Agronomy Research **23**(S1), 151–163, 2025
https://doi.org/10.15159/AR.25.024

Temporal analysis of pasture vegetation cover in central-western Brazil using remote sensing

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Received: January 19th, 2024; Accepted: April 7th, 2025; Published: April 20th, 2025

Abstract. Brazil is the world's leading exporter of beef, consolidating beef cattle farming as an important branch of national livestock farming. The expansion of livestock farming and agriculture in recent decades has resulted in a notable increase in pasture areas in Brazil. However, the country faces the growing challenge of pasture degradation, a problem that threatens sustainability and food production. On the other hand, livestock farming in Brazil's Central-West region, the country's largest cattle-producing area, particularly in the state of Goiás, can cause environmental damage when sustainable practices are disregarded. Thus, the objective of this article was to evaluate pasture degradation, at different levels, in the Ribeirão Serra Negra Watershed, in the municipality of Piracanjuba, Goiás, Brazil. Using images from the Sentinel-2A orbital sensor, the NDVI (Normalized Difference Vegetation Index) vegetation index and the vegetation cover classes of pastures were obtained between 2017 and 2021. During this period, the results showed that more than 98% of the areas had some level of degradation, with an average coverage of 6,586.1 ha. There was an upward evolution in the levels of vegetation cover between 2017 and 2019, with the best pasture conditions predominating in 2019. These assessments help identify areas that require greater attention and often necessitate conservation practices and management plans. In this context, monitoring degraded areas is a practice that facilitates the improvement of existing pastures, promotes the rational management of inputs, conserves natural resources, and aligns with development programs focused on sustainability.

Key words: livestock grazing, pasture quality degradation, remote sensing, sustainable, vegetation indices.

INTRODUCTION

In Brazil, the Gross Domestic Product (GDP) of agribusiness accounts 24.8% of the country's economic performance. In 2022, despite a 6.39% decline in the agricultural sector, the livestock sector experienced growth by 2.11%. This progress is attributed with an increase in the gross value of production in the primary segment, linked to a reduction in input costs (CNA, 2023; CEPEA, 2023). According to FAO (2020), the country ranks seventh among the nations with the largest pasture areas, with land use covering 107 million hectares. Globally, it is the second-largest producer of beef, with a cattle herd approaching 224.6 million head.

At the state level, Goiás is the third-largest producer of cattle, accounting for 10.4% of the entire production chain (IBGE, 2023; Bolfe et al., 2024). The municipality of Piracanjuba is characterized by two well-defined seasons, with rainfall occurring between October and April and dry periods ranging from May to September. The average annual temperature ranges from 14 °C to 32 °C (Alvares et al., 2013; Embrapa, 2022; INMET, 2025). According to Instituto Brasileiro de Geografia e Estatística (IBGE, 2023), the number of cattle in the municipality between 2017 and 2021 was 232,567 and 206,000 head, respectively. The abrupt decrease in the cattle population occurred between 2019 and 2020, with a reduction of 26,000 head, from 231,000 to 205,000 animals.

Pasture degradation is a growing problem in various parts of the world, affecting agricultural and livestock productivity and compromising the health of ecosystems (Ferreira et al., 2024). This process results in the loss of soil nutrients, reduction of vegetation, and decline in biodiversity, which undermines the regeneration capacity of the affected areas (Shukla et al., 2019; Parente et al., 2019; Stabile et al., 2020). In Brazil, it is estimated that 60% of the areas (109.7 million hectares) are degraded, with the highest concentration occurring in the Central-Northern region of the country (Bolfe et al., 2024).

To mitigate the impacts of degraded areas, the country has adopted various strategies in partnership with other South American nations, such as pasture recovery through fertilization techniques, rotational grazing management, and the implementation of integrated crop-livestock-forest systems (CLF) (Ayarza et al., 2022). The use of more adapted forage species and the incorporation of agroforestry systems have also shown positive results, contributing to soil fertility recovery and increasing carbon sequestration. These initiatives are essential for reducing environmental damage and promoting more sustainable and efficient livestock farming (Arantes et al., 2018; Souza et al., 2019).

In addition to investing in research, Brazil encourages conservation actions and the adoption of technologies such as the use of satellite imagery coupled with different orbital sensors. These images, which can be accessed for free, offer multispectral bands that are processed through Remote Sensing techniques. Among the free satellite images available, those provided by the Sentinel-2 system stand out, characterized by the Sentinel-2A and Sentinel-2B sensors. These data, available since 2016, are widely used due to their 10 m pixel-1 spatial resolution and five-day revisit time. However, Sentinel-2A was launched in June 2015, becoming operational in 2016, and Sentinel-2B was launched in March 2017, becoming operational in 2018 (ESA, 2022).

In this context, the use of the Normalized Difference Vegetation Index (NDVI) has been the subject of recent studies for identifying and monitoring degraded areas (Hopping et al., 2018). The NDVI is a vegetation index applied to analyse vegetative activity, particularly the pasture cover and large crops (Sousa et al., 2022; Abreu et al., 2024).

Through the Annual Mapping of Land Cover and Land Use in Brazil project (MapBiomas, 2022), it is possible to obtain historical series of geographical information on land use and cover since 1985. The project provides collections of vector and raster data, updated and compiled annually (Lapig, 2022; MapBiomas, 2022).

In this regard, using the MapBiomas and Sentinel-2 databases, the aim of this study was to evaluate pasture degradation through the classes of pasture vegetation cover and biomass variation from 2017 to 2021. The objective of choosing this period was to evaluate the behavior of vegetative vigor in pastures with the aid of remote sensing during the COVID-19 pandemic scenario.

MATERIALS AND METHODS

Study area

The Serra Negra stream watershed is located in the municipality of Piracanjuba, in the Southern Goiás Mesoregion, and is situated within the Meia Ponte Microregion, between the geographic coordinates 17°10'55"S and 17°18'12"S; 49°03'07"W and 49°05'38"W (Fig. 1). Its territorial extension is 11,100 hectares, with 5,843.96 hectares (53%) corresponding to pasture areas. According to Köppen-Geiger, the climate is of the Aw type (Tropical humid), with an average annual precipitation of 1,600 mm (Alvares et al., 2013).

Data acquisition and preprocessing

Through the Copernicus program, orbital images from the Sentinel-2A sensor with a spatial resolution of 10 m were obtained, provided by the European Space Agency (ESA, 2022). The data acquisition, obtained from the Instituto Nacional de Meteorología (INMET, 2025), weather station A003 located in the southeastern region of the state, covered the first half of May, July, and October between 2017 and 2021, a period during which the pastures show differences in vegetative vigor due to the dry and wet seasons. May marks the end of the rainy season, making it useful for understanding the maximum biomass volume of plants after the long vegetative development period influenced by rainfall. July is characterized by extreme dryness, important for identifying the lowest biomass levels in pastures. October marks the beginning of rainfall, ideal for identifying the return of sprouting. In this sense, the average of these data was calculated annually, considering other criteria such as the absence of clouds (cloud cover $< 30\%$) and minimal occurrence of fires (Embrapa, 2022).

The images covered two areas, T22KGF/T22KGG, and the MSIL1C-type bands used for preprocessing were B04 (red) and B08 (near-infrared). The multispectral bands were georeferenced and then atmospheric correction was performed using the Dark Object Subtraction (DOS1) method with the assistance of QGIS for desktop software version 3.16.11.

The land use and land cover vector files were obtained through the Mapbiomas platform. In this process, the evolution of pasture areas within the watershed in the period. Therefore, the watershed was obtained through automatic delineation using the Topodata elevation image, made available by the Instituto Nacional de Pesquisas Espaciais (INPE).

Vegetation index (NDVI) and vegetation cover (Vc)

The evaluation of vegetative vigor was carried out using the NDVI in the pre-processed satellite images proposed by Rouse et al. (1974), with the assistance of the raster calculator in the QGIS software for desktop version 3.16.11 (Eq. 1):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \quad (1)$$

where NDVI – Normalized Difference Vegetation Index; Red – red spectral band; NIR – near-infrared spectral band.

Table 1. Description and NDVI class intervals

Classes	Classification criteria
1 – Bare soil or water	NDVI ≤ 0
2 – Very Low	0 < NDVI ≤ 0.2
3 – Low	0.2 < NDVI ≤ 0.4
4 – Moderately Low	0.4 < NDVI ≤ 0.6
5 – Moderately High	0.6 < NDVI ≤ 0.8
6 – High	0.8 < NDVI ≤ 1

Source: Aquino & Oliveira (2012).

With the acquisition of the vegetation indices (NDVI), which range from -1 to 1, the data were classified according to Aquino & Oliveira (2012), structured into six classes (Table 1).

From the data extracted from the NDVI pixels, the levels of pasture degradation were classified. For this, the vegetation Cover (Vc) data were calculated (Eq. 2):

$$\mathrm{Vc} = \frac{(\mathrm{NDVI} - \mathrm{NDVIs}}{\mathrm{NDVIv} - \mathrm{NDVIs})} \times 100\% \quad (2)$$

where Vc – vegetation cover; NDVI – annual average NDVI value; NDVIs – lowest NDVI value found among bare soil pixels; NDVIv – highest NDVI value found among vegetation pixels.

The annual *Vc* values resulting from Eq. 2 were reclassified according to Gao et al. (2006) into 5 different levels of pasture degradation (Table 2).

Table 2. Vegetation cover classification (Vc)

Classification	Vc
Un-degraded (UD)	Vc > 90%
Lightly degraded (LD)	90 ≥ Vc >75%
Moderately degraded (MD)	75 ≥ Vc > 60%
Severely degraded (SD)	60 ≥ Vc > 30%
Extremely Severely degraded (ESD)	Vc ≤ 30%

Source: Gao et al. (2006).

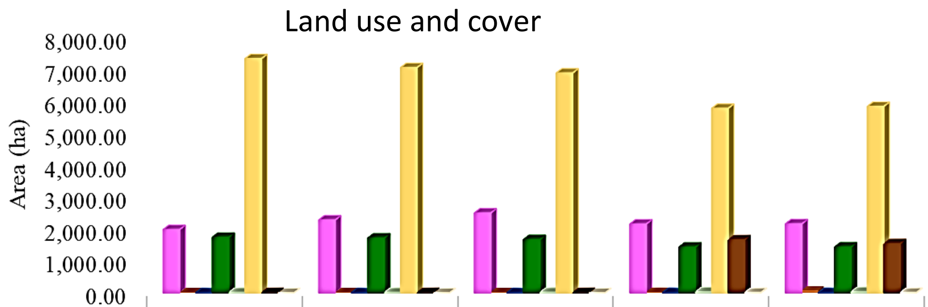
The NDVI and Vc classifications were subjected to descriptive statistics, analysis of variance (ANOVA). Based on the Vc values, biomass analysis was conducted between 2017 and 2021 to assess the increase or decrease (Eq. 3).

$$\mathrm{Vc} = \mathrm{Vc}\,(2017) - \mathrm{Vc}\,(2021) \quad (3)$$

RESULTS AND DISCUSSION

The land use and land cover area, in hectares (ha), in the Serra Negra stream watershed, located in the municipality of Piracanjuba, GO, is represented in Fig. 1. The term 'agriculture' refers to areas planted with annual crops, such as soybeans, corn, sorghum, among others, cultivated on a large scale. ‘Pasture’ is associated with areas designated for livestock farming, with the cultivation of various pasture species that have a perennial cycle and alter their biomass according to the environmental conditions to which they are exposed. Areas with native vegetation, with minimal biome modifications, are represented by ‘forest’, while ‘forestry’ refers to areas with the cultivation of forest species. 'Water body' is used for areas with apparent water resources.

'non-vegetated area' refers to targets such as impermeable surfaces (infrastructure, urban expansion, or mining). The ‘non-forest natural formation’ includes grassland formations with a predominance of herbaceous layers (e.g., scrubland, open grassland, and rocky fields). The ‘land use mosaic’ is characterized by agricultural use, where agriculture and pasture are not distinguished (MapBiomas, 2022).



	2017	2018	2019	2020	2021
Agriculture	1,980.34	2,282.34	2,500.84	2,155.04	2,161.27
Non-vegetated area	19.30	21.13	21.99	28.05	79.00
Water body	4.19	4.10	4.70	6.24	6.24
Forest	1,737.72	1,714.59	1,665.19	1,431.31	1,431.99
Non-forest natural formation	11.46	11.28	13.68	30.36	33.26
Pasture	7,343.60	7,063.16	6,891.91	5,784.13	5,843.96
Forestry	5.50	5.50	3.79	1,659.03	1,538.17
Mosaic of uses	0.00	0.00	0.00	7.95	8.21

Figure 1. Land use and land cover in the Ribeirão Serra Negra stream watershed in the municipality of Piracanjuba, Goiás, Brazil.

However, the temporal analysis showed that pasture areas decreased, dropping from 66% of land occupation in 2017 to 52% in 2021. During this period, it was observed that silviculture experienced the largest growth in the interval, approximately 13.8%. This increase is related to the potential of the Cerrado biome and the adoption of sustainable practices such as the Integrated Crop-Livestock-Forest System (ICLF) and the national Low Carbon Agriculture Program (ABC Plan), approved in 2011 (EMBRAPA, 2020). Also noteworthy is the promotion of conservation practices developed by Emater-GO, which, in a survey conducted in 2020 and 2021, identified between 81 and 244 different practices in the Southern region of the state of Goiás. These practices ranged from pasture management, production and property management, guidance on spring protection, pasture formation/renewal, and environmental management on the property, resulting in an improvement in the percentage of silviculture (Emater, 2022).

This increase is related to the potential of the Cerrado biome and the adoption of sustainable practices such as the Integrated Crop-Livestock-Forest (ICLF) (Embrapa, 2020). Over the last 35 years, pastures in Brazil totalled 64 Mha, with 18 Mha of pre-existing pastures being converted into agriculture and silviculture (Feltran-Barbieri & Féres, 2021). The average area of ‘agriculture’ over the years, the second most extensive class, was 2,215.97 ha. The other land uses and land covers showed no significant variations, with changes of less than 1% at the end of the 5-year period.

Other land uses and covers did not show significant variations, with changes of less than 1% by the end of the 5-year period. The average of ‘agriculture’ over the years, the second most widespread class, was 2,215.97 ha. In the Cerrado, the Non-vegetated area refers to targets such as impermeable surfaces (infrastructure, urban expansion, or mining). The ‘non-forest natural formation’ includes grassland formations with a predominance of herbaceous layer (scrubby field, clean field, and rocky field). The land ‘use mosaic’ is characterized by agricultural use, where agriculture and pasture are not distinguished (MapBiomas, 2022).

Through the mapping of pastures and the application of NDVI, vegetative vigor was evaluated (Fig. 2). It was observed that the variability of vegetation indices showed symmetric dispersion in most years, according to the classification by Aquino & Oliveira (2012). In 2017 and 2021, the greatest variability was observed, ranging between the ‘moderately low’ and ‘high’ classes.

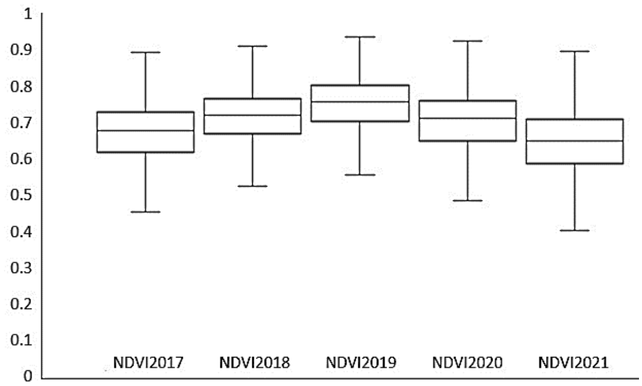
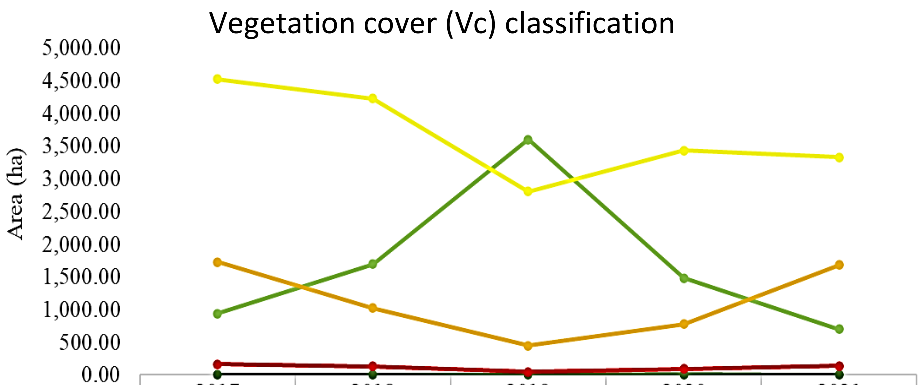


Figure 2. Variation of vegetative vigor, determined by the Normalized Difference Vegetation Index (NDVI), as a function of temporal variation in the Serra Negra stream watershed in the municipality of Piracanjuba, Goiás, Brazil.

The best year was represented by 2019, with a ‘moderately high’ average, NDVI values close to 0.8, and a slight amplitude, compared to the other years. There were no differences over time regarding the pasture degradation classes, considering that the results were within the variance limits.



	2017	2018	2019	2020	2021
Un-degraded	0.00	0.05	3.72	4.49	1.10
Lightly degraded	935.26	1,689.20	3,597.78	1,476.25	697.19
Moderately degraded	4,517.12	4,221.77	2,799.77	3,431.22	3,323.31
Severely degraded	1,727.01	1,021.95	446.61	776.81	1,682.57
Extremely Severely degraded	164.22	130.18	44.04	93.87	139.80

Figure 3. Evolution of pasture degradation classification from 2017 to 2021 in the Ribeirão Serra Negra Watershed in the municipality of Piracanjuba, Goiás, Brazil.

The pasture degradation classification highlighted the predominance of the ‘moderately degraded’ class throughout the period, with areas exceeding 2,700 ha (Fig. 3). ‘Non-degraded’ areas represented discrete values, accounting for less than 2% of the total evaluated area over the 5 years, and were not considered representative. On the other hand, more than 98% of the areas exhibited some level of degradation, with an average of 6,583.10 ha.

All pasture classes with some level of degradation showed reductions in the values obtained in 2021 compared to those in 2017, resulting in a slight increase in the level of non-degraded pastures over the study period. However, although variations in the data were observed over the years, no statistically significant differences were found between the years (p-value ≥ 0.05) (Table 3). The lack of significance can be explained by the wide variability within the ‘lightly degraded’, ‘moderately degraded’, and ‘severely degraded’ classes, which makes it difficult to identify significant differences between classes.

Table 3. Analysis of variance for the different pasture classes evaluated from 2017 to 2021 in the Ribeirão Serra Negra Watershed in the municipality of Piracanjuba, Goiás, Brazil

Source of variation	GL	SS	MS	F	*p*-value	F critical
Between groups	4	418,246.44	104,561.61	0.04	1.00	2.87
Within groups	20	52,175,454.52	2,608,772.73	-	-	-
Total	24	52,593,700.97	-	-	-	-

The increase in the class of lightly degraded pastures in 2019 was driven by better rainfall distribution and higher average temperatures in the early months of the year, with considerable precipitation volumes maintained until May (Table 4). In other years, there was less precipitation between January and May, a period characterized by the establishment and greater vegetative development of the crops in the field. It is also noteworthy that the higher rainfall volumes between October and December, observed in 2017, 2018, and 2020, were not sufficient to reduce the level of pasture degradation, as although the start of rainfall was late in some years, after the onset of precipitation, the plants began the sprouting period similarly. Only after a few days of the plants' exposure to reduced water availability could differences in vegetative growth be identified. This limitation typically begins in the months of April and May.

Studies indicate that higher levels of precipitation are associated with increased soil moisture, both at the surface and in depth, which results in higher NDVI values, as plants would have sufficient water availability to perform photosynthesis (Ribeiro et al., 2019; Jucá et al., 2019; Souza, 2019). Similarly, Rezende (2023) highlights that, during the dry season, vegetation indices show greater sensitivity to soil moisture variations, indicating that when water becomes a limited resource, it is possible to obtain more responsive NDVI values to the conditions to which the plants are exposed. Thus, the lower level of precipitation in May resulted in reduced vegetative growth of pastures in the years 2017, 2018, 2020, and 2021.

Besides the water conditions, the reduction in the level of degraded pastures is associated with farmers' adoption of the Barreirão System, an integration model developed by Embrapa Arroz e Feijão, with the Fazenda Barreirão, located in the municipality of Piracanjuba, GO, serving as the model for implementing this system (Kluthcouski et al., 1991). The Barreirão system proposes the renewal of pastures through the intercropping of annual crops with pastures (Vilela et al., 2019). Due to the success of this system for the recovery/renewal of degraded pastures, the states of Mato Grosso, Minas Gerais, and Goiás have adopted the Barreirão system as an official government program. In this context, since the launch of the Barreirão system, there has been an increase in the adoption of pasture renewal practices by regional producers, justifying the improvement. Other sustainable policies, such as the national Low Carbon Agriculture Program (ABC Plan), have also been adopted by regional producers.

Table 4. Meteorological data from the southeastern region of the state of Goiás, obtained at station A003, during the period from January 2017 to December 2021 (INMET, 2025)

Months	2017		2018		2019		2020		2021	
	Prec.[1]	Temp.[2]	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.	Temp.
Jan.	219.2	23.8	224.0	23.6	182.8	24.7	204.6	24.6	125.4	24.0
Fev.	64.0	23.9	155.6	23.8	153.4	24.5	354.8	24.2	297.8	23.7
Mar.	112.8	23.9	103.2	24.4	251.6	23.8	114.8	24.1	150.4	23.5
Apr.	112.2	23.5	88.6	22.0	97.6	23.5	41.8	23.0	49.6	22.3
May	75.4	21.8	4.6	20.0	92.4	22.0	9.0	19.6	1.6	21.2
Jun.	4.2	19.7	0.4	20.6	0.0	19.8	0.0	20.6	3.2	20.0
Jul	0.0	18.0	0.0	19.8	0.2	19.3	0.0	20.9	null[3]	null
Aug.	0.0	22.1	2.0	22.1	0.0	22.1	0.0	22.0	null	null
Sep.	10.8	23.9	74.4	23.7	15.4	26.4	8.6	26.0	null	null
Oct.	58.6	25.9	125.8	24.7	38.0	26.0	138.0	26.4	null	23.9
Nov.	334.8	23.6	287.2	23.4	164.0	25.1	165.8	24.7	null	23.9
Dec.	226.4	23.6	143.2	24.6	317.0	24.3	300.8	24.4	174.2	24.1
Total	1,218.4	-	1,209.0	-	1,312.4	-	1,338.2	-	802.2	-

[1]Prec.: monthly precipitation obtained in millimeters (mm); [2]Temp.: monthly average temperature obtained in degrees Celsius (°C); [3]null: precipitation and temperature data not provided by the weather station.

All classes showed reductions; however, they did not present statistically significant differences. The severely degraded class showed a reduction of 5.7%. Nationally, severely degraded pastures decreased from 34.3% to 25.2% between 2010 and 2018 (MAPA, 2020). This is due to the adoption of sustainable policies by farmers, such as the National Low Carbon Agriculture Plan (ABC Plan).

Fig. 4 shows the occurrences of degradation classes through spatial distribution. It is worth noting that the 'severely degraded' class decreased considerably in the first three years (1,280 ha). In 2019, the slightly degraded class showed the highest occurrence, followed by moderately degraded pastures, reflecting the year with the best pasture quality in the watershed.

Since 2019, there has been a decrease in lightly degraded pastures and an increase in moderately degraded and severely degraded classes. It is inferred that these negative results are a reflection of the Covid-19 pandemic on agricultural input costs (Lizot et al., 2023). The authors report a global average cost increase of 39.47% and a weighted average increase of 34.7%, mainly affecting small rural properties due to their limited negotiating capacity and smaller-scale purchases.

Among the inputs that saw an increase, chemical fertilizers essential for the implementation of crops such as corn, sorghum, and pasture management stand out. According to the World Health Organization (WHO), the forecast for a global trade setback was 32% (Porsse et al., 2020). However, according to the International Monetary Fund (IMF, 2021), the setback exceeded 35%.

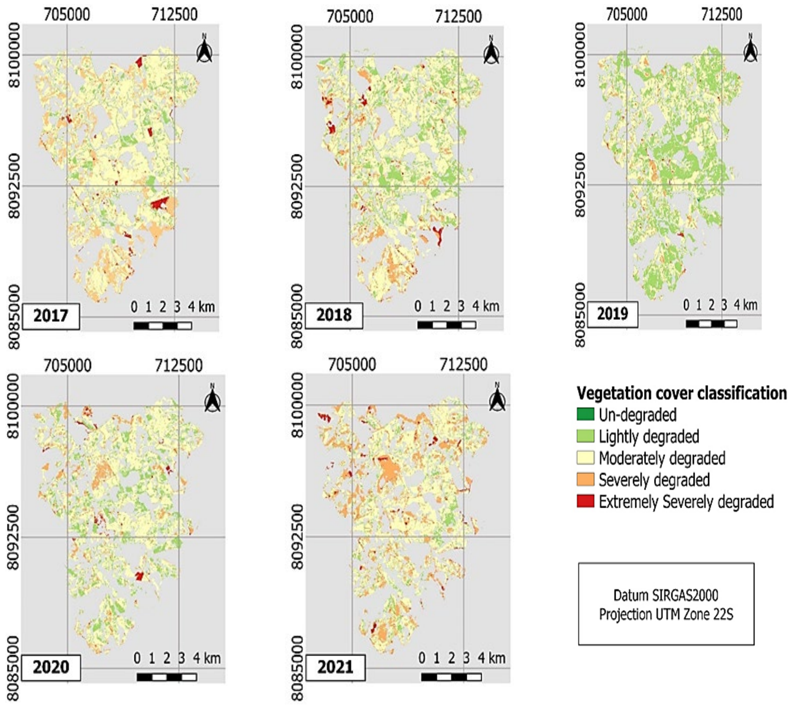


Figure 4. Occurrence of degradation classes in pastures of the study areas from 2017 to 2021.

For livestock, a higher occurrence of non-degraded pasture is expected. However, the presence of this class was negligible, with few events occurring, representing an outlier with a negative aspect, being imperceptible in the spatial variability. This scenario reflects the need for proper management in the existing areas. On the other hand, the low representativeness of extremely degraded pastures characterizes a positive outlier, meaning there are fewer areas to recover, given that recovery plans are costly.

The biomass results from 2017 to 2021 are shown in Fig. 5. It is observed that due to the predominance of the yellow color, there were no changes. The 'No Changes' class represented approximately 62.1%, equivalent to 3,629 ha.

In the comparison between biomass gains and losses, the data showed that losses were greater, with area values close to 1,269 ha, while gains were

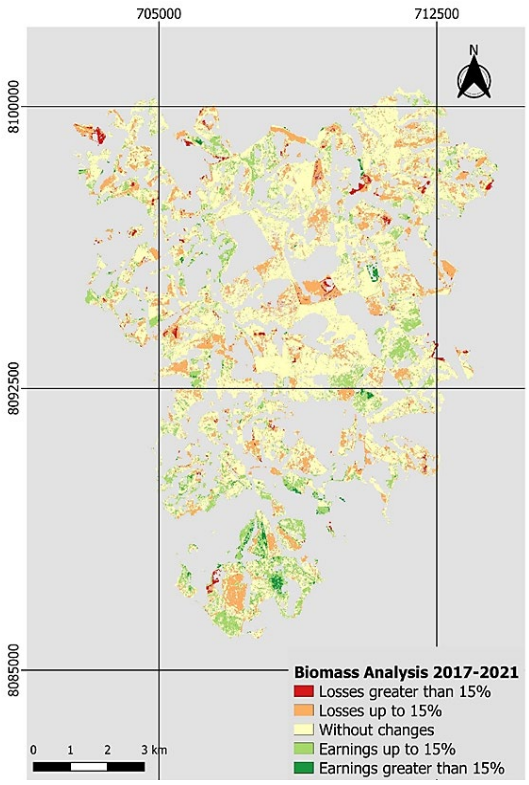


Figure 5. Analysis of biomass gains and losses between 2017 and 2021 in the Ribeirão Serra Negra Watershed in the municipality of Piracanjuba, Goiás, Brazil.

approximately 945 ha. The largest losses were recorded in the ‘losses up to 15%’ class, and the greatest gains in the ‘gains up to 15%’ class.

From a socioeconomic perspective, pasture evaluations through vegetative vigor and vegetation cover conditions proved to be a valuable tool for producers and the implementation of public policies, guiding them to areas that require more attention and, often, need conservation practices and management plans in this watershed, a tributary of the Meia Ponte River. In this regard, monitoring degraded areas is a practice that enables the improvement of existing pastures, allowing for the rational management of inputs, conserving natural resources, and supporting programs like the 2023/2024 Safra Plan, which aims at sustainability (MAPA, 2023).

CONCLUSION

The different land use and land cover classes for the Serra Negra stream watershed remained largely unchanged during the study period (2017 to 2021). For the pasture class, more than 98% (6,583.10 ha) of the areas showed some level of degradation, with the best vegetation cover conditions occurring in 2019, a period characterized by the adequate distribution of rainfall in the first months of the year (from January to May). Remote sensing techniques involving the NDVI index and Vc analysis were effective in monitoring pasture degradation and the results showed associations with climatic conditions.

The transformations observed in the pasture class were primarily influenced by climatic conditions, rather than by public policies adopted in the context of the Covid-19 pandemic. Thus, for improvements in pasture quality, livestock farmers should adopt appropriate management practices to maintain vegetation in stressful conditions, such as soil fertilization, pasture renovation using adapted forage species, implementation of rotational grazing techniques, and the adoption of integrated systems. These actions not only promote pasture recovery but also contribute to the protection of the watershed's water resources, ensuring the maintenance of local ecosystems and promoting long-term environmental stability.

ACKNOWLEDGEMENTS. The authors would like to thank the Federal University of Goiás (UFG), whose support is appreciated. This work was conducted with the support of the Fundação de Amparo à Pesquisa do Estado de Goiás (FAPEG) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

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