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Multi-Temporal Analysis Of The Landcover Using Remote Sensing At Private Natural Heritage Reserve Santa Cecília II (Corumba, MS)

Análise Multitemporal da Cobertura Vegetal Utilizando Sensoriamento Remoto na Reserva Particular do Patrimônio Nacional Santa Cecília II (Corumbá, MS)

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Abstract: The Private Natural Heritage Reserve (RPPN) Fazenda Santa Cecília II, established in 1998 in the municipality of Corumbá, Mato Grosso do Sul, Brazil, covers an area of 87.29 km². This study assessed the dynamics of vegetation cover in the area through a multitemporal analysis of the Normalized Difference Vegetation Index (NDVI). Remote sensing images were obtained from the USGS website for two distinct dates: one prior to the RPPN's creation, in 1996, and another more recent, in 2020. The images, from Landsat 5 (TM sensor) and Landsat 8 (OLI sensor), were processed using the open-source QGIS software, with classification based on NDVI ranges associated with four land cover types: water, exposed soil, herbaceous vegetation, and woody-shrub vegetation. The results indicated a significant increase in woody-shrub vegetation, from 55.85% to 70.83% of the area. This change was strongly associated with a river avulsion process involving the Taquari River, which led to increased water availability in the region. The creation of the RPPN, while having a secondary role, also contributed to local conservation. The study highlights the potential of using open-access data and free tools to evaluate protected areas.

Keywords: Spectral Index; GIS; NDVI.

Resumo: A Reserva Particular do Patrimônio Natural (RPPN) Estadual Fazenda Santa Cecília II, criada em 1998 no município de Corumbá – MS, ocupa uma área de 87,29 km². Este estudo avaliou a dinâmica da cobertura vegetal da área por meio de análise multitemporal do Índice de Vegetação por Diferença Normalizada (NDVI). Foram analisadas imagens de sensoriamento remoto obtidas através do site da USGS, considerando duas datas distintas: uma anterior à criação da RPPN, em 1996, e outra mais recente, em 2020. As imagens, dos satélites Landsat 5 (sensor TM) e Landsat 8 (sensor OLI), foram processadas no software livre QGIS, com classificação baseada em faixas de NDVI associadas a quatro tipos de cobertura: água, solo exposto, vegetação rasteira e vegetação arbóreo-arbustiva. Os resultados indicaram um aumento expressivo da vegetação arbóreo-arbustiva, de 55,85% para 70,83% da área. Este incremento esteve fortemente associado ao processo de avulsão do rio Taquari, que resultou em maior disponibilidade hídrica na região. A criação da RPPN, embora com papel secundário, também contribuiu para a conservação local. O estudo destaca o potencial do uso de dados abertos e ferramentas livres na avaliação de áreas protegidas.

Palavras-chave: Índice Espectral; SIG; NDVI.

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1. Introduction

Over the past 40 years, Brazil has achieved significant gains in agricultural productivity, transitioning from a food importer to a global supplier. Agriculture has modernized, enabling higher yields per hectare and promoting better conservation of natural resources. However, this progress has led to intensified land use and the expansion of agricultural frontiers, especially in sensitive areas. Thus, despite Brazil's prominence as an agricultural powerhouse, new consumption patterns, increasing urbanization, and population growth are imposing ever-greater demands for water, food, and fiber—pressures that directly impact natural resources. This scenario requires both public and private organizations to develop new processes, methods, systems, and products aimed at mitigating environmental impacts and promoting sustainable practices in the agricultural sector (Embrapa, 2018).

An important public measure to ensure the preservation of natural resources was the establishment of specially protected territorial spaces across all federal units (BRASIL, 1988; BRASIL, 1981). The criteria and regulations for the creation, implementation, and management of conservation units are outlined in Law No. 9.985 of July 2000, which established the National System of Conservation Units (SNUC) (BRASIL, 2000). Conservation units (UCs) are divided into two groups and twelve categories, with only one being managed by the private sector — the Private Natural Heritage Reserves (RPPNs). These are categorized as sustainable use UCs, allowing scientific research and visitation for tourism, recreational, and educational purposes, provided such activities are included in their management plan (BRASIL, 2000). Although classified as sustainable use areas, in practice, they are managed as full protection conservation units due to the presidential veto of Article 21, Item III, which originally allowed sustainable use. Consequently, only indirect use of their natural resources is permitted.

The Mato Grosso do Sul Environmental Institute (IMASUL) is the regulatory and supervisory body responsible for the state of Mato Grosso do Sul. Within its jurisdiction, 52 RPPNs have been recognized—39 state-level and 13 federal-level—preserving an area of approximately 150,000 hectares (IMASUL, 2023). Among these, the RPPN Santa Cecília II (Fig. 1) was established through CECA Resolution No. 002/1998 (IMASUL, 2023).

Beyond the creation of conservation units, continuous management over the years is necessary to assess whether they fulfill their environmental role satisfactorily. In this regard, geotechnology is a valuable tool (OLIVEIRA, 2018). This field encompasses technologies for collecting, processing, analyzing, and providing geographically referenced information. It includes solutions in hardware, software, and peopleware, which together form powerful decision-making tools. Key components include geographic information systems, digital cartography, remote sensing, global positioning systems, and georeferenced surveying (ROSA, 2005; PARANHOS FILHO et al., 2008). Thus, this study aimed to assess, using remote sensing techniques, the impact of RPPN Santa Cecília II's delineation on soil conservation and restoration within its area and surroundings. To achieve this, an analysis of land cover variation over time was conducted by applying the Normalized Difference Vegetation Index (NDVI) between the years 1996 and 2020.

1.1. Study Area

Pantanal is a biome with an approximate area of 179,300 km², occurring in Brazil, Bolivia, and Paraguay. In Brazil, it is present in the states of Mato Grosso and Mato Grosso do Sul, with 65% of its territory located in Mato Grosso do Sul (SILVA & ABDON, 1998). It is the largest continental wetland on the planet and is classified as a large natural region—that is, an area that maintains more than 70% of its original vegetation intact and supports a rich diversity of species and ecological services. A significant portion of the biome consists of private properties, with rural landowners, known as pantaneiros, playing a key role in conserving biodiversity and regional culture (REPAMS, 2016). Pantanal is divided into 11 sub-regions: Abobral, Aquidauana, Barão de Melgaço, Cáceres, Miranda, Nabileque, Nhecolândia, Paraguai, Paiaguás, Poconé, and Porto Murtinho, each with its own natural characteristics (SILVA & ABDON, 1998).

The Private Natural Heritage Reserve (RPPN) Santa Cecília II, the focus of this study, was established through CECA Resolution No. 002/1998 (IMASUL, 2023). It is located in the municipality of Corumbá (MS) and is primarily situated in the Paiaguás Pantanal, though part of its territory extends into the Nhecolândia Pantanal (Fig. 1). Paiaguás is located north of the Taquari River, bounded by the São Lourenço, Piquiri, and Paraguai rivers. Nhecolândia is situated south of the Taquari River, bordered by the Paraguai and Negro rivers and, to the east, by the edge of the Plateau (POTT, 1982).

The region has a tropical climate with distinct wet and dry seasons, and an average annual rainfall ranging from 800 to 1,400 mm. The monthly average temperature varies between 18°C and 28°C (GARCIA, 1981). The area is characterized by very low slopes, and due to the lack of hydraulic gradient, it remains flooded—not as a result of rainfall, but due to the region's geomorphological conditions (POTT, 1982). The soil in the area is sandy, with low to medium fertility, which hinders economic activities such as cattle ranching due to nutritional deficiencies in the soil and low cattle birth rates (SOS PANTANAL).

The plateaus that define the sedimentary basin of Pantanal are partially covered by cerrado vegetation and partially by Amazon rainforest. When precipitation occurs in the plateaus, rivers transport sediments and nutrients that nourish Pantanal. As the rivers cross the floodplain, heavier and coarser sediments accumulate, obstructing riverbeds. As a result, the waters breach the banks and disperse, leading to a phenomenon known as fluvial avulsion. This process is most frequent in the final stretches of the Pantanal rivers. Although it is a natural phenomenon, human activities—such as agriculture and livestock farming—accelerate the process by increasing sediment loads originating from the plateau (ASSINE et al., pp. 172–184, 2014). Fluvial avulsions cause significant river course changes within a few decades. This process is particularly prevalent in the Taquari River, where a massive fluvial fan spreads across nearly 50,000 km², covering approximately 37% of the total Pantanal area in Brazil (ASSINE et al., pp. 172–184, 2014).

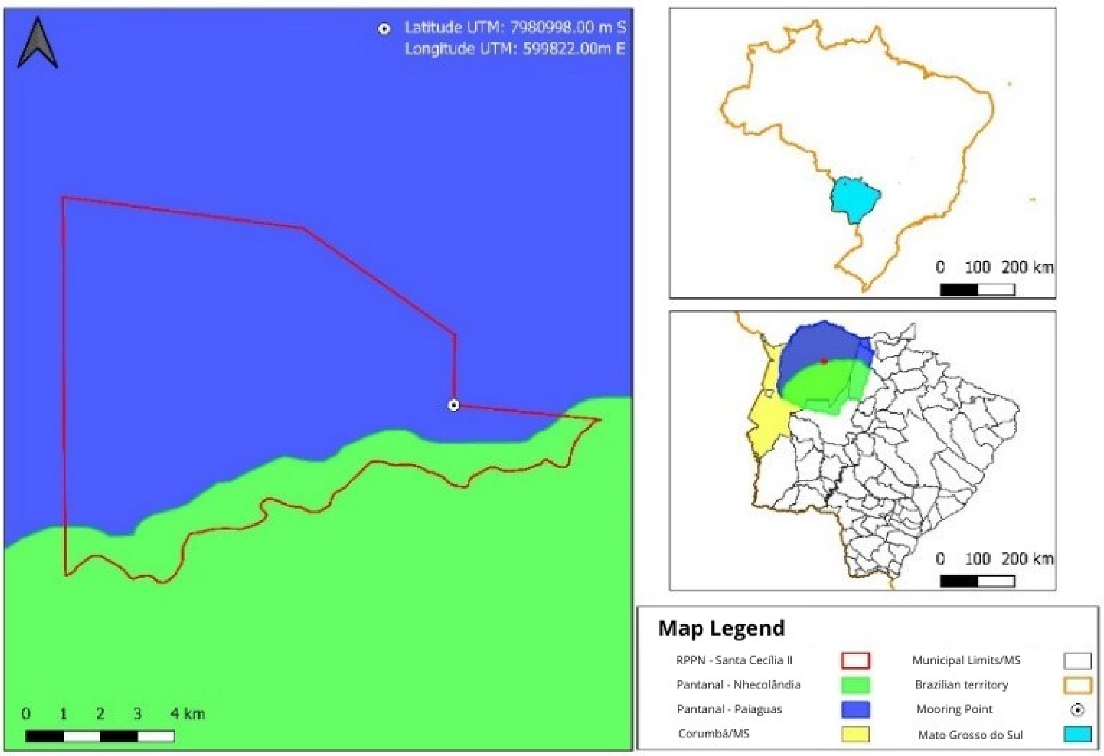

Figure 1 – Location of the RPPN Santa Cecília II in the Municipality of Corumbá, in the state of Mato Grosso do Sul, and in Brazil.
Source: Authors (2024).

2. Methodology

2.1. Database and Study Area

Remote sensing images obtained from the USGS website were analyzed, considering two distinct dates: one prior to the creation of the RPPN, in 1996, and a more recent one from 2020. Images without cloud presence and taken during the dry season were selected. Thus, one scene from the LANDSAT 5 satellite, dated August 18, 1996, and another scene from the LANDSAT 8 satellite, dated August 4, 2020, were used. Data processing and analysis were conducted using the QGIS 3.16 (HANOVER) geographic information system (QGIS Development Team, 2021). For the representation of land cover maps of the influence area and the RPPN area, the images were reprojected to UTM, SIRGAS 2000 UTM 21S.

To assess the effectiveness of the RPPN in conservation, it is necessary to evaluate its surroundings, as they may exert pressure on the reserve (e.g., deforestation) or serve as a protective buffer. This analysis aids in understanding the negative impacts of external activities that may influence the RPPN, including anthropogenic activities such as wildfires, noise pollution, environmental contamination, and erosion. According to Article 25 of Federal Law No. 9.985/2000 (SNUC), all Conservation Units must have a Buffer Zone, except for Environmental Protection Areas (APA) and Private Natural Heritage Reserves (RPPN). In this study, a 10 km radius was considered to create the buffer for evaluating the surroundings of the RPPN. This radius follows the definition of Article 27 of Decree No. 99.274/1990 (BRASIL), which establishes the buffer zone (ZA) of a Conservation Unit, with activities subject to regulations issued by CONAMA (Decree No. 99.274/1990). Although buffer zones are recognized as an important legal and scientific tool, there is no consensus regarding the efficiency of this radius. Its definition should consider the particularities of the study area, as well as the implementation of a management plan, integration of the buffer zone with local public policies, and enforcement of legal restrictions to ensure its role is fulfilled effectively.

2.2. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) (ROUSE et al., 1973) is calculated using Equation 1.

$$NDVI = (NIR-R) / (NIR+R) \quad \text{(Equation 1)}$$

Where NIR represents the near-infrared band, and R corresponds to the red band. In LANDSAT 5, these bands correspond to bands 4 and 3, respectively, while in LANDSAT 8, they correspond to bands 5 and 4. NDVI enables the characterization and analysis of biophysical parameters such as phytomass and vegetation density through remote sensing. Its values are normalized within a range of -1 to +1, where values closer to +1 indicate denser vegetation cover (Ponzoni & Shimabukuro, 2007).

The index was calculated using the Raster Calculator tool in QGIS software. For each type of land cover, 5 to 10 samples were selected from the images and delineated through polygon creation to perform descriptive statistical analysis of NDVI values (maximum, minimum, mean, and standard deviation). Once the NDVI range corresponding to each type of land cover was defined, the NDVI classification was conducted to quantify the proportion of each type of land cover within the total study area.

2. Results and Discussion

2.1. Study Area

The first administrative act establishing the regulations and guidelines for the official management of Private Natural Heritage Reserves (RPPNs) in Brazil was Decree No. 98.914/1990, recognized as the first regulatory framework that legally formalized RPPNs and provided clearer and safer rules for the creation and management of these areas. It was later replaced by Decree No. 1.922/1996, and in the year 2000, Law No. 9.985/2000 was enacted, instituting the National System of Conservation Units (SNUC), which classified RPPNs as Sustainable Use Conservation Units (UCs). These reserves are considered a valuable option for the expansion of SNUC, particularly because they integrate public authorities and civil society to promote the preservation and conservation of Brazilian ecosystems.

The Santa Cecília II Private Natural Heritage Reserve was established through CECA Resolution No. 002/1998. At the time of its creation, it was governed by Decree No. 1.922/1996, and with the enactment of Law No. 9.985/2000, it came under the regulatory framework of SNUC.

2.2. Results

The NDVI intervals for each type of land cover showed little variation across the analyzed years (Table 1). This small variation is primarily associated with factors linked to plant health (chlorophyll content, phytomass) and photosynthetic activity, rather than changes in land cover type (Ponzoni & Shimabukuro, 2007). Thus, the images were classified according to the NDVI ranges recorded for each respective analysis year.

Table 1 – NDVI Ranges for 1996 and 2020.

Year	Water	Bare Soil	Herbaceous Vegetation	Arboreal Vegetation
1996	<= -0,001	-0,001 – 0,114	0,114 – 0,291	0,291 – 1
2020	<= -0,001	-0,001 – 0,129	0,129 – 0,270	0,270 - 1

Source: Authors (2022).

In 1996 (Table 2, Figure 2), the most representative land cover class in RPPN Santa Cecília II was arboreal vegetation, occupying 55.85% of the reserve's area. In descending order relative to total area, herbaceous vegetation covered 39.51%, bare soil accounted for 2.13%, and water bodies comprised 2.51%.

The results for the year 2020 were considered positive (Table 2, Figure 3), given the increase in arboreal vegetation area and the reduction of bare soil and herbaceous vegetation. The decrease in water body areas can be explained by the severe drought at the time the image was captured. According to the Climatological Report issued by IMASUL in April 2020, the average rainfall for September between 1981 and 2010 was 40.4 mm, while in 2019, it dropped to 19.8 mm, representing a 50% reduction compared to the long-term average. This decline, combined with above-average temperatures for the period, was influenced by the El Niño phenomenon (IMASUL, 2020).

Table 2 – Representation of Each Land Cover Class in the RPPN.

Year	Unit	Water	Bare Soil	Herbaceous Vegetation	Arboreal Vegetation
1996	m²	2224800	1891800	35067600	49572900
	ha	222,48	189,18	3506,76	4957,29
	%	2,51	2,13	39,51	55,85
2020	m²	1304100	1342800	23239800	62870400
	ha	130,41	134,28	2323,98	6287,04
	%	1,47	1,51	26,18	70,83

Source: Authors (2022).

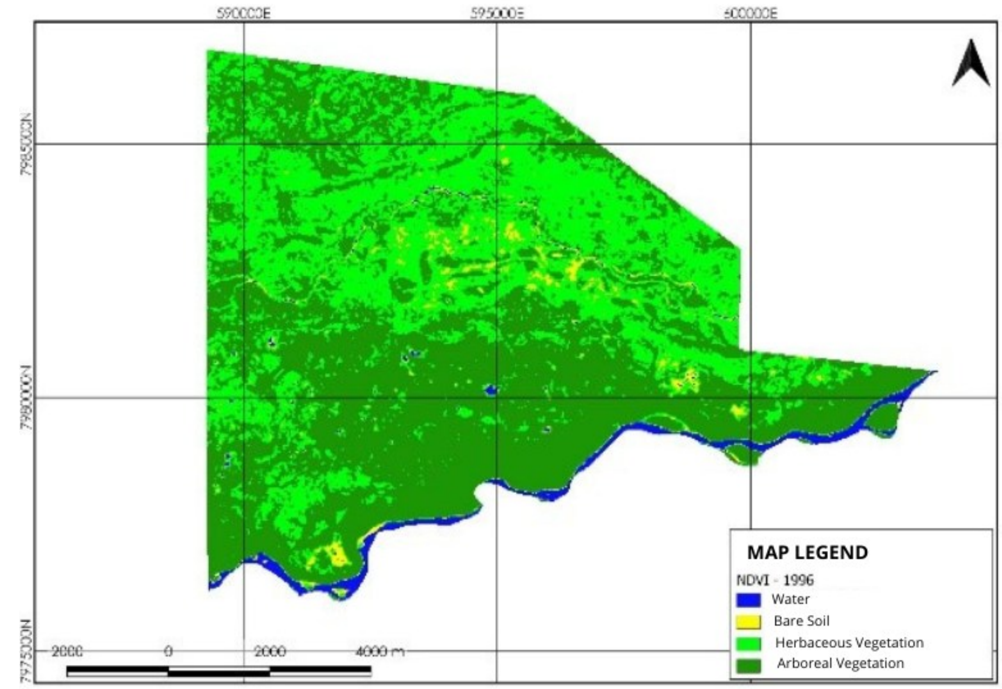

Figure 2 – Land Cover Map of the RPPN Area Generated Using NDVI (1996). Source: Authors (2022).

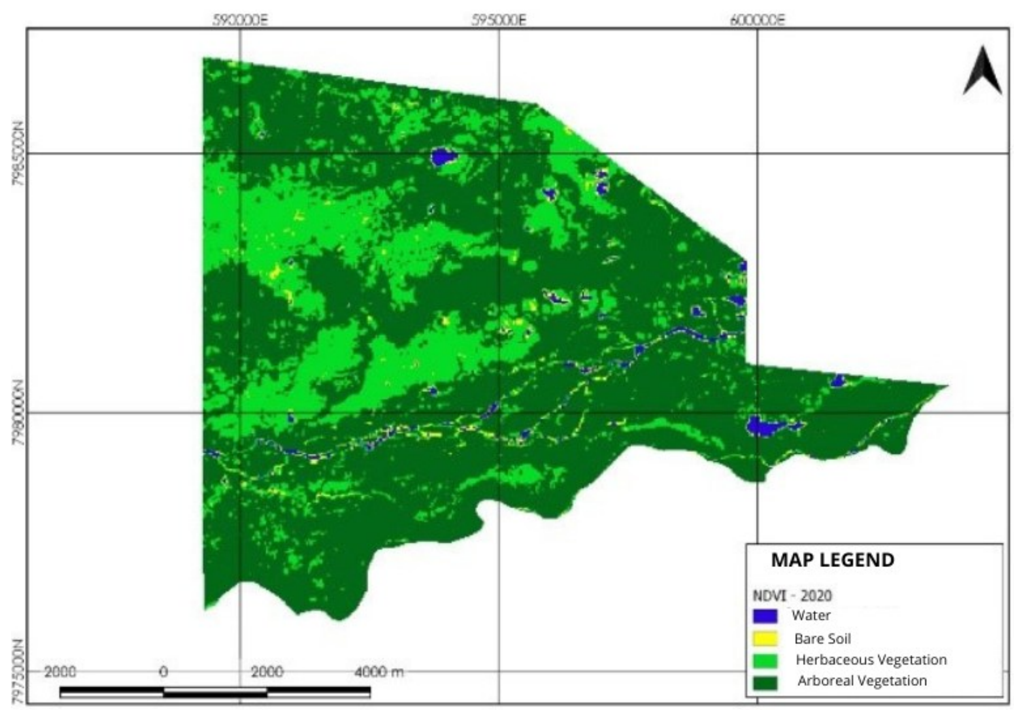

Figure 3 – Land Cover Map of the RPPN Area Generated Using NDVI (2020). Source: Authors (2022).

It is observed that there was a 14.98% increase in arboreal-shrub vegetation within the RPPN area (Tables 2 and 3), along with a reduction in the other three land cover classes, with the most significant decrease occurring in herbaceous vegetation (13.33%) (Figure 4). This suggests that herbaceous vegetation areas were likely replaced by arboreal-shrub vegetation, demonstrating a considerable increase in this vegetation type—equivalent to 1.26 times the area at the time of its creation.

It is noteworthy that this increase occurred independently of the severe drought in recent years due to the El Niño phenomenon.

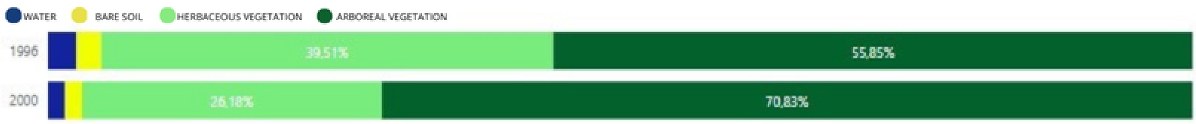

Figure 4 – Comparative Analysis of Land Cover Evolution in the RPPN.
Source: Authors (2022).

A similar pattern was also observed in the adopted buffer zone (Table 3, Figures 5, 6, and 7). There was a 24.91% increase in arboreal-shrub vegetation, along with a reduction in herbaceous vegetation, water bodies, and bare soil areas, with the most significant decrease occurring in herbaceous vegetation (23.87%) (Figure 7). It is evident that the buffer zone also underwent a substantial replacement of herbaceous vegetation areas by arboreal-shrub vegetation.

Table 3 – Representation of Each Land Cover Class in the Buffer Zone of the RPPN.

Year	Unit	Water	Bare Soil	Herbaceous Vegetation	Arboreal Vegetation
1996	m²	4679100	9229500	386883000	346417200
	ha	467,91	922,95	38688,3	34641,72
	%	0,63	1,24	51,78	46,36
2020	m²	2612700	4263300	207798300	532529100
	ha	261,27	426,33	20779,83	53252,91
	%	0,35	0,57	27,81	71,27

Source: Authors (2022).

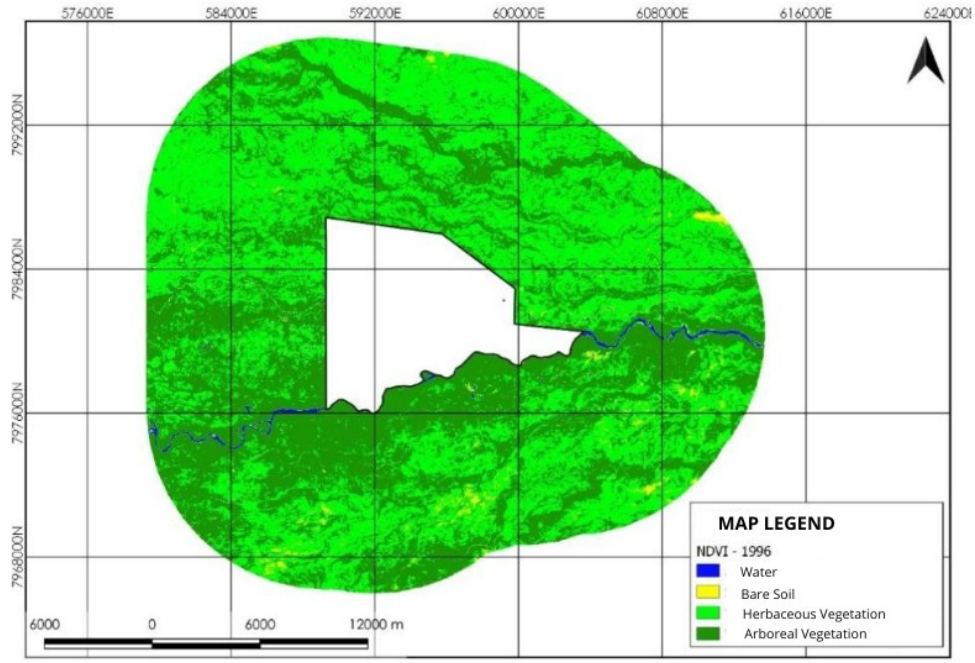

Figure 5 – Land Cover Map of the Buffer Zone of the RPPN Generated Using NDVI (1996). Source: Authors (2022).

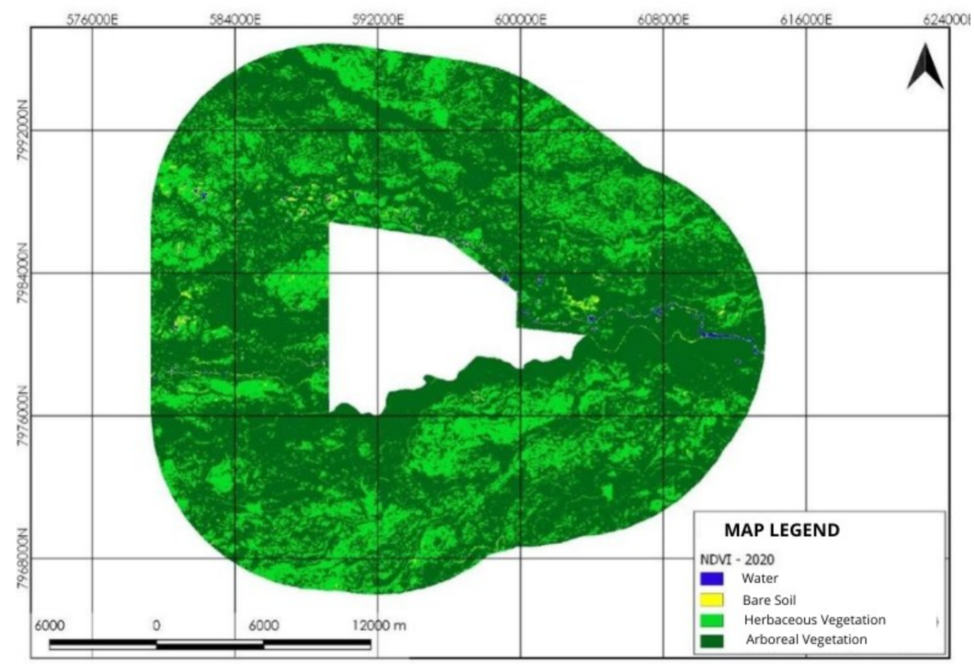

Figure 6 – Land Cover Map of the Buffer Zone of the RPPN Generated Using NDVI (2020). Source: Authors (2022).

Figure 7 – Comparative Analysis of Land Cover Evolution in the Buffer Zone of the RPPN.
Source: Authors (2022).

One of the main causes of the increase in arboreal-shrub vegetation in the region is the fluvial avulsion of the Taquari River. During this process, coarse and heavy sediments accumulate and obstruct riverbeds when passing through areas with low hydraulic energy, causing the waters to breach the banks and spread. This phenomenon is common in the Pantanal floodplain and leads to significant changes in the drainage network over a few decades (ASSINE et al., pp. 172–184, 2014).

This fluvial avulsion was detected in images of the Taquari River between 1996 and 2020 (Figures 2 and 3), influencing both the RPPN area and its surroundings. Instead of continuing its flow along the southern boundary of the conservation unit, the river began to traverse its interior, resulting in an area with greater water availability and conditions favorable for the development of arboreal-shrub formations. With its relocated central position, the floodplain now has a broader zone of influence over the study area (Figures 2, 3, 5, and 6).

However, the replacement of bare soil and herbaceous vegetation by arboreal-shrub vegetation extends beyond the influence of the Taquari River floodplain. This finding suggests that, in addition to hydrodynamic changes in the floodplain, the implementation of RPPN Santa Cecília II has had a positive impact on ecosystem restoration.

Considering that both the Conservation Unit and its Buffer Zone have shown a reduction in bare soil and herbaceous vegetation along with an increase in arboreal-shrub vegetation, it is possible to conclude that the protective measures adopted have been successful—whether in recovering degraded areas or allowing natural processes, such as fluvial avulsion, to contribute to ecological restoration. Thus, the Santa Cecília II Private Natural Heritage Reserve fulfilled its ecological function of preserving and conserving the Pantanal ecosystem until the year 2020.

4. Final Considerations

The NDVI-based multitemporal analysis has proven to be a highly effective method for assessing vegetation cover, offering a faster and more interpretable approach than other classification methods while quantifying different land cover types. The four land cover classes (water, bare soil, herbaceous vegetation, and arboreal-shrub vegetation) were successfully quantified, with arboreal-shrub vegetation showing a significant increase—1.26 times—from 1996 to 2020 (equivalent to a 14.98% increase in the RPPN area over the period).

This increase was strongly influenced by the fluvial avulsion of the Taquari River, which began flowing within the RPPN and, in turn, enhanced water availability in the region, coinciding with the expansion of arboreal-shrub vegetation. Other land cover types showed a reduction in area, with herbaceous vegetation experiencing the largest decline, as it was mostly replaced by arboreal-shrub formations.

However, this vegetation expansion was not limited to the influence zone of the Taquari River. This indicates that, in addition to hydrological changes, the protective measures implemented by RPPN Santa Cecília II have effectively contributed to the preservation and conservation of vegetation cover, ultimately facilitating the recovery of arboreal-shrub formations.

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