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Multitemporal modeling of soil loss estimation and analysis of the efficiency of the water production program in the Araguaia River headwaters basin - GO/MT

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ABSTRACT
The region of the headwaters of the Araguaia River is located in the Brazilian Midwest, covering the states of Goiás, Mato Grosso and Mato Grosso do Sul. This area belongs to the Cerrado domain and comprises the southern sector of the upper basin of the Araguaia River, near the Emas National Park (GO). The relief is characterized by convex, wide and medium hills, and concave valleys, predominantly anthropized due to modernized agriculture. Initiated in the 1970s and 1980s, this agricultural modernization aimed at expanding agricultural frontiers, with massive investments in technology and monocultures of grains for export. The main beneficiaries are large producers, agribusinesses and multinational agribusiness companies.

Keywords: Araguaia River, Modernized agriculture, Regional development.

INTRODUCTION

The region of the headwaters of the great Araguaia River is located in the Brazilian Midwest, distributed in the states of Goiás, Mato Grosso and Mato Grosso do Sul. More specifically, it is located between the borders of the municipalities of Mineiros (extreme southwest of Goiás) and Alto Taquari (extreme southeast of Mato Grosso), as shown in figure 1.

This region is located in the Northern Plateau of the Paraná Sedimentary Basin, in lands belonging to the morphoclimatic and phytogeographic domain of the Cerrado. It corresponds to the southern sector of the upper basin of the Araguaia River, where its proximity to the Emas National Park (GO) stands out.

The one corresponding to the high hydrographic basin corresponds to a surface in a process of differentiated erosion, where elevated areas, lowered, dissected and softened areas can be observed, which contrasts, as it is surrounded by an extensive plateau of residual relief called Chapada or Serra do Caiapó (MAMEDE et al, 1983; CASTRO, 2005).

The relief of the lowered surface is characterized by gentle convex hills, wide and medium, and concave valley bottoms. In these cases, slopes ranging from 0 to 14% predominate, and may vary by 20% at the headwaters of the drains. The lithologies of the Botucatu Formation are preponderant. In the pedological sequence, there are Red-Yellow Latosols and Dystrophic Quartzarenic Neosols, respectively in the upper and middle thirds of the slopes, and Hydromorphic Quartzarenic Neosols in the valley bottoms (SOUSA JUNIOR et al., 1983; NOVAES, et al. 1983).

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The surface described corresponds mostly to the area of the hydrographic basin of the headwaters of the Araguaia River. Almost all of this lowered and dissected surface is anthropized, with only a few patches of vegetation remaining on the middle slopes and along some drainage segments. As the present study demonstrates, savanna vegetation has been extensively replaced by agricultural activities, resulting in severe soil losses due to erosive processes.

This region, as well as a large part of the lands in the morphoclimatic domain of the Cerrados, was subjected to programs for the implementation and development of agriculture, which began in the mid-1970s and early 1980s, through the implementation of policies considered developmental (National Development Plans - PND) that aimed, above all, at the modernization of agriculture. as well as the process of advance of agricultural frontiers and occupation of land to the west in Brazil (MIZUMOTO, 2009).

This modernized agriculture can be characterized by the large volume of capital investments, technological development, land concentration, and grain monocultures, mainly intended for export (FREDERICO, 2013). According to the author, the main beneficiaries of the modernization of the countryside are the large agricultural producers, large agro-industries and multinational companies that manufacture pesticides, agricultural machinery and the world grain trade.

Castro (2005) points out that, associated with the process of advancing the agricultural frontier in the Cerrado, intense and extensive linear and laminar water erosion processes developed in the region of the headwaters of the Araguaia River, with emphasis on the existence of a set of gullies of great extension. There is a high concentration of erosive foci throughout this area, which in turn are related to the process of indiscriminate deforestation of the original vegetation of the Cerrado, replaced by agricultural practices (CASTRO; XAVIER, 2004).

This replacement increased the exposure of the soils of this basin, mostly sandy, to the direct impacts of rainfall, as well as surface runoff. In this region, annual rainfall averages of approximately 1500 mm are recorded, concentrated in the summer (NIMER, 1972; SANTANA, 2007).

The dimension of the environmental impacts in the region of the headwaters of the Araguaia River attracted the attention of some sectors of society, such as the media, the scientific community and environmental movements in the search to minimize and reverse the degradation that was configured (PAULA, M. et al. 2008).

Among the consequences of the unleashing of erosive processes are the loss of biodiversity, of arable soils, siltation of the water courses of the Araguaia River in the region of its headwaters, lowering and compromise of the level of aquifers, as pointed out by Barbalho (2002); Castro (2005); Santana (2007).

For Latrubesse et al. (2009), the agricultural practices adopted in the Araguaia basin from 1970 onwards brought regional economic development, but at a high environmental cost. Deforestation caused the triggering of erosive processes in practically the entire basin, and the most degrading situations were recorded in the upper portion of this basin, where Mesozoic sedimentary rocks outcrop, resulting in the rupture of a critical geomorphic threshold that caused the introduction of large loads of sediments in the channel of the Araguaia River.

Cabacinha et al. (2010) point out that these changes have had an impact on biodiversity, soils and waters in the region of the headwaters of the Araguaia River, in particular the original vegetation. According to these authors, until 1970 this area was covered by savannas penetrated by gallery and riparian forests along the lower order and main channels, respectively, and since then the natural vegetation has been found in large proportion in a fragmentary situation.

In view of the above, the region described consists of the spatial cut of this work. The precise delineation of the study area of this research consists of the delimitation of a hydrographic basin called the hydrographic basin of the headwaters of the Araguaia River (figure 1), an area of 12,760.62 hectares, which has its outlet near the confluence with the Araguainha River.

However, the relationship between agricultural occupation and environmental degradation, especially in relation to erosive processes, does not represent a specific particularity of this area. In several areas of the Brazilian territory, this configuration is repeated, and consequently affects the water and soil resources of the hydrographic basins (ANA, 2013).

In view of this reality, the National Water Agency (ANA) developed the Water Producer Program (PPA) that aims to improve the quantity and quality of groundwater and surface water, through proposals for conservationist management of soils and natural vegetation, simultaneous to agricultural production processes. These proposals aim to ensure agricultural productivity, the reduction of surface runoff processes, as well as erosion and, consequently, the increase in rainwater infiltration (ANA, 2013).

The Water Producer Program (PPA) adopts the rural property as a spatial unit of planning and action. It considers that the reduction of soil loss in each rural property is responsible in the same proportion for the decrease in sedimentation in the watershed (ANA, 2013).

The management and conservation practices adopted by the PPA consist of planting on contour lines, no-tillage, rainwater catchment and infiltration dams (barraginhas), underground dams, readjustment of rural roads, subsoiling, construction of terraces, correction and recovery of pastures, recomposition of Permanent Preservation Areas (APP) and Legal Reserves (RL). As expected results of the PPA, it is expected to increase drought flows, reduce contamination and siltation of watercourses, among others (ANA, 2012).

In order to test and evaluate the efficiency of the conservation techniques proposed by the PPA on hydrosedimentological processes in watersheds, it is necessary to simulate and/or measure the effects of soil and natural vegetation management practices in reducing soil loss.

The simulation or modeling of hydrosedimentary processes can be carried out in a digital environment through hydrological mathematical modeling through procedures previously developed by geoprocessing, simulating phenomena, processes and impacts that occur in the environments.

The integration of the Universal Soil Loss Equation (EUPS/USLE) and Geographic Information Systems (GIS) enables the spatialization of the EUPS factors and, consequently, the resulting product, thus allowing modeling and/or simulation of processes related to laminar erosion, especially in watersheds (BAGHERZADEH, 2012; ZHU, 2014; GOMES et al., 2017).

In view of the above, it is understood that for the hydrographic basin of the headwaters of the Araguaia River, the Water Producer Program (PPA) can contribute to the articulation of a robust public policy for the management of water resources in this region.

OBJECTIVE

The general objective of this research is to analyze through the Universal Soil Loss Equation (EUPS/USLE) the dynamics of the soil loss process in relation to the anthropogenic occupation of the Araguaia River headwaters basin for the years 1984, 1994, 2004, 2014 and 2018. In a second moment, the objective is to simulate the efficiency of the conservation management practices proposed by the PPA in the estimates of soil loss reduction.

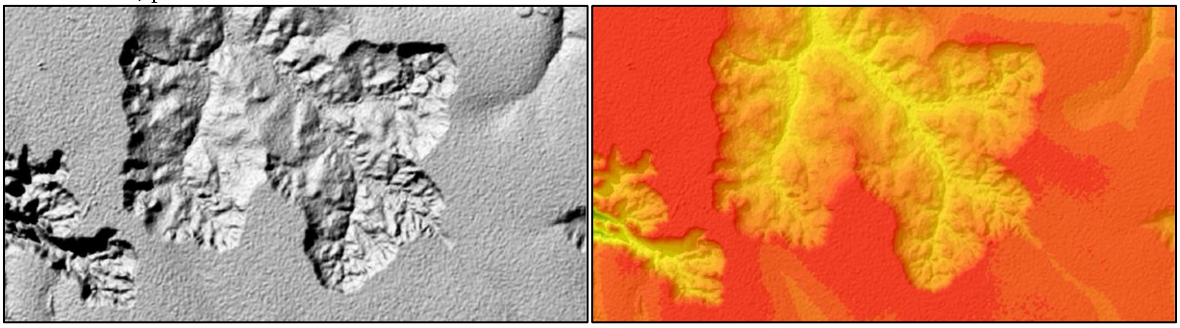
METHODOLOGY

For the development of the present research, it was chosen to work with the systemic method or integrated analysis, thus aiming to contemplate the synergetic mechanisms, that is, exchange of matter and energy, between the components of a system, here considered as the hydrographic basin.

For this reason, a first step considered as a result of the approach method adopted was to recognize the limits of the hydrographic basin system. This is naturally delimited by the higher segments of the interfluves or, more precisely, known as water dividers, thus composing hydrographic systems that gradually interconnect forming channels and basins of larger size. To this end, as a base product for the interpretation and mapping of this system, the Digital Elevation Model (MDE) PALSAR (Phased Array L-band Synthetic Aperture Radar) of the ALOS (Advanced Land Observation Satellite) satellite with a spatial resolution of 12.5m was used. After downloading or downloading from the <https://search.asf.alaska.edu/#/ website> they were designed with SIRGAS 2000 geodetic datum, and Mercator's Universal Transverse projection, with the Central Meridian 51° W Greenwich.

From the Digital Elevation Model, a first product to be highlighted concerns the shading model in relief illustrated in part **a** of figure 21. This product provides a view of the relief resulting from shading on the slopes that are opposite to the incidence of the sun's rays. Consequently, it allows, even if in a first approximation and in a qualitative way, to visualize the features of the relief such as the roughness of the terrain and, mainly, the hydrographic basin. In part **b** of the same figure, there is the hypsometry map or elevation map, with an opacity of 30% and superimposed on the shadow model with a vertical exaggeration of 9 times. This association allows us to visualize, albeit approximately, the fluvial and interfluvial areas, such as drainage channels and water dividers, respectively. It also allows an understanding of how the elevations are distributed and their respective areas of coverage along the basin. Consequently, it consists of a first approximation of the hydrographic system under study, with special emphasis on its limits in the redder colors.

Figure 1 - Materials used in the definition and mapping of the study area: shadow model part a; Hypsometric model associated with the shadow model, part B.



UNIVERSAL SOIL LOSS EQUATION

The Universal Soil Loss Equation (USLE) consists of an empirical model, whose purpose is to estimate soil loss in a given interval of space and time, considering climatological, pedological and morphometric conditions, especially slope and flow length, and especially the types of use and forms of soil management (WISCHMEIER & SMITH, 1978)

It represents the combination of climate (rainfall), soils (physical characteristics), topography (length and slope of slopes) and land use (with/without conservation management) in order to investigate soil laminar erosion. These are related to the amount and intensity of rainfall, surface runoff, land use and cover, and mainly, to the management and protection against the impact of rain and surface runoff, and to the length, slope and shape of the slopes (BAGHERZADEH, 2012).

The EUPS/USLE quantitatively estimates soil erosion in tons/hectare/year (ton.ha-1.year-1) by the empirical product:

$$A = R.K.L.S.C.P$$

Where:

A = estimated soil loss, in ton/ha/year;

R = rainfall erosivity factor, in Mj.mm/ha.h.ano;

K = soil erodibility factor, in ton.ha/Mj.mm;

L = slope or ramp length factor, in m;

S = slope factor of the slope or ramp, in %;

C = land use and management factor, dimensionless;

P = conservation practices, dimensionless.

R FACTOR - RAINFALL EROSIVITY

The elaboration of the erosivity of the rains resulted from the evaluation of data from various sources, as well as from works already developed in the area. Among the studies, the one by Santana et al. (2007) stands out, which is based on the calculation of the rainfall erosivity index for each month resulting from data from 28 rainfall stations located in the Upper Araguaia River Basin. Another work of great relevance refers to the one developed by Oliveira et al. (2012), which consists of a broad review of rainfall erosivity for the whole of Brazil based on the main databases of scientific articles, dissertations and theses on rainfall erosivity in Brazil. In both studies, the erosivity of rainfall in the region was between 8,000 and 10,000 Mj mm a year ago. Among the most recent studies, the one developed by Gomes et al. (2017) stands out, whose erosivity values were between 8,000 and 10,000 MJ mm $^{ha-1\ h-1\ year-1}$. After the evaluation of these works, a new erosivity map was elaborated, considering a more consistent set of monthly and annual precipitation data, which result from the collection of data by the stations of the National Institute of Meteorology - INMET, incorporated into other databases.

Specifically, for the calculation of rainfall erosivity, data from the TerraClimate project (ABATZOGLOU et al., 2018) developed by the Climatology Laboratory of the University of Idaho - United States, from the site <http://www.climatologylab.org/>, were used. It is a series of data on several climatological variables, including monthly and annual precipitation, modeled for almost the entire Earth's surface in the period from 1958 to 2019 plus updates, with a spatial detail level of 4 km. It is important to emphasize that, although much of the spatial variability of these data results from modeling complemented by Remote Sensing products, they remain reliable in relation to the empirical data recorded by the climatological stations. The main difference is that, while the work of interpolating point data occurs via statistical procedures, TerraClimate spatial data derive from the physical modeling of variables that determine precipitation, thus remaining reliable in relation to the physical conditions of each area (ABATZOGLOU et al., 2018).

From these data, the series of monthly and annual rainfall for the period 1984 - 2018 was elaborated, and then the equation of monthly and annual rainfall erosivity proposed by Oliveira et al. (2011) was applied to the city of Coxim, Mato Grosso, which, according to the review made by Oliveira et al. (2012) is the closest to the research area, having, including, climatic behavior very similar to the area of the headwaters of the Araguaia River. Thus, the erosivity of the area is represented by the following equation:

$$Ei30 = 247.35 + 41.036 (p^2/P)$$

Where: Ei 30 is the rainfall erosivity index considering the maximum intensity in a 30-minute period, in MJ mm $^{ha-1\ h-1\ year-1}$; 247.35 and 41.036 are constants in the equation representative of the area; p = average monthly precipitation, in mm; and P average annual precipitation, in mm.

Thus, with the monthly rainfall data for the period 1984 -2018 and the erosivity equation, the next step was the preparation of the monthly erosivity calculations, as well as the annual sum through geoprocessing programming. For both monthly and annual erosivity, the average monthly rainfall of each month was considered, as well as the annual rainfall in the period 1984 - 2018, thus seeking to work with values more representative of the behavior of the climate of the area.

MAPPING OF SOIL CLASSES AND ASSIGNMENT OF K FACTOR VALUES

The elaboration of the soil map with a better level of detail, especially regarding the number and limit of the known classes, as well as their correspondence and erodibility, was developed in three stages. The first consisted of the survey and analysis of the cartographic materials and respective reports already existing at various scales, which also presented important aspects such as materials and methods used in the mapping process. Among the existing mappings, the pioneering work of Novaes et al. (1983) carried out within the scope of the RADAMBRASIL project stands out; Barbalho and Castro (2002); Marinho and Castro (2003); Resende (2003); Martins (2003); and Nunes (2015). These works cover the part of the upper basin, known as the Southern Sector of the upper basin of the Araguaia River, at the scale of 1:100,000, whose soil classes include up to the third categorical level. Concomitant with the survey of soil types, the erodibility or K factor of each class was also surveyed through a bibliographic survey, prioritizing the studies found for the area or close to it. It is important to emphasize that all these mappings were developed through a rereading and evaluation of previously developed products and complemented by means of toposequences in transects of greater variability and doubts about soil types. All the identified classes were updated according to the nomenclature contained in the most recent Brazilian Soil Classification System - SiBCS (EMBRAPA, 2018).

In view of the need to obtain a more precise cartographic product with better accuracy with the terrain, the second stage consisted of the refinement of the soil classes using morphometric and morphographic variables elaborated from the digital elevation model - PALSAR - ALOS - with a spatial resolution of 12.5 meters. The redefinition of the boundaries of the Hydromorphic Quartzarenic Neosols was carried out by the analysis of the altimetric gradient along the drainage channel associated with the curvature of the profile and the slope slope. These soils tend to occur in places of high concavity, associated with slopes of a maximum of 3%, and along channels with a low altimetric gradient that allow the permanence of much of the precipitated water, conferring humidity most of the time, which causes the reduction of iron compounds (EMBRAPA, 2018). In general, upstream of the areas of Hydromorphic Quartzarenic Neosols there are more active sediment-producing areas.

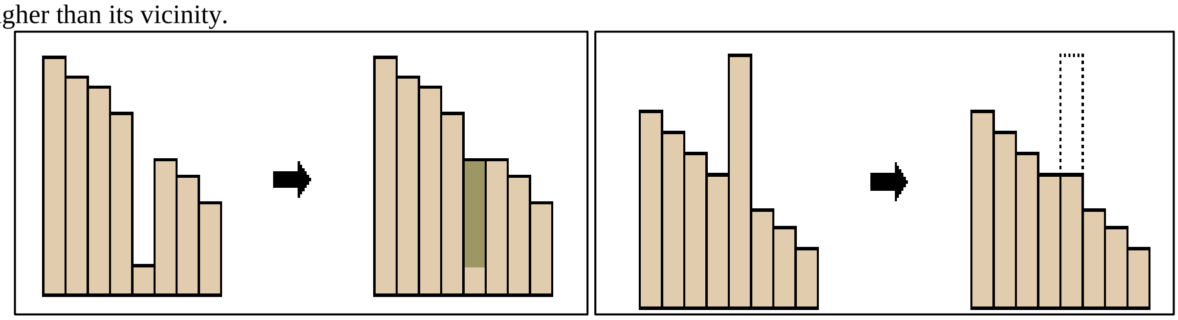
A similar procedure was adopted for the refinement of areas with the occurrence of Red Latosol. For this, the slope was used as a parameter, in which for the occurrence of the Red Latosol classes up to 8% is allowed. For the occurrence of Ortic Quartzarenic Neosol, slopes of up to 13% were admitted, but occurring over aeolian sandstones of the Botucatu Formation.

The third stage consisted of the reelaboration of the soil map through supervised classification, based on all the data and information collected and correlated with the continuous morphometric and morphographic variables elaborated from the Digital Elevation Model.

LS FACTOR OF THE UNIVERSAL SOIL LOSS EQUATION

To calculate the topographic factor LS of the Universal Soil Loss Equation, the PALSAR - ALOS Digital Elevation Model was used with a spatial resolution of 12.5 meters. After receiving cartographic projection, it was subjected to a detailed analysis of the anomalies resulting from the interference of the canopy of the denser vegetation, as well as the soil moisture conditions at altitude values. After this stage, the procedure of filtering or correcting pixels that were markedly in disagreement with the features of the terrain was applied, as shown in figure 23. This procedure was necessary since interferences resulting from the vegetation canopy, especially the densest vegetation, and soil moisture can result in altitude values in disagreement with the elevation of the terrain. Consequently, it can interfere with all other morphometric and morphographic models derived.

Figure 1 - Procedure for correcting the anomaly of pixel values. In the pixel part with a slightly lower value and in b with a value slightly higher than its vicinity.



With the filtered and hydrologically corrected Digital Elevation Model, the next step was the extraction of the flow segments corresponding to the drainage channels. This procedure was necessary, since the calculation of the estimated soil loss should be restricted to the length of the slopes. The drainage channels, because they are part of the fluvial dynamics and, consequently, are longer, if inserted in the calculation of the flow length, result in overestimated LS factor values. Thus, the points of occurrence of the springs represent the limit for inserting the ramp length in the calculation of the LS factor.

With the Digital Elevation Model properly prepared, the next step was the calculation of the flow lengths, as well as the slope and application of the respective exponents. All procedures, as well as the application of the LS factor equation were performed using the *Hydrology* and *Math* modules available in the ArcGIS software. To this end, the equation proposed by Bertoni and Lombardi Neto (1999) was used, which consists of a modification of the original equation proposed in the Agriculture Handbook of the United States Department of Agriculture, better meeting the Brazilian conditions, as presented below:

LS = 0.00984 x L0, 63 x S1, 18

Where:

L = corresponds to the length of the ramp or slope, starting from the highest point of the interfluves to the beginning of each drainage channel, in m; and S = corresponds to the slope slope, in %.

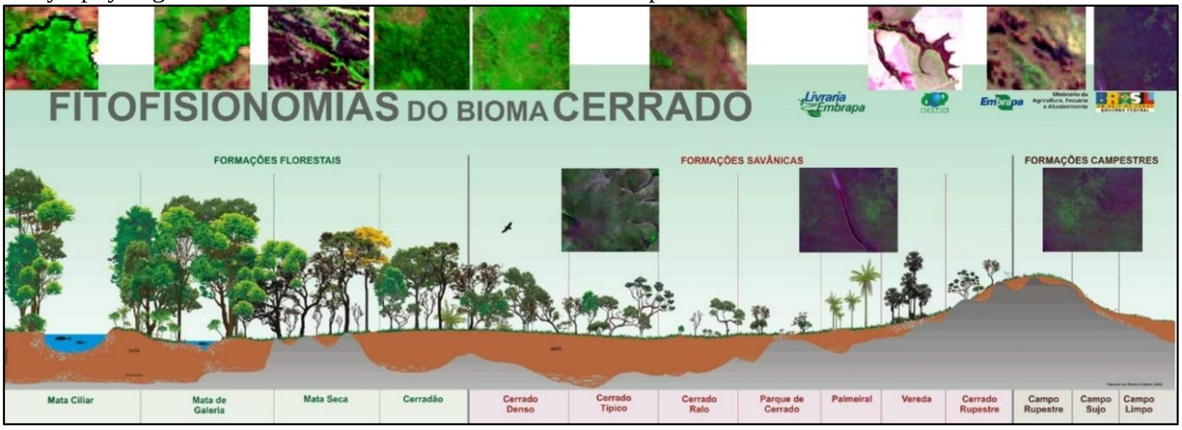
In this equation it can be seen that the exponent 0.63 of the slope length factor prevents it from resulting in overestimated values, thus avoiding an equally overestimated weight for very long slopes. Such a trend is correlated to the behavior of water flows on the ground, since the increase in runoff velocity does not depend only on the length, but on this associated with the slope slope. Similarly, it can be seen that the exponent 1.18 of the slope factor gives greater weight to this variable, showing that the flow velocity tends to be higher whenever in conditions of steeper slopes.

VEGETATION COVER AND LAND USE

For the elaboration of the vegetation cover maps (plant formations and respective phytophysiognomies) the assumptions of RIZINNI (2007) were followed, which defines that the vegetation classification process should occur mainly by the physiognomic appearance exhibited by the species, thus forming patterns recognized by the size and vegetation cover. Additionally, the classification nomenclature proposed by Ribeiro and Walter (2008) was used, which present and characterize the main phytophysiognomies present in the plant formations of the Cerrado morphoclimatic domain (Forest, Savannah and Grassland Formations), as shown in figure 24. To this end, after the systematization of their respective geographic coordinates, a detailed evaluation of the satellite images was carried out in order to identify and associate each point with the spectral signature in the satellite image.

The result of this exercise was the elaboration of an interpretation key that sought to associate the coordinates of the sample of each phytophysiognomy with the spectral signature in the satellite image, as well as its representativeness in the schematic profile of Ribeiro and Walter (2008).

Figure 3 - Phytophysiognomies of the Cerrado biome and their correspondence in color and texture from OLI Landsat 8 images.



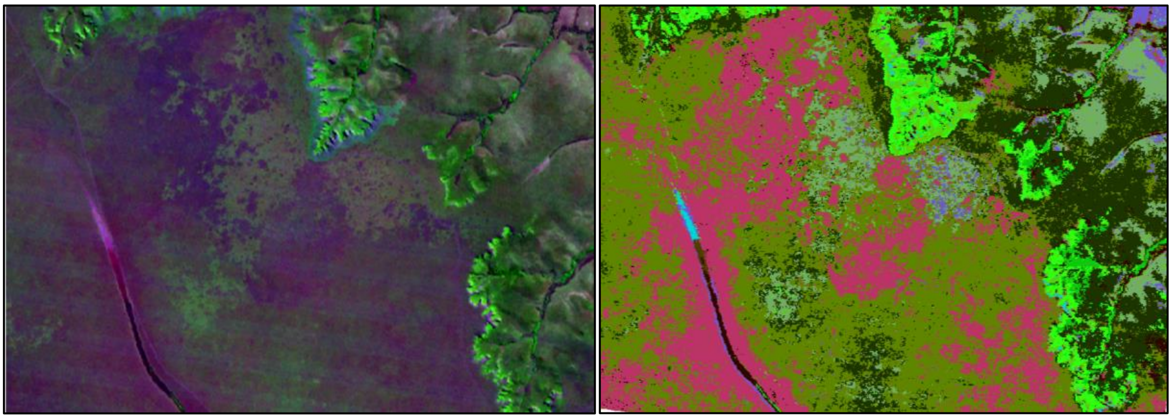
Source: adapted by the author from Ribeiro and Walter (2008).

After a bibliographic survey on the main phytophysiognomies and forms of land use in the area, images from the TM sensor of the Landsat 5 Satellite orbit 224 and point 072 were used, referring to September 4, 1984; September 30, 1994 and July 25, 2004, in RGB 543 composition, spectral enhancement of 2% and spatial resolution of 30 m. For the years 2014 and 2018, OLI images from the Landsat 8 satellite, orbit 224, point 072, were used, referring to July 21, 2014 and August 17, 2018 in the RGB 654 composition and spectral enhancement of 2% and with the same spatial resolution.

For the process of detecting spatial patterns and recognizing possible classes of land use and land cover, the Mean Shift algorithm available in the ArcGIS software was used, through which the images were segmented into spatial patterns in terms of texture and coloration, adopting spectral detail of 18; spatial detail of 12, both on a scale of 1 to 20; and minimum mappable area of 4 pixels or 3600 m². With the segmented images, a classification key was elaborated which was related to the bibliographic review, inventory of photographs and observations of representative areas of each phytophysiognomy, enabling the identification of colors and textures present in the images.

In this way, and considering the classification key elaborated, the previous classification of each possible class of vegetation cover, as well as land use, was carried out, thus resulting in a first approximation, as illustrated in figure 4.

Figure 4 - OLI Landsat 8 image in RGB 654 color composition (part a); and image segmented into color and texture patterns (part b).



DETERMINATION OF THE COVERAGE/USE FACTOR AND CONSERVATION PRACTICES

The multitemporal determination of the CP factor (Cover/Use and Conservation Practices) of the Universal Soil Loss Equation (EUPS/USLE) took place in two stages, namely. The first consisted of mapping the classes of vegetation cover (plant formations and respective phytophysiognomies) and land use, through georeferencing, digital treatment and analysis of satellite images of the Landsat series (5 and 8) as described in the previous topic. The next stage comprised the bibliographic survey about the factors C and P that were compatible with the conditions of land cover and land use in force on the date of acquisition of each image. A similar procedure was adopted in the determination of the CP factors related to conservation practices recommended by the Water Producer Project of the National Water Agency.

In this way, the values of the CP factor were respectively added to the vector physical file of each of the land cover and land use maps, thus allowing the spatial representation of the Cover/Use factor values and Conservation Practices.

CP FACTOR AND ITS INFLUENCE ON SOIL LOSS ESTIMATION (EUPS/USLE)

Coverage and Management Factor (C factor)

It represents in the Universal Soil Loss Equation (EUPS/USLE), the relationship between soil loss under specific cultivation conditions and the corresponding continuous fallow loss (WISCHMEIER & SMITH, 1978). Bertoni & Lombardi Neto (2008) consider the soil cover and management factor (C) as the ratio of soil loss in both cultivated and uncovered areas. Factor (C) measures the combined effect of all interrelated land cover and land management variables (WISCHMEIER & SMITH, 1978).

The C value of a given area is determined by many variables, one of which is climate. The main variables related to the management and land cover factor (factor C) include crop canopy, residue mulch, residues incorporated into the soil, tillage, residual land use and their interactions. Each of these effects can be treated as a subfactor whose numerical value is the ratio of soil loss with the effect to the corresponding loss without it. The C factor is the product of all the pertinent sub-factors (WISCHMEIER & SMITH, 1978).

Factor (C) is also based on the integration of factors that influence erosive processes, such as types of vegetation cover, land management and soil surface (WISCHMEIER & SMITH, 1978; RENARD et. al, 1997; GOMES et. al, 2017).

For some authors, after the erosive processes have begun, certain factors of the EUPS/USLE acquire greater or lesser importance in soil loss. For them, topography (LS factor) is the factor with the greatest influence, while factor C corresponds to the second most important factor in USLE/EUPS (BESKOW et.al, 2009; VAN DER KNIJFF et. al, 2000; FARHAN et.al, 2015).

However, changes in land use and management can intensify erosive processes. On the other hand, it is the factor (C) that represents the conditions that can be easily changed to reduce surface runoff and soil erosion (CORRÊA et. al, 2016; GOMES et. al, 2017).

Although treated as an independent variable in the equation, this factor depends on other factors. Factor C ranges from near zero (for good erosion protection; conservationist management systems) to 1 (poor erosion protection; non-conservation systems) (PROCHNOW et al., 2005; CORRÊA et. al, 2016; GOMES et.al, 2017).

Support Practice Factor (P)

In general, whenever soils of sloping land are cultivated and exposed to erosive rainfall, in addition to the protection offered by grasses or crops, support practices are necessary that reduce the surface runoff of water, and thus reduce the amount of soil transported. The P factor in EUPS/USLE is the ratio of soil loss with a specific support practice to the corresponding loss in the up-and-down crop (WISCHMEIER & SMITH, 1978).

For Bertoni & Lombardi Neto (1990), the P factor corresponds to the ratio or intensity between the loss of soil that occurs in a given conservation practice and those when the crop is planted in the direction of the slope.

The factor (P) varies according to soil conservation practices and, therefore, has a strong influence on soil loss (BESKOW et.al, 2009; GOMES et. al, 2017).

The most common support practices (P factor) for soil loss on arable land, applied in the EUPS are: contour planting, contour strip planting, terracing and alternating weeding (WISCHMEIER & SMITH, 1978; BERTONI & LOMBARDI NETO, 2008).

Improved tillage practices, grass rotations, fertility treatments, and increased amounts of plant residues left in the field and on soils contribute materially to erosion control. However, these are considered conservation practices and conservation management, and the benefits derived from them are included in factor C (WISCHMEIER & SMITH, 1978).

RESULTS AND DISCUSSION

DYNAMICS IN THE USE AND LAND COVER OF THE ARAGUAIA RIVER HEADWATERS BASIN (1984, 1994, 2004, 2014, 2018)

The delimitation of the hydrographic basin of the headwaters of the Araguaia River included by this research corresponds to an area of 12,567.60 hectares (ha), which is fundamental information aimed at analyzing the dynamics of land use.

The analysis of the dynamics of land use and vegetation cover of the hydrographic basin of the headwaters of the Araguaia River was carried out from the series of image maps and land use maps (figures 27 and 28) corresponding to the years 1984, 1994, 2004, 2014 and 2018.

The interpretation of the landscape of the basin of the headwaters of the Araguaia River in 1984 through the TM Landsat 5 image, shows a broad process of deforestation through indiscriminate burning (especially in the entire western part of the basin), demonstrated in the satellite image by the magenta-grayish aspect. This aspect of the image is also observed in the following decade, in the year 1994.

According to figure 28 corresponding to the multitemporal series of land use (1984, 1994, 2004, 2014 and 2018) of the hydrographic basin of the headwaters of the Araguaia River, it was observed that in 1984 the configuration and planning of land use were unconsolidated and undefined, due to the broad process of deforestation and degradation, which is why the highest percentage of areas with characteristics of exposed soil/deforestation was observed, considering the entire multitemporal series.

Consequently, in 1994 there was the highest percentage of areas destined to anthropic land use (grain agriculture and livestock) and the lowest percentages of areas attributed to natural vegetation, considering all the years of the multitemporal series, as shown in Table 10. It is also important to highlight that the areas characterized as exposed soil/deforestation in 1984 were occupied by agriculture in 1994.

From 2004 onwards, there was a better definition and ordering of the environments occupied by both anthropic activities and natural vegetation. The agricultural areas extensively occupied the dissected and lowered portion of the basin, where Red-Yellow Latosols and Ortic Quartzarenic Neosols of the Botucatu Formation predominate; and also the altiplane portions of the basin covered by thick Red Latosols of the Cachoeirinha Formation.

It is possible to state generically that the areas where the sandstones of the Botucatu Formation predominate were intended for anthropic use, while the areas of Hydromorphic Quartzarenic Neosols were intended for the conservation of natural vegetation. In 2004, it was observed that land use was almost exclusively for grain agriculture, making areas for livestock practically non-existent.

In 2014, there was a trend towards the delimitation, definition and ordering of environments for anthropic activities (agriculture) and natural vegetation, similar to the year 2004. As for anthropic use, there was a predominance of agricultural land use, and eucalyptus silviculture was observed in specific areas of the basin.

In 2018, the expansion of areas for natural vegetation stands out, with the highest percentages of this form of land cover in relation to all years of the multitemporal series. It is also important to highlight the widespread substitution of grain agriculture for sugarcane, in areas corresponding to 22% of the total basin.

In general, table 10 shows in percentage terms the spatio-temporal variation of the main types of land use and of the remnants of natural vegetation in the hydrographic basin of the headwaters of the Araguaia River. This, together with the multitemporal mapping of land use (figure 28) constitute the basis for discussion of this chapter, which aims to analyze the changes in land use and land cover in this basin in the period under analysis.

Using as reference the land cover and land use maps, prepared in the five time frames (1984, 1994, 2004, 2014 and 2018), together with the maps of characterization of the physical environment, it was possible to establish spatial patterns of both the processes of deforestation and replacement of natural vegetation, the occupation and expansion of types of land use, as well as the areas destined for the conservation and recomposition of natural vegetation.

The following figures also support the multitemporal analysis of the dynamics of the use, cover and occupation of the basin of the headwaters of the Araguaia River, presenting respectively, (i) a picture of the multitemporal dynamics of the phytophysiognomies and forms of land use (chart 11); (ii) collection of maps of physical attributes (Figure 26); (iii) set of image cards (figure 5); and (iv) set of land use maps (Figure 6).

Chart 1 - Multitemporal dynamics of phytophysiognomies and forms of land use – Araguaia River headwaters basin.

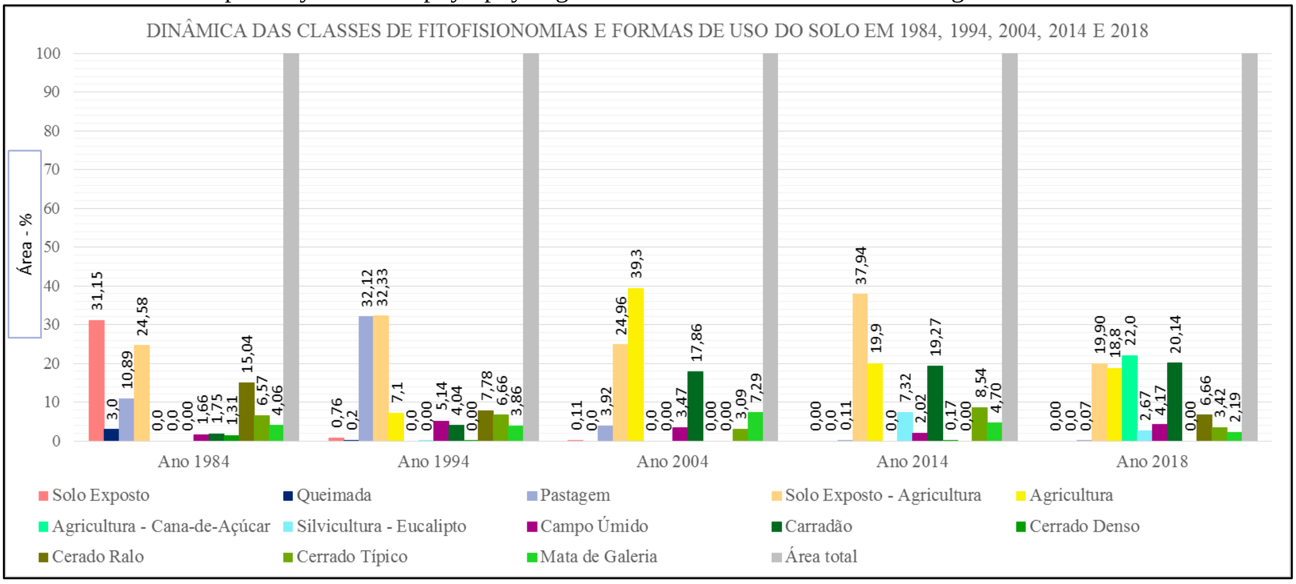


Figure 8 - Multitemporal series of image maps (Landsat 5 TM and Landsat 8 satellite) – Araguaia River headwaters basin.

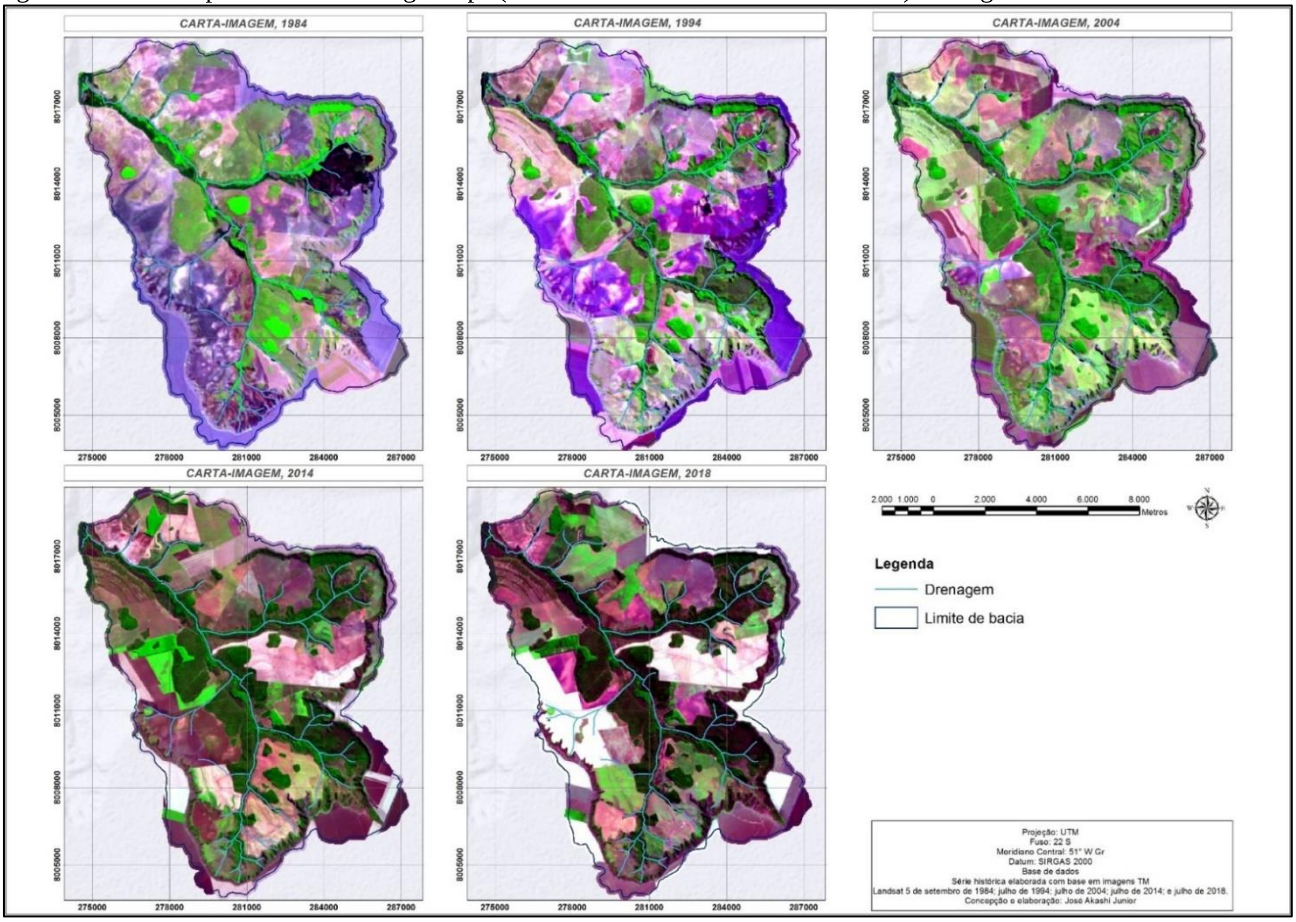
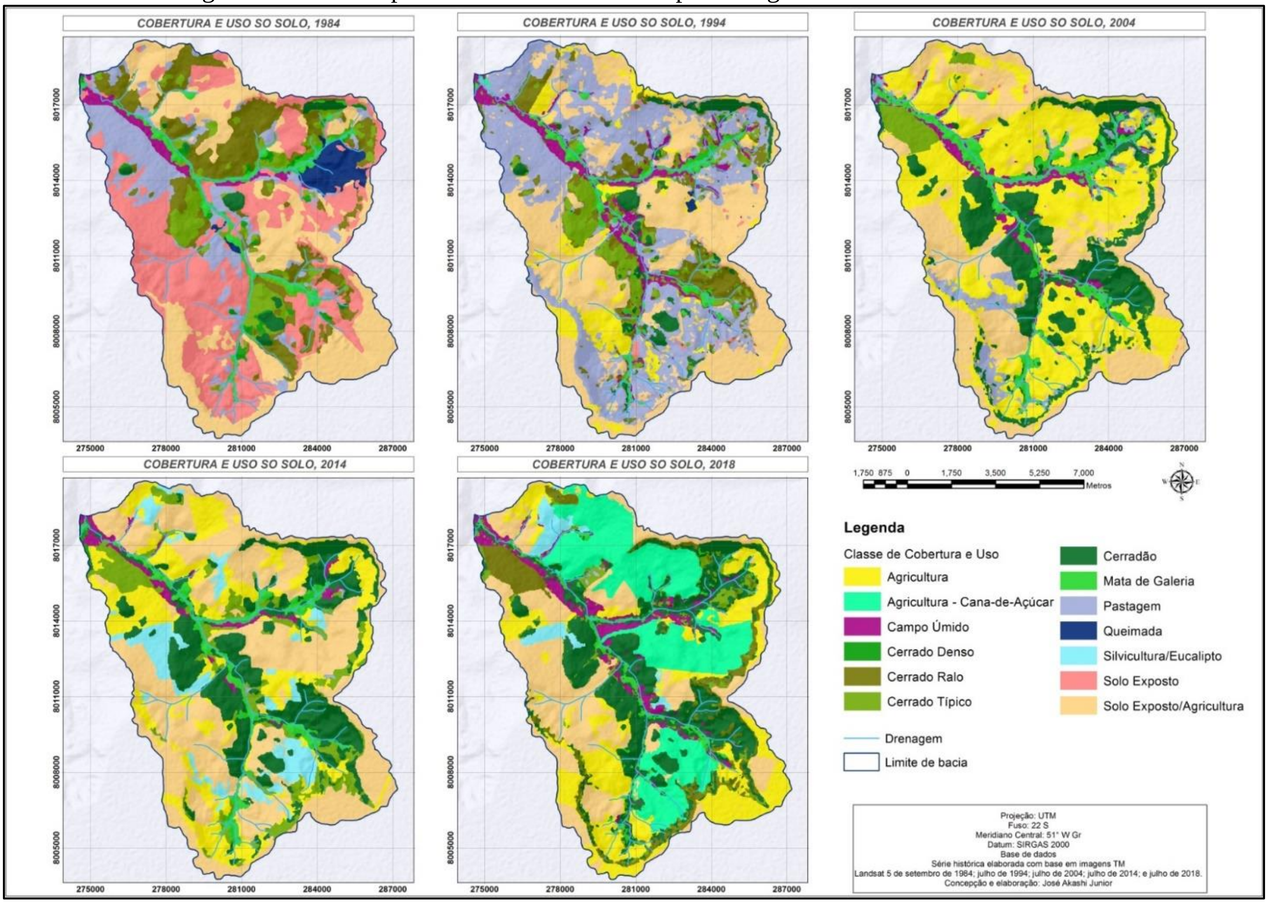


Figure 9 - Multitemporal series of land use maps – Araguaia River headwaters basin.



MULTITEMPORAL ANALYSIS (1984, 1994, 2004, 2014 and 2018) OF CHANGES IN LAND COVER AND LAND USE IN THE ARAGUAIA RIVER HEADWATERS

Land cover and land use – 1984

In 1984, a broad process of deforestation and anthropization was evidenced. It is possible to observe that the areas most affected by the removal of vegetation cover and anthropic occupation in the basin of the headwaters of the Araguaia River were those preferably of flat to gentle undulating relief, especially in the areas in the form of pediments.

These are located in the dissected and lowered terrains corresponding to the Botucatu Formation, located at altimetric levels immediately below the erosive escarpments, whose average slope is around 8%. They are environments consisting of extensive slopes where there is predominantly Red-yellow Latosols with clayey texture, which has reasonable agricultural potential.

The satellite image from 1984 shows a deforestation process carried out through extensive and indiscriminate burning (evidenced by the magenta-grayish color), which reached areas even inappropriate for agricultural activities.

The removal of vegetation cover in the form of fires advanced, among others, over areas of steep slope, such as the headwaters of drainage of dissected reliefs and erosive escarpments, the latter with slopes of up to 59% and predominance of poorly developed soils, such as Haplic Cambisol and especially Litholic Neosol. These areas presented difficulties in recomposing the vegetation cover over the period 1984/1994.

Other areas greatly affected by deforestation and anthropic occupation were those that mark the transition of pediments to the river plain. These environments are distinguished by a slight increase in slope, reaching up to 14%, and marked by the predominance of Ortic Quartzarenic Neosols from the aeolian sandstones of the Botucatu Formation. Such soils, which are commonly shown to be of great fragility due to the ease of degradation, have high susceptibility to erosion, are difficult to recompose due to their sandy composition (medium to fine texture), little occurrence of organic matter and, consequently, low water retention capacity (EMBRAPA, 2015).

The environments intended for the conservation of natural vegetation corresponded to the fluvial plains of the Araguaia River, where there are low slopes (0 – 3%), low altimetric gradient, and predominance of Hydromorphic Quartzarenic Neosols, which are conducive to water saturation for a longer period.

In these areas, Cerrado phytophysiognomies associated with watercourses predominate, such as humid grasslands, gallery forest and riparian forest, which proved to be more resistant to degradation by fire. It is also possible to say that these phytophysiognomies of greater size and leaf density were less affected by the deforestation process.

Other areas with a greater predominance of vegetation remnants corresponded to those of dissected reliefs upstream of the basin. These comprise areas with a higher occurrence of springs, associated with first-order drainage channels, or close to erosive escarpments.

Land cover and land use – 1994

The areas destined for anthropic use in 1994 totaled 72.36% of the area of the basin of the headwaters of the Araguaia River or 9,093.92 hectares, the highest percentage of anthropic occupation observed between 1984 and 2018. Consequently, the areas destined to natural vegetation corresponded to 27.64% of the total area of this basin or 3,473.68 hectares, the lowest percentage of areas occupied by natural vegetation.

It is important to emphasize that the land use classes: exposed soil/deforestation and fires evidenced in 1984 were occupied by agricultural use in 1994.

According to the 1994 land use map, it is possible to generalize that the lands destined for cattle ranching occupied areas of dissected reliefs associated with the headwaters of drainage. Consecutively, agricultural occupation was predominantly installed in areas of flat to gently undulating reliefs.

In both situations, such land use occupations were directly correlated to the lowered and dissected surface, where the Red-Yellow Latosols with slopes of up to 8% and the Quartzarenic Neosols with maximum slopes of 14% occur.

Natural vegetation intended for conservation was predominantly associated with riparian zones and along the length of the river plains, areas that predominate Hydromorphic Quartzarenic Neosols.

The phytophysiognomy 'thin cerrado' corresponded to the main typology of natural vegetation suppressed in the 1984/1994 interval, located in environments corresponding to the Red-Yellow Latosols and Quartzarenic Neosols, replaced by agricultural use.

In turn, the recomposition of natural vegetation occurred in an area adjacent to the fluvial plain and in another case, next to the headwater of drainage in an area of dissected relief.

Land cover and land use – 2004

The year 2004 essentially marks the existence of only two modalities of land use and occupation in the hydrographic basin of the headwaters of the Araguaia River: grain agriculture and natural vegetation.

It was found through the multitemporal analysis (1984/2018) of the dynamics of land use and cover in the basin of the headwaters of the Araguaia River, that in the interval of 1994/2004 a process of definition of the environments destined to anthropic occupation and also to the conservation of natural vegetation was consolidated, and consequently, designating the basin predominantly to agricultural use.

It is important to note that between the years 1984 and 2004, the expansion of agriculture in this basin corresponded to the cultivation of soybeans, as pointed out by Castro and Xavier (2004), in a compilation of agricultural censuses of the IBGE (1980 – 2000) of the region.

In turn, the natural vegetations, as in previous decades, presented spatialization correlated to the fluvial plains of the Araguaia River associated with the Hydromorphic Quartzarenic Neosols, and also to the drainage headwaters in dissected reliefs.

Land cover and land use – 2014

In 2014, the trend towards the delimitation and planning of areas destined for anthropic use and the conservation of natural vegetation observed in 2004 stands out.

In relation to the 2004/2014 interval, it is possible to state that the anthropic occupation in 2014 maintained a spatiality relatively similar to that of 2004. However, the areas intended for agricultural use have been reduced. In 2004 they corresponded to 64.36% of the total area of the basin or 8,088.51 hectares, while in 2014 they corresponded to 57.97% of the basin or 7,285.44 hectares.

In addition to the agricultural predominance in the basin, a new modality of land use was observed in 2014, characterized by eucalyptus silviculture, occupying areas previously intended for agriculture. The definitive extinction of cattle ranching was also observed.

Eucalyptus silviculture, together with agriculture and natural vegetation, corresponded to the predominant land use and occupation classes in the hydrographic basin of the Araguaia River springs in 2014.

Land cover and land use – 2018

Land use in 2018 is marked by a vast substitution of grain agriculture for sugarcane. The impact of this change will have great implications in reducing the estimate of soil loss in the basin.

Overall, the areas occupied by sugarcane agriculture corresponded to 22% of the total area of the basin or 2,764.87 hectares. They are related to areas previously destined for human occupation, so that they have not advanced into areas of natural vegetation. Thus, they predominantly occupied areas of flat and smooth undulating reliefs, associated with Red-Yellow Latosols and Quartzarenic Neosols, with slopes of up to 8% and 14%, respectively.

Despite the vast area destined to sugarcane cultivation, the predominant type of land use in the basin was grain agriculture, and small areas were also observed that were destined to eucalyptus silviculture.

DEVELOPMENT

UNIVERSAL SOIL LOSS EQUATION (EUPS/USLE), CP/LAND USE FACTOR AND SOIL LOSS ESTIMATES – ARAGUAIA RIVER HEADWATERS

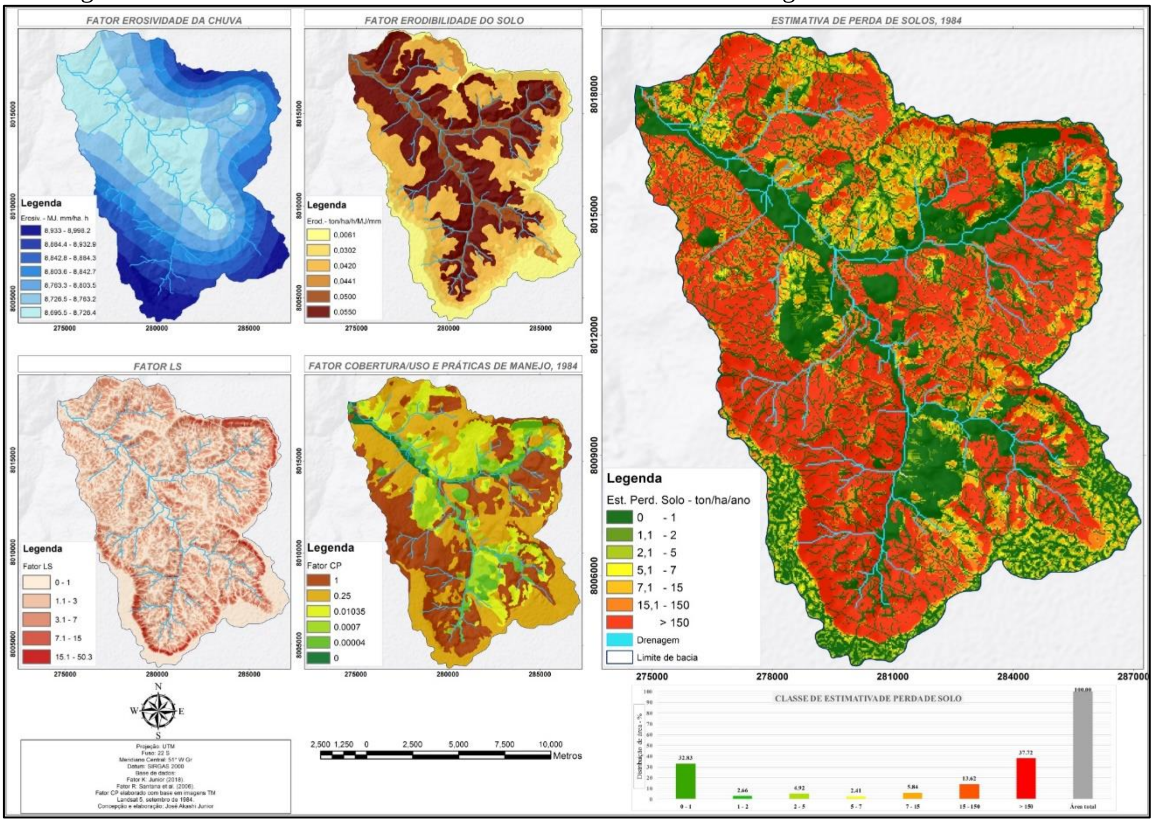
CP factor/land use and land cover and soil loss (EUPS/USLE) – Araguaia River headwaters (1984)

In 1984, in the basin of the headwaters of the Araguaia River, due to the high intensity of the deforestation process, anthropic conversion of natural vegetation and the vast areas with exposed soils/deforestation (34.15% of the area), the highest rates of soil loss were estimated considering all the years of the EUPS/USLE multitemporal analysis for this basin. As a result of these processes, the use of the soil in the hydrographic basin of the headwaters of the Araguaia River was quite undefined and disorderly, given the extensive areas of exposed soil/deforestation, still not destined for anthropic use.

Thus, in 1984 the areas of anthropic land use became the majority, totaling 69.62% of the total area of the basin or 8,749.56 hectares.

The main types of land use observed were: grain agriculture, livestock, exposed soil/deforestation and burning. The values of the CP factors adopted for these types of land use were, respectively, 0.25; 0,25; 1; 1.

Figure 10 - EUPS/USLE Factors and Soil Loss Estimate 1984 - Araguaia River headwaters basin

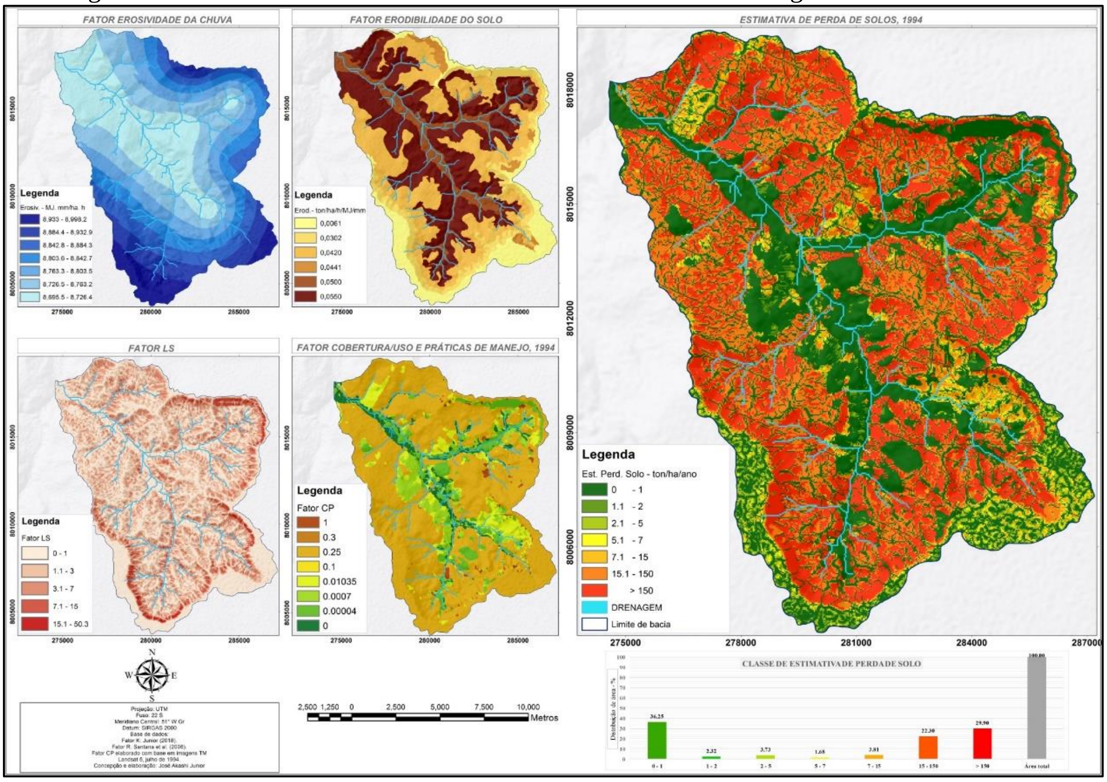


CP factor/land use and cover and soil loss (EUPS/USLE) – Araguaia River headwaters (1994)

In 1994, the use and occupation of the land in the hydrographic basin of the headwaters of the Araguaia River presented traces of better definition and ordering in relation to the year 1984, when there was a strong lack of definition of these. In this sense, it was observed that the areas of 'exposed soil/deforestation' extensively present in 1984 were fully occupied/replaced by agriculture in 1994.

On the other hand, in 1994, agriculture and livestock totaled an occupation corresponding to 72.36% of the basin area or 9,093.92 hectares, the largest area destined to anthropic occupation observed in the time series of land use (1984, 1994, 2004, 201, 2018). Consequently, the areas covered by natural vegetation were the smallest observed in the entire time series of land use.

Figure 11 - EUPS/USLE Factors and Soil Loss Estimate 1994 - Araguaia River headwaters

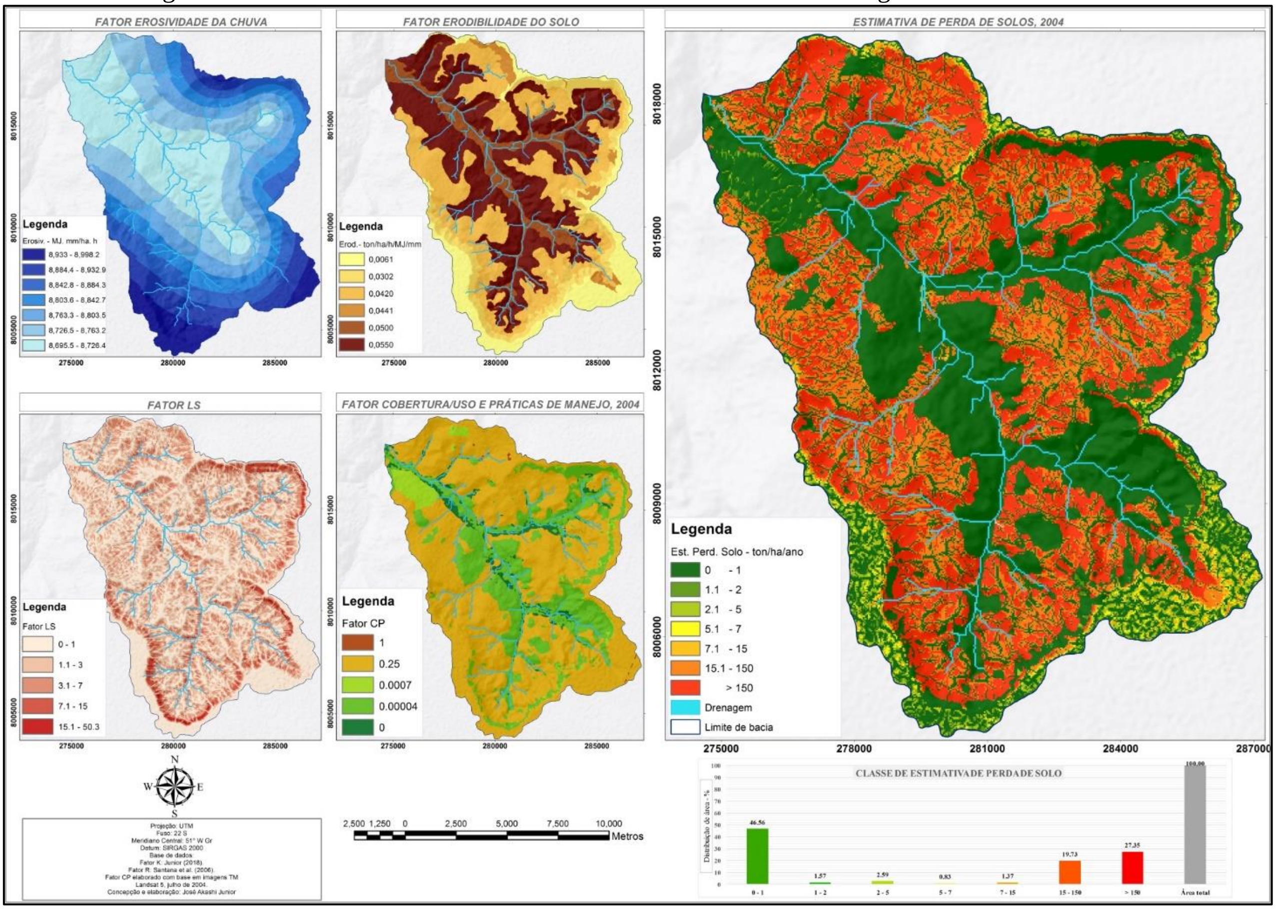


CP factor/land use and land cover and soil loss (EUPS/USLE) – Araguaia River headwaters (2004)

In 2004, a better definition was observed in the planning of the areas intended for the conservation of natural vegetation, as well as the areas destined for anthropic use, both generically defined and delimited in accordance with the levels of relief and types of soils. Agricultural areas were the majority, while the practice of cattle ranching was restricted to very small areas.

The types of anthropogenic land use observed in the basin corresponded to grain agriculture (64.26% of the basin area) and livestock (3.92% of the basin area), and together totaled 68.18% of the total basin area or 8,581.16 hectares.

Figure 12 - EUPS/USLE Factors and Estimated Soil Loss 2004 - Araguaia River Headwaters



CP Factor/Land Use and Land Cover and Soil Loss (EUPS/USLE) – Araguaia River Headwaters (2018)

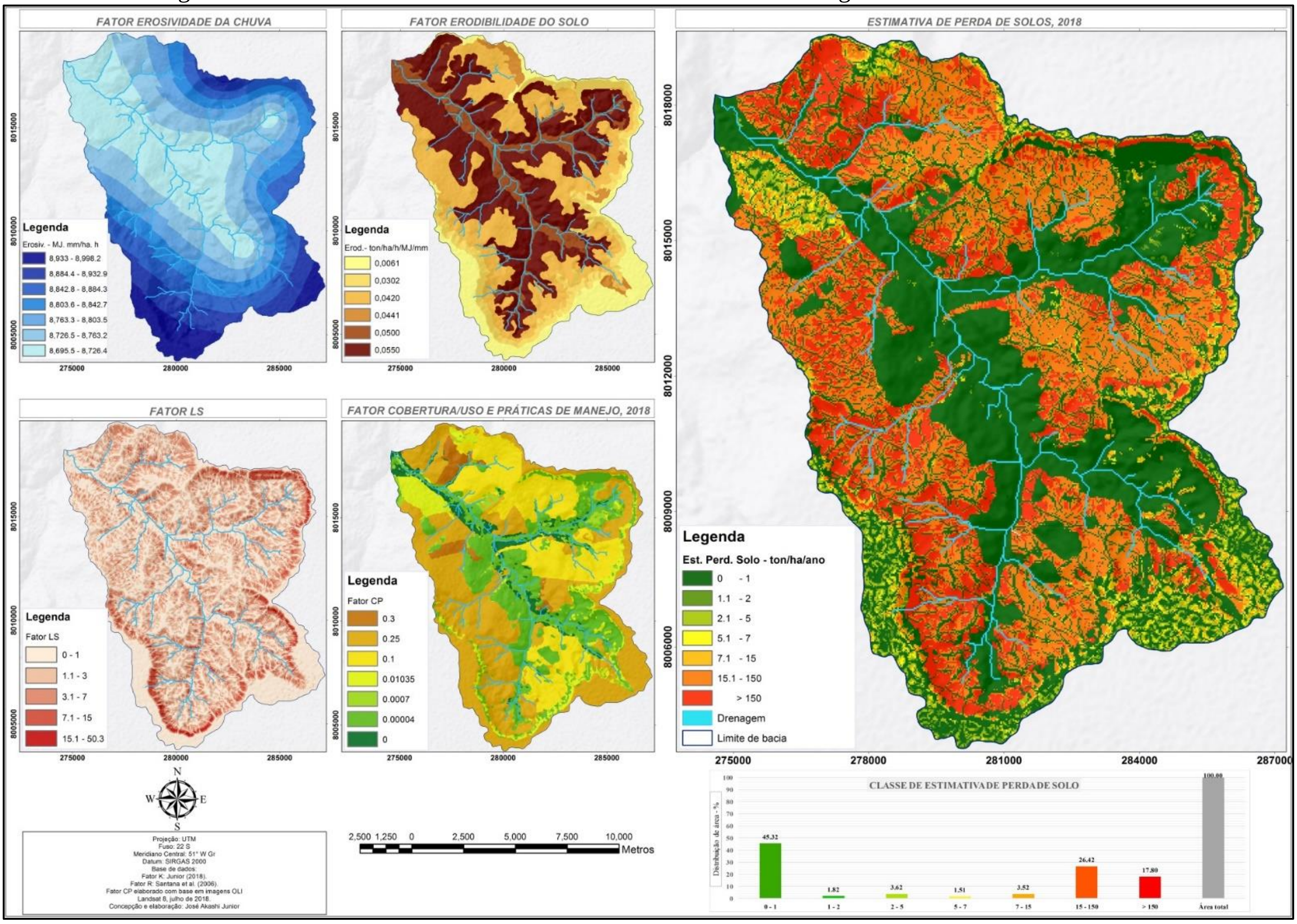
The dynamics of land use in 2018 follows the ordering of land use and land cover evidenced since 2004, when it was observed the anthropized areas generically occupying the areas corresponding to the Botucatu and Cachoeirinha Geological Formations, and the areas of natural vegetation occupying the areas corresponding to the Araguaia River plain and the erosive escarpments.

Considering the entire multitemporal series of land use, it is important to highlight that in 2018 there were the largest extensions of areas destined to natural vegetation, totaling 36.55% of the basin area.

Regarding the agricultural occupation in 2018, it was observed the introduction of sugarcane cultivation in areas corresponding to 22% of the total basin or 2,764.87 hectares, replacing areas of grain cultivation. Due to the extension of the sugarcane areas and their low CP factor value (CP=0.1 factor), a significant reduction in the total soil loss of the basin was observed.

Another factor associated with the reduction in soil loss in the basin was due to the increase in density and areas of natural vegetation. Consequently, this year the lowest total soil loss for the basin was estimated considering the entire multitemporal series of soil loss of the EUPS/USLE.

Figure 13 - EUPS/USLE Factors and Soil Loss Estimate 2018 - Araguaia River headwaters basin.



FINAL CONSIDERATIONS

1. In general, it was observed throughout the multitemporal series of soil loss (1984, 1994, 2004, 2014, 2018) of the Araguaia River headwaters basin, that the progressive consolidation and definition of land use and land cover planning resulted in a gradual reduction in soil loss.

2. This work demonstrated through modeling (EUPS/USLE) the extraordinary efficiency of the Water Producer Program (PPA) in the conservation hydrosedimentary management of the Araguaia River headwater. Due to the very high reduction in the estimates of soil loss, it is possible to say that the PPA consists of a point of convergence between agricultural interests as well as conservationist interests.

The spatialization of the PPA demonstrates the importance and/or need for conservationist management of watersheds. In the basin of the Araguaia springs, the large reduction in soil loss in the region of the lowered and dissected surfaces (pedimento) is noteworthy, where the sandy Red-Yellow Latosols and the Ortic Quartzarenic Neosols, from the Botucatu Formation, predominate. and in the altiplane portions of the basin, where the Red Latosols of the Cachoeirinha Formation predominate.

However, it is necessary to highlight throughout the period under analysis, the expansion of the areas corresponding to natural vegetation, especially the riparian vegetation of the Araguaia River and its tributaries. These have the character of buffer zone, favoring the minimization of sediment deposition in the riverbed, in addition to their extensive continuity in the form of natural ecological corridors.

This research did not deal with the discussion of biodiversity losses or other types of negative environmental impacts from agricultural practices in the basin, even considering their importance. It was assumed that the increase in rainwater infiltration, the minimization of surface runoff and the management of the watershed, are starting points for the (re)establishment of environmental balance.

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