

Spatiotemporal Analysis of Wetland Conversion and Water Body Decline in the Brazilian Pantanal

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Abstract

Anthropogenic changes, such as deforestation and agricultural expansion, are altering Earth's ecosystems, particularly in vulnerable regions like the Brazilian Pantanal. Recognized as a biodiversity hotspot and a wetland of international importance, the Pantanal faces critical environmental pressures. In this context, this research analyses spatiotemporal land use dynamics using geospatial technologies in the Brazilian Pantanal. The Land Cover Indicator was employed, representing physical phenomena associated with land use characteristics. Our land use and land cover data were sourced from MapBiomass, utilizing a two-year dataset (2004-2022) to conduct a spatiotemporal analysis of land use dynamics. The results revealed a combined 18.76% decrease in wetlands and water bodies between 2004 and 2022, primarily concentrated in the central and southern regions of the study area. This dynamic coincides with a significant transition from forest formations to pastures. Consequently, the Land Cover Indicator, a metric for anthropogenic pressure, increased by an average of 2.22% across the region. Understanding these spatiotemporal relationships is therefore crucial for developing effective conservation strategies and maintaining sustainable management of this globally important wetland.

1. Introduction

Global changes resulting from anthropogenic activities are affecting the Earth's ecosystem, leading to apparent negative impacts on the degradation and depletion of surface water (Lane et al., 2023). The changes are particularly intense in the Pantanal, one of the world's largest continuous wetland systems designated a national heritage by the 1988 Brazilian Constitution and an Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site (Brazil, 1997).

Nevertheless, the Pantanal has undergone challenges, including wildfires (Berlinck et al., 2022) and extreme drought conditions (Marengo et al., 2021). To contain a decrease in biodiversity, the Brazilian government instituted the Priority Areas for Biodiversity Conservation, Sustainable Use, and Benefit Sharing plan. This framework was established in 2004 and revised in 2018 (MMA, 2007, 2018), with the plan outlining areas through a participatory methodology that involves experts and stakeholders. The Priority Areas aim to identify key areas for conservation across different biomes, including 10% of the priority areas located in the Pantanal (Brazil, 2007).

In the Pantanal, water security for sustainable development will primarily rely on how well we can map the hydrological, biological, and biogeochemical processes in this region (Oliveira et al., 2022; Lopes et al., 2020). Land use and cover changes directly influence the quantitative and qualitative aspects of the water, leading in some cases to a change in the phosphorus and nitrogen levels when the forest fragments are replaced by agriculture (Carvalho et al., 2024; Marques and Rodriguez, 2022).

Such advances are essential, considering that the Pantanal is a biodiversity hotspot (Nunes et al., 2021; Alho et al., 2019). The scientific and technological importance of monitoring diffuse pollution in this area is amplified by progress in geospatial solutions.

Some studies illustrate the advantages of using geospatial methodologies for monitoring large and complex wetlands like the Pantanal. Cuartas et al. (2023) use spatial-temporal fluctuations of suspended sediment concentration (SSC) in the fluvial systems that drain into and traverse the Pantanal wetland. Pereira et al. (2019) analyse the seasonal variations and hydrological dynamics within the Pantanal by radar imagery obtained from the Sentinel-1 satellites. The findings underscore the spatial and temporal heterogeneity of inundation patterns in the Pantanal.

This paper not only aims to contribute to the academic knowledge of the Pantanal but also seeks to support the Millennium Development Goals (MDGs) (UN, 2000) and the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development (UN, 2015). Promoting collective action is essential to tackling the complex environmental challenges of the 21st century, particularly concerning MDG 7, which focuses on ensuring environmental sustainability by promoting the reasonable use of natural resources and safeguarding the quality of life of local populations.

Therefore, we hypothesize that the reduction of surface water bodies is intensified by anthropogenic activities, particularly through changes in land use. Therefore, it is essential to apply

integrated geospatial technologies to identify critical areas and support water management in the region.

2. Materials and Methods

2.1 Study area

The Pantanal (Figure 1) is situated in the south-central region of South America, with the majority of its area located within Brazilian territory. This vast wetland is one of the largest continuous flooded areas on the planet, primarily extending across the Brazilian states of Mato Grosso and Mato Grosso do Sul, encompassing the Upper Paraguay River basin (Brasil, 1997)

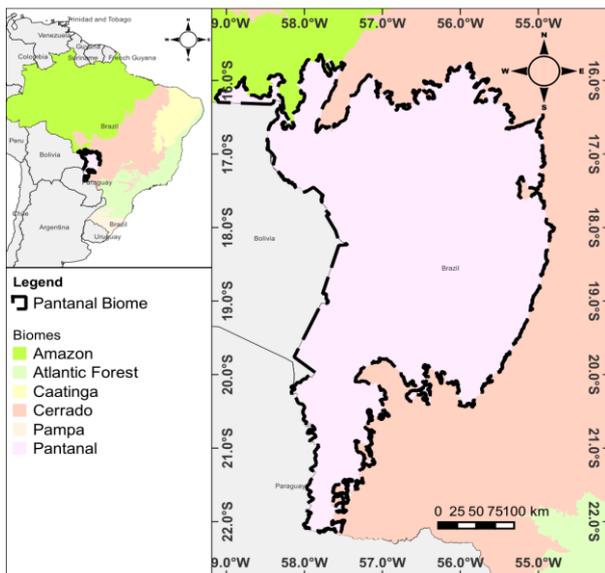


Figure 1. Location of the Brazilian Pantanal biome, the study area. Inset maps show its position within Brazil and South America, highlighting the biomes of the country.

The average maximum temperature ranges from 32.3°C to 32.8°C (Dallacort et al., 2014), with an annual rainfall of approximately 1000 mm, occurring from November to March, influenced by the Intertropical Convergence Zone (Ivory et al., 2019). The altitude ranges from 90 to 150 meters above sea level (ANA, 2005; Alho and Silva, 2012).

The vegetation of the Pantanal biome includes Arboreous Savanna, Forested Savanna, and Grass-woody Savanna (IBGE, 2013), harboring a variety of species adapted to the floodplain dynamics (Alho, 2008). However, the Pantanal faces several threats that jeopardize its rich biodiversity. Although the region retains about 80% of its native vegetation cover, factors such as deforestation, climate change, and unsustainable agricultural practices have caused significant impacts on local ecosystems (Alho et al., 20; Silgueiro et al., 2021).

2.2 Methodological Procedures

To evaluate land use and land cover (LULC), we obtained layers for the years 2004 and 2022 from the free MapBiomias database (Souza Jr. et al., 2020). The MapBiomias project (mapbiomas.org) provides detailed land use and land cover data and is based on mosaics of Landsat satellite images with a spatial

resolution of 30 meters. This mapping covers the period from 1985 to 2023.

Analyses were performed using raster layers in the ArcGIS Pro software (ESRI, 2025). They were reclassified based on the Corine Land Cover (Coordination of Information on the Environment – Land Cover, or CLC) legend (EEA, 2006). This system was chosen due to its widespread application in landscape analysis and because it forms the methodological basis for the Land Cover Indicator (LCI) used in this study (Cecchi et al., 2007), ensuring consistency between the classification and the indicator.

The reclassification was based on the Instituto Brasileiro de Geografia e Estatística (IBGE) Land Use Manual (IBGE, 2013). The reclassification, MapBiomias–IBGE–CLC, was used because the Brazilian manual was developed following the same methodological procedures as those employed in the CLC land use and land cover mapping.

This approach also integrates the hydrological interactions between the studied years, as it accounts for the distinct hydrographic conditions throughout the years. For each year of the study, the class designated as water bodies from the MapBiomias land use mapping was used. Using the union tool, these were merged with the state database (ANA, 2025) (Figure 2).

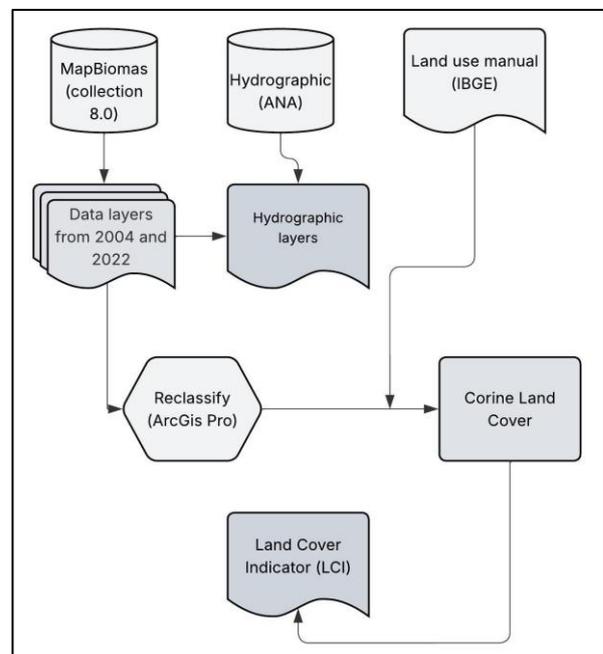


Figure 2. Conceptual flowchart of the data integration and processing methodology. It illustrates the harmonization of MapBiomias land cover data with the IBGE Land Use Manual and ANA hydrographic data to generate the final Land Cover Indicator (LCI).

The Land Cover Indicator (LCI) was based on the European CORINE Land Cover (CLC) classification system and employed for landscape analysis (Cecchi et al., 2007). The calculation of the LCI for the years 2004 and 2022 followed a systematic GIS-based workflow designed to translate land cover changes into a quantifiable measure of anthropogenic pressure (Figure 2 and Figure 3).

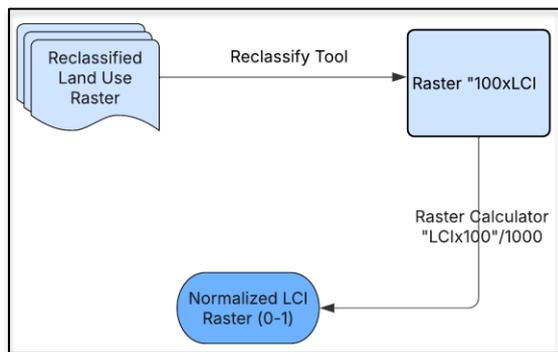


Figure 3. Workflow for generating the normalized Land Cover Indicator (LCI) raster in ArcGIS Pro.

First, the primary land use and land cover classifications from the MapBiomas dataset (Collection 8) were harmonized with the CLC system. This crucial step was mediated by the IBGE's Land Use Manual, which served as a technical bridge to ensure methodological consistency between the Brazilian-specific classes and the standardized CLC nomenclature.

The core of the analysis was the assignment of a weighted LCI coefficient to each harmonized class, based on the expert-derived values from Cecchi et al. (2007). This hierarchical process spatially differentiates the landscape based on environmental impact (Table 1).

CLC	LCI
Continuous urban fabric	0.822
Discontinuous urban fabric	0.689
Mining areas	0.778
Fruit trees and berry plantations	0.789
Pastures	0.400
Annual crops associated with permanent crops	0.744
Complex cultivation patterns	0.690
Broad-leaved Forest	0.056
Mixed Forests	0.044
Degraded forest areas	0.078
Bare rock	0.000
Wet forest	0.089
Water courses	0.088

Table 1. Land Cover Indicator (LCI) coefficients for each harmonized CORINE Land Cover (CLC) class, based on the methodology by Cecchi et al. (2007).

Finally, this process generated two distinct LCI raster maps, one for each year of analysis. In these maps, the value of each 30-meter pixel represents the localized anthropogenic pressure, providing a powerful spatial tool to analyze the dynamics of environmental change across the Pantanal biome.

3. Results and Discussion

Figure 4 shows the results of the hydrographic layers. For each year of the study, mappings from MapBiomas were used, which include water bodies and hydrography. This analysis reveals a decrease in water bodies in the Pantanal, particularly in the south-central region of the study area.

Justino et al. (2024) present a decrease of approximately 9.9% in the area of water bodies over a three-decade period in the Pantanal. This decline is critical, as it reflects environmental changes that are affecting the region's ecosystems. The Pantanal region has been severely affected by an extended drought since 2019, which is considered one of the most severe droughts observed in the past 50 years. This has led to significant ecological and economic consequences for the area (Marengo et al., 2021).

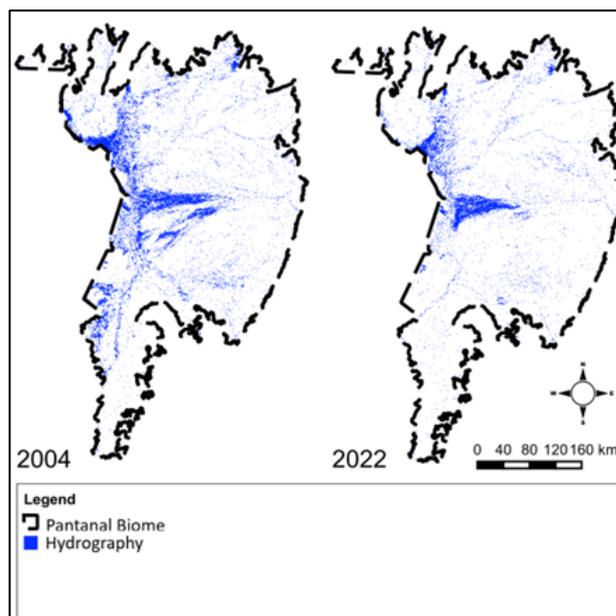


Figure 4. Comparison of hydrographic layers for 2004 and 2022.

When analysing land use changes over the years (Figure 5), it was found that the Pasture and Shrubland-to-Forest Transition class experienced a combined growth of 8.85%, broadleaf forests decreased by 1.46%, while wetlands and water bodies showed a joint decrease of 18.76% (Figure 5), demonstrating the transition occurring between these classes, which aligns with the hydrography mapping presented in Figure 4.

Miranda et al. (2018) elucidate that the Pantanal has experienced an increase in short vegetation (including grasslands and pastures) alongside a reduction in dense vegetation, thus indicating significant transformations in the landscape and subsequent implications for hydrological dynamics.

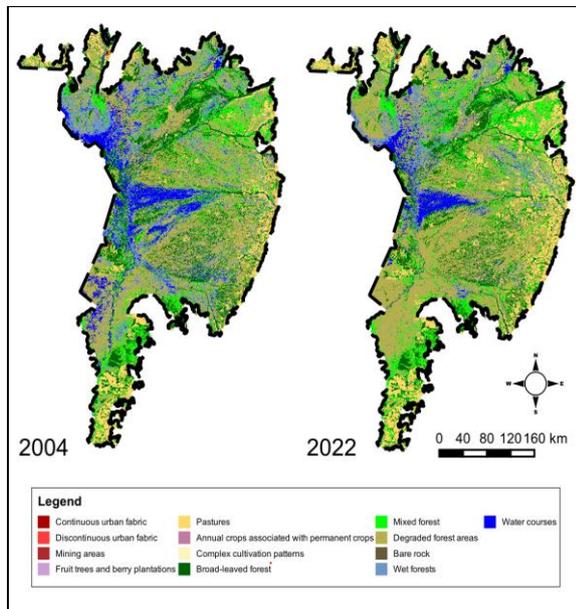


Figure 5. Spatiotemporal dynamics of land use and land cover in the Pantanal between 2004 and 2022.

The literature suggests that anthropogenic activities, including livestock expansion and urbanization, frequently drive these land-use changes. Marques and Rodriguez (2022) reported that the conversion of natural vegetation into pastures has modified the hydrological behavior of the headwaters of the Paraguay basin in Mato Grosso, similar to what was observed in this study. Moreover, Zedler (2003) notes that the conversion of wetlands to pastureland can eliminate essential ecosystem functions, such as water quality improvement and habitat for diverse biodiversity.

These changes not only modify the land cover but also have implications for the regional hydrological cycle and environmental processes. The reduction of wetlands makes the region more vulnerable to extreme events related to droughts and floods, as shown by Endter-Wada et al. (2018).

The spatial dynamics of the LCI powerfully illustrate this landscape transformation (Figure 6). Between 2004 and 2022, the region experienced a notable increase in anthropogenic pressure, reflected by an average rise of 2.22% in the LCI. This expansion of high-impact areas is a direct spatial consequence of the conversion of Wetlands and Broad-leaved forest to Pastures, as observed in the land use analysis (Figure 5), consolidating the evidence of agricultural pressure in the region.

These findings align with broader evidence of deforestation in Brazil, where forest replacement by pasture is a primary driver of change (Pavão et al., 2017) this action not only changes the other side of the landscape, but it also affects the ecosystem services directly; the action influences, e.g., water regulation and local biodiversity. Moreover, land cover change can lead to higher greenhouse gas emissions, which are a derivative of climate change (Rocha et al., 2015).

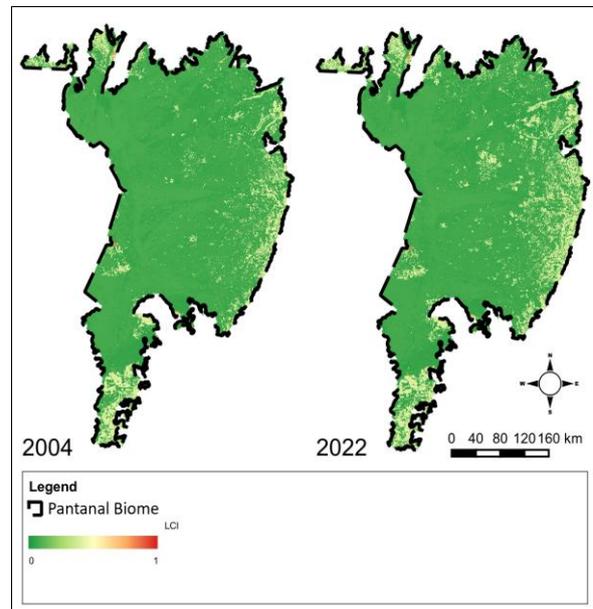


Figure 6. Map of the Land Cover Indicator (LCI) dynamics. The values represent the level of anthropic impact, where 0 = Low Impact (e.g., Forests, Wetlands) and 1 = High Impact (e.g., Pastures, Urban Areas).

Considering the velocity of environmental changes occurring in the Pantanal, the findings of this study have the potential to contribute directly to the management of public policies for conservation in the region. In this sense, the produced data could serve as the support for legal projects, such as Bill 2334/24 (Brasil, 2024), which intends to establish an integrated set of norms for the protection and management of the Pantanal biome, and the recently enacted Pantanal Law 6160/23, which establishes regulations for the conservation, security, and sustainable use of the biome (Brasil, 2023).

GIS technologies may be applied to the continuous monitoring of the land use/land cover change and the enforcement of environmental regulations. These tools demonstrate their capacity to contribute to better and adaptive management of the Pantanal's natural resources.

4. Conclusions

Based on the hypothesis that land-use changes drive the decline in water bodies, the findings demonstrate how these transformations can directly impact water resources. Replacing forests with pasturelands not only modifies land cover but also reduces the availability of wetlands and water bodies.

This study suggests that the use of integrated geospatial technologies is essential for mapping vulnerable zones and providing support for managing water resources within the Pantanal's ecosystems.

It is crucial to highlight the importance of understanding how environmental changes impact biodiversity conservation in the Brazilian Pantanal. It provides essential knowledge that can guide the formulation of effective policies and strategies for environmental management in the region.

However, it is essential to recognize the study's limitations, including the dependence on the spatial resolution of the utilized

data and the absence of detailed socioeconomic information. These factors may influence how the results are interpreted and should be considered when extending the findings to broader contexts. This research establishes insights for subsequent studies on land use and land cover changes and their effects on the Pantanal.

For future research, adapting the methodology to more recent standards, such as the INSPIRE directive, would be a valuable step. This could enhance data interoperability across different platforms and potentially offer greater thematic detail. However, for this study, the CLC standard was intentionally chosen because the LCI methodology is explicitly built upon and validated for the CLC classification system. This choice ensured methodological consistency and robustness, allowing for a direct application of the established indicator.

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