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EVALUATION OF THE SUSTAINABILITY OF THE PRETO RIVER WATERSHED BASED ON ECOSYSTEM SERVICE INDICATORS

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Abstract: The hydrographic watershed of the Preto River is located in the Cerrado biome, which is crucial for the country's biodiversity and water resources. Due to the expansion of agribusiness, especially monoculture and pasture, the region has experienced an elevated level of deforestation and changes in land use and land cover. The work aims to generate indicators of ecosystem services to assess the sustainability of the Preto River watershed. For evaluation, five indicators were used - erosion control, aquifer recharge potential, aquifer contamination, food production, and biodiversity maintenance - to create maps, using ArcGIS software, illustrating changes in ecosystem services in the Preto River watershed in the years 1953, 1994, and 2019. The results show that between 1953 and 2019, indicators for aquifer recharge, aquifer contamination, soil erosion, and biodiversity maintenance deteriorated, while the food production indicator showed positive results. These findings highlight a significant decrease in ecosystem services, which may adversely affect agricultural production and sustainable development. Therefore, it is essential to promote responsible land use to mitigate environmental problems and ensure the region's sustainable development.

Keywords: ecosystem services, indicators, agribusiness.

AVALIAÇÃO DA SUSTENTABILIDADE AMBIENTAL POR MEIO DE INDICADORES DE SERVIÇOS ECOSSISTÊMICOS NA BACIA HIDROGRÁFICA DO RIO PRETO

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Resumo: A bacia hidrográfica do Rio Preto é predominantemente composta pelo bioma Cerrado, o qual é crucial para a biodiversidade e os recursos hídricos do país. Devido à expansão do agronegócio, especialmente monocultura e pastagem, a região tem sofrido um alto nível de desmatamento e mudanças no uso e cobertura da terra. O trabalho tem como objetivo gerar indicadores de serviços ecossistêmicos para avaliar a sustentabilidade da bacia do Rio Preto. Para avaliação, utilizaram-se cinco indicadores - controle de erosão, potencial de recarga do aquífero, contaminação do aquífero, produção de alimentos e manutenção da biodiversidade - para criar mapas, a partir do software ArcGIS, que ilustram as mudanças nos serviços ecossistêmicos na bacia hidrográfica do Rio Preto nos anos de 1953, 1994 e 2019. Os resultados mostram que entre 1953 e 2019, os indicadores de recarga do aquífero, contaminação do aquífero, erosão do solo e manutenção da biodiversidade pioraram, enquanto o indicador de produção de alimentos apresentou resultados positivos. Estes achados destacam a diminuição significativa dos serviços ecossistêmicos, que pode ter efeitos adversos na produção agrícola e no desenvolvimento sustentável. Portanto, é essencial promover o uso consciente da terra para mitigar os problemas ambientais e garantir o desenvolvimento sustentável da região.
Palavras-chave: serviços ecossistêmicos, indicadores, agronegócio.

EVALUACIÓN DE LA SOSTENIBILIDAD AMBIENTAL A TRAVÉS DE INDICADORES DE SERVICIOS ECOSISTÉMICOS EM LA CUENCA HIDROGRÁFICA DEL RIO PRETO

Resumen: La cuenca hidrográfica del Río Preto está predominantemente compuesta por el bioma del Cerrado, que es crucial para la biodiversidad y los recursos hídricos del país. Debido a la expansión del agro-negocio, especialmente la monocultura y la ganadería, la región ha experimentado un alto nivel de deforestación y cambios en el uso y cobertura del suelo. El trabajo tiene como objetivo generar indicadores de servicios ecosistémicos para evaluar la sostenibilidad de la cuenca del Río Preto. Para la evaluación, se utilizaron cinco indicadores: control de la erosión, potencial de recarga del acuífero, contaminación del acuífero, producción de alimentos y conservación de la biodiversidad, para crear mapas a partir del software ArcGIS, que ilustran los cambios en los servicios ecosistémicos en la cuenca del Río Preto en los años 1953, 1994 y 2019. Los resultados muestran que entre 1953 y 2019, los indicadores de recarga del acuífero, contaminación del acuífero, erosión del suelo y conservación de la biodiversidad empeoraron, mientras que el indicador de producción de alimentos mostró resultados positivos.

Estos hallazgos destacan una disminución significativa en los servicios ecosistémicos, lo que puede tener efectos adversos en la producción agrícola y el desarrollo sostenible. Por lo tanto, es esencial promover un uso responsable de la tierra para mitigar los problemas ambientales y garantizar el desarrollo sostenible de la región.
Palabras clave: servicios ecosistémicos, indicadores, agroindustria.

Introduction

The Cerrado biome is globally recognized as one of the hotspots for biodiversity conservation (MYERS et al., 2000; CARDOSO DA SILVA & BATES, 2002). However, compared to other Brazilian biomes, the Cerrado has the poorest preservation plan, with more than half of its vegetation area being converted for pasture, cash-crop agriculture, and other uses (KLINK & MACHADO, 2005). The deforestation rate in this biome is increasing rapidly. According to INPE (2020), between August 2019 and July 2020, there was a 12.3% increase in deforestation compared to the previous year, resulting in the loss of 7.3 thousand km² of vegetation. Furthermore, it is noteworthy that smaller countries, such as the Netherlands, with 1.8 million hectares of productive area (WORLD BANK, 2020), are more productive in terms of agricultural goods than Brazil, which has a much larger area of 66 million hectares of productive area (IBGE, 2012; DANIEL et al., 2009; GIL et al., 2019).

In addition to its biodiversity, the Cerrado biome is recognized as the “Water’s Cradle” due to its crucial role in the water cycle and the preservation of the baseflow for eight of the twelve major Brazilian watersheds (DE SOUZA et al., 2019). The Cerrado has two main seasons: a rainy season from October to March, and a dry season from April to September. Despite having a high rainfall rate during the rainy season, the biome still experiences water scarcity during the dry season, which is further intensified by deforestation caused by agricultural expansion (LIMA et al., 2018).

The Federal District is entirely located within the Cerrado biome, and three of the eight major watersheds with headwaters in the biome are in this region, such as Paraná, São Francisco, and Tocantins-Aragua. The agricultural development in this area began with the creation of Brasilia and then expanded over the years. The economic development of the region was also linked to a political plan to occupy Brazil’s western region (SANTOS, 1964).

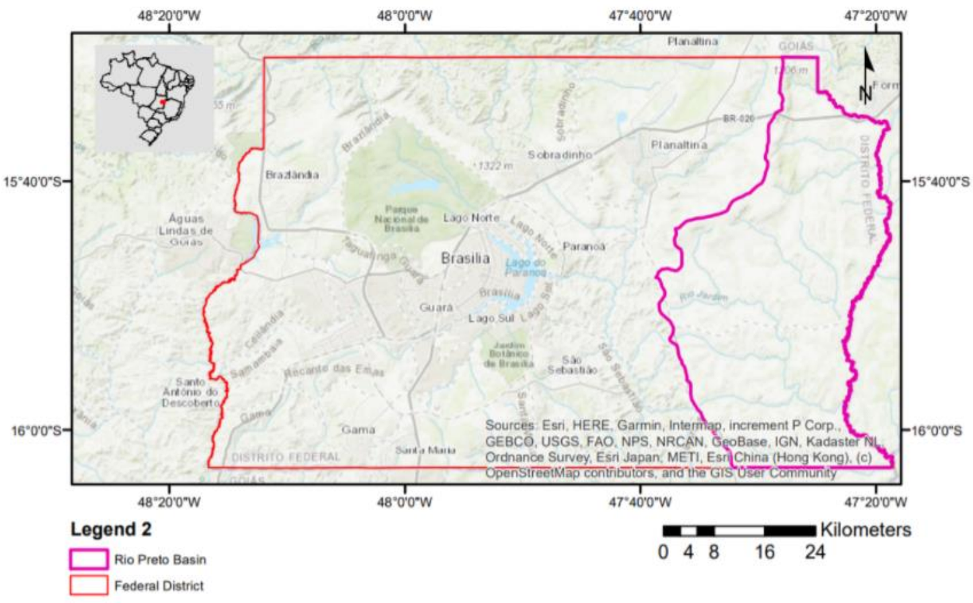
The conversion of natural vegetation into agricultural areas leads to a decrease in ecosystem services (ES), which are vital for sustaining human well-being (CALIXTO, 2003; MARSELLE et al., 2021; LAI et al., 2019). These services can be classified into four categories, namely provisioning, supporting, regulating, and cultural services (ANDRADE & ROMEIRO et al., 2009). In the Cerrado biome, ecosystem services are decreasing due to changes in land use leading to biodiversity loss, invasive species, soil erosion, water pollution, and land degradation (SANO et al., 2019). This paper aims to assess the impact of agriculture on ES, particularly in the Preto River watershed, with high agricultural activity, in 1953,1994 and 2019. The paper explores indicators that quantify the degree of change in ES resulting from land use alterations. (EGOH et al, 2012).

Material and Methods

Study Area

The Preto River watershed, which covers a total area of 10,200 km² and flows into the Paracatu river in Minas Gerais state, originates in Goiás. This paper focuses on a studied area of approximately 1,331 km² located in the eastern part of the Federal District, as shown in Figure 1.

Figure 1. Location of Preto River watershed.



Source: original research data

The Federal District is situated within the Cerrado biome and experiences temperatures ranging from 22°C to 27°C. The annual average rainfall is 1500 mm, with most of it occurring during the rainy season. Spontaneous natural fires are common during the dry season due to infrequent rainfall. Although the Cerrado is a fire-adapted ecosystem, frequent burning regimes for pasture have become a significant problem, resulting in issues such as soil compaction, erosion, and leaching, particularly in large areas of eastern Goiás and western Minas Gerais (KLINK & MOREIRA, 2002).

The watershed has an extensive area of commodities production, vegetables, and livestock, with intensive use of water resources in large irrigation systems. The Preto River watershed was planned to concentrate agricultural activity, with rural centers, and agricultural colonies, in isolated areas, due to its favorable topography, fertility, and water availability, among other factors. Even though it is a planned area, in recent years, the Federal District and Preto River watershed have been facing problems related to water insecurity due to many issues, such as deforestation in permanent preservation areas that protect the water cycle (LIMA et al., 2018). The study was conducted for three years, namely 1953, 1994, and 2019, to observe the development of agriculture and the growth of the Federal District and Preto River watershed.

The methodology used to obtain the indicators was based on the works of Lima et al. (2017) in the Sarandi Experimental Catchment and Lima (2019) in the entire Federal District. Erosion control, aquifer recharge and contamination, biodiversity maintenance, and food production were based on the works of Lima (2017) and Lima (2019). All the maps were developed with ArcGIS software.

Ecosystem Services

Ecosystem services play a crucial role in evaluating environmental sustainability (HASAN et al., 2020). In agricultural areas such as the Preto River watershed, it is essential to assess ecosystem services to determine the impacts of agriculture on the environment, including both the negative and positive effects.

Given the characteristics of the study area, five ecosystem service indicators were selected and analyzed, as shown in Table 1.

Table 1. Data used in the indicator's elaboration.

Indicator	Methodology	Data	Source
Erosion control	Wischmeier & Smith (1978)	Land use map Pedologic map Digital elevation model Rainfall	CODEPLAN (2019) NASA (2013) ANA*
Aquifer Recharge Potential	Gonçalves et al. (2009)	Land use map Pedologic map Digital elevation model Rainfall	CODEPLAN (2019) NASA (2013) ANA*
Aquifer Contamination	Aller et al. (1987)	Porous aquifer hydrogeology Aquifer recharge Fractured aquifer hydrogeology Pedologic map Topography	Campos J.E.G Freitas Silva F.H (1998) Original research data Campos J.E.G Freitas Silva F.H (1998) Santos et al. (2011) Geoportal (2009)
Food Provision	Lima et al. (2017)	Land use map	CODEPLAN (2019)
Biodiversity Maintenance	Lima et al. (2017)	Land use map	CODEPLAN (2019)

*The years of ANA were the media (mm/year) of 1953, 1994 and 2019.

Erosion control

The erosion control indicator was calculated using the Universal Soil Loss Equation (USLE) model, which requires the creation of four data inputs included in the formula: rainfall (R), soil erodibility (K), slope length and steepness (LS), cover management and erosion control practices (CP). The USLE formula is presented as follows in equation 1:

$$USLE = R \times K \times LS \times CP \quad (1)$$

To generate the R factor, the spline tool was used to calculate the average rainfall (mm/year) in the Preto River watershed. The K factor map was calculated by taking the average value of K found in the literature for each soil type present in the watershed, including Ferralsols, Cambisols, Argisol, Gleysols, Neosols, Plinthosol, and Nitisol (CODEPLAN, 2019).

For the C and P factors, the average values were found in the literature for each land use type, considering changes in land use over time. We obtained various sources, including UNESCO (2002) and CODEPLAN (2019), to gather the necessary information.

To calculate the LS factor, we used the Digital Elevation Model (DEM) to generate the slope, flow direction, and flow accumulation. Then, we applied the raster calculator tool to calculate equation 2.

$$LS = \left(\frac{FA}{22{,}13}\right)^{0{,}4} x \left(\frac{sen(S)}{0{,}0896}\right)^{1{,}3} \quad (2)$$

Where,

LS = Slope length and steepness

FA = Flow Accumulation

S = Slope

Aquifer Recharge Potential

The aquifer recharge indicator is used to assess an area's ability to regenerate through the water cycle. This capacity is dependent on various factors, such as the land use map, digital elevation model (DEM), and hydrogeology. The methodology was developed by adapting the framework presented by Gonçalves et al. (2009). To create the Curve Number (CN) map, the soil map had to be reclassified into hydrologic soil types, further classified into A, B, C, or D (as shown in Table 2). The resulting map was then associated with the land use map to derive the CN values. This method allowed for a more accurate assessment of the aquifer recharge potential in the Preto River watershed.

Table 2. CN Values

Land Use	A	B	C	D
Water	0	0	0	0
Agriculture	63	75	83	87
Bare Soil	**77**	86	91	94
Natural Grassland	39	61	74	80
Natural Woodland	26	52	62	69
Paved Roads	98	98	98	98
Urbanized Areas	89	92	94	95

Source: Mockus (1964); (USDA, 1986)

With Curve number (CN) values, the soil water holding capacity (S) maps were calculated applying the equation 3:

$$S(mm) = \frac{25400}{CN} - 254 \quad (3)$$

Water availability (WA) was calculated, in equation 4, from S maps combined with rainfall maps.

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

To build the aquifer recharge (AR) maps, slope maps were reclassified into the infiltration rate (Irate) and the water availability map, according to equation 5.

$$AR = \frac{WA \ x \ Irate}{100} \quad (5)$$

Aquifer Contamination

To enhance food production, the use of pesticides and fertilizers has increased in the last few decades worldwide (DAVYDOV et al., 2018; BASHIR et al., 2020). In Brazil, the use of these chemicals has helped agricultural productivity to expand due to the nutrient-deficient soil types in some parts of the country. However, it has also resulted in water contamination. A recent study found that in one out of four municipalities in Brazil, a glass of water contains twenty-seven different pesticides (SISAGUA, 2019).

In the Preto River watershed, which is an agricultural area, the use of pesticides can represent a significant problem concerning aquifer contamination. The aquifer contamination indicator can demonstrate how the watershed is impacted by pesticides and fertilizers. The methodology used to obtain this indicator was the DRASTIC tool, which was developed by Aller et al. (1987) for the US Environmental Protection Agency (EPA). The method hierarchically ranks the hydrogeological parameters, constituting a physical and static scale that does not account for the external changes that occur over time. To improve the scale, the methodology was adapted by incorporating land use (LU), with agricultural areas being associated with higher values, thereby accounting for the impact of pesticides and fertilizers on the result. The chosen weight value for the LU parameter was 5, given that the parameter has a significant impact on aquifer contamination in an agricultural watershed since water and soil can be contaminated by pesticides. The calculation of all parameters requires assigning weights (w) on a scale of 1 to 5, where the most important parameters receive a weight of 5 and the least important ones receive a weight of 1. The weights were established by Aller et al (1987). The parameters and their weights are:

- **Depth to groundwater (D) - (5)** - The depth is measured from the ground surface to the water table in an unconfined aquifer and to the bottom of the confining layer in a confined aquifer.

- **Net recharge (R) - (4)** - The total quantity of water that is applied to the ground surface and infiltrates to reach the aquifer.
- **Aquifer media (A) - (3)** - Consolidated or unconsolidated rock which serves as an aquifer.
- **Soil media (S) - (2)** - The uppermost portion of the vadose zone characterized by significant biological activity.
- **Topography/slope (T) - (1)** - The slope and slope variability of the land surface.
- **Vadose zone (I) - (5)** - The zone above the water table, which is unsaturated or discontinuously saturated.
- **Hydraulic conductivity of the aquifer (C) - (3)** - The ability of the aquifer materials to transmit water.
- **Land use (LU) - (5)** - Land use related to fertilizers and pesticides.

Additionally, each parameter is assigned an index (r), on a scale from 1 to 10, where higher values (closer to 10) indicate greater contamination potential. The parameters and index values used were adapted from Aller et al. (1987). For each parameter (DRASTIC), a map was created associating it with the corresponding index values and then multiplied by the assigned weight. The resulting values can be used to determine the vulnerability rate, as shown in Table 3.

Table 3. Vulnerability rate DRASTIC

DRASTIC Value	Vulnerability Rate
< 100	Negligible
101 to 119	Very low
120 to 139	Low
140 to 159	Moderate
160 to 179	High
180 to 199	Very high
> 200	Extreme

Source: Aller et al., (1987)

Food Provision

Preto River is an important agricultural watershed for food production in the Federal District region. To evaluate the extent of food provision, the methodology proposed by Lima et al. (2017) was adopted. The methodology involves using the land use and land cover (LULC) map to assign values ranging from 0 to 100, which higher values indicating greater significance. The calculation of the food provision indicator considers reduction factors that are associated with soil type and slope, which may decrease the value of the indicator. The raster calculator tool was employed to estimate the value of the indicator by multiplying the main value with the reduction factors.

Biodiversity maintenance

The biodiversity of the Cerrado biome has decreased in direct proportion to the increase in agricultural production. Agricultural practices have been linked to forest fires and deforestation, which lead to the loss of fauna and flora. To assess the impact of agriculture in the Preto River watershed, we adopted the same methodology as the one used for calculating the food provision indicator, developed by Lima et al. (2017). The LULC map was combined with soil type and slope reduction factors. The raster calculator tool was then used to estimate the value of the biodiversity indicator, by multiplying the main value with the reduction factors.

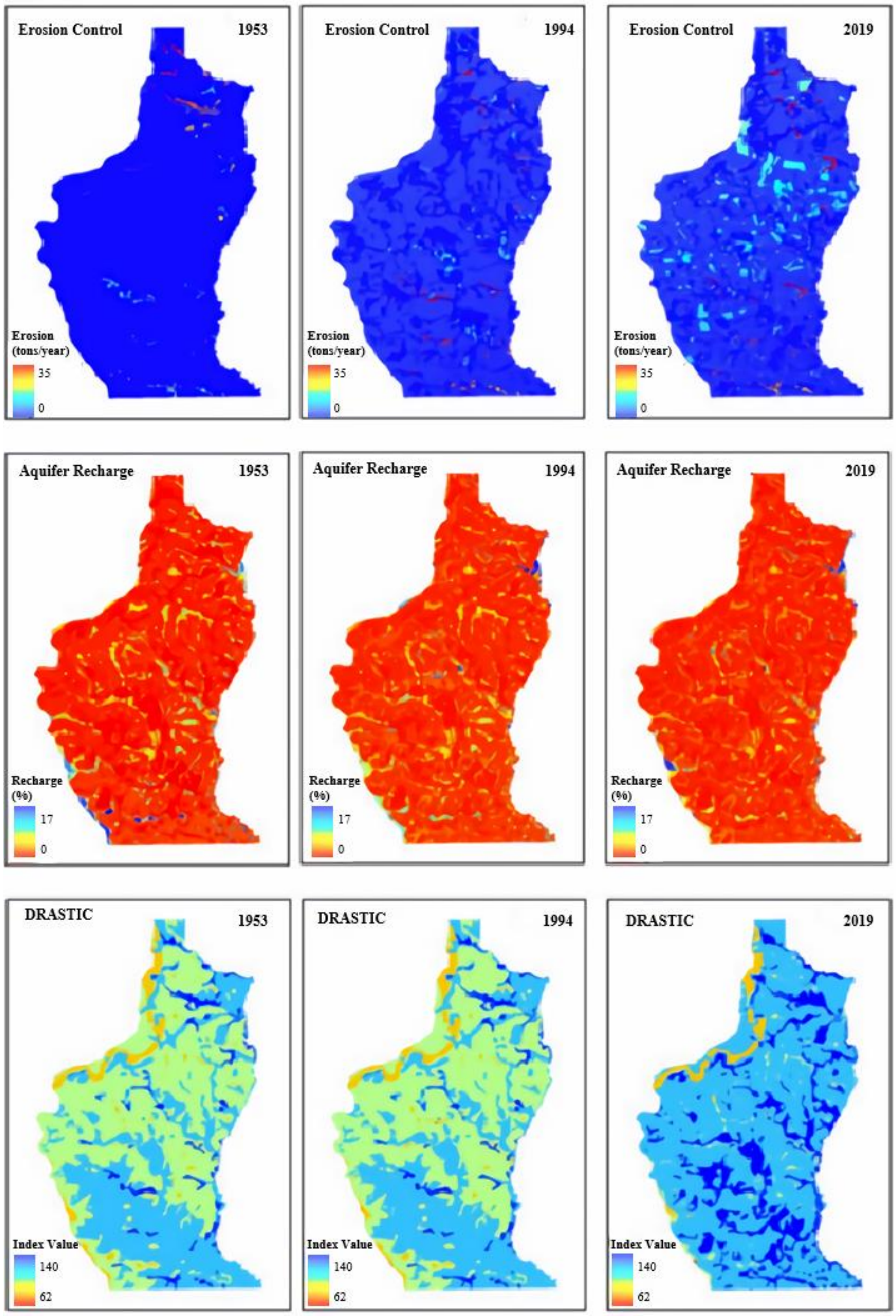
Results and discussion

Lima (2019) identified a decrease in water resource indicators, such as groundwater quality, related to aquifer contamination and recharge, in the Federal District area due to urbanization. In the Preto River watershed, the indicators also decreased, mainly due to agribusiness. Regarding erosion control, although Lima (2019) did not find a significant difference between the years, it is evident that even a slight increase in erosion occurred in the watershed. In Lima's (2017) study, conducted in a smaller area (The Sarandi Experimental Catchment), the biodiversity in the watershed decreased by 42%, while food production increased by over 50%, indicating a correlation between the increase in agribusiness (agriculture and pasture) and the decline in biodiversity.

Erosion Control

Figure 2 displays an increase in soil loss in 2019 compared to 1953, as indicated by the erosion indicator map. Despite the increase, there was no significant aggravation, as erosion is not as severe in agricultural areas as in urban areas due to the vegetation cover in the watershed. Additionally, the natural vulnerability of the Federal District area is not high, given that it is a plateau (LIMA, 2019).

Figure 2. Erosion, Aquifer Recharge, and Aquifer Contamination Indicators.



Source: original research data

There was almost no erosion in 1953, as the area was entirely covered by natural vegetation. A small increase occurred in 1994 compared to 1953, and the largest increase in erosion values was observed in 2019, mainly due to agricultural expansion and the establishment of new settlements linked to the success of the development program led by Embrapa, since 1975 (EMBRAPA, 2021).

Aquifer Recharge Potential

The infiltration rate (IR) was a critical factor and was used for all three years. It was noticeable in Figure 2 that in almost all areas, the IR was very low, around 5%, making the area not conducive to aquifer recharge. Consequently, the maps of the three years were not significantly different from one another. However, some points had higher IR, and it was possible to perceive the differences through the years.

Analyzing the aquifer recharge map of 1953, it was possible to observe that when the vegetation was untouched, the areas, mainly in the center of the watershed, had a higher aquifer recharge potential. Between the years 1994 and 2019, it was noticeable that the areas where the aquifer recharge was higher decreased, especially in the center and bottom of the watershed. In 1953, these areas were almost at their maximum potential (blue), but in 2019, they were closer to zero.

Aquifer Contamination

Aquifer contamination is closely related to the low infiltration rate. The map in Figure 2, generated without the land use factor, shows a decline in contamination over the years due to the reduced infiltration rate resulting from the soil's loss of infiltration capacity. However, by adding the land use factor, as shown in Figure 3, it is evident that aquifer contamination has increased over the years due to the growth of the agricultural area and the consequent use of pesticides and fertilizers.

In 1953, when the area was not used for human activities, contamination was relatively low, but still not at the lowest level due to the hydraulic capacity factors of the aquifer. The opposite can be seen in 1994 and 2019, where contamination levels increased despite reduced infiltration capacity, mainly due to the increase in agricultural production.

It is important to emphasize that previous studies in the area did not identify contamination in deep aquifers, as the soil in the watershed is relatively developed and, therefore, deeper. However, in shallow aquifers, which most of the population relies on, there is a higher probability of contamination (ARAÚJO, 2006).

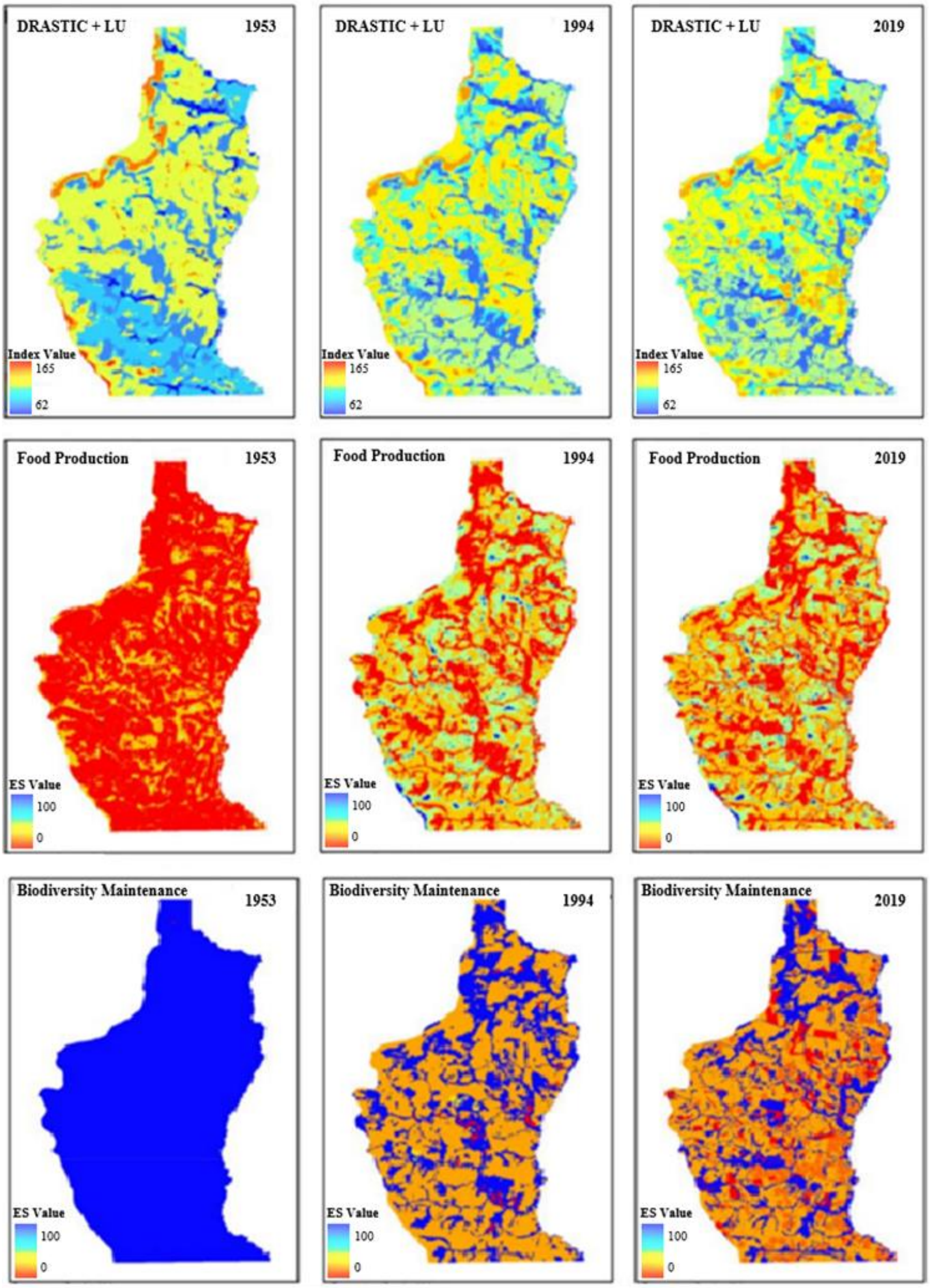
Food Provision

Comparing the three chosen years, the 1953 map, as being all covered by natural hedging, had a low potential for food provision, seeing those natural areas, in the methodology, were classified as low (0-10). The highest value in 1953's map was 34, on a scale from 0 to 100. The year of 1994, the highest value found was 85. It is noticeable that over the years, agricultural and pasture activity increased. In the last year, 2019, the higher value obtained was 100, showing that the agricultural and pasture activities continued increasing and got more developed, being an extremely important area for food supply in the Federal District.

Biodiversity Maintenance

Figure 3 shows that the year with the least human intervention was 1953, with excellent conditions for maintaining biodiversity. According to the methodology, the area was almost entirely classified with the highest value (100) for biodiversity maintenance. In 1994, the values decreased due to the expansion of agricultural activity and some urban areas. Most of the area was valued at 20, indicating a considerable increase in agricultural activity. In 2019, it is noticeable that almost all areas were valued at 20, indicating that the watershed is an agricultural area. However, the map also indicates that biodiversity is preserved in gallery forests, an area protected by Brazilian law.

Figure 3. Drastic + LU, Food Production and Biodiversity Maintenance indicators.



Source: original research data

Conclusion

- Agribusiness is undoubtedly one of the cornerstones of the Brazilian economy and essential for providing food to the country's population and beyond. However, the way it interacts with the environment needs to be reviewed, as it is impossible to maintain production with the massive destruction of biomes and biodiversity, especially when much of the production is based on monoculture, such as soy and corn and pasture.

- The study indicates that when the food production indicator has a higher value, the aquifer contamination, aquifer recharge, erosion control, and biodiversity maintenance indicators have a lower value, reducing the quality of ecosystem services provision. The aquifer contamination indicator shows an increase in contamination, while the aquifer recharge indicator indicates a decrease in the amount of water seeping into the shallow aquifer, which is simultaneously contaminated with pesticides and fertilizers. The erosion control indicator shows a decline in the ecosystem service capacity to prevent slopes, caused by changes in land use, as the increase in agricultural activity in the watershed has led to a decline in biodiversity. The loss of biodiversity can be observed in the biodiversity maintenance indicator, as the Cerrado has already lost much of its natural cover to agribusiness land use, resulting in the loss of part of its natural fauna and flora. With the reduction in biodiversity in the Brazilian Savanna, the provision of ecosystem services decreases, reducing the quality of human life and increasing environmental and social problems, such as water scarcity, landslides, and contamination of drinking water. Additionally, the loss of several biological treasures that have not yet been discovered may potentially provide cures for diseases in the future.
- Therefore, this work demonstrates the risk areas, how they are affected, and where there is a tendency for ecosystem services to decline. This study can support the creation of public policies that promote sustainable agribusiness development, with less contamination and suppression of native vegetation, thereby increasing ecosystem services provision.

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