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Land use around Corumbá IV reservoir: analysis and alignment with PACUERA guidelines

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ABSTRACT

Analyzing land use over time is essential for understanding the landscape's geoecological changes, which directly affect vital resources like water and biodiversity. This study investigates changes around the Corumbá IV Reservoir to track landscape modifications and evaluate local planning since the reservoir's establishment. We utilized digital cartographic data from IBGE (municipal boundaries), DGI/INPE (digital terrain model), MapBiomas, and satellite imagery from Google's database, processing all inputs in QGIS 3.34 to create maps that compare observed land use with the strategy outlined in the PACUERA. Results indicate increased lakeshore urbanization between 2016 and 2023, along with reductions in forested and agropastoral areas and non-compliance with the original plan. We conclude that environmental planning needs restructuring.

KEYWORDS: environmental planning; urbanization; geoecological dynamics.

INTRODUCTION

Since the earliest times, human societies have reshaped the environment to sustain their existence, triggering progressive and accelerated alterations in landscapes and natural habitats (Araújo, 2007). These transformations necessitate effective strategies to mitigate damage to ecological services that are essential to survival (Nguyen et al., 2023).

To grasp the complexity of these phenomena, technologies that integrate the multiple variables interacting within anthropo-natural systems are indispensable (Fonseca et al., 2024). In the context of environmental change without precedent in rate and magnitude (Antunes et al., 2019), this study analyzes transformations in the environs of the Corumbá IV Reservoir.

The objective is to analyze land-use change in an area reclassified from rural to discontinuous urban perimeters of municipalities affected by dam construction. The study identifies these changes and assesses the effectiveness of territorial planning carried out after the reservoir's creation, determining whether policies and actions successfully promoted the orderly environmental sustainability of the new landscape.

Land-use data from MapBiomas were used for 2000, 2006, 2012, 2018, and 2023, a platform widely employed in Brazil. To improve the representation of urban expansion, manual mapping was done using high-resolution Google™ satellite imagery, which allowed for the identification of new gated communities and subdivisions.

Analysis also relied on the Environmental Zoning outlined in the 2011 Plano Ambiental de Conservação e Uso do Entorno de Reservatórios Artificiais (PACUERA). This framework was essential for comparing urban growth with the plan's guidelines and for assessing whether landscape development adhered to its directives, especially regarding conservation areas and zones open to development.

Slope analysis based on Embrapa's (1979) relief classification was used to identify potential environmental-risk areas. These datasets offered insight into land-use changes and the socio-environmental effects of urban growth in the local landscape (Bertrand, 1972).

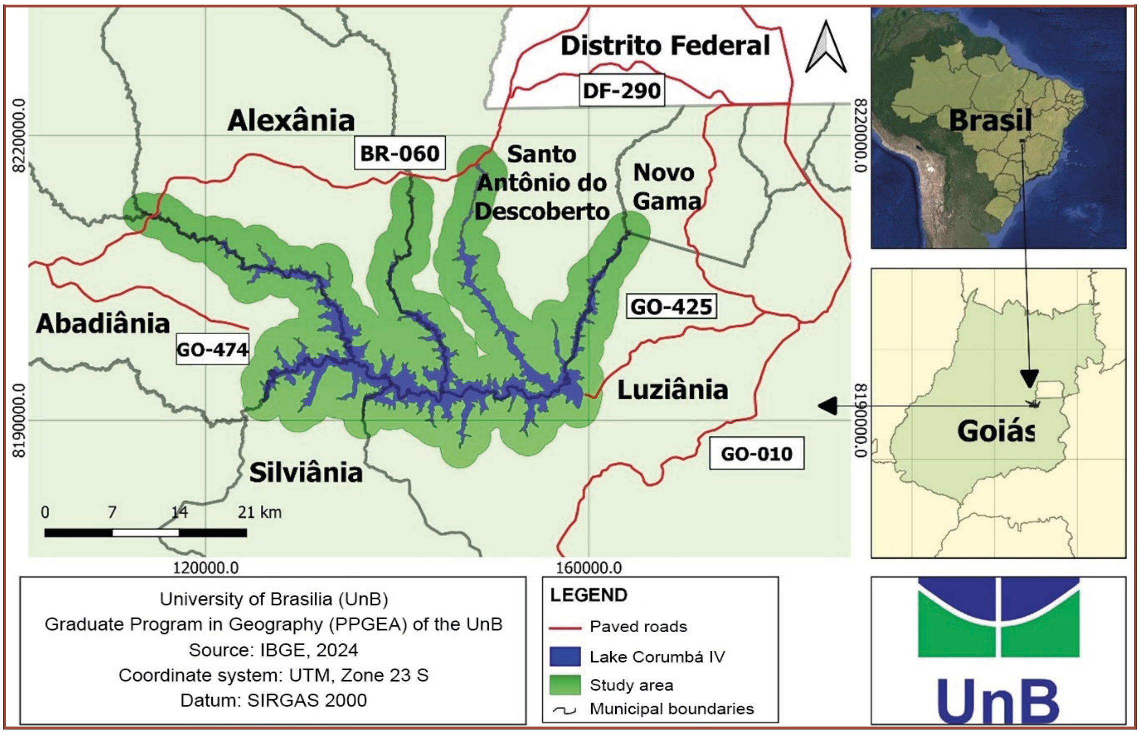
Implementing and carefully monitoring management tools is essential for understanding urbanization and planning strategic actions that foster environmental sustainability (Yang & Zhang, 2021). Such analysis should include ecological impact studies that account for both physical and socioeconomic factors; an integrated approach allows for recognizing the complex relationship between human activities and the environment (Rodrigues; Silva; Cavalcanti, 2022).

Geotechnologies, by enabling precise monitoring and analysis of environmental impacts and landscape management (Furtado et al., 2020), offer the essential tools for detailed oversight. Protecting these areas is vital for safeguarding water resources and gene flow, as well as preventing erosion, which helps inform planning for sustainability (Prochazka et al., 2023).

MATERIAL AND METHODS

This study examined a 1.2 km stretch from the Corumbá IV Reservoir shoreline, an area directly impacted by reservoir construction and rapid landscape changes driven by the expanding, discontinuous urban boundaries in nearby municipalities. The affected localities include Luziânia, Silvânia, Novo Gama, Santo Antônio do Descoberto, and Alexânia (Figure 1). Notably, the lake is located in an area originally classified as rural, with no direct connection to urban centers, and it now supplies drinking water to 1.3 million residents of the Federal District.

Figure 1 – Location of Corumbá IV Lake and affected municipalities



Source: IBGE (2024). Prepared by: Anderson Muzzolon.

To analyze change around Lake Corumbá IV, land-use maps from MapBiomas (collection 2023) for the years 2000, 2006, 2012, 2018, and 2023 were used, utilizing the platform's RGB palette. These products provide a per-pixel time series from 1985, generated from Landsat-5 and Landsat-8 imagery, enabling detailed temporal tracking. The dataset is widely used in Brazil for land-use and land-cover studies, as well as to inform public policy, including deforestation control and assessments of biome status (Xavier; Menezes; Silva, 2024).

Image processing—buffer creation, editing, digitizing, clipping, overlay, and georeferencing—was carried out in QGIS 3.34. Areal calculations for mapped classes were obtained using the r.report extension in QGIS. Charts and tables were generated in Excel.

Because MapBiomas often labeled street grids with sparse buildings as "agropasture," manual delineation of new street layouts (gated subdivisions/condomínios) was conducted using 0.5 m-resolution 2023 Google™ satellite imagery. A map of new subdivisions was then generated and intersected with urbanized-area layers (MapBiomas indicators) to identify additional landscape transformations. Subsequent interpretation highlighted the most significant modifications and the types of change.

The PACUERA (Plano Ambiental de Conservação e Uso do Entorno de Reservatório Artificial) was adopted as a legal-technical framework for shoreline land-use guidance around hydroelectric reservoirs (Brasil, 2002). It seeks to reconcile environmental conservation with human activities by setting rules for construction and agriculture to ensure water quality and bank stability, complementing the Código Florestal (BRASIL, 2012).

Accordingly, the Environmental Zoning defined in the 2011 PACUERA served as the analytical baseline. The method compared this zoning, which partitions the area into specific use zones (preservation, agriculture, and controlled urbanization), with maps showing the formation of new urban areas. MapBiomas information was combined with high-resolution, manually mapped Google™ data.

These urbanization maps included new street grids and condominium development. The analysis assessed whether emerging urban areas were being implemented within zones designated for such use or encroaching on areas intended for other purposes, such as environmental conservation.

Slope in the study area was mapped from a 30 m Digital Elevation Model (DEM) derived from the TOPODATA sheet 16S495ZN, generated by the Shuttle Radar Topographic Mission (SRTM) and distributed via INPE's Topodata database (Instituto Nacional de Pesquisas Espaciais).

The DEM was first clipped to the study site to focus analysis on the target landscape, and then the slope (%) was computed. To ensure analytical consistency, slope classes followed Embrapa's classification (1979), as shown in Table 1, which provides clear, standardized categories for interpreting terrain inclination.

After producing the slope map in QGIS 3.34, the area of each class was calculated with the r.report extension. Urbanized areas were then extracted from the vector layer of condominium polygons. This workflow yielded indicators identifying settlements located on terrain deemed suitable versus environmentally risky, according to slope thresholds.

Table 1 – Relief classification following Embrapa (1979)

Relief class	Slope range	Characterization
Flat	0–3%	Nearly level or horizontal surface with very minor elevation differences
Gently undulating	3–8%	Slightly dissected surface composed of low hills/ knolls with gentle slopes
Undulating	8–20%	Moderately dissected surface formed by sets of hills and/or knolls
Strongly undulating	20–45%	Dissected surface of knolls and/or hills with 100–200 m of relative relief
Mountainous	45–75%	Rugged terrain with predominantly irregular forms (hills, mountains, massifs, and aligned ranges)
Escarped (very steep)	> 75%	Areas dominated by abrupt forms, comprising scarps with very strong slopes

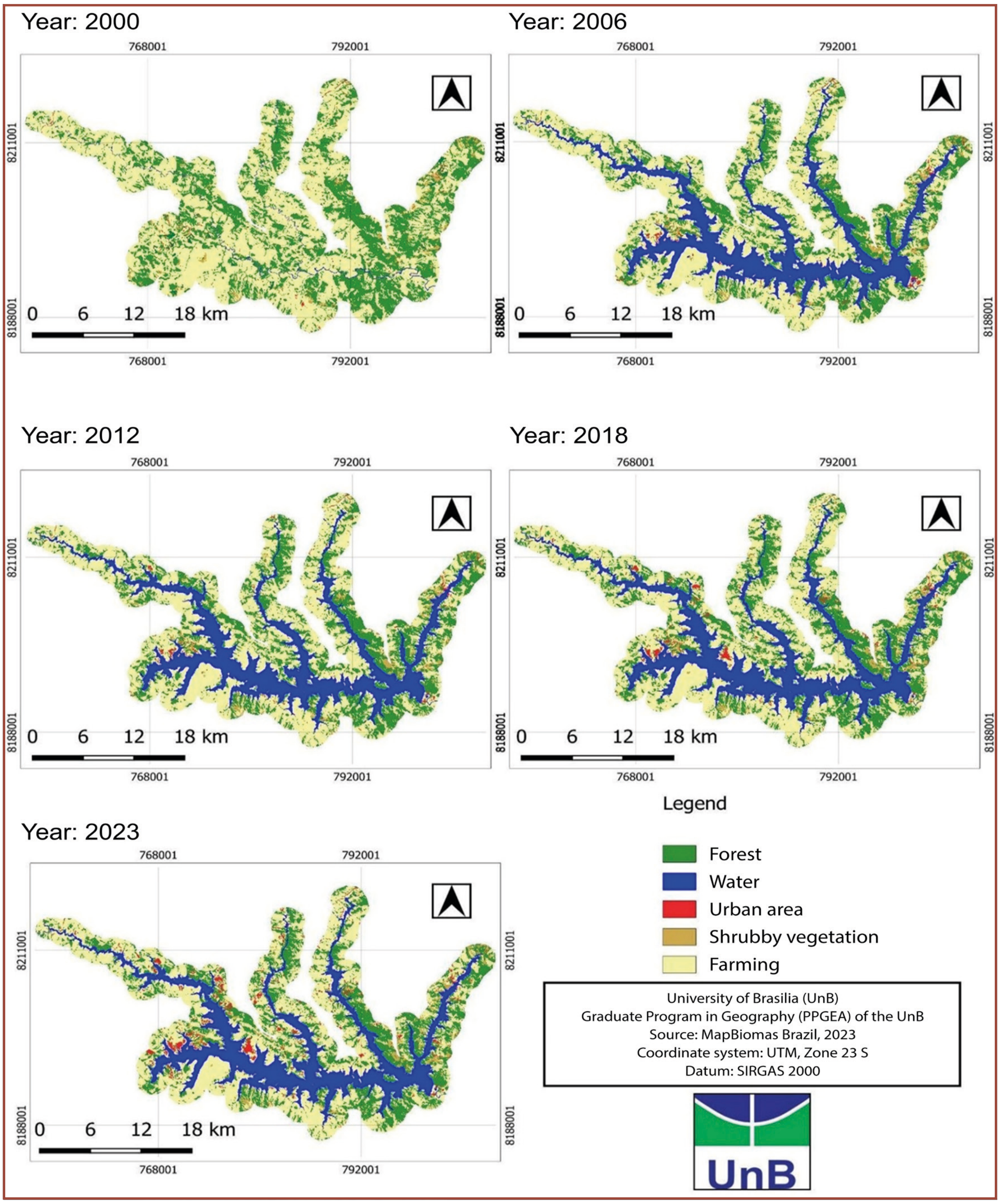
Source: Embrapa (1979). Prepared by: Anderson Muzzolon.

In this study, a geoecological approach to landscape was adopted, viewing it as a complex physical space created by the dynamic—and therefore unstable—interaction of natural and human-made components across multiple spatial and temporal scales (Bertrand, 1972). The landscape is thus a unique, inseparable combination of dynamic natural and anthropo-natural systems, in which societies and their social systems are intertwined with nature in an indissoluble relationship (Rodriguez; Silva; Cavalcanti, 2022). Adopting this approach is essential for the area around Lake Corumbá IV, since its environmental dynamics in a geoecological context define its characteristics. This landscape comprises interlinked ecological factors that directly condition its vulnerability. The presence of water bodies, relief, vegetation, and land-use processes—driven by human activities and natural phenomena—renders the area particularly sensitive to environmental change.

RESULTS AND DISCUSSION

Urbanization driven by hydropower infrastructure has accelerated land-use change, disrupting the local landscape balance (Bertrand, 1972) and creating a new socio-economic dynamic. Spatial analysis reveals a disorderly pattern of occupation (Figure 2).

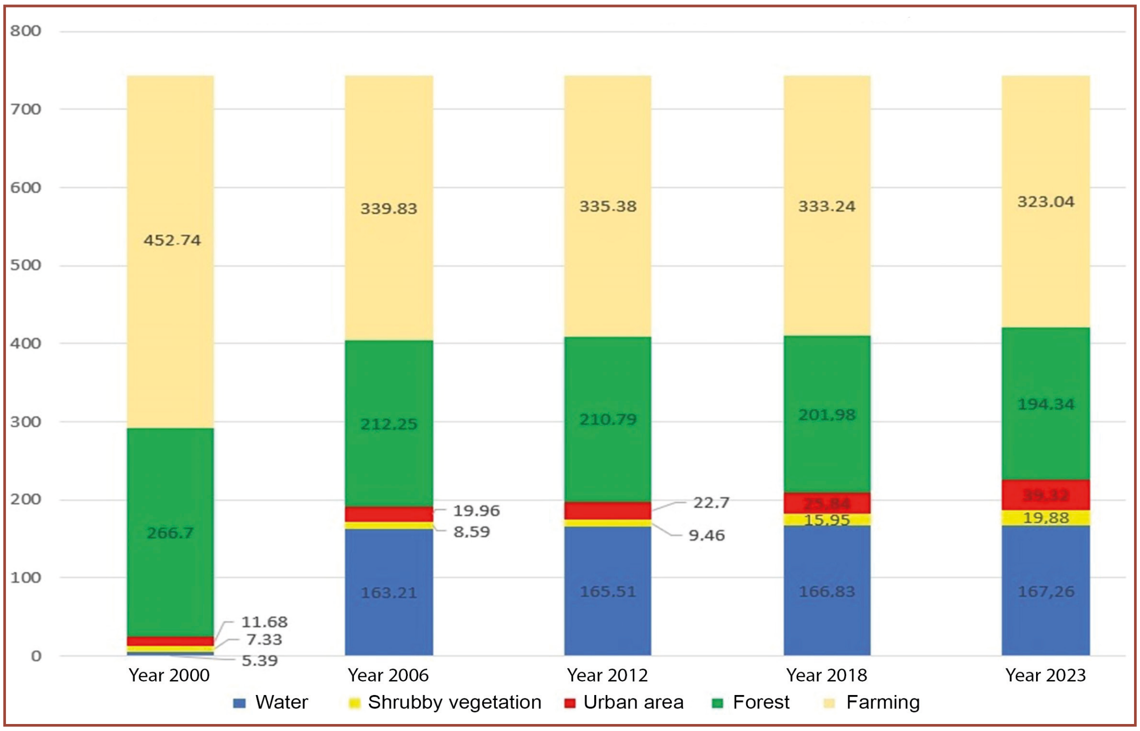
Figure 2 – Land use in different years around Corumbá IV Lake



Source: MapBiomas data (2023). Prepared by: Anderson Muzzolon.

For this survey, five classes were mapped: Forest (gallery forests and cerradão), Water bodies (lakes and rivers), Urbanized (areas with street grids and buildings), Shrub vegetation (cerrado *stricto sensu* and campo sujo), and Agriculture/pasture. Based on these indicators, urbanized areas began forming immediately after the reservoir came online and have expanded steadily, from 19.96 km² in 2006 to 39.32 km² in 2023. This growth has occurred at the expense of agricultural/pastoral areas and forest patches (Graph 1).

Graph 1 – Temporal analysis of land use in the study landscape (km²)

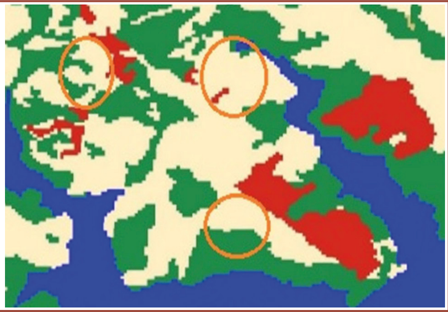
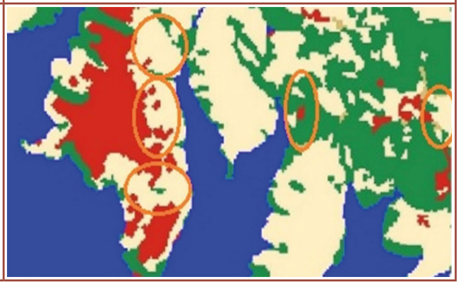


Source: MapBiomas data (2024). Prepared by: Anderson Muzzolon.

These transformations may be even more pronounced. Although MapBiomas data corroborate the acceleration of environmental dynamics in the landscape, classification errors can occur due to several factors, including map resolution, misassignment of pixels to land-use classes, and high proportions of misclassified samples (Xavier; Menezes; Silva, 2024).

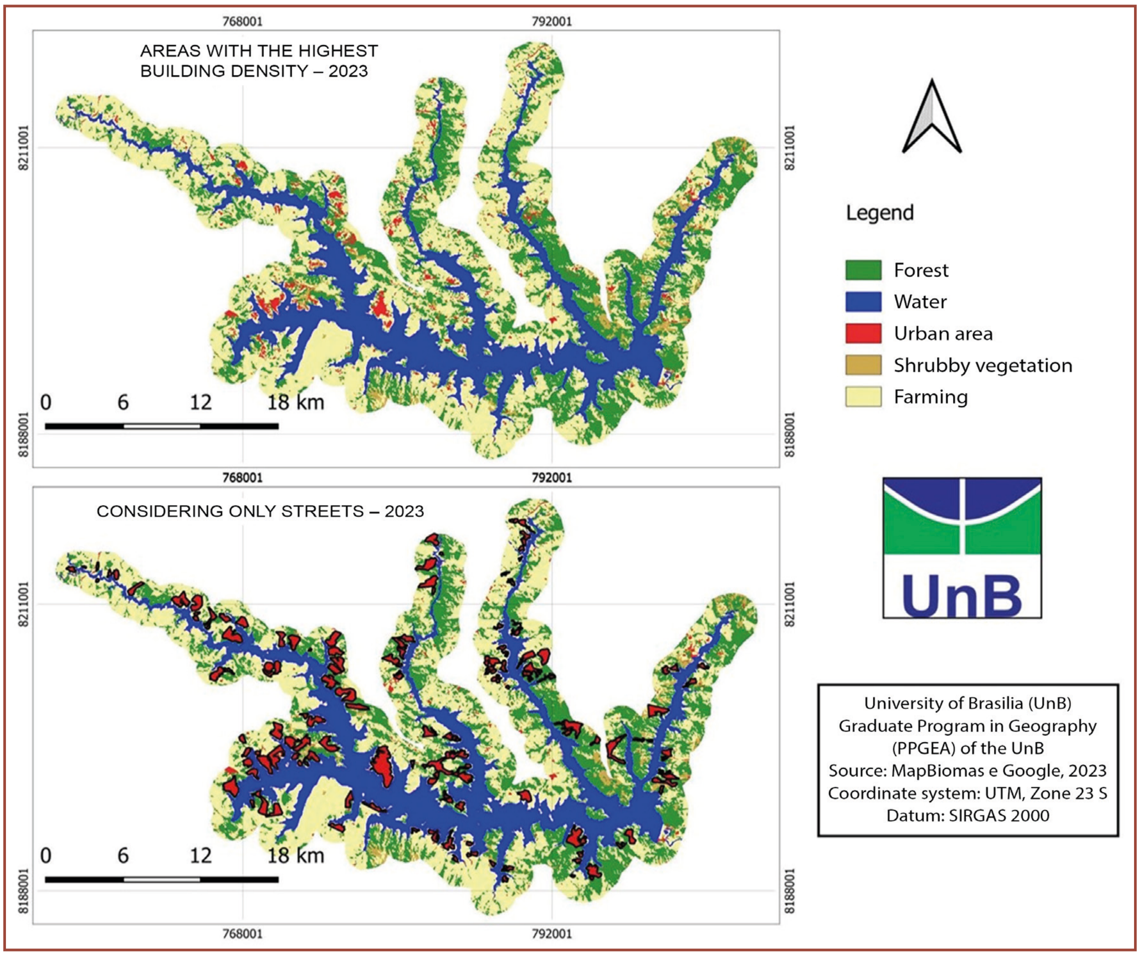
Accordingly, street-grid areas were manually mapped (Google™ satellite composites for 2023 at 0.5 m resolution) to approximate on-the-ground conditions and identify subdivisions still under development. At MapBiomas's 30 m spatial resolution, street grids and low-density built areas are often absorbed into non-urban classes (here, Agriculture/pasture). As shown by the orange-circled locations (Table 2), several newly forming subdivisions were classified as agricultural/pastoral because of extensive grasses and sparse construction.

Table 2 – Divergent classifications under different image resolutions

Condominium	Google™ composite 2023	MapBiomas land use 2023
Real Ville (1) Porto do Sol (2) Bora Pescar (3)		
Bougaville (4) Sabiá (5) Enseada Park (6)		

Source: Google™ image bank and Map Biomes (2023). Prepared by: Anderson Muzzolon.

Figure 3 – MapBiomas land use and manual mapping



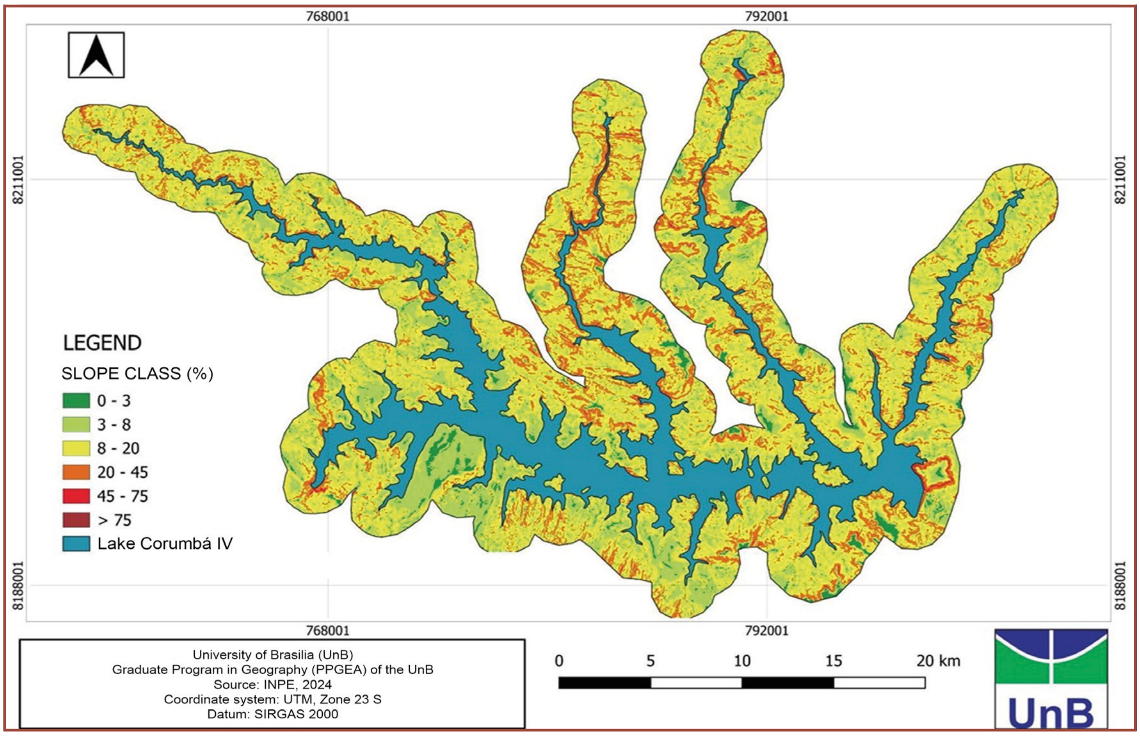
Source: MapBiomas and Google™ (2023). Prepared by Anderson Muzzolon.

Map overlay is a powerful technique that enables visual comparison across layers, integrating disparate datasets and supporting decision-making (Fushita et al., 2010). Its utility increases in multi-criteria analyses, where multiple factors are evaluated simultaneously to clarify the mapped situation (Vestena et al., 2024). By digitizing polygons of street-grid subdivisions on 0.5-m Google™ satellite composites for 2023, a vector layer totaling 53.27 km² of urbanized area was produced and overlaid on MapBiomas statistics for comparison (Figure 3).

The higher resolution made it possible to identify internal urban arrangements—street networks and subdivision boundaries—often understated or generalized in coarser data. Capturing these internal details improved the delineation of built-up areas and yielded a more faithful view of expansion dynamics and land use.

To assess whether projects are being built on slopes suitable for urban expansion, a percent-slope map was produced (Figure 4), following EMBRAPA's (1979) classification.

Figure 4 – Slope classes around Corumbá IV Reservoir



Source: INPE data (2024). Prepared by: Anderson Muzzolon.

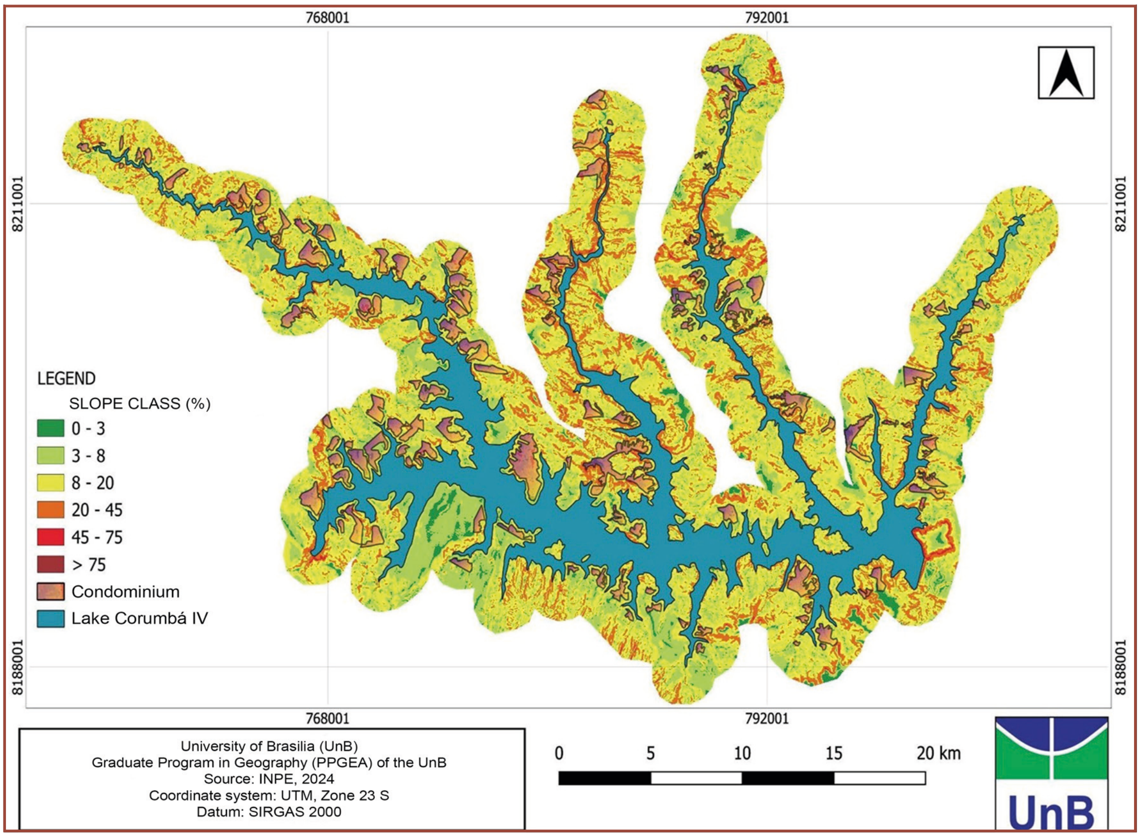
Steep areas pose greater infrastructure challenges and require stricter control measures—e.g., retaining structures and tailored drainage (Zhang; Huang, 2014). Conversely, low-gradient areas are advantageous for urbanization, as the implementation of streets, buildings, and other urban structures can proceed at lower cost and with reduced environmental impact. Slope mapping thus supports careful landscape analysis, guiding urban planning so that development respects terrain constraints and avoids unsuitable locations (Guerra, 2011).

Table 3 – Slope intervals, class names, areas, and percentages around Corumbá IV

Class	Characterization	Area (km²)	Percent
0–3	Flat	11.71	1.975
0–3	Gently undulating	140,71	23.736
8–20	Undulating	338.13	57.039
20–45	Strongly undulating	99.12	16.720
45–75%	Mountainous	3.12	0.526
>75	Mountainous	0.02	0.003

Source: Survey data (2024). Prepared by: Anderson Muzzolon.

Figure 5 – Location of subdivision street grids relative to slope classes around Corumbá IV



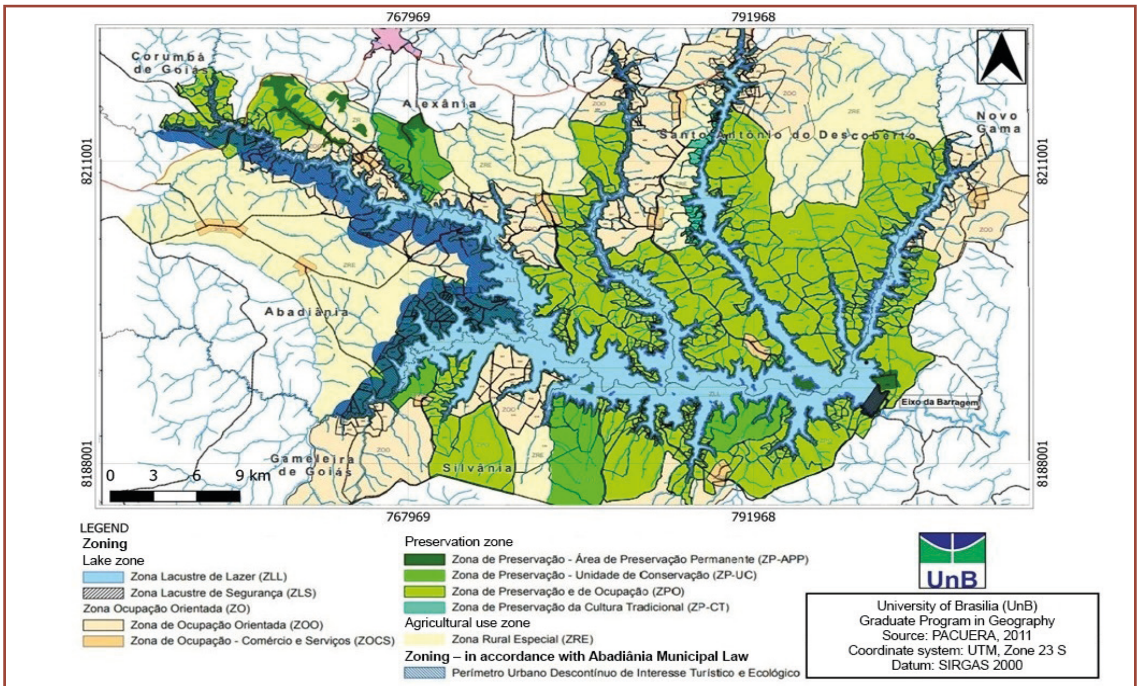
Source: INPE/Google™ (2024). Prepared by: Anderson Muzzolon.

Slope analysis indicates predominance of undulating terrain. As Table 3 shows, 57.03% of the area has slopes between 8% and 20%, mainly due to hillslopes descending toward the reservoir. Gently undulating terrain (3–8%) accounts for 23.73%, while strongly undulating (20–45%) totals 16.72%. Mountainous, escarped, and flat classes together comprise under 3% of the area.

To flag potential risk areas, subdivision polygons were overlaid on the slope map (Figure 5), focusing on slopes >20% per EMBRAPA (1979). This identified zones of heightened environmental vulnerability.

Of the 53.27 km² of subdivision street grids, 2.56 km² lie on strongly undulating terrain (20–45%). Such a condition poses significant risks to both the population and the lake, given the high propensity for erosion and landslides on steep slopes. Slopes exceeding 20%—classified as strongly undulating, mountainous, or escarped—present significant challenges for urbanization, making development costlier and more complex. In such areas, specialized engineering techniques are required due to the high risk of accelerated runoff, erosion, and landslides (Zhang; Huang, 2014). These areas are generally more appropriate for environmental preservation, thereby preventing ecological damage (Guerra, 2011).

Figure 6 – Environmental zoning around Corumbá IV



Source: PACUERA (2011). Modified by: Anderson Muzzolon.

To mitigate these issues, Corumbá Concessões S.A. prepared an environmental zoning intended to guide landscape management. The 2011 PACU-

ERA defined four macro-zones, each with specific use zones and varying restrictions: the Lacustrine Zone (ZL), Preservation Zone (ZP), Occupation Zone (ZO), and Rural Zone (ZR) (Figure 6).

The Preservation Zone (ZP) covers the most sensitive areas—steeper terrain, riparian forests, and key vegetation fragments— and should prioritize fauna and flora protection. It includes a 100-m buffer around the reservoir's shoreline and all reservoir islands.

The Occupation Zone (ZO) encompasses areas with lower environmental fragility— low slopes and limited conservation-relevant remnants.

The Rural Macro-zone (ZR) includes a Special Rural Zone (ZRE), created in anticipation of settlement pressure; it is predominantly agricultural, farther from the reservoir, and less likely to compromise water quality.

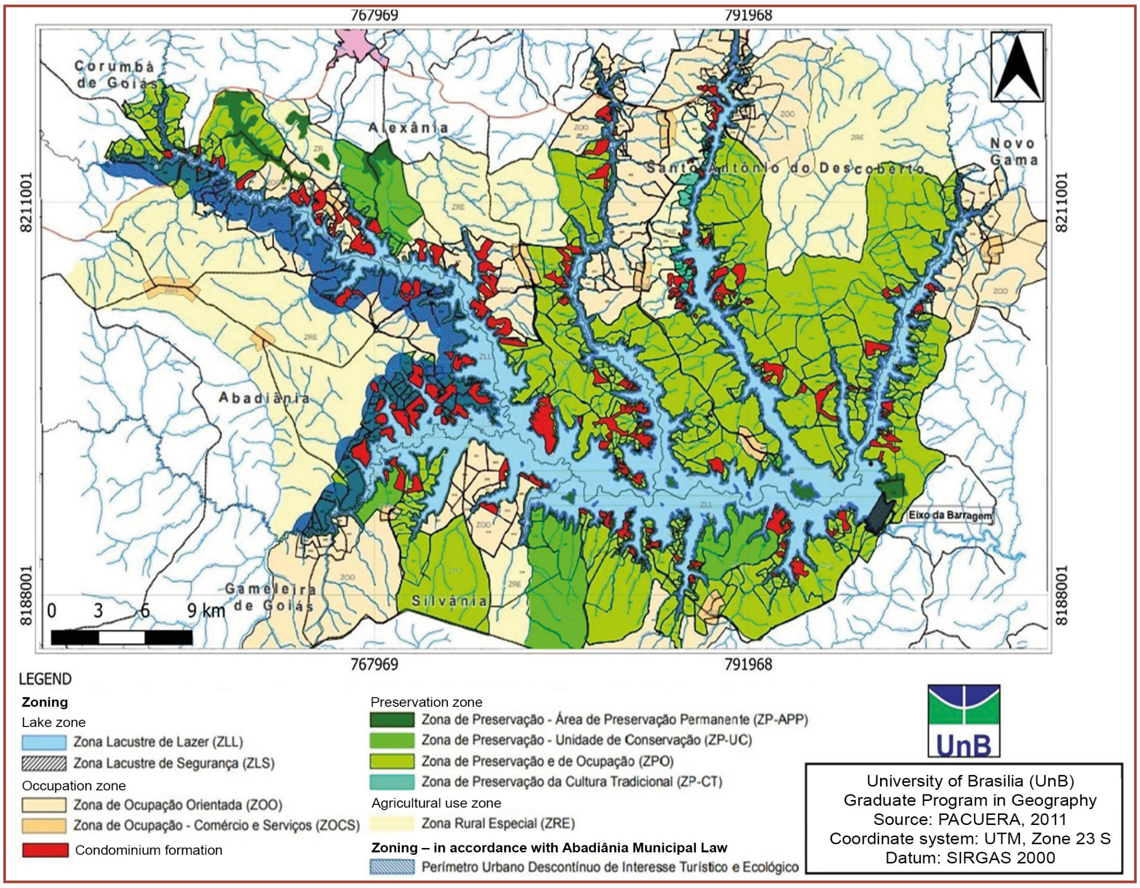
The Environmental Plan for Conservation and Use of the Surroundings of the Artificial Reservoir of Corumbá IV is intended to guide land use, fostering regional economic development (tourism, recreation, fishing, agriculture, and livestock) and improving residents' quality of life, with landscape and biodiversity conservation as explicit targets. (PACUERA, 2011, p. 8).

The zoning—which set a minimum lot size of 20,000 m²—was deliberately ignored by the region's municipalities (Coelho; Queiroga; Leonardi, 2021). None adhered to PACUERA. Instead, the area was reclassified from rural to urban-expansion, and master plans authorized lots smaller than INCRA's minimum parcel (2 hectares) (PACUERA, 2011).

This is evident when the mapped subdivisions (red) are overlaid on PACUERA's recommended uses: areas earmarked for Conservation Units and Permanent Preservation were occupied by new subdivisions, most notably in Alexânia and Abadiânia (Figure 7). The lack of harmonization across municipal laws—with each municipality enforcing its own rules without alignment to PACUERA—produced this outcome. Driven by local group interests, this disarticulation signals a collusive, conflict-ridden approach to land-use management vis-à-vis environmental concerns (Coelho; Queiroga; Leonardi, 2021).

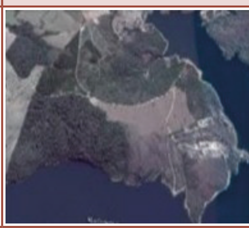
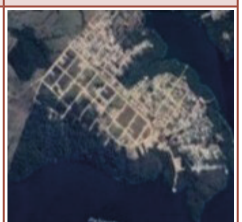
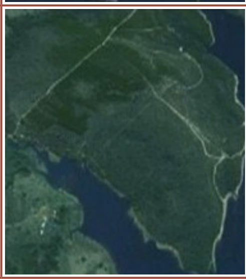
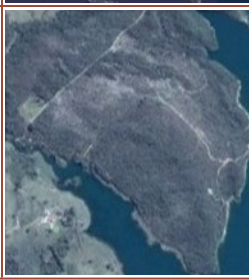
Satellite imagery (2006, 2012, 2018, 2024) shows rapid urban expansion (Table 4), especially along the lakeshore, where both the extent and density of buildings are striking. Beyond surface sealing, urban growth brings additional pressures: population increases, lack of sanitation, inadequate stormwater drainage, and insufficient solid-waste collection. These transformations intensify hydrological energy fluxes (Bello; Hashim; Haniffah, 2014), transporting sediments and waste into the reservoir.

Figure 7 – Subdivision overlay relative to environmental zoning around Corumbá IV Reservoir

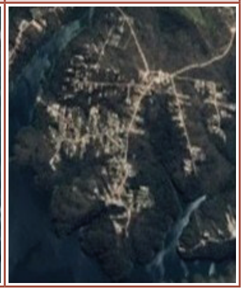


Source: PACUERA, 2011. Prepared by: Anderson Muzzolon.

Table 4 – Urbanization of the Porto do Sol, Vaca Brava, and Recanto Pescador 2 condominiums around Lake Corumbá IV

Cond.*	Year 2006	Year 2012	Year 2018	Year 2024
Porto do Sol, Alexânia – Goiás				
Vaca Brava, Abadiânia – Goiás				

Continued on next page...

Cond.*	Year 2006	Year 2012	Year 2018	Year 2024
Recanto Pescador 2, Nova Gama – Goiás				

*Condominium
Source: GOOGLE™ imagery repository (2024). Prepared by: Anderson Muzzolon.

Anthropogenic interventions that disregard zoning and land-use planning undermine landscape conservation and degrade biodiversity, natural cycles, and resource quality (Ochoa, 2024; Xavier; Menezes; Silva, 2024). Habitat loss, species extinction, and ecosystem degradation demand intensive conservation efforts (Fonseca et al., 2024). Proper management of altered landscapes is therefore essential to mitigate human impacts and ensure resource sustainability, placing the human–nature relationship at the center of debates on landscape sustainability (Sánchez, 2008).

CONCLUSION

The creation of Lake Corumbá IV in 2005 changed the local landscape, leading to faster and more chaotic urban growth. An area that was once rural was incorporated into the irregular urban boundary of nearby municipalities; urbanized land grew from 19.96 km² in 2006 to 53.27 km² in 2023. This expansion—mainly over pastures and Cerrado vegetation—created a new land use and settlement pattern.

The analysis showed that occupation did not comply with PACUERA's environmental zoning (BRASIL, 2002), which complements the Brazilian Forest Code (BRASIL, 2012). Map overlays revealed that areas designated for conservation and preservation were occupied by new condominiums, especially in Alexânia and Abadiânia, increasing pressure on the Permanent Preservation Area (APP) around the lake.

Slope analysis revealed that 2.56 km² of urbanized land is on steep terrain (20–45%), increasing the risk of erosion and landslides. Although this vulnerable area makes up only 0.4% of the total analyzed territory (excluding the lake surface), careful monitoring is crucial to prevent further development on unsuitable sites.

The gap between planning and practice—driven by local interests and the lack of alignment among municipal statutes—highlights the ineffectiveness of current land-use governance. Given the landscape's complexity and the growth of urbanization into natural areas, urgent, coordinated actions are needed to prevent disorderly occupation, promote efficient infrastructure planning, and protect the natural resources of Lake Corumbá IV. ●

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Anderson Muzzolon: led the theoretical–conceptual development and produced the data.

Ruth Elias de Paula Laranja: reviewed the data and technical procedures and their interpretations; revised the manuscript and provided a critical reading.

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