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Evolution of land cover from 1989 to 2023 in the southern region of the Ñeembucú department, Paraguay

Evolução da cobertura do solo de 1989 a 2023 na região sul do departamento de Ñeembucú, Paraguai

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Abstract

This research study, conducted in the southern region of the Ñeembucú Department, Republic of Paraguay, aims to investigate the evolution of land cover from 1989 to 2023. The study area encompasses the districts of Pilar, Humaitá, Paso de Patria, General Díaz, Mayor Martínez, Isla Umbú, Desmochados, Guazu Cuá, Tacuaras, Villalbín, and Laureles. The research was initiated due to concerns regarding the degradation of wetlands, especially since this region is considered unique in the country. In recent years, the southern region of the Ñeembucú Department has undergone numerous human interventions, primarily for productive purposes. The study area, covering a total surface of 6,636.5 km², was demarcated. Subsequently, LANDSAT satellite images were obtained through the U.S. Geological Survey, selected for less than 20% cloud cover. The selected area was then delineated by cropping the images to the specified extent using QGIS 3.32 software and the Semi-Automatic Classification plugin, facilitating the semi-automatic classification of land cover. Significant deforestation, an increase in areas without land cover, urban areas, and sparse vegetation, as well as a decrease in the extent of swamps, forests, grasslands, and prairies were observed.

Keywords: Land cover. Semi-automatic classification. Rivers. Forests

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Resumo
Na região sul do Departamento de Ñeembucú, República do Paraguai, foi realizado o presente trabalho de pesquisa com o objetivo de conhecer a situação da evolução da cobertura do solo, desde o ano de 1989 até 2023. A área de estudo delimitada abrange os distritos de Pilar, Humaitá, Paso de Patria, General Díaz, Mayor Martínez, Isla Umbú, Desmochados, Guazu Cuá, Tacuaras, Villalbín e Laureles. A pesquisa surgiu devido à preocupação existente em relação à degradação dos pântanos, considerando que essa região é única no país. De fato, a região sul do Departamento de Ñeembucú, nos últimos anos, foi objeto de numerosas intervenções humanas, principalmente com fins produtivos. Para a realização do trabalho, a área foi delimitada, com uma superfície total de 6.636,5 km²; em seguida, as imagens do satélite LANDSAT foram baixadas através do U.S. Geological Survey, captadas com menos de 20% de nuvens. Posteriormente, delimitou-se a área selecionada, recortando as imagens até a extensão estabelecida, utilizando o software QGIS 3.32 e o plugin Semi-Automatic Classification; assim, foi realizada a classificação semiautomática da cobertura do solo. Foi verificada uma importante desflorestação, aumento das áreas de solos sem cobertura, áreas urbanas e vegetação rasteira, bem como a diminuição na extensão de pântanos, florestas e pastagens e pradarias.

Palavras-chave: *Cobertura do solo. Classificação semiautomática. Rios. Florestas.*

1. Introduction

The use of satellite imagery, combined with GIS technologies and advanced algorithms, has revolutionized the study of land cover, especially forests and forest ecosystems. These tools enable accurate and up-to-date analysis of forested areas, crucial for resource management, conservation, and sustainable development. Long-term monitoring of land cover through satellite imagery is essential for understanding environmental and socioeconomic changes. This understanding is vital for developing effective conservation strategies and formulating sustainable natural resource management policies.

Several studies worldwide have utilized satellite imagery to assess land cover variation, such as Dinh et al. (2023) in Vietnam, Christovam et al. (2018) in the Brazilian Amazon, and Osgouei et al. (2022) in Turkey. Land cover changes are one of the most visible signs of human activity, evidenced by the transformations people impose on the ecosystems they inhabit. Currently, we are witnessing the legacy of past human exploitation based on a traditional utilization system, where both the economy and societal maintenance rely on efficient resource use (Llorente, 2019).

The exploitation of land cover for productive purposes often involves the removal of forested areas or swamp-dominated zones or ecosystems that alternate between land and water surfaces. This last point is crucial, as wetland ecosystems are characterized by their fragility; even minor influences can significantly impact their properties. Wetlands are biologically rich areas, so any productive activity in them must consider this characteristic. The loss of a forested area or estuary also implies the loss of all the flora and fauna within it.

Wetlands are typically flat land areas that are permanently or intermittently flooded. When regularly covered with water, the soil becomes saturated and oxygen-depleted, creating a hybrid ecosystem between aquatic and terrestrial. In recent years, the southern region of the Ñeembucú Department has been subject to numerous human interventions, primarily for productive purposes, necessitating a detailed study of the evolution and current occupation of land cover.

Wetlands have been affected by pollution, overpopulation, settlements, indiscriminate logging, solid waste, construction materials, and other issues (Vargas Cubillos, 2021). According to the Ramsar Organization (2018), the "Global Wetlands Outlook" report indicates a dramatic decrease in wetlands, with a 35% loss (both inland and coastal) from 1970 to 2015, in cases where data is available (Valdivia Beltrán, 2022). Wetlands are central to sustainable development, as their care and preservation through rational management can contribute significantly to human communities' subsistence.

The United Nations notes that land is a tangible asset with a quantifiable value being lost due to degradation, mainly due to the combined effect of climate variations and poor human practices (Campos, Guerrero, and Gines, 2018). Ecosystem degradation processes not only persist but are also intensifying, largely due to anthropogenic activities driven by human needs. Changes in land cover and usage alter the water cycles of basins, temperature regimes, carbon sequestration, and are a driving force behind biodiversity loss (Suarez Soto, 2020).

Changes in soil surface conditions affect the climatic dispositions of a particular area or region; this transformation alters the territory's specific conditions, causing significant, nearly irreversible changes. However, another crucial aspect often ignored or misunderstood is its impact on human populations; environmental changes in an area inevitably affect local communities or groups.

Understanding land cover and usage is one of the most critical aspects of biophysical analysis for territorial planning, influencing soil formation and evolution, and impacting ecosystem service provision (Sepúlveda-Varaset al., 2019). Changes in land cover, while sometimes necessary, should adhere to established parameters to avoid significant environmental impact, as regulations govern land use and productive activities.

Typically, changes in land cover occur in disregard of regulatory norms set by environmental authorities, which often show little efficiency in controlling and overseeing transformative activities. Soil is the basis of production, supporting various human-driven activities. However, its role is not limited to production and social aspects; it is significant as a foundation for all ecosystems. Nonetheless, continual human actions, especially in production, have led to a gradual loss of soil properties.

The soil's central role in the system means that its conservation and improvement have decisive impacts economically, environmentally, and socially (Martínez et al., 2017), highlighting the importance of soil and its role in moisture systems. Despite this, soil deterioration seems to be a frequent concern for human populations.

There are official and unofficial plans and programs that, in their execution and practice, fail to have the necessary impact to become a permanent solution. Alternatives to combat soil degradation aim to recover and improve crop yields through simple, accessible measures for local producers, not overly complex. Conservation practices may involve a combination of agronomic, vegetative, structural, or management actions (Cotler and Cuevas, 2017).

Soil conservation measures, combining agronomic, vegetative, and mechanical or structural practices, must be fully applied for successful soil conservation and productivity (Loayza Espinoza, 2021). For instance, these measures aim to restore soil properties, seeking to regain natural fertility through organic fertilizers that retain moisture, regulate temperature, and provide and retain nutrients.

Thus, smallholders can combat soil degradation on their farms, significantly improving crop yields and offsetting economic losses. It's essential in the context of developing conservationist measures that producers understand soil's various functions, not just production but also ecosystem maintenance, from which they can benefit sustainably. This implies that something substantial must be returned to the soil. For this dynamic to be effective, it should be permanent and not isolated, preferably carried out collectively.

According to Cisneros (2018), the goal is to integrate soil as part of an organized territorial system in basins, as a provider of goods and environmental services, including its conservation, with a future vision of an orderly territory to achieve sustainable development. This research aims to evaluate the evolution of land cover from 1989 to 2023 in the southern region of the Ñeembucú Department, Paraguay.

2. Methodology

The study area encompasses human populations in the following districts and their respective companies: Pilar, Humaitá, Paso de Patria, General Díaz, Mayor Martínez, Isla Umbú, Desmochados, Guazu Cuá, Tacuaras, Villalbín, and Laureles (Figure 1).

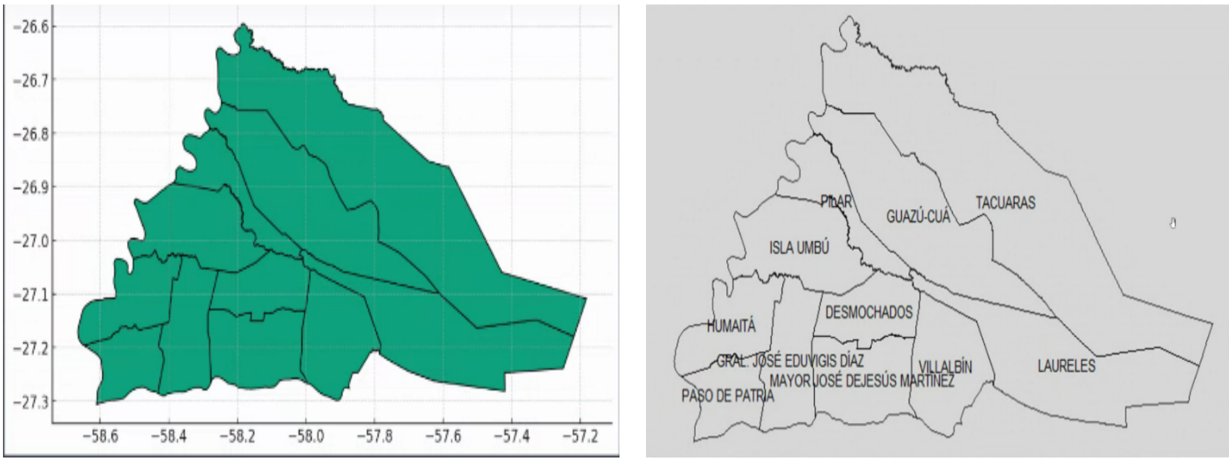

Figure 1 – Coordinates and municipalities of the study area.

Initially, based on the Japan International Cooperation Agency (JICA) 1999 report, the southern area of the Ñeembucú Department was demarcated, covering 6,636.499 km2, located at the following coordinates: minimum longitude: -58.66491223954913, minimum latitude: -27.306219282698216, maximum longitude: -57.18209360492629, maximum latitude: -26.595706376858836. Subsequent LANDSAT 5 satellite images were downloaded from the U.S. Geological Survey: LT05_L1TP_226079_19890612_20200916, LT05_L1TP_226079_19990131_20200908, LT05_L1TP_226079_20090110_20200828, LC08_L1TP_226079_20230101_20230110. All images were captured with less than 20% cloud cover.

After delineating the selected area and cropping the corresponding images, semi-automatic land cover classification was performed using QGIS 3.32 software and the Semi-Automatic Classification plugin (Congedo, 2021). Bands 5-4-3 of Landsat 5 and bands 7-5-4 of Landsat 8 were combined. Identified classes included: Rivers, bare soil, urban areas, sparse vegetation; swamps, forests, grasslands, and prairies. Finally, the temporal evolution of the identified classes was surveyed and quantified in percentages, with measurements taken in 10-year intervals, starting from 1989 and ending in 2023.

3. Results and discussion

The maps obtained through the natural color from the overlay of bands 5-4-3 of LANDSAT and bands 7-5-4 of LANDSAT 8 can be seen in figures 2 and 3, with the respective land use classes obtained through semi-automated supervision.

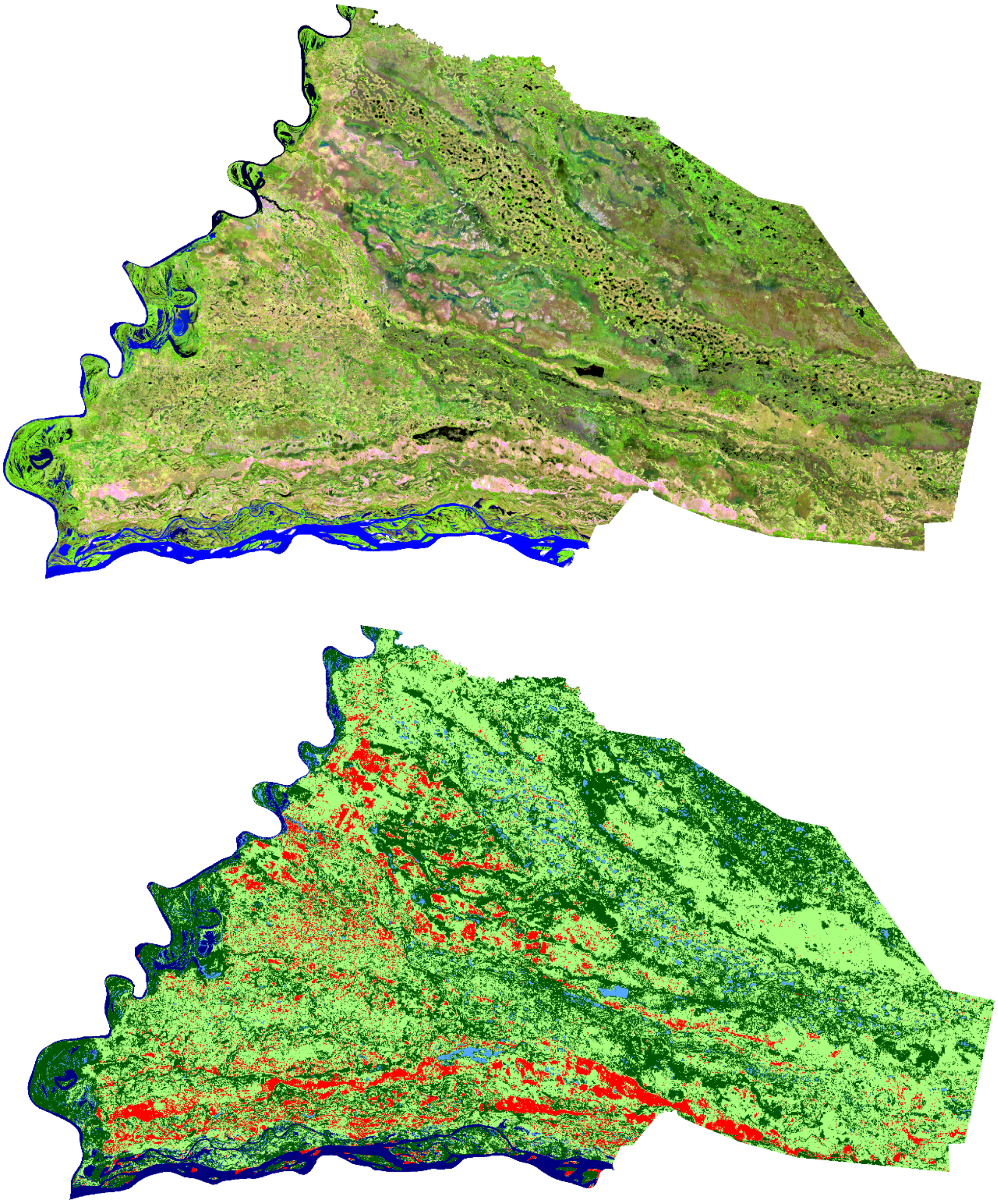

Figure 2 – Overlay of bands 5-4-3 and classified image from 1989.

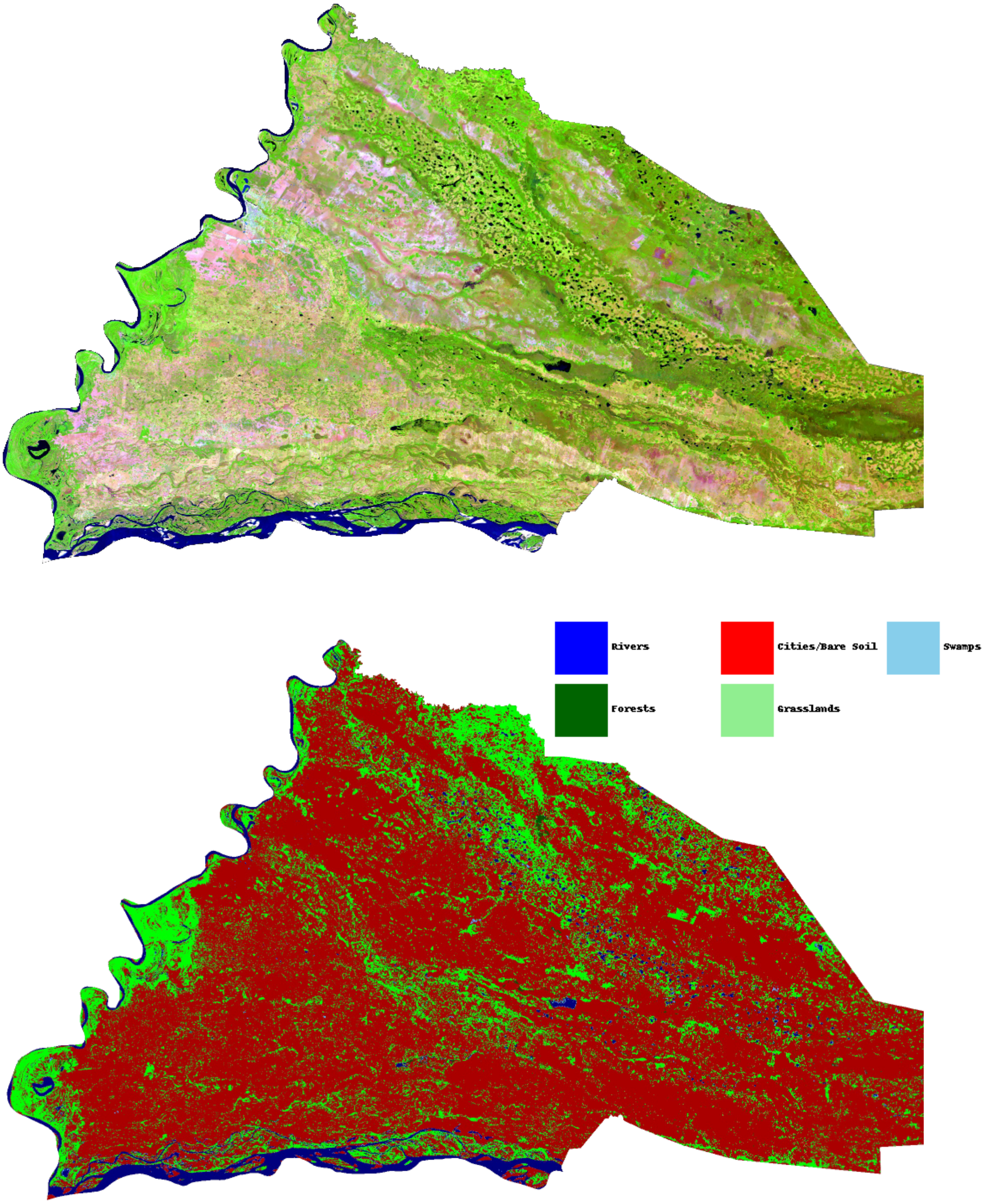

Figure 3 – Overlay of bands 7-5-4 and classified image from 2023.

The first class referenced corresponds to rivers, whose surface coverage did not significantly change, except in 1999, which matched the coverage in 1989, a period of heavy rainfall (Figure 4). The year that could be established as a decrease in rivers and their areas of influence is 2009, coinciding with a drought in the region, reducing levels to 3.0% compared to the study area.

In studying the different land use classes, a significant increase was noted in bare soils, sparse vegetation, and urban areas (Figure 4). Since 1989, coverage increased from 8.6% to 75.8% of the total area considered in the study. This marked difference of 67.2% between 1989 and 2023 is significant, particularly since the study area is a wetland.

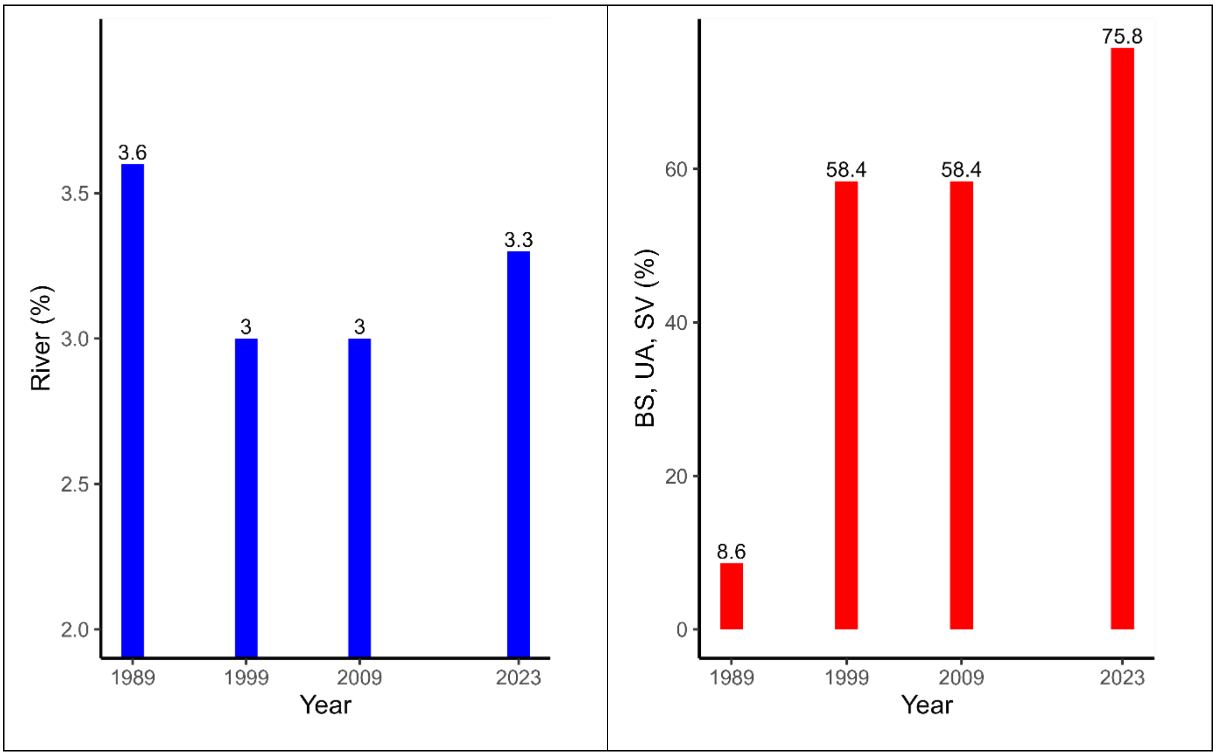

Figure 4 – Percentage of area covered by rivers and bare soils (BS), urban areas (UA), and sparse vegetation (SV) over the years.

The class corresponding to swamps, characterized by persistent water, aquatic vegetation, and muddy soil, showed a noticeable decrease. From 2.8% coverage in 1989, it reduced to 1.6% in 2009 and 0.7% in 2023 (Figure 5). Although a peak of 5.6% was observed in 1999, a period of increased rainfall and flooding in the study area, the overall trend is a reduction.

Regarding the forest land cover class (Figure 5), from a 34.1% coverage in 1989, it decreased to just 0.8%. The graph clearly shows a substantial reduction in forested areas, which play an important role in the water cycle in wetland zones. This decline from 1989 to 2023 is noteworthy, indicating a significant deforestation process, reducing forested areas to just 0.8% in the current year.

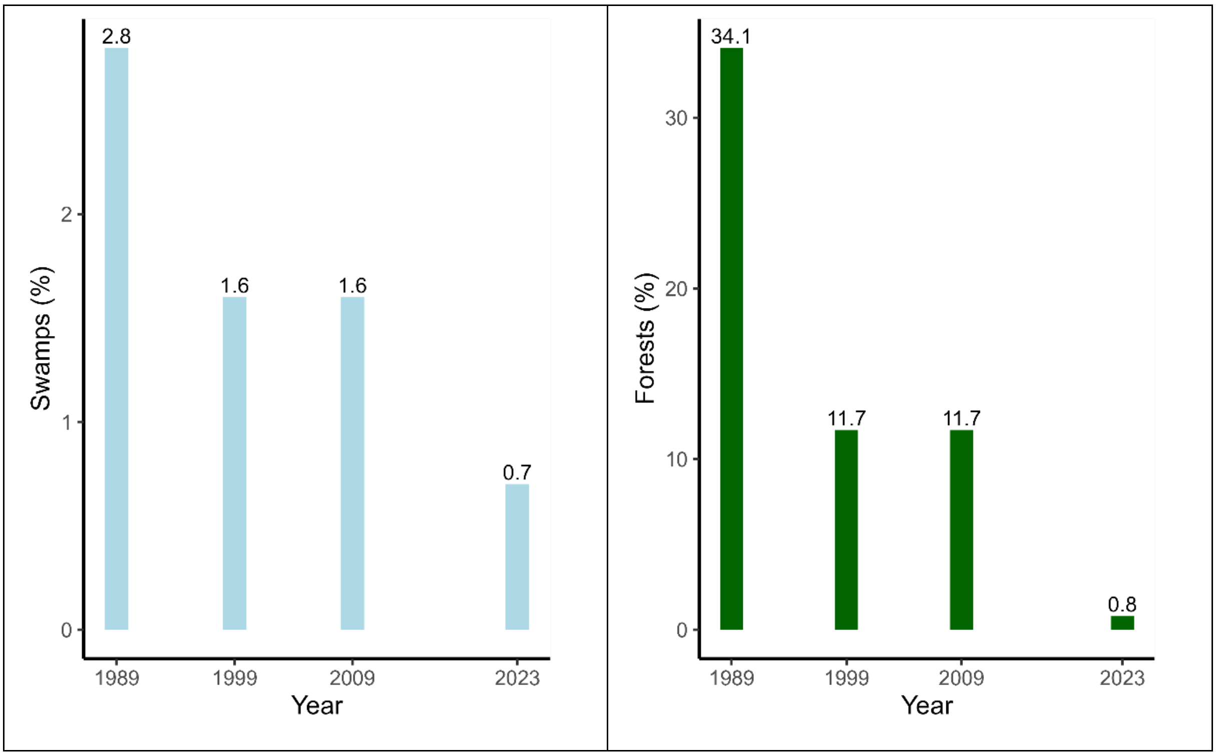

Figure 5 – Percentage of area covered by swamps and forests over the years.

In terms of grasslands and prairies, there was a significant decrease from covering 50.9% in 1989 to 19.4% in 2023 (Figure 6). This progressive decrease intensified from 53.6% coverage in 1999 to 2023, a significant difference in the percentage of occupied surface area of 34.2%. Similar results were obtained by Dinh et al. (2023), using high-resolution satellite imagery and advanced classification algorithms like Random Forest, achieving 90.53% mapping accuracy. However, this approach proved more precise compared to the techniques used in this research, based on LANDSAT band overlays for semi-automated land use classification.

It was verified that river surfaces have remained relatively stable, with notable exceptions like 1999 and 2009, characterized by variations in rainfall and droughts, respectively. This behavior of the rivers is a critical indicator of the health of wetland ecosystems, intrinsically linked to river dynamics. The overall stability of river coverage, despite temporal fluctuations, suggests resilience in the region's hydrology. However, the observed decrease in 2009 is concerning, as a reduction in water resources can have adverse impacts on biodiversity, agriculture, and human water supply.

The dramatic reduction in forested areas, from 34.1% in 1989 to only 0.8% in 2023, is alarming. Forests in wetland areas are crucial for the water cycle and biodiversity conservation. Deforestation on this scale not only implies habitat loss for countless species but also a significant alteration in water and carbon cycles. This drastic change in forest cover may have long-term consequences on climate regulation and the sustainability of wetland ecosystems.

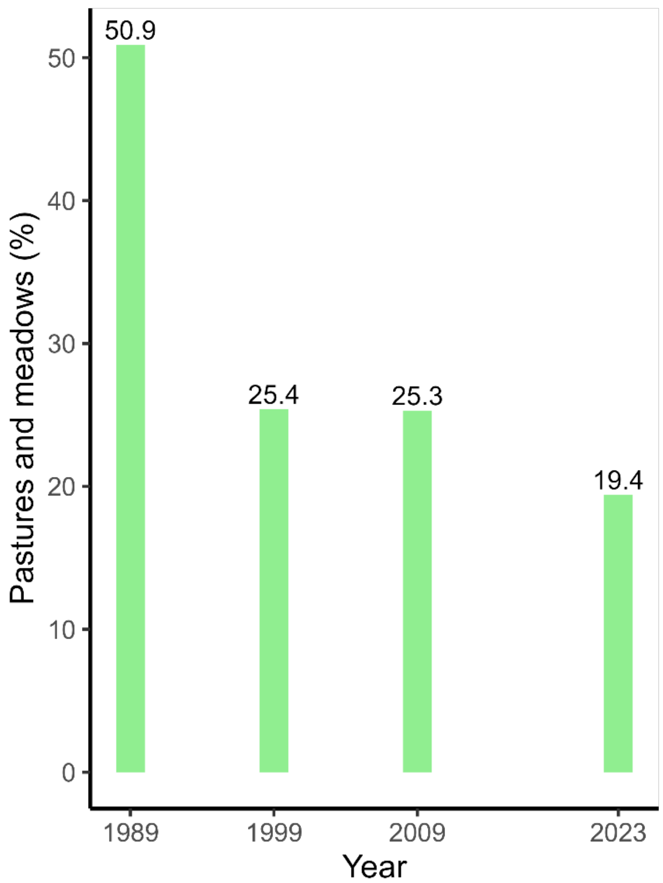

Figure 6 – Percentage of area covered by pastures and prairies over the years

The decrease in grasslands and prairies, from 50.9% in 1989 to 19.4% in 2023, reflects a significant change in land use. Grasslands and prairies are essential for maintaining biodiversity, especially in wetlands, where they provide habitat for various flora and fauna. Additionally, these ecosystems play a crucial role in carbon capture and water cycle regulation. The observed decline may be related to human activities like urban and agricultural expansion, highlighting the need for more effective management and conservation policies to protect these valuable ecosystems.

4. Conclusions

Although river coverage has shown relative stability over time, specific drought events, especially in 2009, highlight the vulnerability of wetland ecosystems to climatic variations.

The reduction of forested areas in wetlands, from 34.1% to 0.8% between 1989 and 2023, indicates a concerning deforestation process. This change not only represents a significant loss of habitat but also negatively affects water and carbon cycles.

The decrease in grasslands and prairies, from covering 50.9% to 19.4% of the study area, reflects a significant change in land use with potential implications for biodiversity and environmental regulation.

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