infrastructure conditions, exposure to environmental risks, and low response capacity to natural disasters are factors that likely contribute to this high vulnerability.

On the other hand, less vulnerable municipalities demonstrate higher resilience, possibly due to better socioeconomic conditions and more robust infrastructure. Cuiabá, Tangará da Serra, Rondonópolis, Várzea Grande, and Barra do Garças are among the ten least vulnerable and have very low vulnerability rates. These municipalities, which are more developed urban centers, have a better capacity to prevent and respond to disasters, which is reflected in the low vulnerability rates.

This comparison between the most and least vulnerable municipalities demonstrates a disparity in security and resilience conditions within the state. While some municipalities face major challenges in mitigating the risks associated with natural disasters, others are better prepared, with infrastructure and resources that contribute to protecting the population.

Figure 2. Comparison between the municipalities in Mato Grosso that are most and least vulnerable to geo-hydrological disasters in 2015



Source: prepared by the authors based on the platform https://sistema.adaptabrasil.mcti.gov.br/, 2024.

However, when we consider vulnerabilities related only to drought, the scenario changes drastically (**Figure 3**). The average drought vulnerability index for Mato Grosso is approximately 0.290. This value reflects a relatively low vulnerability to drought compared to

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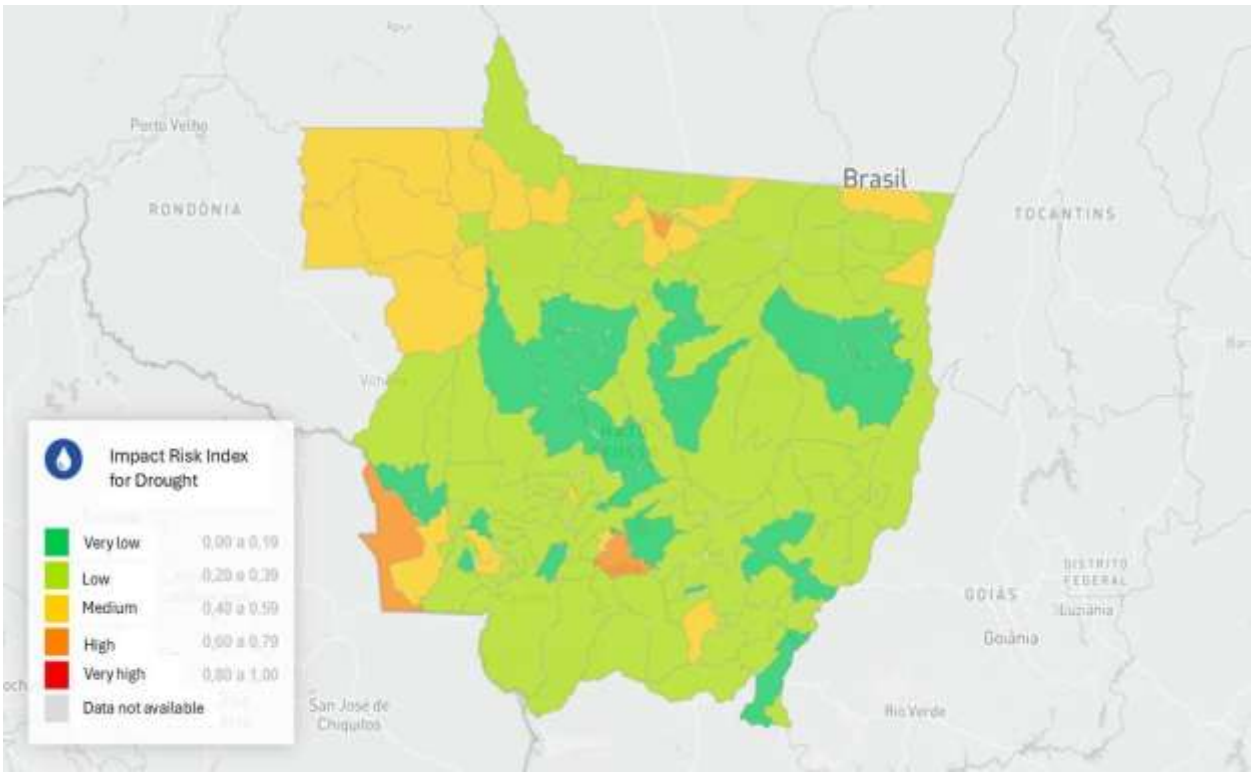
geo-hydrological vulnerability. Still, concerning vulnerability to drought, most municipalities in the state are categorized as having low (61%) and very low (22%) risk. Few are categorized as medium (14%) and high (2.8%) risk, and none as very high.

Figure 3. Vulnerability to drought in municipalities in Mato Grosso



Source: https://sistema.adaptabrasil.mcti.gov.br/, 2024.

Municipalities with higher vulnerability to drought presented high rates, which indicates higher susceptibility to the negative impacts of drought events (**Figure 4**). Among the most vulnerable municipalities are Várzea Grande, Cuiabá, Vila Bela da Santíssima Trindade, Rondolândia, and Aripuanã. These municipalities face significant challenges, including limitations in water infrastructure and greater exposure to adverse weather conditions. The high vulnerability in these locations can be attributed to disorderly population growth, inadequate management of water resources, and climate variability. For example, Várzea Grande and Cuiabá are important urban centers in the state and have shown high levels of vulnerability to drought, possibly due to pressure on water resources caused by rapid urbanization and intensive water use.

On the other hand, municipalities less vulnerable to drought, such as Itanhangá, Porto dos Gaúchos, Chapada dos Guimarães, Cotriguaçu, Nova Lacerda, and Conquista D'Oeste, presented very low vulnerability rates, with the last two having a zero rate. These municipalities demonstrate higher resilience, possibly due to their lower population density, efficient water resource management, and lower exposure to extreme drought conditions. Chapada dos Guimarães, for example, is a region known for its natural beauty and tourist attractions and has shown low vulnerability to drought, possibly due to its geographic location and preserved areas that contribute to maintaining the local water cycle. Even though a state of water emergency was declared in August 2024 for 120 days, this municipality still has a

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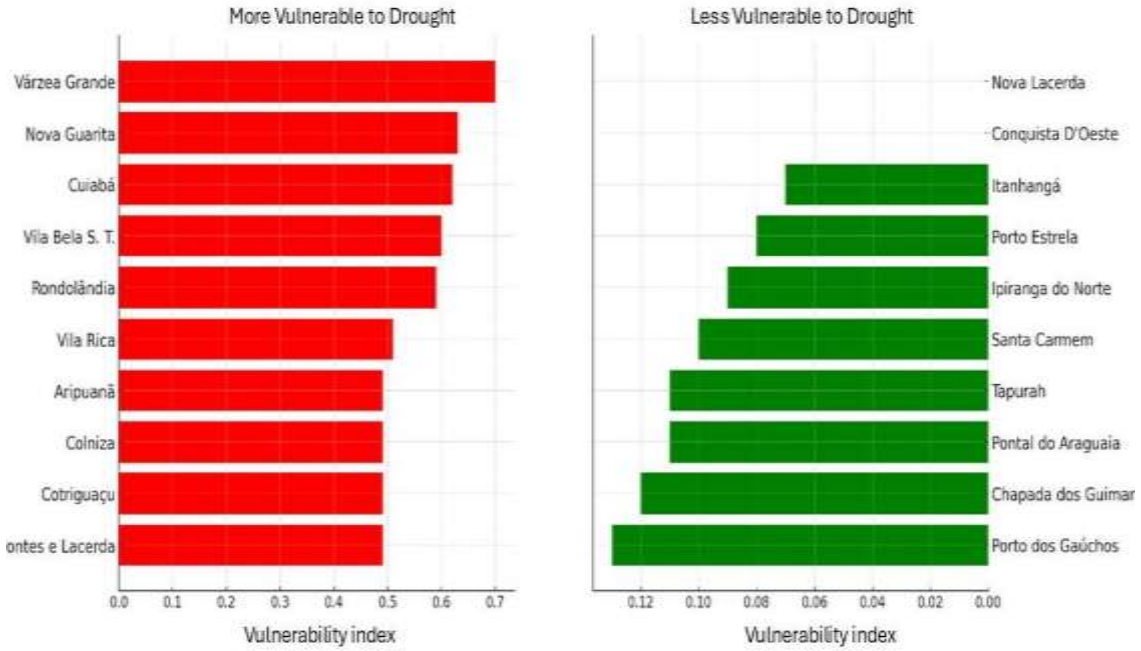
very large resource from the various springs in the surrounding area. This state of emergency is due to the water crisis that the State of Mato Grosso is facing in 2024.

Figure 4. Comparison between the municipalities in Mato Grosso that were most and least vulnerable to drought in 2015



Source: prepared by the authors based on the platform https://sistema.adaptabrasil.mcti.gov.br/, 2024.

The general vulnerability index encompasses a wide range of factors, including socioeconomic, environmental, and infrastructure, while the drought vulnerability index focuses exclusively on the susceptibility of municipalities to drought events. When comparing these two factors, it is possible to observe that in Mato Grosso, it is possible to diagnose that some municipalities, such as Várzea Grande and Rondolândia, have high vulnerability in both measures. However, Cuiabá, the state capital, demonstrates a peculiar situation: it is among the least vulnerable in the general index with a relatively robust infrastructure and a diversified economy, and it appears as one of the most vulnerable to drought. Cuiabá has a low overall vulnerability index, indicating significant socioeconomic resilience. However, when exclusively analyzing vulnerability to drought, the municipality stands out negatively, with an index of 0.62. This contrast points to specific challenges in water resource management in a rapidly growing urban context, where pressure on water supply systems is intense.

The contrast between the high geo-hydrological vulnerability and the low vulnerability to drought in Mato Grosso can also be understood through the analysis of socioeconomic, environmental, and infrastructure aspects. The Amazon region, characterized by a humid climate and abundant water resources, has a crucial role in minimizing the impacts of drought. On the other hand, the state's geology and topography, associated with powerful rivers and significant deforestation, increase the risk of geo-hydrological disasters, such as floods and landslides. Deforestation, combined with agricultural expansion, changes water absorption and surface runoff patterns, contributing to environmental vulnerability. At the same time, the presence of large river basins and the natural resilience of biomes such as the Cerrado

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contribute to mitigating the effects of drought, justifying the lower vulnerability to this phenomenon.

This duality in environmental vulnerability requires a complex approach in the formulation of public policies and allocation of resources, with the aim of promoting effective and sustainable management of water resources and territory.

Public policies must prioritize the prevention and mitigation of natural disasters, such as floods, landslides, and erosion, focusing on the construction of adequate infrastructure, mapping risk areas, and regulating land use. Furthermore, investment in improved monitoring and warning systems is essential, as well as protection and recovery of natural areas, including riparian forests and springs, to reduce surface runoff and improve water infiltration. The adoption of strict sustainable land use policies is imperative to avoid deforestation and agricultural practices in highly vulnerable areas. Urban planning must be conducted considering geo-hydrological vulnerability, avoiding construction in risky areas and promoting resilient practices and efficient management of rainwater. Finally, it is essential to invest in training local technicians and managers and involving communities in risk management to increase the effectiveness of public policies. These policies must be continually updated and reviewed to ensure their effectiveness in new and emerging challenges.

It is important to highlight that Mato Grosso, in general, has had a water surface deficit in recent years. In a temporal analysis, there has been a significant reduction over the last few decades. When comparing the average water surface area between the first and last decade studied (1980 and 2010), there was a decrease of 49.73% (**Figure 5**).

This reduction by almost half reflects environmental changes that may be associated with several factors, such as climate change, land use, deforestation, and changes in precipitation patterns. Studies show climate change has significantly impacted water resources in several regions, including Brazil, leading to a higher frequency of extreme events and changes in rainfall distribution (Marengo *et al*., 2020). Furthermore, land use, especially the conversion of forests to agricultural areas, has altered the hydrological cycle, contributing to the reduction of water surface areas (Davidson *et al*., 2012). Deforestation, in particular, directly affects evapotranspiration and surface runoff, affecting water availability (Silvério *et al*., 2015). Finally, changes in precipitation patterns observed in regional studies are also factors to be considered to understand the decrease in water surface in tropical regions (Espinoza *et al*., 2019).

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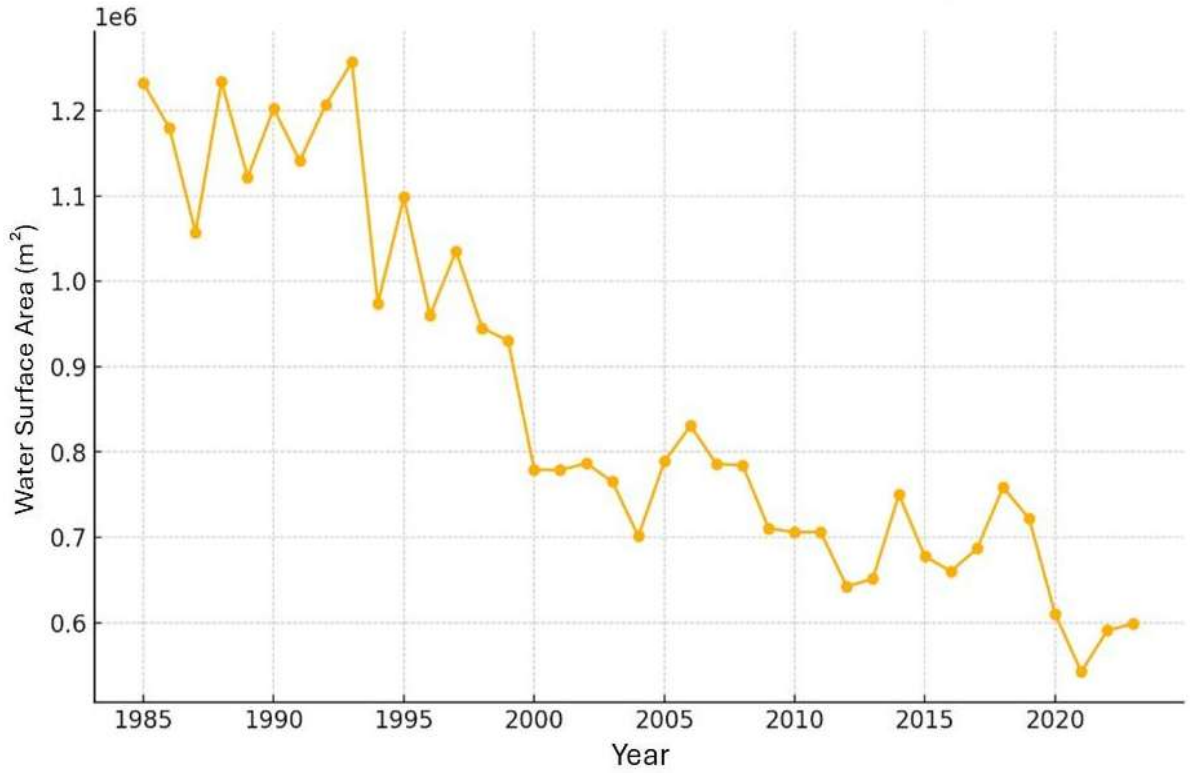
Figure 5. Water dynamics of Mato Grosso from 1985 to 2022. Note the drastic reduction in the water surface area (m^2) over 35 years



Source: prepared by the authors based on the platform https://plataforma.brasil.mapbiomas.org/agua, 2024.

When we compare Mato Grosso with other regions of Brazil, such as the Northeast (known for its high vulnerability to drought), we discover that the situation is different but equally worrying. Municipalities in Ceará have high rates of vulnerability to drought, often above 0.80, due to the semi-arid climate and water scarcity. As discussed by De Sousa *et a*l. (2017), the implementation of cisterns, underground dams, and coexistence practices in the semi-arid region have been crucial to reducing the impacts of drought. Despite having a different climate and more abundant water resources, Mato Grosso is beginning to present similar challenges, especially in areas of agricultural expansion.

In the Southeast region, which includes states such as São Paulo and Minas Gerais, vulnerability to drought has increased in recent years due to the growing demand for water in densely populated urban areas. In São Paulo, during the 2014-2015 water crisis, many municipalities faced serious challenges in guaranteeing water supply (Marengo *et al*., 2015). Although São Paulo has an advanced infrastructure, the overload on the system due to the lack of prolonged rainfall has revealed significant vulnerabilities. Comparatively, cities like Cuiabá in Mato Grosso face a similar risk, where urban infrastructure, although developed, may not be sufficient to deal with prolonged droughts if effective water management policies are not implemented.

The Amazon and Pantanal regions, known for their vast biodiversity and rich water resources, are currently facing a worrying water deficit. This phenomenon, driven by climate change and anthropogenic pressure, has the potential to trigger large-scale environmental and socioeconomic impacts. In recent studies, Lázaro *et al*. (2020) and Ikeda-Castrillon *et al*.

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(2022) confirm the gravity of the situation, reinforcing the need for immediate actions to mitigate these effects.

The Amazon, the world's largest tropical forest, is crucial in regulating the global water cycle. However, in recent years, exacerbated by deforestation and climate change, the region has also faced a significant decrease in water availability. Davidson *et al*. (2012) highlight that continuous deforestation and the conversion of forest areas into pastures have altered the hydrological cycle of the Amazon, resulting in a reduction in precipitation and an increase in evapotranspiration.

The Pantanal, the largest floodplain in the world, is also not immune to these challenges. Recent studies indicate a significant change in flood and drought patterns, with direct implications for biodiversity and economic activities in the region. Ikeda-Castrillon *et al*. (2022) demonstrate that the Pantanal has experienced increasingly severe and prolonged droughts, which has led to the degradation of natural habitats, which could have a cascading effect on several other activities in the region.

The water deficit in the Amazon and Pantanal regions affects the environment, local communities, and the regional economy. Water scarcity compromises agriculture, fishing, tourism, and other activities that directly depend on water resources. Furthermore, the reduction in the availability of drinking water poses a growing risk to public health.

Marengo *et al*. (2021) and Lapola *et al*. (2018) emphasize that, without coordinated action to mitigate the effects of climate change and protect water resources, these regions will face increasingly challenges. It is necessary to note that public policies must be implemented to promote the sustainable use of natural resources, restore degraded ecosystems, and strengthen the resilience of local communities. Some aspects to be considered include the integration of traditional sustainable management practices, combined with modern water monitoring and management technologies, which can offer effective solutions to mitigate the impacts of water deficit. Furthermore, cooperation between governments, non-governmental organizations, and local communities will be essential to face the challenges posed by this new climate scenario.

CONCLUSIONS

The results of this study identify the geo-hydrological and drought vulnerabilities in Mato Grosso, highlighting the importance of public policies that regard both the general vulnerability index and the specific index for water deficit. The implementation of rainwater harvesting systems, improvements in supply infrastructure, and promotion of agricultural practices that conserve water are essential in mitigating the effects of droughts in the most vulnerable areas.

The integration of state policies with federal initiatives, such as those implemented in the semi-arid Northeast, can strengthen Mato Grosso's resilience in the face of climate change. These results are crucial for directing and establishing public policies and infrastructure investments, focusing mainly on the most vulnerable municipalities, in order to reduce regional inequalities and increase the resilience of the entire state.

While AdaptaBrasil data provides a comprehensive view, it is essential to consider that specific local conditions may not have been fully captured. Therefore, it is recommended that complementary field studies be conducted in highly vulnerable municipalities and that less vulnerable municipalities be continuously monitored, ensuring that they maintain their resilience in the face of climate change and land use. Thus, this study offers a solid basis for

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directing public policies and infrastructure investments, promoting better regional equity.

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