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SUSTAINABLE ASSESSMENT OF RIDE-DF BASINS BASED ON ECOSYSTEM SERVICES INDICATORS

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Abstract

This paper assesses the sustainability of the Integrated Development Region of the Federal District and Surrounding Areas (RIDE-DF, >46,000 km², 32 municipalities) through key ecosystem service indicators. Using quantitative spatial modeling based on geoprocessing, the study evaluates erosion potential (USLE), aquifer recharge (curve-number method), aquifer contamination vulnerability (adapted DRASTIC), and biodiversity maintenance in the Paraná, São Francisco, and Tocantins-Araguaia basins between 1985 and 2020. Results show non-homogeneous trends: in the Paraná basin, which concentrates the Federal District's urban expansion, areas with low soil loss declined by 12%, high-contamination areas increased by 8%, and high biodiversity potential areas fell by 20%; in the São Francisco basin, the area exposed to high contamination doubled; the Tocantins-Araguaia basin improved in soil loss and recharge but lost biodiversity potential. Native vegetation loss emerges as the central driver of ecosystem service degradation, supporting future public planning, management, and monitoring policies in the RIDE-DF region.

Keywords: Ecosystem Services, Sustainability Indicator, Brazilian Savanna, Basins.

Resumo / Resumen

AVALIAÇÃO DA SUSTENTABILIDADE DAS BACIAS HIDROGRÁFICAS DA RIDE-DF A PARTIR DE INDICADORES DE SERVIÇOS ECOSISTÊMICOS

O objetivo deste artigo é avaliar a sustentabilidade da Região Integrada de Desenvolvimento do Distrito Federal e Entorno (RIDE-DF), com mais de 46.000 km² e 32 municípios, por meio de indicadores de serviços ecossistêmicos. Com base em uma abordagem quantitativa de modelagem espacial por geoprocessamento, o estudo avalia o potencial de erosão (USLE), a recarga de aquíferos (método Curve Number), a vulnerabilidade à contaminação (DRASTIC adaptado) e a manutenção da biodiversidade nas bacias do Paraná, São Francisco e Tocantins-Araguaia entre 1985 e 2020. Os resultados indicam tendências não homogêneas: na bacia do Paraná, que concentra a expansão urbana do Distrito Federal, as áreas de baixa perda de solo recuaram 12%, as de alta contaminação cresceram 8% e as de alto potencial de conservação da biodiversidade caíram 20%; na bacia do São Francisco, a área exposta a alto risco de contaminação dobrou; a bacia do Tocantins-Araguaia melhorou em erosão e recarga, mas perdeu potencial de biodiversidade. A supressão da vegetação nativa emerge como fator central da degradação dos serviços ecossistêmicos e os resultados subsidiam futuras políticas públicas de planejamento, gestão e monitoramento ambiental na região.

Palavras-chave: Serviços Ecossistêmicos, Indicador de Sustentabilidade, Cerrado, Bacias Hidrográficas.

EVALUACIÓN SOSTENIBLE DE LAS CUENCAS DE RIDE-DF BASADA EN INDICADORES DE SERVICIOS ECOSISTÉMICOS

Este artículo evalúa la sostenibilidad de la Región Integrada de Desarrollo del Distrito Federal y Alrededores (RIDE-DF), con más de 46.000 km² y 32 municipios, a través de indicadores de servicios ecossistémicos. Basado en un enfoque cuantitativo de modelado espacial por geomática, el estudio evalúa el potencial de erosión (USLE), la recarga de acuíferos (método Curve Number), la vulnerabilidad a la contaminación (DRASTIC adaptado) y el mantenimiento de la biodiversidad en las cuencas del Paraná, São Francisco y Tocantins-Araguaia entre 1985 y 2020. Los resultados indican tendencias no homogéneas: en la cuenca del Paraná, que concentra la expansión urbana del Distrito Federal, las áreas de baja pérdida de suelo se redujeron un 12%, las de alta contaminación crecieron un 8% y las de alto potencial de conservación de la biodiversidad cayeron un 20%; en la cuenca del São Francisco, la superficie expuesta a un alto riesgo de contaminación se duplicó; la cuenca del Tocantins-Araguaia mejoró en erosión y recarga, pero perdió potencial de biodiversidad. La pérdida de vegetación nativa surge como el factor central de la degradación de los servicios ecossistémicos, y los resultados respaldan futuras políticas públicas de planificación, gestión y monitoreo ambiental en la región.

Palabras-clave: Servicios Ecossistémicos, Indicador de Sostenibilidad, Cerrado, Cuencas.

INTRODUCTION

The Cerrado biome is the second largest biome in Brazil, occupying a quarter of the entire country, in its central portion, sheltering about a third of the Brazilian fauna and flora (Dias & Klink, 2019), being considered one of the world's biodiversity hotspots (Klink & Machado, 2005). Besides its great biodiversity, Cerrado is also very important for the country's water supply, hosting the sources of the greatest water basins in Brazil (Dias & Klink, 2019; Souza et al., 2019).

Despite its ecological importance and the ecosystem services provided, the Cerrado savanna is under strong anthropogenic pressure, mainly due to monocultures of soy, corn, cotton, sugarcane, and cattle grazing expansions. The biome is responsible for about half of Brazilian agricultural production and also responsible for deforestation (Ferreira et al., 2013).

Deforestation is not homogenous, fragmenting habitats on increasingly smaller and isolated islands of vegetation, compromising ecological connectivity and, consequently, the viability of local species (Grande et al., 2020). The low degree of legal protection aggravates the vulnerability of the Cerrado (Ganem et al., 2013). Most of the remnants of the biome are found in rural properties (EMBRAPA, 2007). The Brazilian Forest Code provides for the mandatory preservation of 20% of rural properties as Legal Reserves (areas of native vegetation that should be preserved or used in a sustainable way). Currently, farms in Cerrado still host 41% of natural vegetation, equivalent to approximately 305,000 km² (or 30% of what is left of the biome) that could still be legally suppressed. Therefore, even if existing law is effectively enforced, there is still legal room for deforestation (Chaves et al., 2023).

In 1960, the Brazilian capital was transferred from the coast (Rio de Janeiro) to the center of the country. The brand-new city to be the capital, Brasília (Federal District), was built in only 4 years (between 1956-1960). The Brazilian hinterland was considered “empty”, with a few scattered towns and low population density. The transfer of the capital aimed at bringing industrialization and development to the Brazilian Midwest (Santos, 1964). Agriculture expansion was at the core of this plan. However, Cerrado's conditions were not favorable for large-scale agriculture: acidic soils, poor rainfall distribution during the year (EMBRAPA). In the 1970s, the government funded research and innovation for adapting modern agricultural systems to Cerrado, allowing large-scale agriculture to be possible (Hosono et al., 2016). Furthermore, investments in infrastructure along with subsidies and specific development programs prompted a strong agricultural sector (Hosono et al., 2016). As a result, the Cerrado became the most important biome for agribusiness expansion in Brazil since the second half of 20th century, as well as the most threatened by land use change.

In 60 years, Brasília has grown from 12,000 people in late 1950's to be the 3rd populous city in Brazil, with a total of 2,8 million people according to Census 2022 (IBGE, 2022). Its surroundings also had grown, becoming a functional unity with Brasília and the 4th largest metropolitan region in Brazil, named Integrated Development Region of the Federal District (RIDE – DF in Portuguese acronym). In 2022, RIDE-DF had more than 6 million people (IBGE, 2022). It functions as a socioeconomic unity. The other RIDE-DF municipalities developed functionally interdependent of its core - Brasília. They concentrate most of agricultural production and a significant percentage of their work force flow daily to Brasília. At the same time, Brasília provides many critical services to the population from other municipalities located in RIDE-DF, such as healthcare and education (Tonhá et al., 2015).

From both ecological and strategic perspectives, it hosts river springs to three of the most important Brazilian water basins: São Francisco, Paraná and Tocantins-Araguaia. It also partially covers one of the last expressive blocks of native Cerrado vegetation, emerging as a key area for Conservation of the biome (Klink & Machado, 2005).

Deforestation and loss of biodiversity impacts the quality of ecosystem services within the RIDE-DF and are related to a set of socio environmental issues that can affect high urbanized areas (Sobrinho et al., 2011). For instance, they are related to the magnitude of recent local events, such as the water crisis that occurred in DF (2017-2018) (Lima et al., 2018). The present work aims at discussing the land use and land use change impacts in the last 40 years on key ecosystem services within RIDE-DF. The results allowed us to identify trends, drivers and critical areas for ecosystem service conservation and restoration.

THE ECOSYSTEM APPROACH

The concept of Ecosystem Service (ES) has been widely used to describe the benefits, both direct and indirect, that the functioning of ecosystems provides to human populations (Costanza, 1997). The Millennium Ecosystem Assessment (MA) (2005) features the ecosystem approach as a bridge between the environment and human well-being and, therefore, organizes the ecosystems services in four categories: (i) provisioning services (products obtained from ecosystems); (ii) regulating services (benefits obtained from regulation of ecosystem process); (iii) supporting services (services necessary for the production of all other ecosystem services) and (iv) cultural services (nonmaterial benefits obtained from ecosystems) (CICES, 2018; Teeb, 2012).

Biodiversity and ecosystems processes are the cornerstones from which the ecosystem services emerge (Potschin & Haines-Young, 2016). Biodiversity loss and ecosystem degradation due to land use and land use change (LULUC) are a main source of pressure on ecosystems services (Biedemariam, 2022; Blumenstein & Thompson, 2015).

In this context, assessments of ES can be challenging. One critical challenge is the scale definition, once the ecosystems are a continuum and heterogeneous system, characterized by hierarchical nested processes in both space and time (Ratzé et al., 2007). Consequently, there is not a correct scale for ecosystem assessment. One-level scale approaches may ignore important cross-scales interactions and powerful insights may come from multiscale approaches (Scholes et al., 2013).

Another critical challenge is both adjusting the assessment approach to the assessment goal and selecting indicators. There are three different approaches: Ecosystem Quality Assessment (EQA); Biodiversity Status Indicator (BSI); and Environment Impact Assessment (EIA) (Feld et al., 2010). All approaches focus on one or more dimensions of the DPSIR framework (Driver-Pressure-State-Impact-Response) (EEA, 1999). A variety of indicators have been proposed since the early 2000s. In 2004, the Convention on Biological Diversity (CBD) established a set of indicators to monitor trends and status of biodiversity and linked them to ecosystem services at a global scale (CBD, 2004). The European Environmental Agency (2012) adopted a list of 26 indicators related to biodiversity and ecological processes. Mostly of them measure trends in drivers and pressures.

METHODOLOGY

STUDY AREA

The RIDE-DF and surroundings are an integrated economic development region and was created in 1998 (Andrade, 2020). The area is in the Midwest of Brazil, covering municipalities located in three different Brazilian states: Goiás, Minas Gerais and Federal District (Figure 1). Currently, RIDE-DF contains 32 municipalities.

The method adopted in the present paper consists of a quantitative assessment of ecosystem services impact in the RIDE-DF, using spatialized environmental indicators, generated by geoprocessing tools. The analysis was made regarding two years (1985 and 2020), aggregated for the three RIDE-DF's basins (Paraná, Tocantins-Araguaia and São Francisco), allowing a comparison related to the development of RIDE-DF.

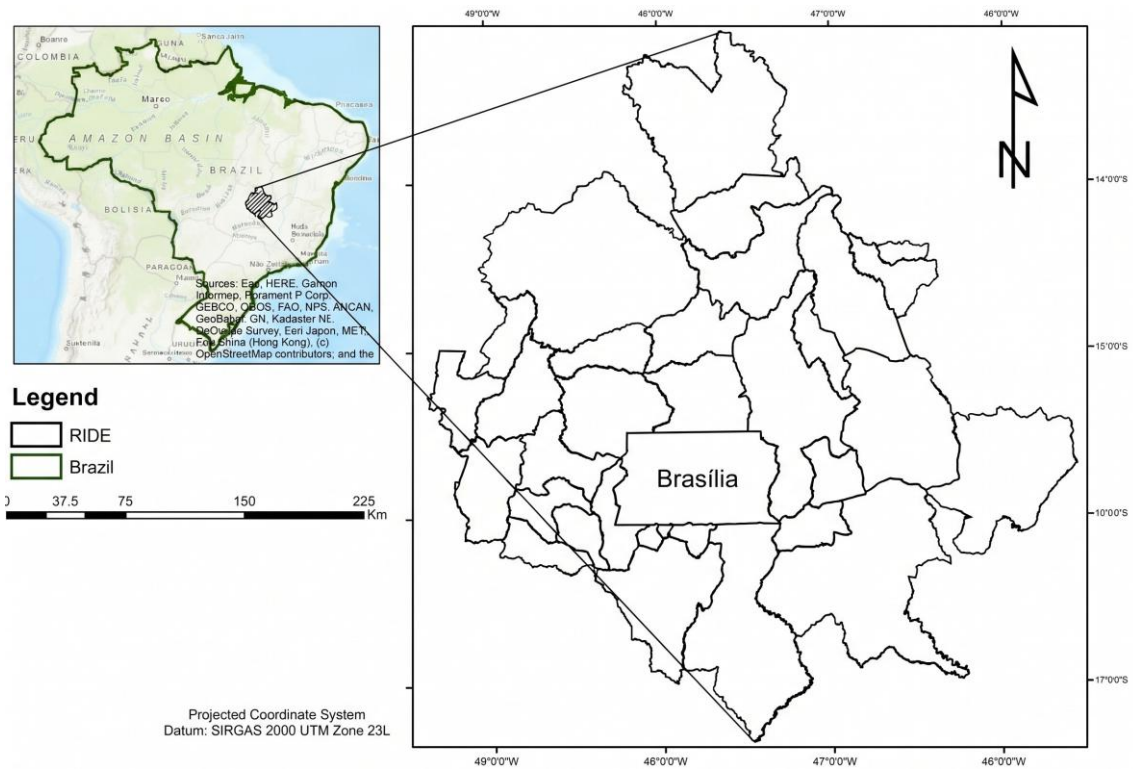


Figure 1 - Location of RIDE-DF. Source: Elaborated by the authors.

The study was carried out based on indicators related to pressures and impacts in ecosystem services (table 1). A biodiversity maintenance indicator was selected as a cross-cutting indicator, once biodiversity is the cornerstone of many provision, regulating and cultural ecosystem services. For analysis, an erosion indicator is used to assess the impact in sediment retention (regulating service). Impacts in water yield (provision service) were measured by two indicators: one related to aquifer recharge and another on aquifer contamination.

Indicator	Methodology	Data	Source
Erosion Control	Wischmeier e Smith (1978)	Land use and land cover, Pedology, DEM, Rainfall	MAPBIOMAS (1985; 2020), EMBRAPA (2020), TOPODATA (2009), NASA
Aquifer Recharge	Gonçalves et al (2009)	Land use and land cover, Pedology, DEM, Rainfall	MAPBIOMAS (1985; 2020), EMBRAPA (2020), TOPODATA (2009), NASA
Aquifer Contamination	Aller et al (1987)	Porous aquifer hydrogeology, Aquifer Recharge, Saturated aquifer hydrogeology, Pedology, DEM	CPRM; Elaborated by the author. SBG/CPRM; EMBRAPA (2020); TOPODATA (2009)
Biodiversity Maintenance	Lima et al (2017)	Land use and land cover	MAPBIOMAS (1985; 2020)

Table 1 – Ecosystem service indicators used in the study. Source: Compiled by the authors.

SEDIMENT RETENTION - USLE

The Universal Soil Loss Equation parameters (R,K,LS,C,P) were derived from established empirical equations calibrated for tropical conditions, following Wischmeier and Smith (1978) and adapted for Brazilian watersheds by Lombardi Neto and Moldenhauer (1992) and Silva et al. (2010). The resulting soil loss values (ton/ha/year) were grouped into five standardized class intervals (0-0.2, 0.2-1, 1-3, 3-5, and 5-22), reflecting stable soils versus severe erosion vulnerability driven by land cover conversion.

The calculation of USLE is made by the formula:

$$A=R \times K \times L \times S \times C \times P \quad (1)$$

Where:

A = soil loss per unit area and time, in ton per year;

R = rainfall erosivity factor, expresses the erosive power of the average annual precipitation;

K = soil erodibility factor, expresses the tendency of each soil type to be eroded by rain;

L = topographic factor, expresses the length of the slope

S = topographic factor, expresses the slope of the terrain or the degree of slope;

C = factor of land use and management;

P = factor of conservationist practices;

AQUIFER CONTAMINATION – DRASTIC

The DRASTIC methodology, developed by Aller et al (1987), was made so that it was possible to classify the vulnerability assessment of an aquifer, hierarchically classifying the hydrogeological parameters, such as water depth, aquifer recharge, aquifer lithology, soil type, topography, texture of the floodplain zone and hydraulic conductivity of the aquifer (Silva, 2014). In the present work, an adaptation was made, including a parameter of land use and coverage, because the methodology presented only hydraulic parameters of the aquifer, thus containing difficulty in pointing out how land use and land cover can affect the aquifers, such as contamination by pesticides, fertilizers, sewage spills, mining and other problems that occur on the surface, mainly by human actions, which reach the groundwater.

To calculate the final DRASTIC index, a weighted sum is made using the equation:

$$DH = \frac{S}{Rainfall} \quad (4)$$

Where:

Dr = Index of the range of water depth values;

Dw = Weight of water depth;

Rr = Water recharge value range index;

Rw = Weight of water recharge;

Ar = Index of the aquifer lithology value range;

Aw = Weight of aquifer lithology;

Sr = Soil type value range index;

Sw = Soil type weight;

Tr = Index of the topographic slope value range;

Tw = Weight of the topographic slope;

Ir = Index of the vadose zone value range;

Iw = Weight of the vadose zone;

Cr = Index of the range of hydraulic conductivity values;

Cw = Hydraulic conductivity weight;

Or = Index of the land use and occupation value range;

Ow = Weight of land use and occupation.

The resulting vulnerability index values were categorized into five intervals (58-106, 106-134, 134-153, 153-170, and 170-228) representing negligible to extreme contamination risks.

AQUIFER RECHARGE

The hydrological modeling followed Gonçalves, Roig, and Campos (2009), integrating Hydrological Soil Groups (Embrapa), Curve Number (CN) values based on land use and cover, maximum water retention capacity (S), potential hydric availability (DH), and slope infiltration rates (Tdecl). The resulting recharge indices were classified into five proportional intervals (0-7.6, 7.6-21.7, 21.7-40, 40-51.23, and 51.23-72%).

In order to be able to generalize the curve-number (CN) map, the land use and occupation map was needed. With the two maps, being the soil map and land cover and land use map, the integration with the two maps was done. With the integration, it was possible to make the CN map. The CN values were placed on the map from the calculate field tool, making it possible to link CN values to hydrologic soil classification and land use and occupation.

With the CN map, it was possible to continue the methodology, generating the map of maximum water retention capacity of the soils (S).

$$S(mm) = \frac{25400}{CN} (3)$$

Where:

S = maximum water holding capacity of soils;

CN = curve-number.

With S values map, with the average rainfall, the map of potential hydric availability (DH) was generated.

$$DH = \frac{S}{Rainfall} (4)$$

Where:

DH = Hydric availability;

S = maximum water retention capacity of the soils.

The recharge potential of the area was generated from the integration of the water availability map and the infiltration rate as a function of slope (Tdecl), from the following equation:

$$PR = \frac{(DH \times Tdecl)}{100} (5)$$

Where:

PR = Recharge potential;

DH = Hydric availability;

Tdecl = Infiltration rate as a function of slope.

BIODIVERSITY MAINTENANCE

The methodology for maintaining biodiversity is developed by Lima et al (2017). It consists of using the land use and occupation map. With it, it is possible to generate maps with pre-established values for each type of use or occupation.

The values range from 0 to 100, with higher values representing more favorable conditions. These values represent land use and land cover. There are other values that have influence and are called reduction factors. The reduction factors for biodiversity maintenance are related to soil type and slope.

Therefore, to generate the biodiversity maintenance maps, it is necessary to multiply land use and land cover map with the soil map, which has the soil factor reduction values, and the slope map, which has the slope factor reduction values, thus forming a new value, specific for each area. Good values are higher than 70, while bad values are lower than 30, among these values, they are considered intermediate values.

METHODOLOGICAL VALIDATION AND REPRODUCIBILITY

Regarding the validation of the spatial models and assigned weights, the parameter weights and multicriteria classification intervals adopted in this study were cross-validated against official governmental and academic hydro-environmental reports published for the Federal District and surrounding regions, such as basin water plans by ADASA and geological framework data by SGB/CPRM (Geological Survey of Brazil). Furthermore, rather than relying solely on single-point field calibration, which is constrained across a macro-regional extent like the RIDE-DF (>46,000 km²), validation was conducted via temporal cross-checking between 1985 and 2020 datasets.

The observed trajectories, including increased erosion and contamination risks linked directly to native vegetation suppression in the Paraná and São Francisco basins, are statistically and spatially consistent with independent regional land-use change studies (Ferreira et al., 2013; Klink et al., 2020). Finally, to ensure a robust reproducibility framework, all input raster layers originate from public, peer-reviewed, and institutional repositories such as the MapBiomas Collection, Embrapa Solos, INPE Topodata, and NASA Giovanni, ensuring that the mathematical formulations, weighting matrices, and GIS routines described herein can be fully replicated by other researchers.

RESULTS AND DISCUSSION

Between 1985 and 2020, the performance trends of the indicators across the basins were diverse and non-homogeneous. The Paraná River basin showed the worst overall performance, with deterioration in all indicators (Figure 2). There was a significant reduction (–12%) in areas characterized by low soil losses (0-0.2 t/ha/year) and an increase in areas with moderate erosivity. The impact indicators for aquifers also demonstrated a degradation trajectory. The area classified as having a high contamination index saw a significant increase (8%), while areas classified as low and moderate contamination decreased in extent between 1985 and 2020.

At the same time, the aquifer recharge potential generally declined in the basin, with a reduction in areas of higher potential, which were converted into areas of intermediate and low potential. Similarly, the biodiversity conservation potential in the Paraná basin was substantially reduced during this period, with a 20% decrease in areas of high potential, accompanied by an increase in areas with lower potential. The degradation of ecosystem services associated with the Paraná basin was expected, given that the Paraná River basin within the RIDE-DF region concentrated most of the Federal District's urban expansion over the past 40 years. This expansion developed in the south-southwest quadrant of the RIDE-DF, a region historically connected to the axis linking the new capital to the south-central part of Brazil.

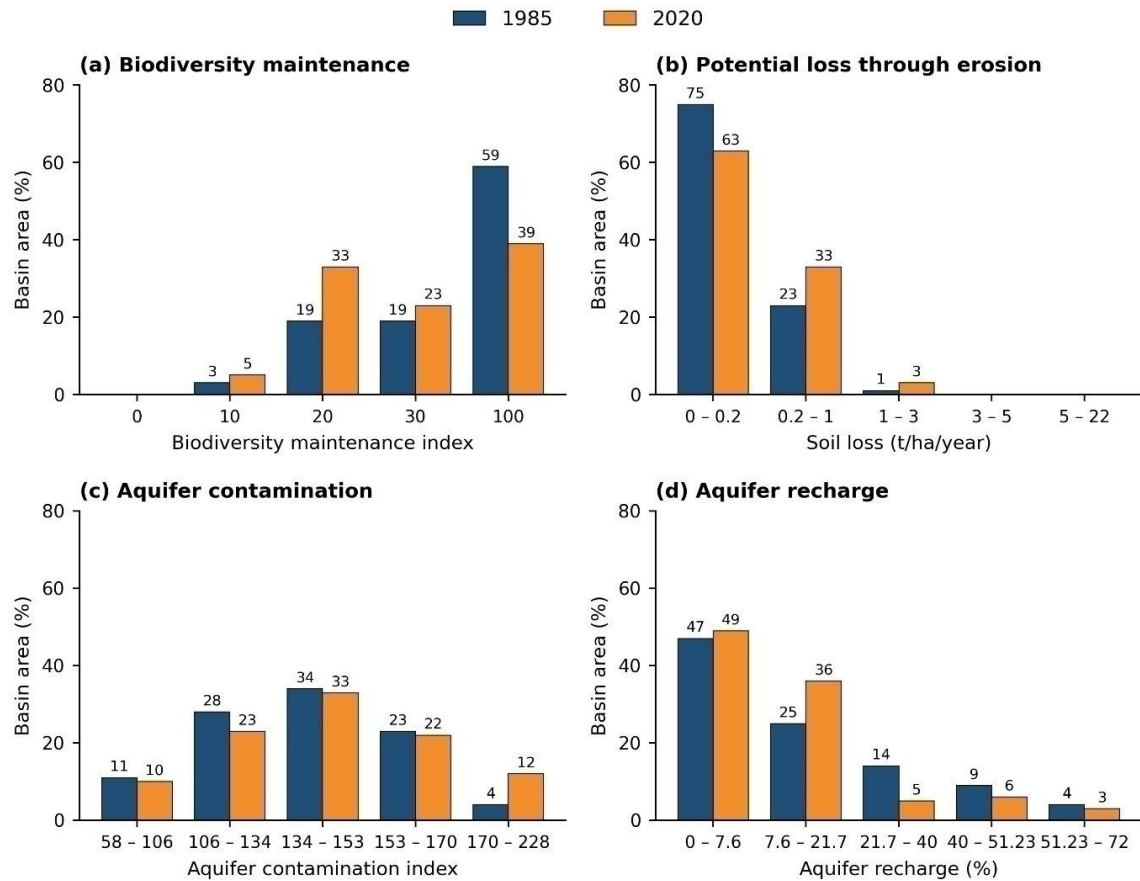


Figure 2 - Potential Indicators for the Paraná River basin in the years 1985 (blue) and 2020 (orange). (a) Biodiversity maintenance, (b) Potential loss through erosion, (c) Aquifer contamination, and (d) Aquifer recharge. Source: Elaborated by the authors.

The São Francisco River basin, in turn, showed a general trend of decline in the quality of the analyzed ecosystem services, worsening in three of the four considered indicators between 1985 and 2020 (Figure 3). The decline in aquifer recharge potential and biodiversity conservation potential is evidenced by the reduction in areas classified with higher potential, while in the case of the aquifer contamination index, the deterioration is marked by the doubling of the area exposed to a high degree of contamination. Only the soil loss indicator showed improvement, with a slight increase in areas of lower erosivity and a corresponding reduction in areas of medium and medium-high vulnerability. The underlying dynamic behind this trend is linked to the expansion of agriculture, particularly grain crops (MAPBIOMAS, 2024).

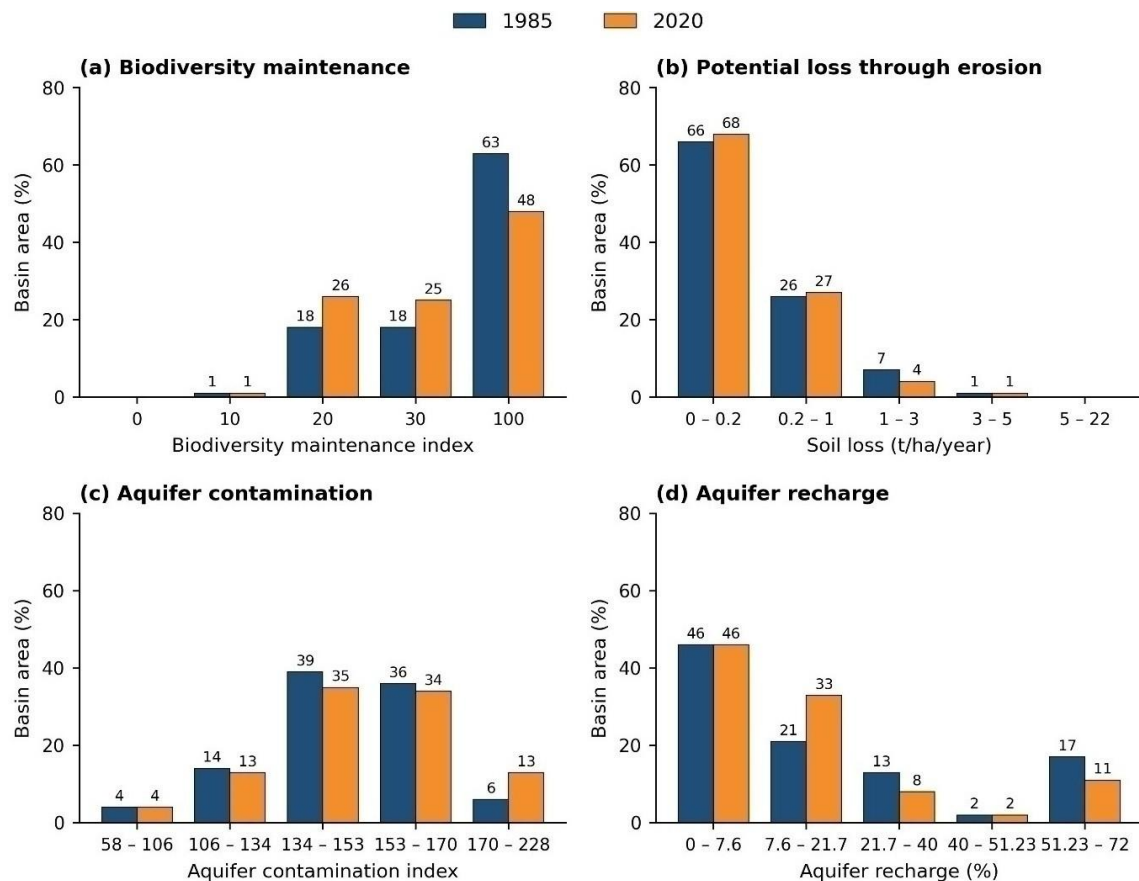


Figure 3 - Potential Indicators for the Paraná River basin in the years 1985 (blue) and 2020 (orange). (a) Biodiversity maintenance, (b) Potential loss through erosion, (c) Aquifer contamination, and (d) Aquifer recharge. Source: Elaborated by the authors.

Finally, the Tocantins-Araguaia basin exhibited divergent trends in the performance of the indicators (Figure 4). While there was improvement in two (soil loss and aquifer recharge), a decline in biodiversity conservation and stabilization of the pressure on groundwater quality due to aquifer contamination since 1985 were observed. The ambiguity in trends among the indicators is related to specific characteristics of this section of the basin. The rugged and rocky topography makes the soil relatively more erosive compared to the other basins analyzed, and favors surface runoff over infiltration. The combination of irregular terrain and the historical isolation of this region from the main roadways connecting RIDE-DF to other parts of the country resulted in less extensive and more recent urban and agricultural development.

The expansion of grain crops in the last decade has adjusted land cover and applied soil conservation practices, leading to reduced soil loss and increased aquifer recharge potential. However, the suppression of the Cerrado vegetation associated with this expansion resulted in a substantial loss of habitats, as measured by the decline in biodiversity conservation potential between 1985 and 2020. Nevertheless, the absolute performance of this index remains the best among the three basins, both because it is a newer agricultural frontier and because the Tocantins-Araguaia basin within the RIDE area contains some of the most important protected areas of the Cerrado, such as the Pirineus State Park, Chapada dos Veadeiros National Park, and the Kalunga Quilombo Territory.

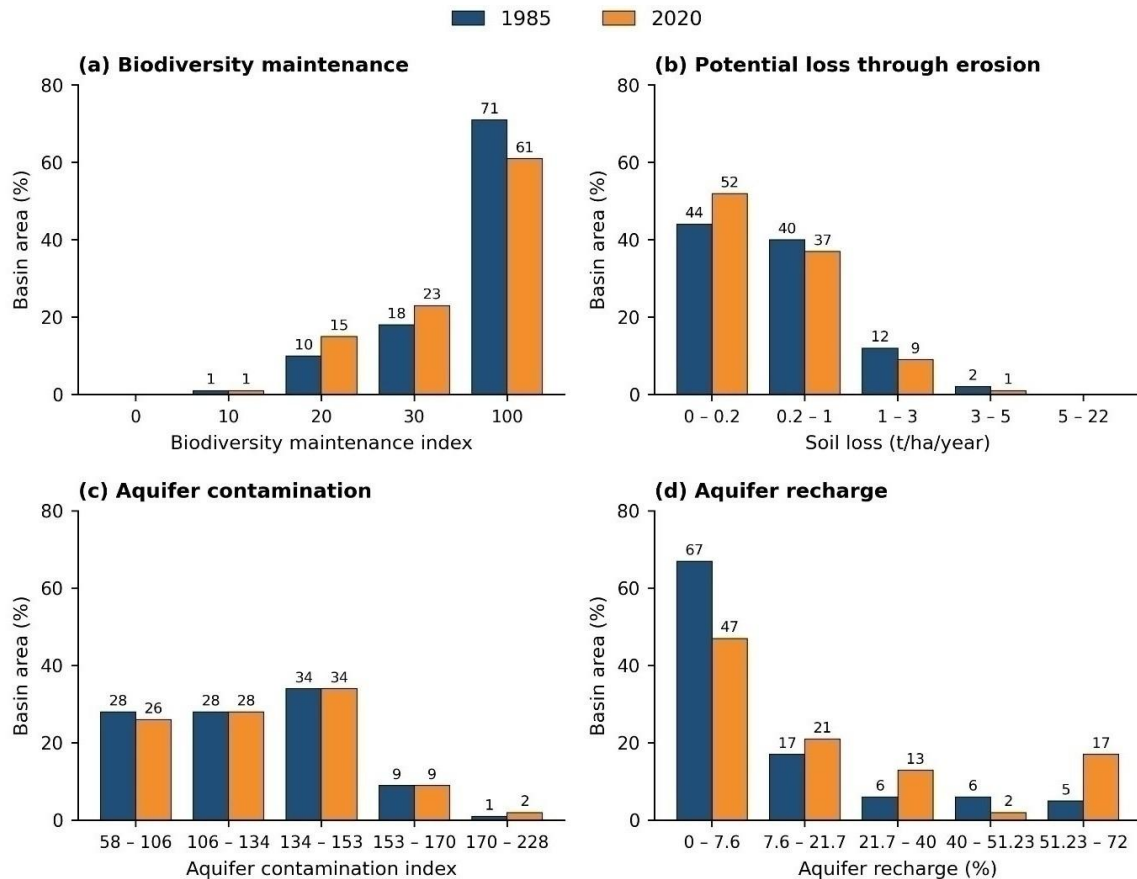


Figure 4 - Potential Indicators for the Paraná River basin in the years 1985 (blue) and 2020 (orange). (a) Biodiversity maintenance, (b) Potential loss through erosion, (c) Aquifer contamination, and (d) Aquifer recharge. Source: Elaborated by the authors.

Overall, it is possible to observe the centrality of the Federal District as the organizing and distributive hub of pressures and impacts on the three analyzed basins (Figure 5). First, it serves as the heart of the RIDE-DF and the core of the metropolitan region, concentrating most of the population and urban sprawl, as well as the supply of goods and services. The rapid growth of the capital over the past 40 years (an 86% increase in population) and its role as a centralizing force in the surrounding municipalities make this nucleus an area of intense socio-economic dynamics, accompanied by the suppression of native vegetation, the expansion of impervious zones, and increased pressure on water resources.

Additionally, the fact that the Federal District (DF) serves as a watershed divide among the three basins, despite its disproportionate coverage across the district's territory, must be considered. In terms of area, most of the DF lies within the Paraná River basin (63%), followed by the São Francisco River basin (23%) and the Tocantins-Araguaia River basin (13%) (CODEPLAN, 2020). This disproportionality in area means that the impact of the DF's dynamics is also uneven among the basins. It is observed that the impact was particularly intense in the western quadrant of the DF, where urbanization processes were more intense. This area primarily encompasses the Paraná basin.

In contrast, the eastern quadrant of the DF also shows significant degradation of indices. This trend is primarily associated with the accelerated expansion of agriculture in the Preto River valley, which is part of the São Francisco basin. On a broader scale, it is evident that this region of the DF expanded both north and south between 1985 and 2020, connecting previously isolated and/or nascent areas, thus forming an axis of biodiversity loss potential that traversed areas in all three considered basins, reflecting the conversion of native areas into agricultural land.

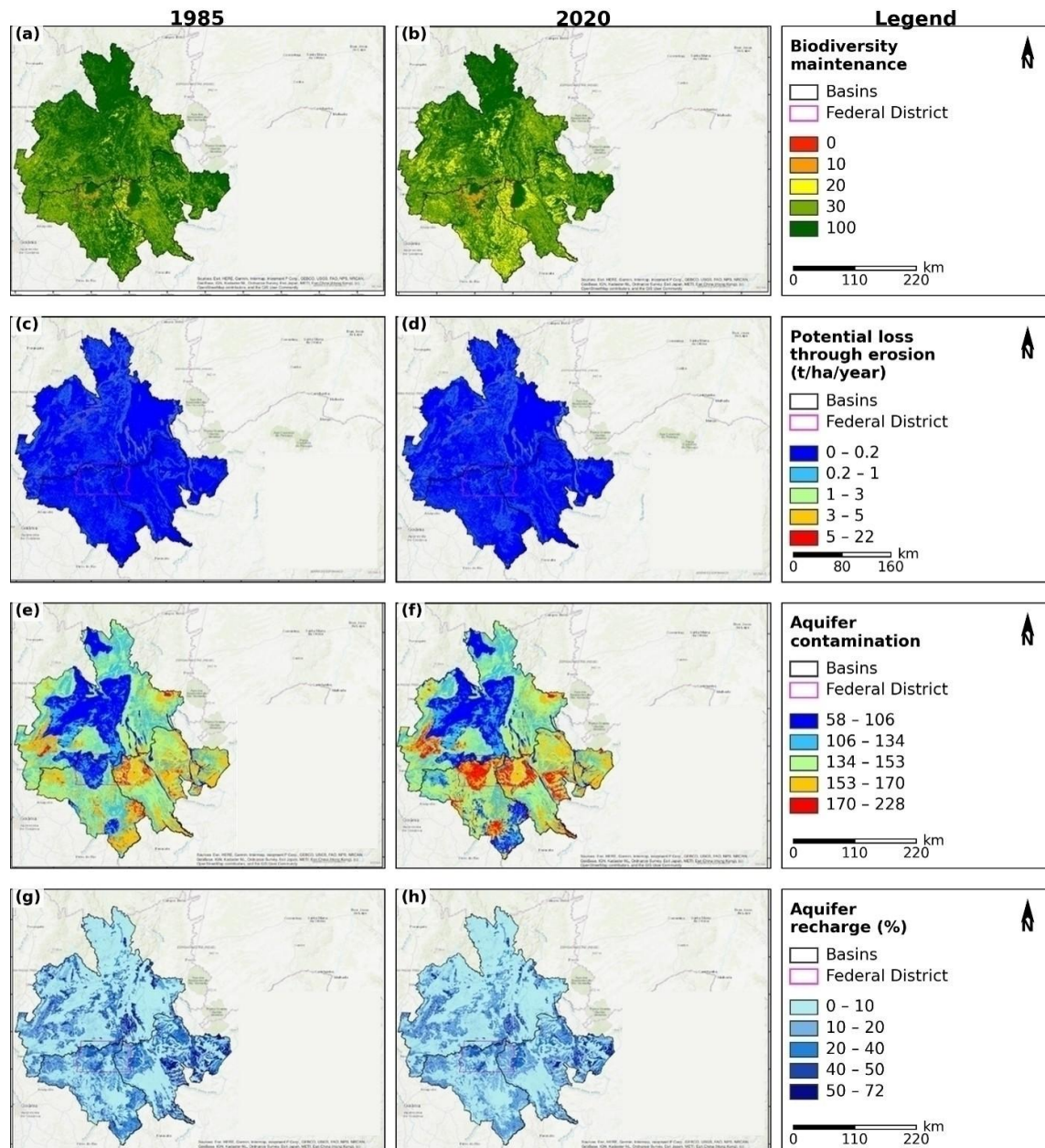


Figure 5 - Maps of the Biodiversity Maintenance Potential Indicator; Soil Loss Potential Indicator (t/ha/year); Aquifer Contamination Potential Indicator; and Aquifer Recharge Potential Indicator for the Paraná, São Francisco, and Tocantins-Araguaia River basins located in the RIDE-DF for the years 1985 and 2020. (a, b) Biodiversity maintenance; (c, d) Potential loss through erosion; (e, f) Aquifer contamination; (g, h) Aquifer recharge. Source: Elaborated by the authors.

CONCLUSIONS

The indicators created for RIDE-DF point out that the area presented urban and agricultural development throughout the years 1985 and 2020. However, with the development, there was a decrease in the sustainability of the region, which can be observed in the generated maps.

The maps, in general, show bigger urban development in the Paraná basin, where the Federal District and its surroundings are located. In these areas, there were a decrease in the aquifer recharge potential, along with its contamination, since the areas tend to be sealed, making it impossible for the water to infiltrate into the aquifer. The maps of soil loss by erosion present an increase, represented

mainly by exposed soil. The maps of biodiversity maintenance show low values, since urban areas cannot maintain biodiversity in the same way as natural areas. Other parts of the Paraná basin, especially in the south area, show an increase in agricultural production, especially in the municipality of Cristalina.

The São Francisco Basin exhibited some worsening factors, although not as intense as those observed in the Paraná Basin. The area of the basin within the Federal District (DF) is primarily agricultural, with less soil impermeabilization compared to urban areas. Consequently, the values for erosion potential, aquifer contamination, and aquifer recharge remained relatively stable or underwent slight changes. However, there was a significant loss in biodiversity maintenance, as the basin is primarily agricultural, with native vegetation being replaced by monoculture or livestock farming.

Contrary to the Paraná basin, the region of the Tocantins-Araguaia basin remained more preserved between the 35 years studied. In this region, it is possible to observe that there was no significant increase for practically any of the indicators. The maps of biodiversity maintenance show how the area remained more preserved than the other basins. The indicator for aquifer recharge potential reveals that the region has a low recharge trend, however, the most favorable points for recharge have not worsened. The aquifer contamination maps also did not indicate worsening, since the area has a low recharge trend.

With the three exemplified areas, it was possible to have a perception of the RIDE-DF, possessing agricultural, urban, and preserved areas. However, it is visible that the agricultural areas predominate the region, as well as a large part of the biome. Agricultural areas have great importance in the food security of the population, however, with the environmental imbalance, caused by deforestation for the creation of pastures and crops, it will no longer be possible to maintain a satisfactory production, being therefore important to increase the environmental sustainability of RIDE-DF.

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DATA AVAILABILITY

Not applicable.

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