Degradation of Phytophysiognomies of Cerrado and linear water erosive impacts in southwestern Goiás – Brazil

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Abstract

Changes in soil cover and use have become a leading environmental degradation factor, especially soil erosion. In the last four decades, Cerrado environments have undergone an intense conversion to anthropic use, especially agriculture, bare soil and, mainly, pasture. This work evaluates the relationship between these changes and water erosion, highlighting the most affected phytophysiognomies and the consequent emergence of critically degraded areas. The methodology comprises the correlation between the CP factor dynamics (Land cover and use and management practices) of each phytophysiognomy class and land use from 1985 to 2014 and the density of outbreaks and area of erosive contribution in 2014. The results indicate that the period 1985-1995 was noteworthy for converting Savannah, Thin Savanna, and Typical Savanna to Agriculture, Bare Soil and Pasture, while the period 1995-2005, consolidated this type of use. In 2005-2014 there was a low conversion of phytophysiognomies and consequently increased consolidation by anthropic use. The areas with a high density of up to 3.5/km², a high percentage of erosive contribution (up to 48%), and in critical stages of degradation are associated with converting these three phytophysiognomies to Bare Soil and mainly Pasture, both of high CP values. Throughout the period, 53.32 % of the erosive contribution area was due to the same type of conversion. Another 33.88 % occurred in areas where similar use already prevailed in 1985 and persisted in this condition all through the analyzed period.

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INTRODUCTION

Changes in land cover and use induced by anthropic actions are among the factors that directly and indirectly contribute the most to bigger and more severe environmental changes, whose consequences are manifest from local to global scales (CAPITANI *et al.*, 2016; ELLIS, 2015). These alterations result from feedback mechanisms related to these conversions and imply the distribution and balance of energy, especially thermal and kinetic, and its interaction with continental and oceanic surfaces (FINDELL *et al.*, 2017). Consequently, there are observable impacts on biodiversity, climate, the availability and quality of natural resources, especially soil and water, the economy, and, above all, the well-being of populations (ARNOUS *et al.*, 2017; BAJOCCO *et al.*, 2012; GRIGGS *et al.*, 2014).

In recent decades, the gradual increase in soil loss, especially over large areas, has become one of the leading causes of environmental degradation (HASSAN *et al.*, 2016; ÖZŞAHIN *et al.*, 2018; ÖZŞAHIN; UYGUR, 2014). This scenario highlights a key challenge for contemporary societies' sustainable use and management of land surface resources to guarantee a fairer legacy for future generations. Likewise, in many cases, it is evident that these degradation processes are already irreversible; the substantial environmental liabilities generated over decades of inappropriate use and management have led to increasingly uncertain recovery possibilities.

The characteristic Cerrado plant formations covered the Brazilian Central Plateau, comprising an extensive area with one of the most diversified landscapes and biodiversity on the planet. In the early 1950s, the primary use was extensive cattle raising, and from the 1960s onwards, there was a new phase of change driven by the modernization of agriculture and, more recently, the implementation of agro-industrial complexes (GRAZIANO DA SILVA, 1996). In this context, in recent decades, the Cerrados region has undergone significant changes in land cover and use, gaining new, mainly economic, meanings. It has become a strategic region for agribusiness due to its location and relief, which is mostly favorable to mechanized agricultural management (OLIVEIRA, 2014; SILVA *et al.*, 2015).

Public incentives promoted the arrival of the agricultural frontier and were associated with the availability of extensive areas of plateaus with climatic and soil conditions favoring agricultural activities during most of the year. The ease of acquiring large areas at very low prices resulted in migratory waves, mainly from the South and Southeast regions of Brazil. The implementation of government programs intensified the changes, mainly linked to the 1972-1974 I Plano Nacional de Desenvolvimento (PND, brazilian economic plan), such as the Programa de Desenvolvimento do Centro-Oeste (PRODOESTE, destined to increase the economic development of the southern states of Mato Grosso, Goiás and Distrito Federal) and the 1975-1979 II Plano Nacional de Desenvolvimento, with the Programa de Desenvolvimento dos Cerrados (POLOCENTRO, with the objective of promoting the development and modernization of agricultural activities in the Centro-Oeste) and Programa de Cooperação Nipo-Brasileira para o Desenvolvimento Agrícola dos Cerrados (PRODECER, technical and financial cooperation with the objective of making the cerrado region productive). These initiatives promoted the region's development and integration into the national productive system, as recollected by Barbalho and Castro (2014), Menezes *et al.* (2009), Oliveira *et al.* (2018), and Rocha *et al.* (2014).

However, the lack of systematic studies about the potential and limitations of each environment and the forms of use and management practices used at the time resulted in extensive levels of degradation, mainly through linear water erosion processes involving ravines and gullies. In this context, this work aims to evaluate the relationship between the process of conversion of Cerrado vegetation types to anthropogenic use and the occurrence of linear water erosion features, and the consequent emergence of critical areas characterized by a high density of foci and the erosion contribution area, highlighting the most degraded phytophysiognomies in the period 1985-2014.

MATERIALS AND METHODS

Location and characterization of the study area

The study area covers the municipalities of Mineiros, Santa Rita do Araguaia, Perolândia, and Portelândia, all located in the Southwest Microregion of Goiás in the highest parts of the Araguaia and Paranaíba river basins (Figure 1). The geological substrate is from the Paraná

Sedimentary Basin, predominantly composed of different sedimentary formations with a predominance of claystones, sandstones, and sand deposits, sometimes permeated by basaltic intrusions. As specified below, these formations have different resistance to weathering processes, resulting in distinct altimetric levels corresponding to staggered geomorphic surfaces. A highlight is the Serra de Caiapó toponym, part of the Paraná Basin's Northern Plateau (AB' SABER; COSTA JÚNIOR, 1950; DRAGO *et al.*, 1981), its highest section is 1010 m high.

Figure 1 - Location of the area (a); Geological formations and lithologies (b); Hypsometry (c); Slope (d); pedology (e); and land cover and use in 2014 (f).
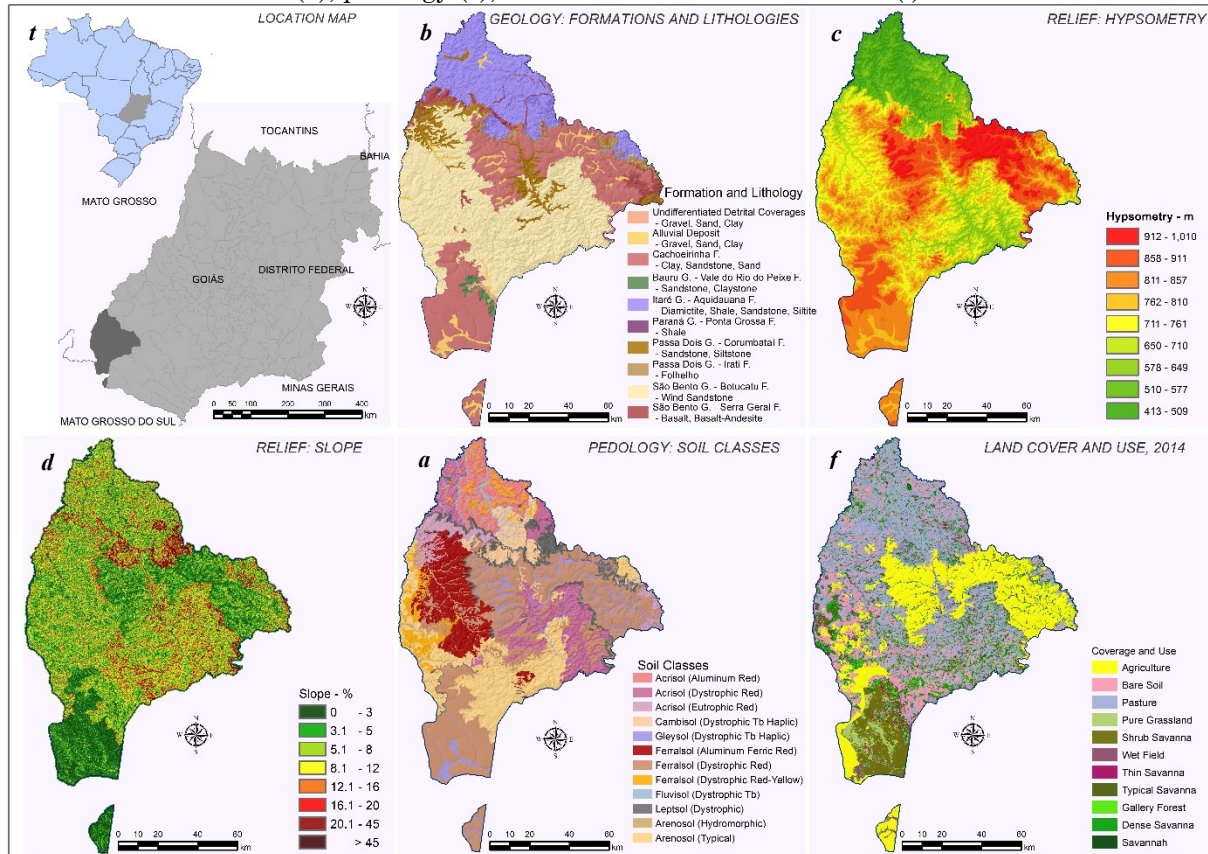
Source: Nunes (2015).

The various altimetric levels have well-established limits since the transition to adjacent areas is marked by a clear-cut reduction in altitudes, accompanied by increased declivity. In turn, these direct consequences of changes in the lithology influence geomorphological, pedological, and predominantly land cover and use patterns, with direct impacts related to linear water erosion processes.

In the central portion and the extreme south of the area, the higher and flatter surfaces have claystones, sandstones, and sand deposits belonging to the Cachoeirinha Formation (BRASIL, 1983; LACERDA FILHO; FRASCA, 2008). The altitudes vary from 857 to 1010 m, with the declivity varying from 0 to 8%, forming extensive plateaus called *Chapadas* or *Chapadões*. The Red Latosol (Ferralsols,

Oxisols), with a clayey to very clayey texture, predominates in slopes up to 8%, and Haplic Gleissol (Haplic Alfisol) with clayey texture along the plains, following low altimetric gradient channels and a declivity of up to 3% (ALVES *et al.*, 2017; PAULINO *et al.*, 2015). Latosol (Ferralsols, Oxisols) areas were the first to be occupied by agriculture in the 1960s, consolidated in the 1970s, with the advent of modernized agriculture (PINTO; WANDER, 2016), linked to the Green Revolution, involving the intense application of technological knowledge to land management.

In the west and southeast segments, eolian sandstones of the São Bento Group – Botucatu Formation predominate, interspersed with sandstones and siltstones of the Passa Dois Group – Corumbataí Formation (BRASIL, 1983). The former is found on higher preserved

levels, with interfluves with more rounded edges and a predominance of medium-textured Red Latosol (Red Oxisol, Ferralsol) associated with a sandy-textured Orthic Quartzarenic Neosol (Typical Quartpsamment, Typical Arenosol) that transitions to a sometimes sedimented/silted Hydromorphic Quartzarenic Neosol (Hydromorphic Entisol, Arenosol) on the valley floor. The predominant uses are agriculture in Latosol (Oxisol, Ferralsol) and pasture in less fertile soils such as sandy Neosols.

In the lower and more dissected southeastern portion with more concave interfluves, mostly sandy Ortic Quartzarênico Neosol (Typical Quartpsamment, Arenosol) and medium-textured Red Ultisol (Red Acrisol) predominate (SCOPEL et al., 2013). These are areas where the conversion process for anthropic use intensified throughout the 1970s and, in particular, the 1980s. Their low capacity for agriculture led to extensive areas being converted to pasture and, more recently, zones of exposed soil, which are subject to the advance of linear water erosion processes (NUNES; CASTRO, 2015).

In the northern portion, diamictites, shales, sandstones, and siltstones belonging to the Itaré Group, Aquidauana Formation preponderate (BRASIL, 1983; MOREIRA *et al.*, 2008). The relief is even lower than the previous area, with altitudes of up to 413 m. There is advanced erosive dissection, resulting in a flat, low gradient, with slopes of up to 20% on the interfluve edges and 3% on the valley floor. Red Ultisols (Red Acrisol) of medium texture predominate, transitioning to Fluvic Neosols (Fluvent Entisol, Fluvisol) with a sandy texture along the main channels. Pasture is the primary land use, and in recent years there are

significant patches of exposed soil.

The climate is tropical sub-humid throughout the area, with two distinct periods. The dry season lasts from June to August, and the rainy one from September to May (SILVA et al., 2006), fitting into the Köppen Aw type (MONTEIRO, 1951; NIMER, 1972).

Mapping of foci and elaboration of density maps and area of erosive contribution

The mapping of the linear erosive foci was carried out in the second half of 2014, based on the interpretation and visual inspection of colored GeoEye images with a spatial resolution of 0.4 m. For mapping purposes, erosion was considered a feature with a linear aspect, slightly deepened and with steep edges, and generally, with a degraded interior, that contrasts with the immediate surroundings, as shown in Figure 2. At this level of detail, the scale of 1:2,000, polygon mapping was possible, which allowed the central point or centroid to be calculated. The area of each feature was subsequently converted into the erosive contribution area (% of the eroded area in 1 km², for example), and, consequently, the stage of degradation could be assessed with more confidence. The images were scanned and analyzed by dividing the polygon surrounding the study area into 1000 x 500 m rectangles, adjusted to a 21" monitor. This procedure permitted the entire study area to be visually inspected at the same level of detail, compatible with the image resolution parameters, thus avoiding misinterpretations and erroneous conclusions about the erosive feature, especially its limits. Thus, it was possible to perceive spatial patterns of occurrence of erosive foci more rigorously and classify them into small, medium, and large dimensions.

Figure 2 - Location and mapping of medium-sized erosive features (*a*); and large erosive features (*b*).
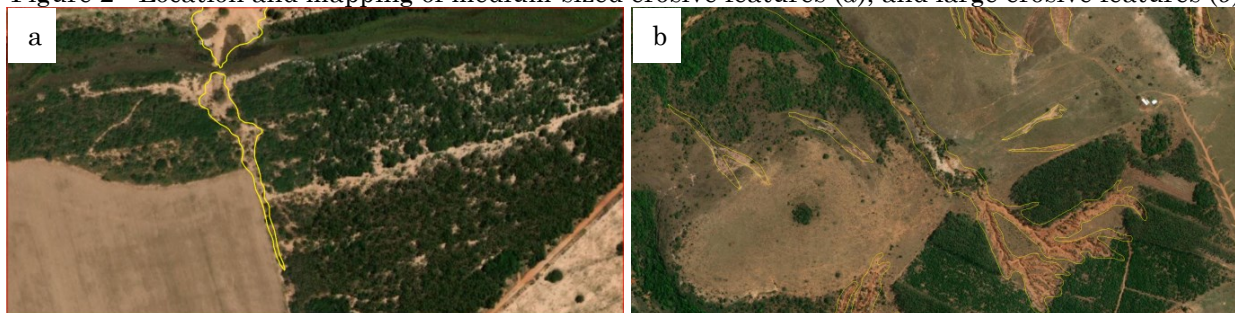
Source: The authors (2018).

The Kernel density, available in the ArcGIS software, was used to create the focus density and erosive contribution area maps. For the density of foci outbreaks, an analysis or

weighting radius of 3700 meters was adopted, corresponding to the average distance between the erosive features' centroids, resulting in the number of foci per km² and an output resolution

of 30 meters in a matrix structure. For the erosive contribution area map, the erosive focus/surrounding area ratio was adopted, considering an analysis radius of 700 meters, which corresponds to the average distance between the edges of the erosive features. Therefore, the percentage dimension of the erosive contribution area also has a matrix structure with an output spatial resolution of 30 meters.

The bivariate map of critical areas was designed by dividing and crossing the five classes of each parameter, thus resulting in a 5x5 class key. This procedure allowed a detailed representation of four different patterns of erosive occurrence in the area, namely: low focus density (0 - 0.5 focus/km²) and low area of erosive contribution (0 - 5 %); low focus density and high erosive contribution area (20 - 48%); high focus density (2 - 3.5 outbreaks/km²) and low area of erosive contribution; and very critical areas where both the focus density and the area of erosive contribution are high.

Multitemporal mapping of coverage and use classes and their correspondence in CP factor (Coverage and Management Practices).

The mapping of the phytophysiognomies and land use classes was elaborated from Landsat images of the months without rainfall. Images from the TM Landsat 5 sensor in the RGB 543 color composition and 2% spectral enhancement were used for 1985, 1995, and 2005. In 2014, the sensor and OLI Landsat 8 used the RGB 654 composition and the same highlight. The definition of the phytophysiognomy classes followed the nomenclature proposed by Ribeiro and Walter (2008), which includes the main phytophysiognomies found in the Cerrado biome's plant formations (Forest, Savanna, and Grassland Formations) (Figure 3).

Figure 3 - Phytophysiognomies of the Cerrado biome and their correspondence in color and texture from TM Landsat 5 images.
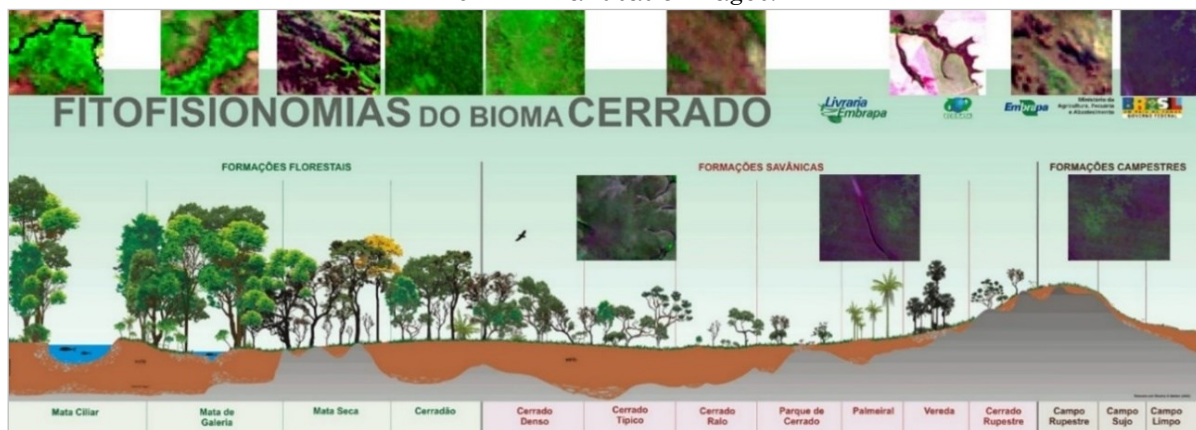
Source: adapted from Ribeiro and Walter (2008).

Therefore, the classification key was created from the correlation between the photographic inventory and observations of representative areas of each phytophysiognomy in the field, whose coordinates were collected with GPS, transposed to a digital environment, and then superimposed on the images, observing the color and texture verified around each point. A similar procedure was adopted by Castro (2014) to identify the phytophysiognomies of the Cerrado biome using aerogammaspectrometry and remote sensing, thus allowing better use of TM Landsat 5 images in the classification of plant physiognomies.

Once the land cover and land use and management maps had been created, the next step was to analyze how each class corresponded with the Use/Management and Conservation Practices factor, C and P factors of the Universal Soil Loss Equation, according to Oliveira (2012) and Stein et al. (1987). Next, the interval was divided into five classes, and each one was assigned a code related to the respective class of the other time frames (Table 1).

Table 1 - Classes of phytophysiognomies, land cover, and land use and their correspondence in Factor C (Coverage/Use and Management) and P (Conservationist Practices).

Plant Formation/Phytophysiognomy and Coverage and Use	Factor C	P factor	CP factor	Class Code
Wet field	0	1	0	1
Savannah, Dense Savanna, Gallery Forest	0.00004	1	0.00004	2
Typical Savanna	0.0007	1	0.0007	3
Shrub savanna	0.01	1	0.01	4
Agriculture	0.12	0.12	0.0144	4
Thin savanna	0.01035	1	0.01035	4
Pure grassland	0.02	1	0.02	4
Pasture	0.1	1	0.1	5
Burnt ground	0.2	1	0.2	5
Bare soil	1	1	1	5

Source: adapted from Oliveira (2012); Stein *et al.* (1987).

This procedure established the bivariate spatial relationships between variables and between each of these and phenomena related to erosive processes. The synthesis flowchart of the materials used, the methodological procedures, and the respective syntheses produced is presented in Figure 4.

Figure 4 - Synthesis flowchart of the methodological procedures adopted.
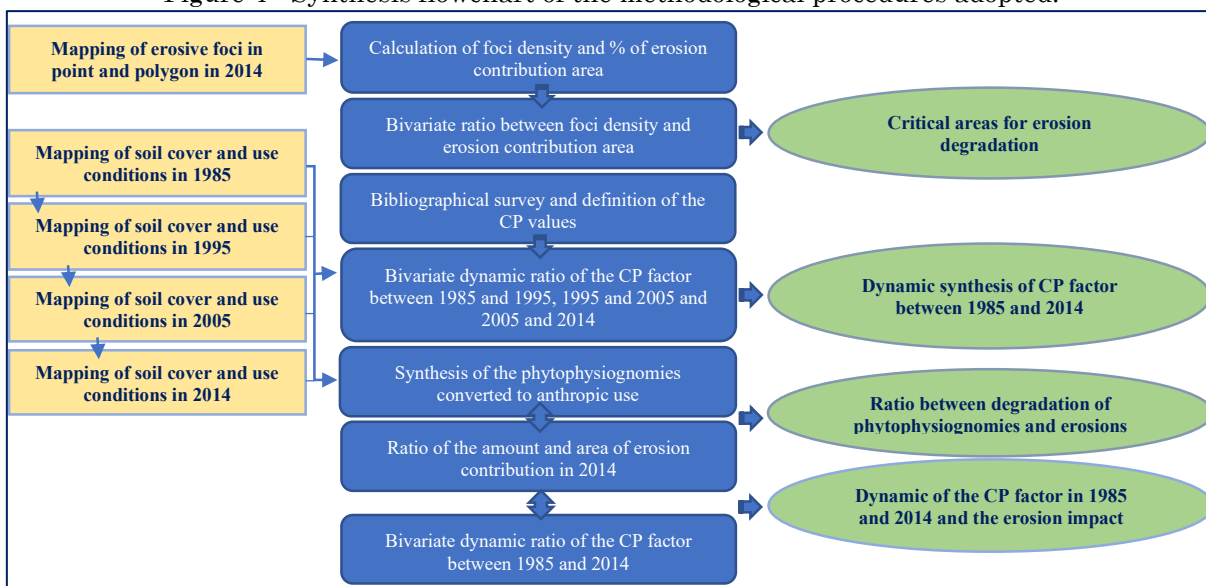
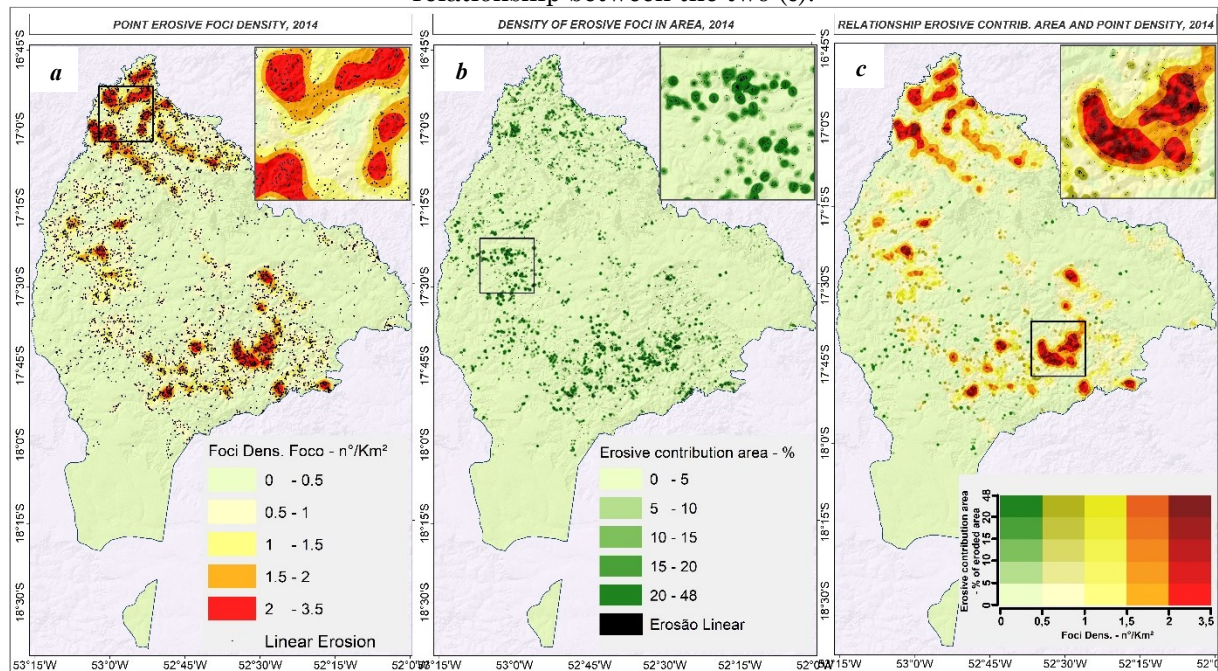Source: Adapted from Nunes (2015).

RESULTS AND DISCUSSION

Bivariate analysis between focus density and erosive contribution area classes in 2014

The mapping analysis highlights four spatial and numerically distinct patterns regarding the distribution of erosive features, as shown in Figure 5. The first results from the low density of foci and low area of erosive contribution, corresponding to the plateau areas covered by Red Latosols (Red Oxisol, Ferralsol) and, to a lesser extent, by Haplic Gleysol (Haplic Alfisol), both of clayey texture and low slope, where agricultural use was consolidated in the 1970s and 1980s. In addition to agricultural use, another decisive factor is the existence of the Emas National Park, whose protected vegetation prevents soil degradation through erosion.

Figure 5 – Point erosive foci density maps (a); area of erosive contribution (b); and the bivariate relationship between the two (c).

Source: Adapted from Nunes (2015).

Another pattern results from areas with high focus density and a low area of erosive contribution (detail in Figure 5 *a*), which concentrates on the transition of the central and northern portions of the study area. In these environments, Lithologic Neosols (Lithic Entisols, Leptsols) and Haplic Cambisols (Haplic Inceptisols) predominate, ranging from medium to gravelly textured, where almost all erosive foci are less than 1 ha. The impression of a large erosive contribution area is due to the high number of foci and the high proximity between the incisions. However, although this spatial distribution pattern resembles areas with large erosions, the shallow depth of these soils principally causes disaggregation in the more superficial portions.

A third pattern results from areas with low foci density and high erosive contribution (detail in Figure 5 *b*). Although it also occurs in the northern and southeastern portions, this pattern is more characteristic of the western part, where the number of outbreaks is small, but the area of erosive contribution tends to be sizeable. Three of the eighteen most extensive foci with areas above 12 ha occur in this section. There is a prevalence of medium-textured Red Oxisols (Red Ferralsol) associated with slopes of up to 8% mainly used for agriculture, although there is some pasture. Large erosive foci tend to occur on the transition from the upper third to the intermediate third of the slopes and the consequent exposure of sandy Quartzarenic

Neosols (Quartzipsamment Entisol, Arenosol) from eolian sandstones of the Botucatu Formation. The triggering of erosive incisions in these environments is strongly associated with pasture use. Its evolution is strongly conditioned by the soils' greater depth and texture, leading to large-scale losses in the form of sizeable incisions.

The pattern resulting from the high density of outbreaks and high area of erosive contribution indicates at least 18 areas with a high level of degradation, of which 15 occur in the southeastern portion, as illustrated in Figure 5 *c*. While they occur in the northern and western portions, the most significant degradation stages are in the southeast, where there are up to 3.5 outbreaks per km², and the contribution area reaches 48%. These are areas of sandy Red Ultisols and, mainly, Quartzarenic Neosols associated with slopes ranging from 8 to 16%. Pasture was introduced to these areas in the 1970s. Due to their low capacity for agriculture, the land use remained the same throughout the study period. As a result of this repeated usage, some erosions occupy up to 25.2 ha and reach the rocky substratum.

Degradation of phytophysiognomies and linear water erosion processes.

The outcome of converting vegetation cover to anthropogenic use in 1985, 1995, 2005, and 2014 is shown in Figure 6. Agricultural use was

concentrated on the highest and flattest surfaces throughout the period, including the vicinity of Emas National Park. At the same time, the emergence and increase of pasture areas and bare soil were concentrated in the lower and more dissected areas, where more

sandy and less fertile soils predominate. This finding corroborates the work of Pinto and Wander (2016) and Silva (2018), who state that the higher areas were the first to be occupied by annual crops, which were consolidated in the 1970s and 1980s.

Figure 6 – Spatial and temporal dynamics of the phytophysiognomies and land use classes in southwestern in 1985, 1995, 2005 and 2014.
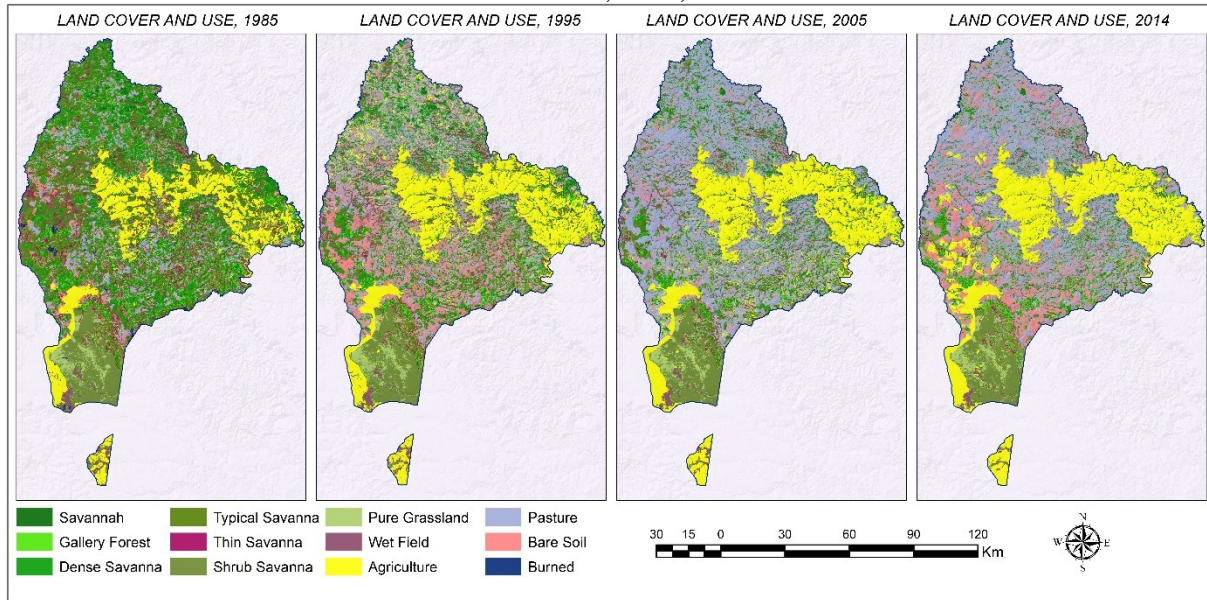

Source: Nunes (2015).

The maps indicate that the most intense consolidation in the study area occurred between 1985 and 1995. From the latter year, the size of the agricultural area stabilized; the land use predominated in about 23.7% of the area.

In 1985, pasture and bare soil areas were already evident in small but numerous spots in the north, west, and southeast portions, making

up just over 9.50% and 4.63% of the study area, respectively. In the same year, the main Cerrado physiognomies occurred in very expressive areas. Figure 7 shows these in order of prevalence: Savannah 23.32%; Thin Savanna 18.03%; Shrub Savanna 6.63%; Gallery Forest 6.24%; Wet Field 6.31%; Typical Savanna 4.93%; Dense Savanna and Pure Grassland with 2.42% each.

Figure 7 - Dynamics of each class of land cover and land use in 1985, 1995, 2005 and 2014 and respective percentages of outbreaks and area of erosive contribution.
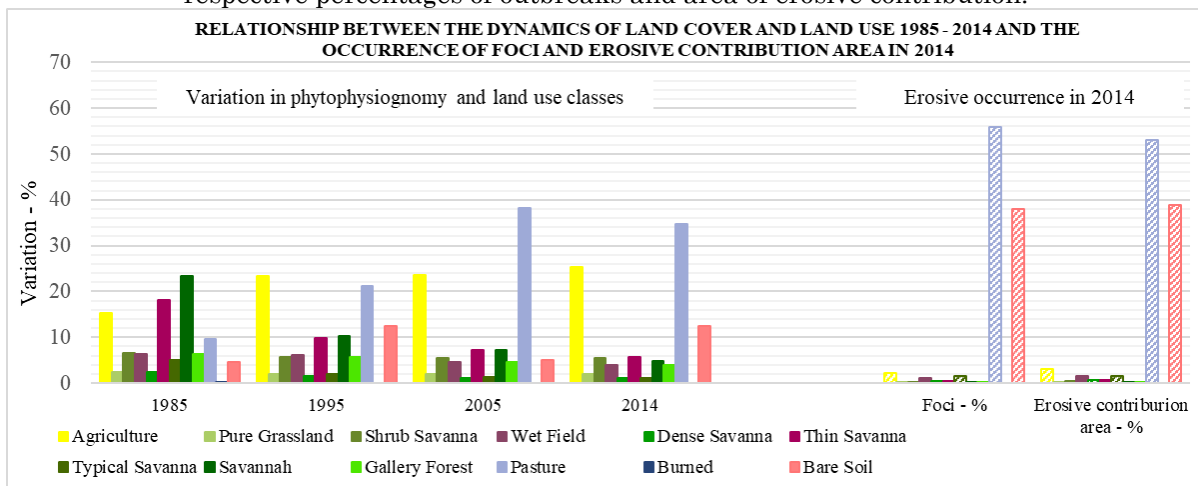
Org.: the authors (2018).

In 1985-1995, there was a marked reduction in vegetation cover and the expansion of areas of bare soil and mainly pasture. The most degraded phytophysiognomies are the Savannah, Thin Savanna, and the Typical Savanna, which dropped from 23.32%, 18.03%, and 4.93% in 1985, to only 10.29%, 9.89 %, and 1.91%, respectively, in 1995. The area of the remaining phytophysiognomies changed little. The greater frequency of Pure Grassland and Shrub Savanna is related to the proximity of the Emas National Park; the Wet Field and Gallery Forests are the closest to the watercourses.

In the 1995-2005 and 2005-2014 intervals, there was a stabilizing trend in land cover and use conditions. The phytophysiognomies, especially those on the top of the interfluve and medium slope, were reduced to small areas. At the same time, bare soil and, mainly pasture, came to predominate in most areas, especially in environments where low soil fertility has discouraged agricultural use.

Areas with bare soil and especially pastures were decisive for the concentration of erosive processes. In 2014, around 38% of the incisions were associated with exposed soil, while 55.8% were associated with pasture, thus totaling 93.80%. As verified by Barbalho and Castro

(2014), these are very expressive amounts; their work indicates that pasture is responsible for more than 60% of the erosion processes in the basins of the Claro and Bois rivers. Regarding the area of erosive contribution, there is a slight increase in the association between bare soil and the incisions, rising to 38.8%, while pastures account for 53.1%, thus totaling 91.9%.

Bivariate analysis of the CP Factor and its relationship with the occurrence of erosive processes

Three situations are evident from the bivariate analysis of the CP factor dynamics over each of the 10-year intervals. The first, less frequent, shows a reduction in CP values, the second increases, and in the third and most frequent, the CP values remained unchanged. Between 1985-1995, almost no environment (only 1.43%) showed a reduction in the CP factor. This is indicated by the near lack of blue-toned areas in Figure 8a. The low reduction occurred at the expense of a significant area with an increase in the CP factor due to the intense anthropization during this period, with extensive areas of natural vegetation being converted to pastures.

Figure 8 – Change maps in the CP factor between 1985 and 1995 (a); between 1995 and 2005 (b) and respective areas of occurrence.
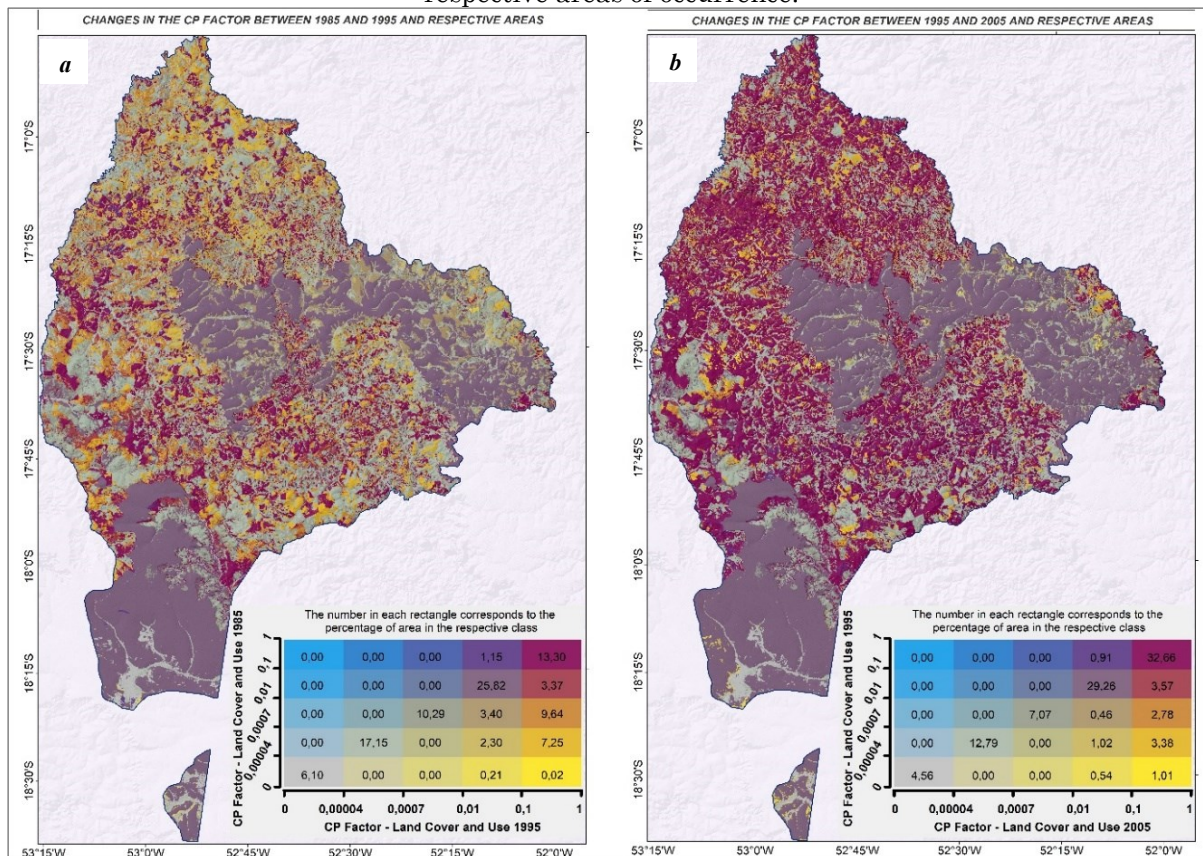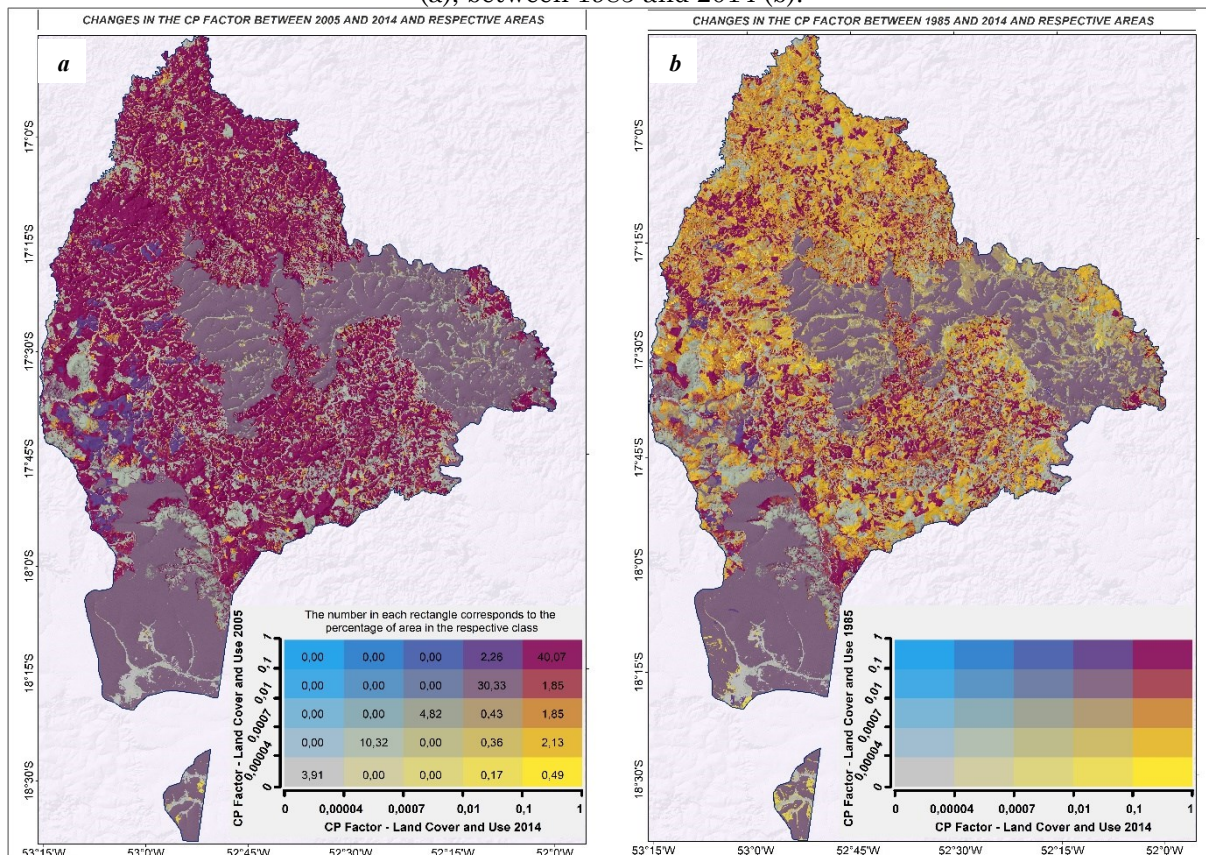

Org.: the authors (2018).

The most frequent situation has an increase in the CP factor, resulting from the conversion of the Savannah*, Typical Savanna and Thin Savanna vegetation partly into agriculture and, mainly, pasture and exposed soil, both with high CP factor values. This fact is clear from the high occurrence of yellow and orange tones and respective percentages in Figure 8a. For all the classes in this condition, it can be seen that, in the period, about 27% of the area showed an increase in CP values, highlighting the fact that the region is undergoing a considerable process of conversion of vegetation cover for human use. The most common situations, covering 72.28% of the area, indicate no change in coverage and especially in land use and, consequently, the CP value was maintained.

The analysis of the dynamics of CP factor values between 1995 and 2005 (Figure 8b) shows a slight increase in areas with a reduction in the CP factor. From 1.43% in the 1985-1995 interval, it rose to 1.59% in the following decade. Of this total, 0.94% corresponds to the conversion of bare soil and pasture to

agriculture. Concerning areas that had an increase in the CP factor, there was a marked reduction compared to the previous period. The analysis of all areas in this condition shows that the CP factor increased in only 13.12% of the area. For most of the area, this period was marked by the consolidation of areas with high CP factor values, especially in soil environments less favorable to agriculture and, therefore, destined for pasture.

The dynamics of the CP factor values between 2005 and 2014 revealed a reduction in CP factor values in about 2.92% of the area. Agricultural use in areas that used to have bare soil and pasture (2.3%) contributed to this slight reduction. In this context, it is worth highlighting the cultivation of eucalyptus in areas heavily affected by erosion, especially in the upper Araguaia River basin. A sharp reduction occurred in the areas with an increase in the CP factor compared to previous periods. From 2005 to 2014, only 7% of the area was converted for anthropic use, as observed in the yellow and orange colors (Figure 9a).

Figure 9 - Change maps in the CP factor between 2005 and 2014 and respective areas of occurrence (a); between 1985 and 2014 (b).
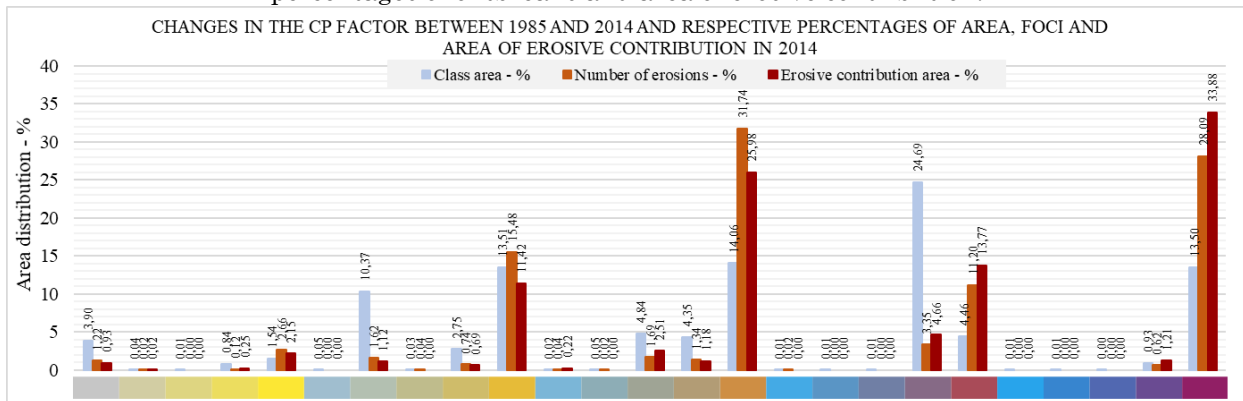

Source: Authors, 2018.

Finally, Figure 9b summarizes the process of converting vegetation cover into anthropogenic use and the consequent increase in areas with high CP factor values. In this context, the areas that underwent an increase in values are noteworthy, especially those whose CP factor values were already high in 1985 and remained unchanged in 2014.

Figure 10 quantitatively synthesizes the bivariate relationship between the CP factors for 1985 and 2014 and the respective percentages of outbreaks and erosive contribution area. The classes with the highest CP factor in 2014 account for most features and the erosive contribution area. This percentage is higher when related to the high CP factor classes of 1985.

Figure 10 - Area distribution between the 1985 and 2014 CP factor classes and respective percentages of outbreaks and area of erosive contribution.

Source: the authors (2018).

Given the anthropization process already observed in previous periods, the main highlight in the 2005-2014 period is the high percentage of areas of bare soil and, mainly, pasture. Thus, it is essential to highlight that this high percentage is due to the cumulative effect verified through the areas where the CP factor increased in 1985-1995 and 1995-2005.

CONCLUSIONS

The analysis verified that degradation by erosive processes is contemporaneous with the expansion process of pasture in areas adjacent to the plateaus where agriculture began in the 1960s and consolidated in the 1970s and 1980s. Expansion to hillier and less favorable land was decisive for the degradation process.

The permanence of unfavorable areas to agriculture as bare soils and, mainly, pastures for long periods proved to be determinant for the occurrence of critical situations of degradation. The areas with the highest density of foci and the largest area of erosive contribution occur in environments where bare soil and pasture predominated throughout the study period.

Regarding the deforestation process, it is noteworthy that the above was true for the

Savannah phytophysiognomy, related to flat terrains and clayey soils on the tops of plateaus. Deforestation and consequent further degradation by erosive processes occurred in the predominant phytophysiognomies in terrains with greater declivity and medium to sandy soils. The Typical Savanna, Dense Savanna, and Thin Savanna stand out, as the conversion process has resulted in environments in advanced stages of degradation.

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REFERENCES

AB'SABER, A. N.; COSTA JÚNIOR, M. Contribuição ao estudo do Sudoeste Goiano. **Boletim Paulista de Geografia**, São Paulo, v. 2, n. 4, p. 3-26, 1950. Available: https://www.agb.org.br/publicacoes/index.php/bolet im-paulista/article/view/1402/1260. Access in: mar. 25, 2020.

ALVES, W. S. et al. Análise da fragilidade ambiental da bacia do ribeirão das Abóboras, em Rio Verde, Sudoeste de Goiás. **Revista Internacional de Ciencia y Tecnologia de La Información Geográfica**, n. 19, p. 81-108, 2017. http://dx.doi.org/10.21138/GF.556.

ARNOUS, M. O.; EL-RAYES, A. E.; HELMY, A. M. Land-use/land-cover change: a key to understanding land degradation and relating environmental impacts in Northwestern Sinai, Egypt. **Environ Earth Science**, v. 7, n. 76, p. 263-283, 2017. http://dx.doi.org/10.1007/s12665-017-6571-3.

BARBALHO, M. G. S.; CASTRO, S. S. Compartimentação morfopedológica como subsídio ao planejamento do uso da terra das bacias dos rios Claro e dos Bois, Estado de Goiás. **Fronteiras: Journal of Social, Technological and Environmental Science**, v.3, n.2, p. 111-131, 2014. http://dx.doi.org/10.21664/2238-8869.2014v3i2.p111-131.

BAJOCCO, S. A. et al. The impact of land use/land cover changes on land degradation dynamics: A Mediterranean case study. **Environmental Management**, v. 49, n. 5, p. 978-989, 2012. http://dx.doi.org/10.1007/s00267-012-9831-8.

BRASIL, RADAMBRASIL, Projeto. **Folha SE.22 Goiânia: geologia, geomorfologia, pedologia, vegetação, uso potencial da terra.** Rio de Janeiro: FIBGE, 1983. (Levantamento de recursos naturais, v. 31), 764 p.

BORGES, R. E. Complexos agroindustriais e desenvolvimento regional: O caso do sudoeste de Goiás. In: **Encontro Nacional de Geografia Agrária, 21, Territórios em disputa: os desafios da Geografia Agrária nas contradições do desenvolvimento brasileiro**, 2012, Uberlândia.**Anais**...Uberlândia:UFU,2012. Available: http://www.lagea.ig.ufu.br/xx1enga/anais_enga_20 12/gts/1217_1.pdf. Access in: Jun. 09, 2020.

CAPITANI, C. et al. From local scenarios to national maps: a participatory framework for envisioning the future of Tanzania. **Ecology and Society**, v. 21, n. 3. p. 1-33, 2016. http://dx.doi.org/10.5751/ES-08565-210304.

CASTRO, B. L. G**. Identificação de fitofisionomias do bioma Cerrado no estado de Goiás, por meio de aerogamaespectrometria e sensoriamento remoto**. 2014. 210 p. Tese (Doutorado em Geociências Aplicadas) – Instituto de Geociências, Universidade de Brasília, Brasília, 2014.

DRAGO, V. A. et al. Contribuição ao estudo geológico do vale do Rio Araguaia. In: **Simpósio de Geologia do Centro-Oeste**, 1, 1981, Goiânia. **Ata**...Goiânia: SBG, 1981, p. 404-421.

ELLIS, E. C. Ecology in an anthropogenic Biosphere. **Ecological Monographs,** v. 85, n. 3, p. 287-331, 2015. https://doi.org/10.1890/14-2274.1.

FINDELL, A. K. et al. The impact of anthropogenic land use and land cover change on regional climate extremes. **Nature Communications**. v. 8, n. 989, p. 1-10, 2017. https://doi.org/10.1038/s41467-017-01038-w.

GRIGGS, D. M. et al. An integrated framework for sustainable development goals. Ecology and Society, v. 19, n. 4, p. 1-24. 2014. http://dx.doi.org/10.5751/ES-07082-190449.

HASSAN, Z. et al. Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. **SpringerPlus**, v. 5, n. 812, p. 1-11, 2016. http://dx.doi.org/10.1186/s40064-016-2414-z.

GRAZIANO DA SILVA, J. *Do complexo rural aos complexos agroindustriais. In:* GRAZIANO DA SILVA, J. **A nova dinâmica da agricultura brasileira***, 2ª ed.,*Campinas: Instituto de Economia - UNICAMP, 1996. 217 p.

LACERDA FILHO, J. V. de; FRASCA, A. A. S. Compartimentação geotectônica. In: MOREIRA, M. L. O. et al. (Org.). **Geologia do Estado de Goiás e do Distrito Federal**. Goiânia: CPRM/SIC-FUNMINERAL, 2008. 143 p.

MENEZES, B. B. et al. Uso e ocupação agropecuária no cerrado brasileiro: transformações da paisagem e seus impactos ambientais no Estado de Goiás. In: **Encontro de Geógrafos da América Latina,** 12, 2009, Montevideo. **Anais**...Montevideo: 12° EGAL, 2009. Available: http://observatoriogeograficoamericalatina.org.mx/ egal12/Procesosambientales/Impactoambiental/26. pdf. Access in: Sep. 12, 2020.

MONTEIRO, C. A. F. Notas para o estudo do clima do Centro-Oeste brasileiro. **Revista Brasileira de Geografia**, v. 13, n. 1, 1951. p. 3 - 46. Available: https://biblioteca.ibge.gov.br/visualizacao/periodico s/115/rbg_1951_v13_n1.pdf Access in: Jun. 22, 2020.

MOREIRA, M. L. O. et al. **Geologia do Estado de Goiás e do Distrito Federal**. Goiânia: CPRM/SIC-FUNMINERAL, 2008. 143 p.

NIMER, E. Climatologia da Região Centro-Oeste do Brasil. **Revista Brasileira de Geografia**, ano 34, n. 4, p. 3-30, 1972. Available: https://biblioteca.ibge.gov.br/visualizacao/periodico s/115/rbg_1972_v34_n4.pdf. Access in: Jun. 22, 2020.

NUNES, E.D. **Modelagem de processos erosivos hídricos lineares no município de mineiros - GO**. 2015. 242 p. Tese (Doutorado em Geografia), Instituto de Estudos Socioambientais, Universidade Federal de Goiás, Goiânia, 2015.

NUNES, E. D.; CASTRO, S. S. Compartimentação morfopedológica aplicada à distribuição de padrões espaciais de processos erosivos em solos frágeis – Município de Mineiros, GO. In: CASTRO, S. S.; HERNANI, L. C. (Orgs.). **Solos Frágeis: Caracterização, manejo e sustentabilidade**. Brasília, DF: Embrapa, 2015, p. 293-324.

OLIVEIRA, A. R. et al. A ocupação do Cerrado goiano

pelo agronegócio canavieiro. **Revista NERA**, ano 21, n. 43, p. 79-100, 2018. https://doi.org/10.47946/rnera.v0i43.5525.

OLIVEIRA, I. J. Chapadões descerrados: relações entre vegetação, relevo, e uso das terras em Goiás. **Boletim Goiano de Geografia**, v. 34, n. 2, p. 311-336, 2014. https://doi.org/10.5216/bgg.v34i2.31734.

OLIVEIRA, J. S. Avaliação de modelos de elevação na estimativa de perda de solos em ambiente SIG. 2012. 103 p. Dissertação (Mestrado em Agronomia) - Escola Superior de Agricultura Luiz de Queiroz - Universidade de São Paulo, Piracicaba, 2012.

ÖZŞAHIN, E.; UYGUR, V. The effects of land use and land cover changes (LULCC) in Kuseyr plateu of Turkey on erosion. Turkish Journal of Agriculture and Forestry, v. 38, p. 478-487, 2014. https://doi.org/10.3906/tar-1306-86.

ÖZŞAHIN, E. et al. Land use and land cover changes (LULCC), a key to understand soil erosion intensities in the Maritsa Basin. **Water** v. 10, n. 3, 2018. https://doi.org/10.3390/w10030335.

PAULINO, H. B. et al. Atributos Bioquímicos do Solo Sob Diferentes Sistemas de Produção no Sudoeste Goiano. **Global Science and Technology**, v. 8, n. 2, p. 74-86, 2015. https://doi.org/10.14688/1984-3801/gst.v8n2p74-86.

PINTO, H. E.; WANDER, A. E. A formação econômica do Sudoeste Goiano e suas implicações à luz da teoria dos custos de transação. **Revista Eletrônica de Economia da Universidade Estadual de Goiás**, v. 12, n. 02, p. 29-41, 2016. Available: https://www.revista.ueg.br/index.php/economia/article/view/5034. Access in: Oct. 15, 2019.

RIBEIRO, J. F.; WALTER, B. M. T. As principais fitofisionomias do bioma Cerrado. In: SANO, S. M.; ALMEIDA, S. P.; RIBEIRO, J. F. (Edit.). **Cerrado: ecologia e flora**. Brasília: Embrapa Informação Tecnológica, 2008. Cap. 6, p.151-212.

ROCHA, M. D. et al. II PND, o POLOCENTRO e o desenvolvimento do Estado de Goiás. **UNINCOR-**

SCOPEL, I.; SOUSA, M.; MARTINS, A. P. Infiltração de água e potencial de uso de solos muito arenosos nos Cerrados (Savanas) do Brasil. Boletim Goiano de Geografia, Goiânia, v. 33, n. 2, 2013, p. 45-61. https://doi.org/10.5216/bgg.v33i2.25556.

Revista da Universidade Vale do Rio Verde, v. 12, n. 1, p. 682-692, 2014. http://dx.doi.org/10.5892/ruvrd.v12i1.1459.g1208.

SILVA, R. B. M. et al. Relação solo/vegetação em ambiente de cerrado sobre influência do Grupo Urucuia. **Ciência Florestal**, v. 25, n. 2, p. 363 – 373, 2015. https://doi.org/10.5902/1980509818455.

SILVA, C. M. Entre Fênix e Ceres: a grande aceleração e a fronteira agrícola no Cerrado. **Varia História**, v. 34, n. 65, 409-444, 2018. http://dx.doi.org/10.1590/0104-87752018000200006

SILVA, S. C. da; SANTANA, N. M. P. de; PELEGRINI, J. C. **Caracterização climática do Estado de Goiás**. Goiânia: Secretaria de Indústria e Comércio, Superintendência de Geologia e Mineração, 2006. 133 p.

STEIN, D. P.; DONZELLI, P.; GIMENEZ, A.F.; PONÇANO, W.L.; LOMBARDI NETO, F. Potencial de erosão laminar natural e antrópica na bacia do Peixe-Paranapanema. In: **Simpósio Nacional de Controle de Erosão**, 4, Marília, 1987. Anais, Marília, p. 105-135.

AUTHORS' CONTRIBUTION

Elizon Dias Nunes conceived the study proposal and was responsible for mapping the linear water erosion features, the cover classes and land use conditions, as well as the data treatment and cartographic elaboration. Selma Simões de Castro was responsible for guiding the article, as well as its initial review. The two authors work together in fieldwork in southwest Goiás and the writing of the manuscript.