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Papers

The role of natural and anthropic factors in the variability of soil loss in the state of Goiás between 1985 and 2018

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Abstract

Soil loss depends on natural and anthropic factors with high spatial and temporal variability, and can be inferred by predictive models such as the Revised Universal Soil Loss Equation (RUSLE). In this sense, the objective of this work is to analyze the spatio-temporal distribution and variation of soil losses in the state of Goiás for the years 1985, 2000 and 2018, based on the application of RUSLE and using the drainage basin as a multiscale unit of analysis. The results generally show that there has been an increase in the average loss of soils in the state between the observed years with the average in 1985 being 2.4 ton.ha-1.year-1, growing to 10.8 ton.ha-1.year-1 in 2000, and 11.56 ton.ha-1.year-1 in 2018. The hydrographic regions of Tocantins and Paraná presented the highest losses. In addition to the general control of the Cerrado conversion expansion, the state of Goiás presents two spatial soil loss patterns; one in which the control of natural factors predominates, being linked to morphogenetic aspects with a strong influence of the topographic factor; and the other being rain erosivity, spatialized in areas such as the "front" of Cuesta Caiapó, Serra Dourada and Serra dos Pireneus. When associated, these two factors define sensitive areas with the highest soil losses in the state of Goiás.

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INTRODUCTION

One of the main problems related to soil degradation has been water erosion processes, fundamentally characterized by the detachment and dragging of particles (CARVALHO, 2008; STEVAUX; LATRUBESSE, 2017). As a natural resource, it is one of the main determinants of a phenomenon known as the "Green Revolution" observed in the Cerrado biome, which is composed of a mosaic of phytophysiognomies such as forest, savanna and grassland formations, and currently has only about 54% of its area conserved, with only 44% in the state of Goiás (AB'SABER, 2003; RIBEIRO; WALTER, 2008; SANO et al., 2019).

On a more detailed scale and fundamentally at the landscape and slope unit level, studies on the genesis and development of erosive processes have mostly been conducted in the headwaters of the Araguaia River and in southwest Goiás. Erosion in these places is caused by the strong influence of the sandstone rocks of the Botucatu Formation, with the consequent development of Quartzarenic Neosols, which are highly susceptible soils to the occurrence of erosive processes, especially when it comes to the low cohesion of their aggregates and the fine sand matrix which do not resist well against drag or sheet erosion (HERNANI et al., 2015; NUNES; CASTRO, 2021). Given the occurrence of these studies, two questions arise: Are these areas the most eroded in the state of Goiás? What are the factors which most contribute to soil losses in this state?

In order to answer these questions, this work aims to analyze the spatio-temporal distribution of soil losses in the state of Goiás starting from the drainage basin as a fundamental unit of analysis and understanding them as open environmental systems.

MATERIALS AND METHODS

Study area

The state of Goiás is associated with the tectonic structures of the Tocantins Province, specifically the Brasília Belt and the Araguaia Belt, with the northeast being demarcated by the Sanfranciscano Craton, both corresponding to the South American Platform. There is the Paraná sedimentary basin in the southwestern portion of the state, up to the municipality of Paraúna (GO) (LACERDA et al., 2009).

Goiás is classified as a sub-humid tropical climate (Aw) according to the Koppen climate classification, showing two well-defined seasons: a dry winter ranging from May to September, and a rainy summer between October and April with accumulated average precipitation of about 1,500 mm.

Goiás has 45% of its area occupied by Ferralsols, 18% by Cambisols, 15% by Acrisols and 15% by Neosols, which together make up 93% of the soils of the entire state and their pedological characteristics present a consolidated bibliography (REATTO, 2008; EMBRAPA, 2018).

It is drained by four hydrographic regions: Araguaia, Tocantins, São Francisco and Paraná, and can be classified into 26 hydrographic microregions composed of 485 basins (Otto Pfafstetter), according to the classification of the *Agência Nacional de Águas* (ANA, which is the National Water Agency of Brazil-).

The choice of drainage basins as the unit of study is because it is an open systemic analysis unit (CHRISTOFOLLETI, 1999), which when adopted at the Otto Pfasfstetter level allows comparison with other basins at the Brazilian level.

Methodological procedures

The RUSLE consists of an improvement of the traditional USLE (the Universal Soil Loss Equation), for example adjusting variables such as the LS factor, which in this model has the best accuracy for slopes greater than 20%, as well as better linear erosion estimates (RENARD et al., 2011). Thus, they are systematized according to:

$$A = R.K.LS.C.P \qquad \textit{Equation (1)}$$

In which: A corresponds to soil loss in $ton.ha^{-1}.year^{-1}$; R corresponds to erosivity in MJ.mm/ha/year; K corresponds to erodibility in Mg.h/MJ/mm; LS respectively corresponds to the slope length and the slope; as well as the CP factor, which corresponds to the use and land cover factor and the conservationist practices, with the latter having dimensionless values.

For this purpose, rainfall data from the TerraClimate project with a spatial resolution of 4 km were used. This product results from the association of satellite data (variables related to precipitation) with data from climatological stations (reanalyzed and validated) with the objective of providing spatial and temporally continuous climatological series for all continental areas. Thus, the erosivity observation adopted the following equation as a methodological procedure (LOMBARDI NETO, MOLDENHAUER, 1992).

$$EI = 68.73\,(p^2/P)^{0.841} \qquad \text{Equation (2)}$$

In this case, EI corresponds to Average Erosivity; 68.730 is an admitted coefficient in the equation; p corresponds to the average monthly rainfall in millimeters; P represents the average annual precipitation in millimeters; and 0.841 is an admitted coefficient in the equation.

Erodibility (K factor) is fundamentally a result of the interaction between soil texture, organic matter, structure and permeability (WISCHMEIER; SMITH, 1978). In addition, it represents intrinsic resistance, meaning the force constituted by the junction of physical, chemical, mineralogical and biological characteristics to the detachment and transport of particles, which act due to a combination of exogenous force effects being the main natural factor related to erosion (BERTONI; LOMBARDI NETO, 2010; WANG et al., 2013); the following values are presented for the state of Goiás (Table 1).

Table 1 - Synthesis of soil erodibility in the state of Goiás.

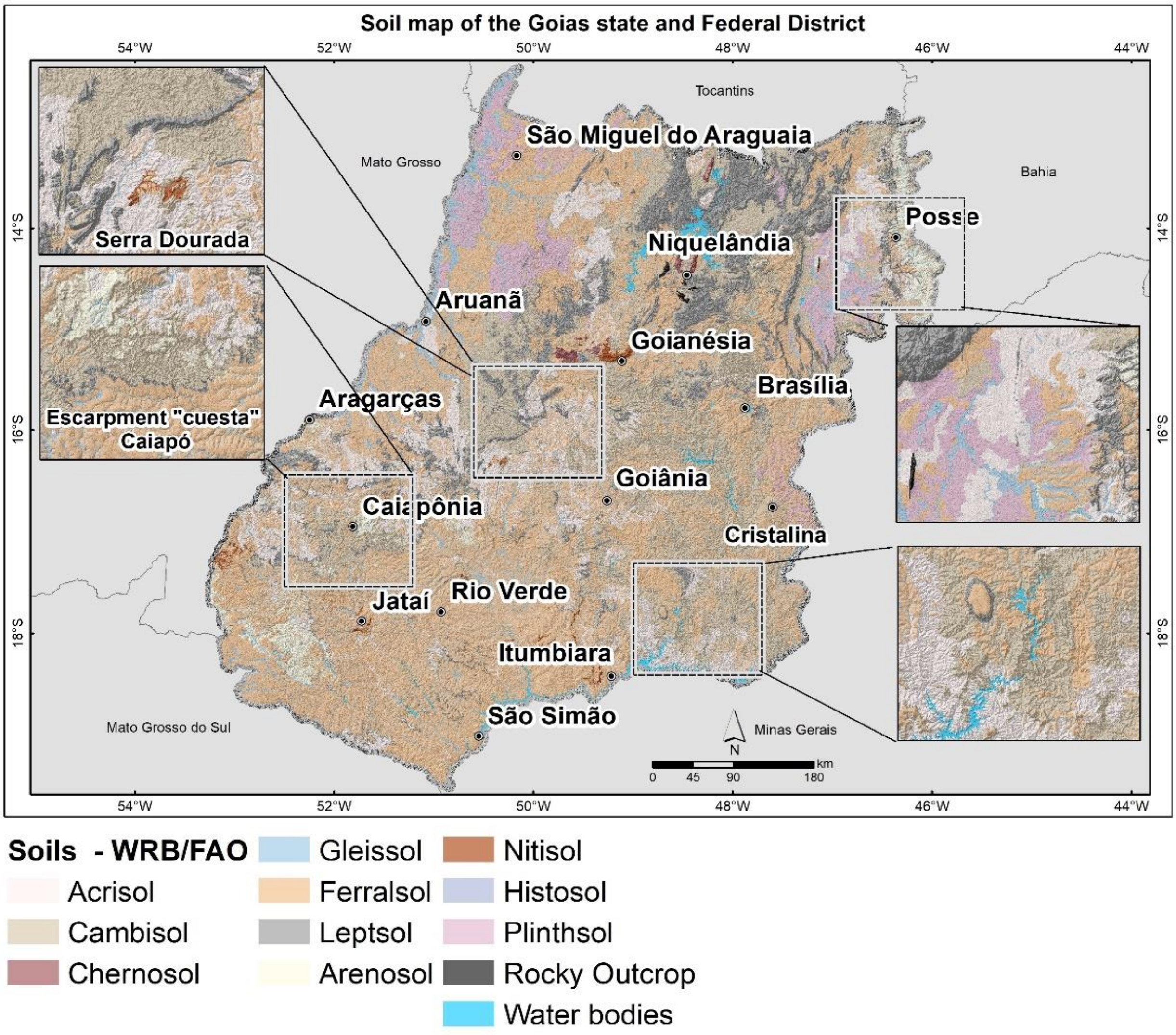
Soils (SIBCs)	Soils WRB/FAO	Erodibility – Mg.h.MJ $^{-1}$ mm^{-1}	References
Rocky Outcrops	-	0	-
Argissolo Vermelho	Red Acrisol	0,03	BERTONI; LOMBARDI NETO (2010)
Argissolo Vermelho-Amarelo	Red Yellow Acrisol	0,04	FARINASSO et al. (2006)
Cambissolo	Cambisol	0,03	SILVA et al. (2009)
Chernossolo	Chernosol	0,03	CUNHA et al. (2019)
Gleissolo	Gleissol	0,02	DEMARCHI; ZIMBACK (2014)
Latossolo Vermelho	Red Ferralsol	0,03	HERNANI et al. (2015)
Latossolo Vermelho-Amarelo	Red Yellow Ferralsol	0,03	DEMARCHI; ZIMBACK (2014)
Water bodies	-	0	-
Neossolo Litólico	Leptsol	0,03	FARINASSO et al. (2006)
Neossolo Quartzarênico	Arenosol	0,04	DEMARCHI; ZIMBACK (2014)
Nitossolo Vermelho	Nitisol	0,04	DEMARCHI; ZIMBACK (2014)
Organossolo	Histosol	0,015	DISCONZI et al. (2014)
Plintossolo Argilúvico	Plinthsol	0,03	MARTINS et al., (2011)
Plintossolo Háplico	Plinthsol	0,01	FARINASSO et al., (2006)
Plintossolo Pétrico	Plinthsol	0,03	CUNHA et al., (2019)

Elaborated by the authors (2022).

The initial procedure for surveying the K factor was to conduct a restitution of the limits of soil classes for the state of Goiás, based on digital soil mapping techniques (LIMA et al., 2013). The possibility of contributions is known via digital soil maps from the association between pre-existing pedological information, relief and source material, and based on the soil-landscape relationship (VIDAL-TORRADO et al., 2005; SOUSA JR; DEMATTÊ; 2008; CATEN et al., 2012; NUNES; CASTRO 2015; CREMON, 2021).

The information had the combination of four basic pieces of information, namely: i) the use of digital elevation models (DEM), extracting information such as slope, altitude and hillshade with 9x exaggeration (stereoscopy); ii) the use of pre-existing pedological information from the compilation of data from the RADAMBRASIL Project, among other databases; iii) the use of observation of the source material, being both the geological substrate and sediment aggregation areas; and finally, iv) the use of photointerpretation from the consortium of previous information with high -resolution images.

Figure 1 - Soils of the state of Goiás and the Federal District.



Source: The authors (2022).

The photointerpretation observation is evident as the most important variable due to the precise observation of the limits between the pedological units (OLIVEIRA et al., 2016), being decisive in differentiating features in sedimentary basin areas such as paths and areas with extensive aggregation features. They also help to observe the photosynthetic state of the vegetation, which reveal less deep and evolved soils when they show less water availability (SOUSA JR; DEMATTÊ, 2008).

The LS factor corresponds to the combination of the slope length (L) and the slope (S), for which data from the SRTM 30 m Arc-Second Global are used. This factor determination has limitations in areas of complex reliefs or large extensions, and therefore correction factors are applied to reduce this noise (RENARD et al., 2011; ZHANG et al., 2017). In this context, the factor L represents a linear dimension that theoretically corresponds to a distance that goes from the beginning of the flow formation to the point where it meets the channel (MINELLA, et al., 2010). The S factor is decisive for measuring soil loss, since losses tend to increase with increasing slope length (RENARD et al., 2011). Thus, the following equation is adopted (ZHANG et al., 2017):

$$L= (\lambda/22.1)^{m}$$

$m = 0.2 \quad \theta \leq 1.7\% \cong 0.97^{\circ};$
$m = 0.3 \quad 1.7\% < \theta \leq 5.2\% \cong 0.97^{\circ} < \theta \leq 2.97^{\circ};$
$m = 0.4 \quad 5.2\% < \theta \leq 9\% \cong 2.97^{\circ} < \theta \leq 5.14^{\circ};$
$m = 0.5 \quad \theta > 9\% \cong 5.14^{\circ}$
$s = 10.8 \operatorname{sen} \theta + 0.03 \; \theta < 9\% \cong 5.14^{\circ}$
$s = 16.8 \operatorname{sen} \theta - 0.5 \geq 9\% \cong 5.14^{\circ}$
FACTOR = L.S *Equation (3)*

In which: L corresponds to the final flow length; λ is the flow length in meters; 22.1 is the coefficient of the formula referring to the standard portion (WISCHEMEIER; SMITH, 1978); m: corresponds to the slope variation coefficient; S corresponds to the S factor; 10.8 is the coefficient for values with a slope less than 9%, which corresponds to 5.14°; 16.8 is for slopes greater than 9% ≅ 5.14°; 0.03 coefficient is applied to the formula for slopes lower than 9%; 0.5 is for slopes greater than or equal to 9%; sin θ of the corresponding angle is extracted from the slope.

The data referring to land use and cover, which indicate the CP factor, were taken from MapBiomas images from 30 m spatial resolution LANDSAT sensors from the 1985, 2000 and 2018 time frames. The CP factor is developed from experimental plots in which different soil covers are compared with the worst-case scenario, meaning exposed soil. When associating different types of uses and coverage, for example, pastures and agriculture, the variable with the highest value was adopted. The individual C values vary between 0 and 1, with values closer to 1 being the most erodible and values closer to 0 being the least erodible (RENARD et al., 2011). It was admitted that the worst scenario occurs in anthropic uses for the survey.

Table 2 - Synthesis of the CP factor for the state of Goiás.

Land Cover	CP	Reference
Field Formation	0,001	Adapted from TOMAZONI et al. (2005)
Forestry Formation	0,0005	SILVA (2008)
Savanna Formation	0,001	Adapted from TOMAZONI et al. (2005)
Forestry Planted	0,026	MARTINS (2005)
Water bodies	0	PARANHAS FILHO et al. (2003)
Urban infrastructure	0	-
Exposed Soil	1	DA COSTA et al. (2005)
Pasture	0,008	SILVA (2008)
Agriculture	0,05	SILVA (2008)

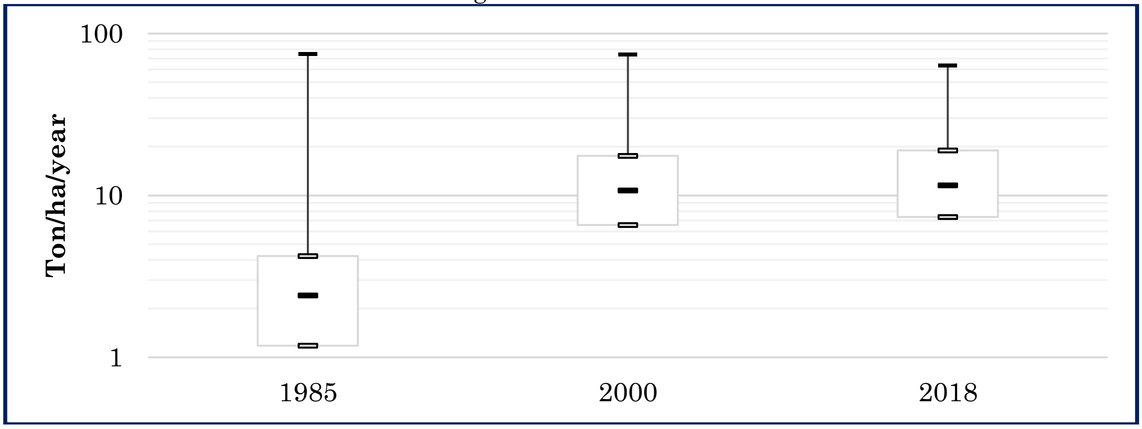
Elaborated by the authors (2022).

Thus, the data represented by the temporal cuts of 1985, 2000 and 2018 gives the dynamic aspect to RUSLE, which demonstrates the variation of the R factor based on the seasonality of rainfall, and by the CP factor expressed by the variation in land use and cover. The data were worked on a scale of 1:50.000. The choice of the time frame between 1985 and 2018 was due to the availability of systematic images at the beginning of the study, which could evaluate the occupation dynamics throughout the state of Goiás in a consolidated way.

RESULTS AND DISCUSSION

The state of Goiás had an average soil loss of 2.4 ton.ha^{-1}.year^{-1} in 1985, growing to 10.8 ton.ha^{-1}.year^{-1} in 2000, and 11.56 ton.ha^{-1}.year^{-1} in the year 2018. The concentration of the largest losses, for example, in the 3rd quartile, shows great growth from 4 ton.ha^{-1}.year^{-1} in 1985 to 17 ton.ha^{-1}.year^{-1} in 2000, and 19 ton.ha^{-1}.year^{-1} in 2018 (Figure 2).

Figure 2 - Synthesis of soil losses in the state of Goiás in the time periods of 1985, 2000 and 2018. Logarithmic base 10.

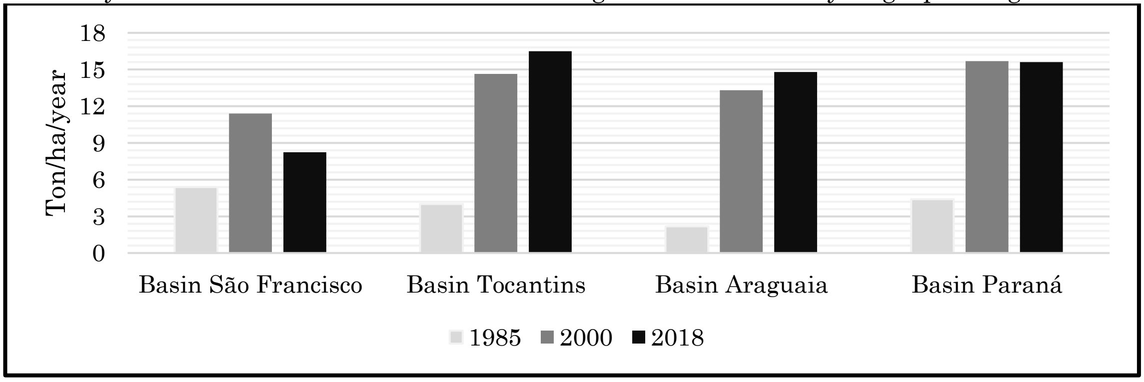


Source: The authors (2022).

The hydrographic regions with the lowest losses in 1985 are the Araguaia and Tocantins rivers, with average losses of 2.2 and 4 ton.ha^{-1}.year^{-1}, respectively. The Paraná river basin shows a loss of 4.4 ton.ha^{-1}.year^{-1} and the São Francisco river basin shows a loss of 5.4 ton.ha^{-1}.year^{-1}, the highest for the 1985 period (Figure 3).

The basins with the greatest losses in 2000 are Paraná, with almost 16 ton.ha^{-1}.year^{-1}, and the Tocantins River with 14.6 ton.ha^{-1}.year^{-1}. The hydrographic regions with the lowest losses in 2000 are those of the São Francisco river basin with losses of 11.4 ton.ha^{-1}.year^{-1} and the Tocantins river with losses of 14.6 ton.ha^{-1}.year^{-1} (Figure 3).

Figure 3 - Synthesis of the distribution of the average soil loss in the hydrographic regions of Goiás.



Source: The authors (2022).

The highest losses in 2018 were in the Tocantins River basin of 16.5 ton.ha^{-1}.year^{-1} and in the Paraná River basin of 15.6 ton.ha^{-1}.year^{-1}. Also in that year, the small portion of the São Francisco river basin shows a loss of 8.25 ton.ha^{-1}.year^{-1}, while the Araguaia river basin shows a loss of 14.8 ton.ha^{-1}. year^{-1}. Thus, the São Francisco hydrographic region has the highest average loss in 1985 and the lowest loss in 2018.

Of the 26 micro-regions of Goiás, those which presented the greatest losses were the Meia-Ponte River, the Claro River, a tributary of the Vermelho River, and the Veríssimo River, respectively (Table 3). It is noteworthy that the Meia-Ponte river presents a growth of 182% in soil loss between 1985 and 2018, placing itself as one of the highest losses in the three time periods.

Table 3 - Synthesis of hydrographic microregions with the highest soil losses in the state of Goiás between 1985 and 2018.

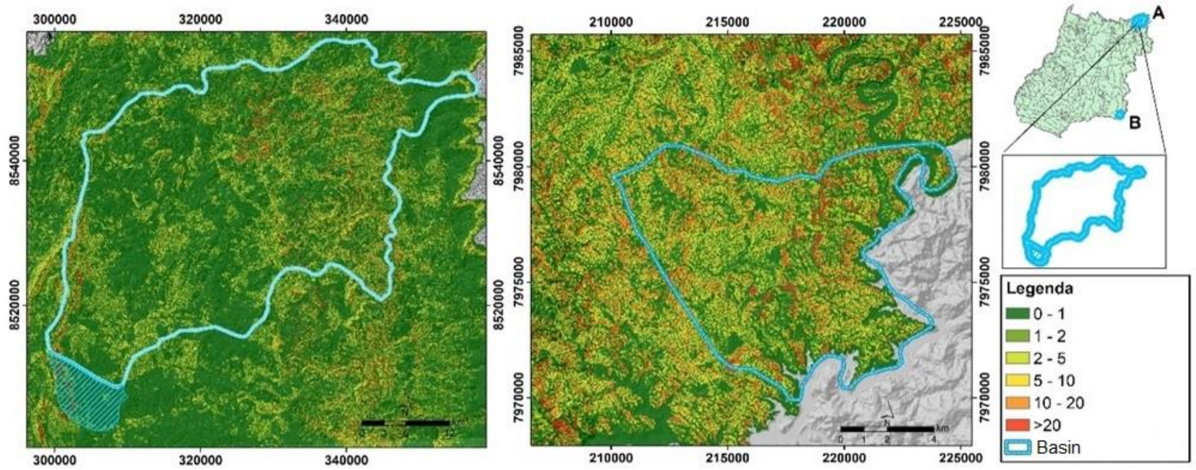
	1985		2000		2018	
Microregions with the highest losses	Meia Ponte river	7	Claro river Vermelho river	22	Claro river Vermelho river	22
	Bois river	4,4	Meia Ponte river	19,73	Verissimo river	20,3
	Paracatú river	4,3	Veríssimo river	18,61	Meia Ponte river	19,8
Microregions with the highest losses	Verde river and Cristalino	0,56	Verde river and Cristalino	3,59	Verde river and Cristalino	4,3
	Almas river	0,77	Almas river	4,34	Alegre river	4,7
	Peixe river	0,78	Peixe river	4,9	Peixe river	4,7

Source: Elaborated by the authors (2022).

The microregion with the smallest loss is the Verde and Cristalino rivers in the region of the municipality of São Miguel do Araguaia, even going from 0.56 ton.ha^{-1}.year^{-1} in 1985 to 4.3 ton.ha^{-1}.year^{-1} in 2018, a growth of 668% (Table 3). The das Almas river basin in the region of Pirenópolis (GO) was also maintained in the Figure 4-A. These three time periods as among those with the lowest losses, as well as that of the Peixe river, a tributary of the Araguaia river.

The analysis at the drainage basin level shows that a sub-basin of the Manso River, in the micro-region of Vão do Paranã, shown in Figure 4-A, shows a loss of 75 ton.ha^{-1}.year^{-1}. The Manso River basin itself has the third highest average loss with 17.85 ton.ha^{-1}.year^{-1} losses are explained by the fact that its tributary basin is located on the high slopes of Serra da Praia, a continuation of Serra Geral do Paranã, supported by orthoquartzites from the Araí Group, which produce a large amount of sediments as a result of exposed soils.

Figure 4 - Sub-basins with the highest soil loss in 1985. The micro basin in Figure “A” has the greatest soil loss and is located within the Manso River basin, the third largest. A tributary basin of the São Marcos river is shown in Figure “B”.

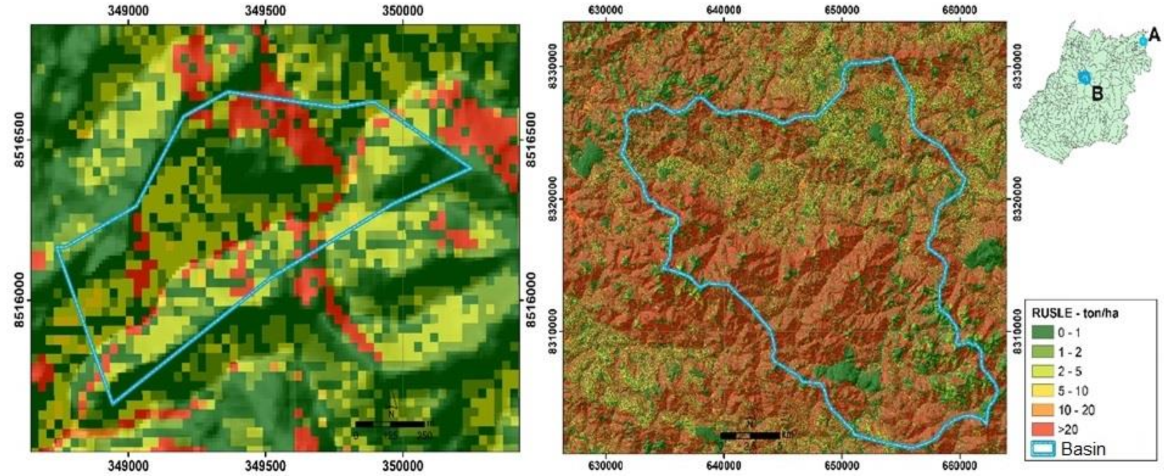


Source: Elaborated by the authors (2022).

The Manso River basin region has soil losses associated with steeper areas, which are correlated to some canyon areas, as well as exposed soils located on the carbonate rocks of the Bambuí Group - Sete Lagoas Formation. A tributary basin of the São Marcos River (Figure 4-B), which for this year shows a loss of 25.76 ton.ha^{-1}.year^{-1}, has the pastures located on the steepest areas as its main cause. The exposed soils in the tributary basin of the São Marcos River are also located on topographic elevations of quartzite rocks of the Araxá Group.

A downstream segment of the Galheiros river basin presented a soil loss of 75 ton.ha^{-1}.year^{-1} in the year 2000 (Figure 5-A). The same sub-basin, a tributary of the Manso River, which presented a loss of 75 ton.ha^{-1}.year^{-1} in 1985, subsequently presented a loss of 44.17 ton.ha^{-1}.year^{-1} in the year 2000. The segment downstream of the confluence between the Uru River and the Almas River in the Seco stream basin has the third highest soil loss with 39 ton/ha (Figure 5-B).

Figure 5 - Sub-basins with higher soil losses in 2000.

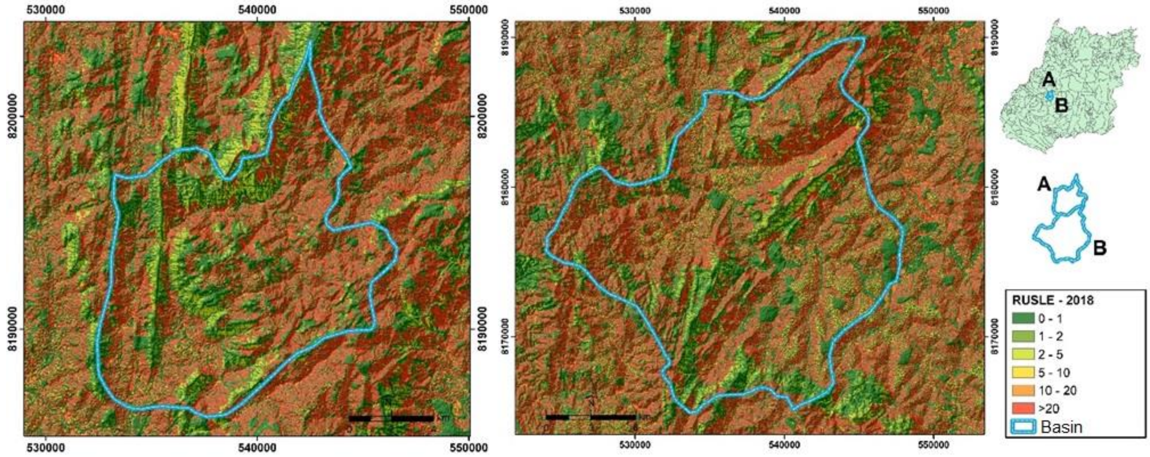


Source: Elaborated by the authors (2022).

The greatest results are related to the high slopes of the study area, which is located in a canyon with high concentrations of exposed soil per area. This region is also composed of pelite-carbonated rocks of the Sete Lagoas Formation, Bambuí Group. The losses in the Seco stream basin (Figure 6-B) are associated with pastures positioned on high slopes or in the lower thirds that receive high upstream kinetic energy from rain dragging. The slopes are produced by the lithological discontinuities of the Canabrava Mafic-Ultramafic Complex.

The Manso River sub-basin tributary again presents the highest loss in 2018 among all the basins evaluated, with average losses of 64 ton.ha^{-1}.year^{-1}. Thus, the greatest erosive potential of this sub-basin stands out, as it is the largest in the state of Goiás in terms of sediment production. The next biggest losses occur in two hydrographic sub-basins, one of the Palmito stream (Figure 6-A) and the other without toponymy (Figure 6-B); both sub-basins are located within the Claro river basin, with respective losses of about 40 ton.ha^{-1}.year^{-1} and 44.4 ton.ha^{-1}.year $^{-1}$ (Figure 6).

Figure 6 - Contiguous sub-basins with higher soil losses in 2018.



Source: The authors (2022).

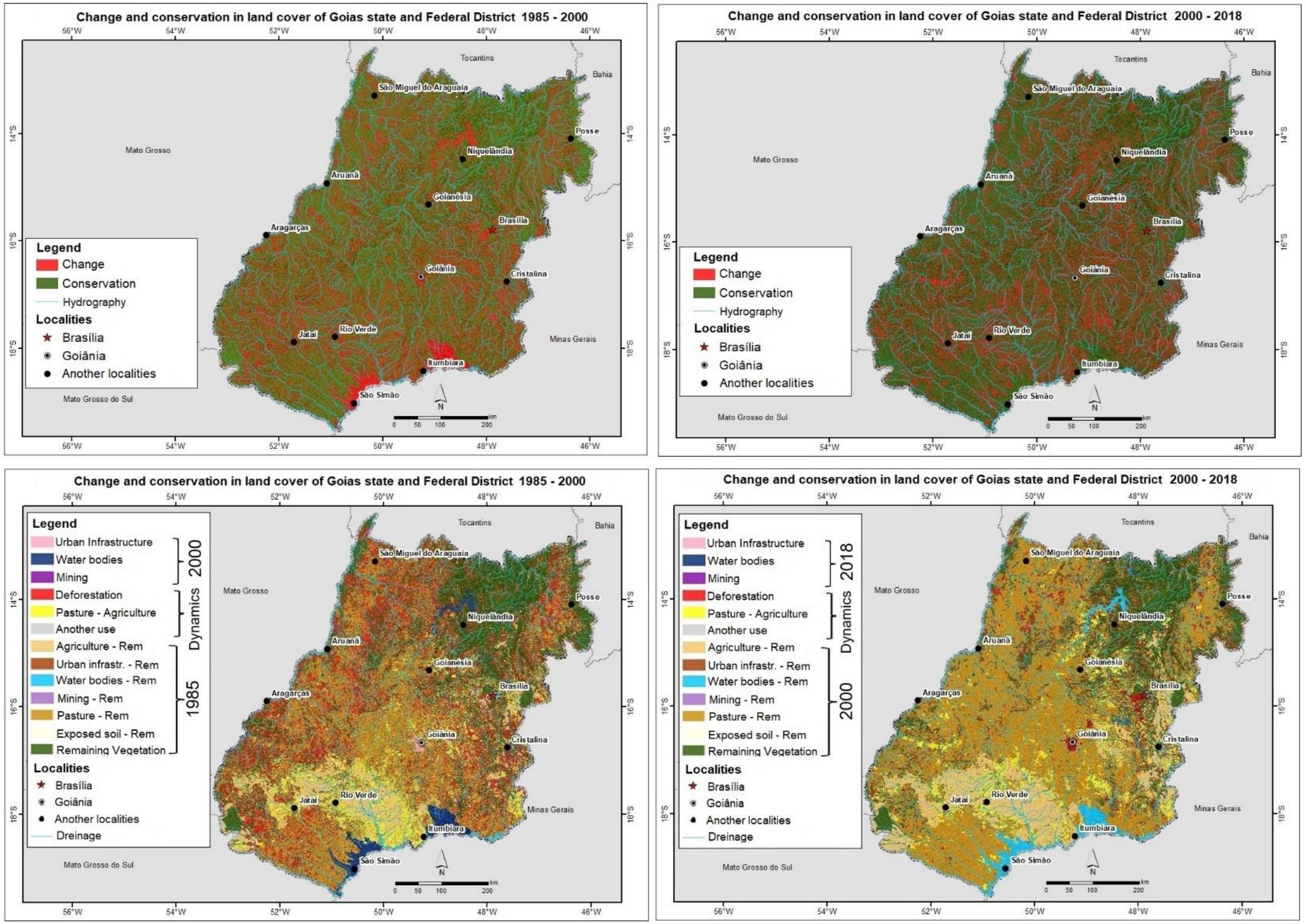
These sub-basins are located in dissected areas of the Brasília Belt in areas close to the Serra Dourada de Goiás fold. It is noteworthy that the greatest soil losses are associated with pastures and high slopes caused by changes in the Serra do Fundão region. As an example, both respectively correspond to 69% and 63% of their areas under pasture use.

One of the main causes of the increase in soil loss is the variation in use and cover (FARHAN; NAWAISEH, 2015). This change can be noticed in the state of Goiás due to the increase in agricultural areas, mainly between the years 1985-2000, in which the direct conversion of remaining vegetation into agricultural areas represents 17% of the state’s areas in this time period, while it corresponds to about 13.4% in the time period from 2000-2018. There is a greater emphasis on the first time period (between 1985-2000), where the greatest losses in the Araguaia river basin region are located approximately between Jataí and Aragarças, in the region of the municipality of Caiapônia (Figure 7).

Pastures show stability in the three time periods, remaining close to 44% of the area of the state of Goiás. The areas corresponding to pasture use since 1985 represent about 33% of the state, demonstrating the scope of deforestation that occurred until 1985. Agricultural areas also show growth in this time frame, from 5.4% in 1985 to 14% in the year 2000, and then to 16% in the year 2018. The agricultural areas which remained, meaning those which remained stable in the same place, went from 4.3% between the time frame of 1985-2000 to 8% between 2000-2018.

Agricultural areas tend to present distinct environmental compartments, while agricultural areas are predominantly located on the plateau areas on the tops of the plateaus and with a predominance of flat and gently undulating reliefs. The pasture areas tend to be established in the more rugged regions, or with less developed soils from a genetic point of view (OLIVEIRA, 2014). Pasture areas tend to be mainly concentrated in the Araguaia Valley region, notable for its Plintosols (MARTINS et al., 2017) with livestock farming, while in the central areas towards the south and east, for example, highlighting dairy basins located in municipalities such as Piracanjuba, Bela Vista and Morrinhos (FERREIRA et al., 2019).

Figure 7 - Synthesis of land use and land cover conversion in the state of Goiás between the years of 1985-2018.



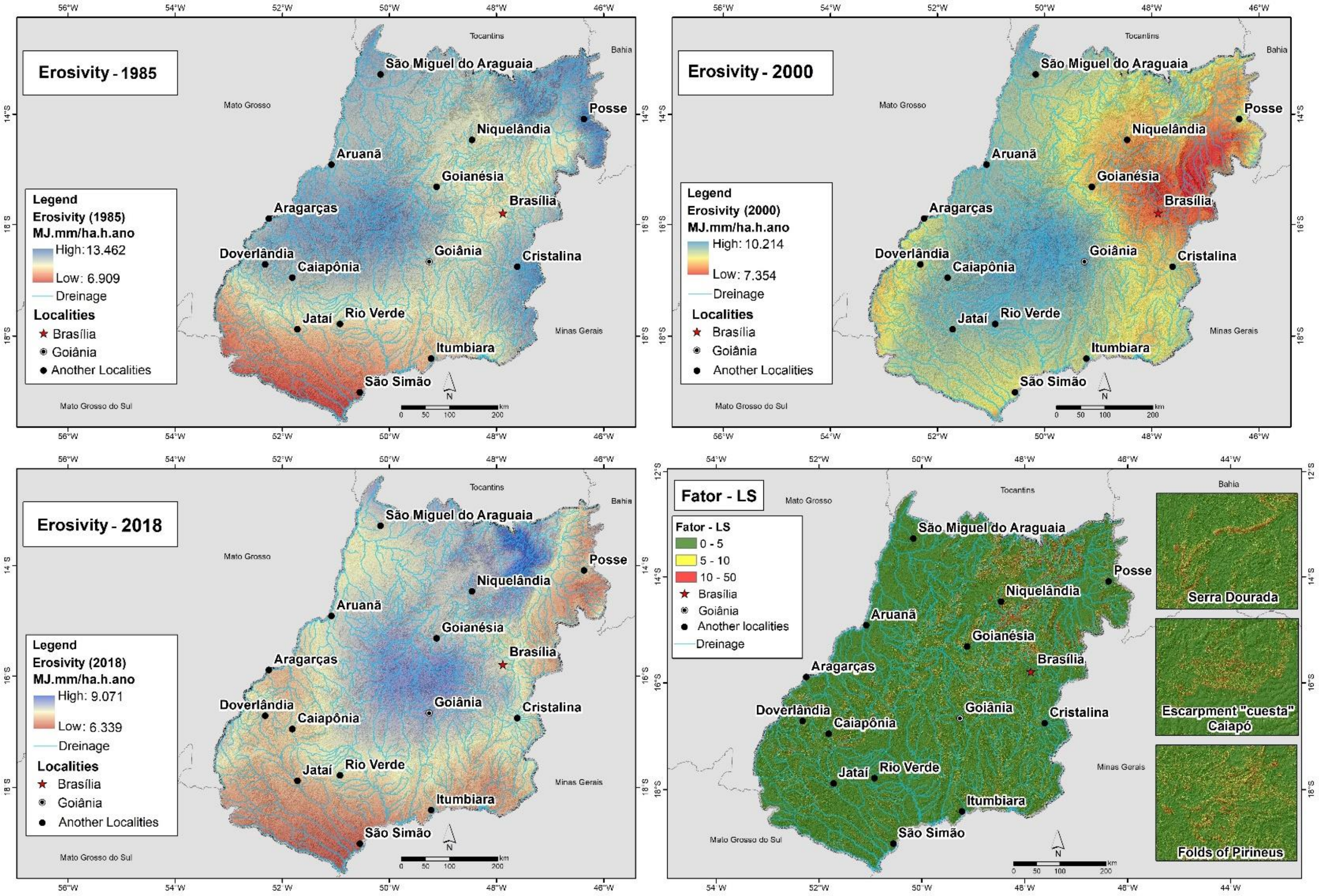
Source: The authors (2022).

The land use and cover conversions in the state of Goiás corresponded to 27% of the cover between the years 1985-2000, and to 25% in the years 2000-2018, with this deforestation being detected as a potentiator of soil losses, with emphasis on the Boa Vista and Bonito river basins, both tributaries of the Caiapó river, which present extensive areas with Quartzarenic Neosols and Latosols of medium texture. Areas converted from pasture to agriculture grew between 1985-2018 from 7.68% of the state's area to 11.24%.

It is noteworthy that the greatest soil losses in the state of Goiás are mainly concentrated in the change of the large geomorphological compartments, for example, on the fronts of the Caiapó cuesta, in the dissected areas of Pirenópolis (GO), represented by the occurrence of the "Syntax of the Pyrenees" – Araxá Group, as well as in the Serra Dourada region. Thus, in addition to the conversion factor of the cover of these areas have gone through a deforestation process, meaning that the predominant remaining vegetation was converted into pasture, the topographic factor represented in these areas associated with high erosivity also contributes to the increase in soil loss (Figure 8).

Erosivity tends to be more concentrated in the central-south region of Goiás, starting from Goiânia towards Jataí and towards Doverlândia forming a large polygon with erosivity that gravitate around 9,000-10,000 MJ.mm/ha.h.year, sometimes larger. Despite the southern region having a smaller number of months of drought as observed in the southern portion of Jataí (GO), it has lower erosivity.

Figure 8 - Erosivity synthesis and topographic factor of RUSLE for the state of Goiás.



Source: The authors (2022).

The results of greater soil losses in the central region of the state of Goiás demonstrate a change in relation to the perception of “fragile” areas, meaning areas of high erodibility, as they constitute more sandy soils with low fertility and cohesion. This has been demonstrated in studies predominantly developed in the southwest region of the state of Goiás, with emphasis on the municipality of Mineiros, which has a strong influence of Quartzarenic Neosols originated on the rocks of the Botucatu Formation (TRINDADE, 2015; NUNES; CASTRO, 2021).

Regarding the conversion of pasture areas into agriculture, especially in southwest Goiás, what can be observed is that areas with more fragile soils have been presented in this spatial time period specifically since 2005, while they previously occupied areas with better agricultural aptitude, especially those destined for grains (TRINDADE, CASTRO, 2015).

The increase in soil losses is corroborated by the increase in agricultural production of sugarcane in the Meia-Ponte river basin region, which consequently brings environmental degradation such as the significant decrease in remaining areas. It is noteworthy that surveys such as de Castro et al. (2010) indicate that the class of sugarcane increased more than nine times between the time frame of 2000-2009, with a reduction of pasture in these areas that were replaced by grains. Thus, the results spatially prove the indicated cycle of pasture replacement by agriculture (TRINDADE, 2015).

The results shown for the state of Goiás in general terms of soil losses are similar to those for the Cerrado biome, which went from 10.4 $ton.ha^{-1}.year^{-1}$ in 2000 to 12 $ton.ha^{-1}.year^{-1}$ in the year 2012 (GOMES et al., 2019), while for the state of Goiás it went from 10.8 $ton.ha^{-1}.year^{-1}$ in the year 2000 to 11.5 $ton. ha^{-1}.year^{-1}$ in 2018.

Studies for the state of Goiás showed a historical average loss of 18 $ton.ha^{-1}.year^{-1}$ in the time frame between 1985 and 2017, with a loss of almost 20 $ton.ha^{-1}.year^{-1}$ in 1985, maintaining similar values for the time periods between 2000 and 2017 (PENA, 2020), even in the face of the high conversion of remaining vegetation in agricultural areas (CASTRO et al., 2010; PARENTE et al., 2019).

These high values observed by Pena (2020) are credited with the option to enter the model's database using a soil map at an inappropriate scale at the level of slopes and drainage basins, as well as satellite information with a spatial clipping of 5 kilometers (CHIRPS) which present wide homogeneity in the erosive areas.

FINAL CONSIDERATIONS

The RUSLE model is suitable for observing soil losses, mainly based on the restitution of the soil map. In this sense, soil losses in the state of Goiás are more associated with morphogenetic processes than with management and use, but even so, the conversion of remaining vegetation to agricultural areas contributed to the increase in losses, verified as 2.4 $ton.ha^{-1}.year^{-1}$ in 1985, 10.8 $ton.ha^{-1}.year^{-1}$ in 2000 and 11.5 $ton.ha^{-1}.year^{-1}$ in 2018. Hydrographic regions also show variation in terms of the greatest losses, with the São Francisco region presenting the greatest loss in 1985, around 5.4 $ton.ha^{-1}.year^{-1}$, the Paraná River region with a loss of something around 15.7 $ton.ha^{-1}.year^{-1}$ in 2000 and the Tocantins River region with something around 16.5 $ton.ha^{-1}.year^{-1}$ in 2018.

The regions with the greatest losses resulting from morphogenetic processes are predominantly associated with the LS factor, which corresponds to the potential energy developed by the surface runoff, which, from the convergence of flows, gains greater kinetic energy from upstream to downstream. Erosivity also contributes, which corresponds to the detachment of soil particles and which (associated with the LS factor) theoretically produces potential conditions for the deflagration of erosive processes. The highest erosivity in the state in the time periods of 1985, 2000 and 2018 tended to continuously be in the central region of the state of Goiás, varying annually in other regions.

In summary, the areas with greater losses or denudation processes correspond to the reverse escarpment region of the Caiapó “cuesta”, the region of Serra Dourada de Goiás, and the “syntax” region of Serra dos Pireneus, being potentiated when using pastures.

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AUTHORS CONTRIBUTION

All authors participated in the conception, elaboration, revision and writing of the papper.