sociedade
& natureza

DOI: 10.14393/SN-v34-2022-63507
Received: October 07, 2021 | Accepted: January 13, 2021 | Published: February 16, 2022

Papers

Multiscale landscape compartmentation of the Uberabinha river basin (Minas Gerais, Brazil) through the geosystemic perspective

***Rafael Mendes Rosa*[1]**
***Vanderlei de Oliveira Ferreira*[2]**

Keywords:
Geosystem
Environmental planning
Landscape units

Abstract
The inappropriate use of natural resources in spatially differentiated contexts under various aspects in watersheds leads to environmental degradation and social problems. In this sense, management actions are fundamental and should start from the principle that hydrographic units are internally heterogeneous, complex and multifaceted, configuring themselves as a set of varied situations. This article reports the results of research dedicated to the application of a methodological procedure to multiscale landscape compartmentalization based on the adaptation of the contributions of two classic authors: Georges Bertrand and Jean Tricart. The Uberabinha river basin, located in the state of Minas Gerais (Brazil), adopted as the study area, was characterized from a physiographic point of view and neatly subdivided into two geosystems, four geocomplexes and eight geofacies. Smaller units, called geotopes, were also identified as examples. From the maps of physiographic components and land cover and use distributed in time intervals between 1985 and 2020, it was possible to categorize the vulnerability of the land to soil loss. Finally, geoecological profiles were elaborated to organize a synthesis of the terrestrial reality of the basin in a vertical perspective (geohorizons). Given the above, the work contributed as an analysis of the Uberabinha river basin based on a geosystemic perspective, since its exploitation has shown to be ecologically predatory, as well as in most Brazilian hydrographic basins.

[1] Universidade Federal de Uberlândia - UFU, Uberlândia, MG, Brazil. rafaelmendesr@hotmail.com
[2] Universidade Federal de Uberlândia - UFU, Uberlândia, MG, Brazil. vanderlei.ferreira@ufu.br

INTRODUCTION

The inappropriate use of natural resources in spatially differentiated contexts in watersheds leads to environmental degradation as well as social problems. Hence, the partition of the landscape is useful for proposing improvements in environmental quality, as the watersheds are heterogeneous, complex and multifaceted. The internal particularities must be considered in the management proposals, mainly because the watersheds are territorial units universally accepted for planning and environmental management (SANTOS, 2004).

For Rodriguez, Silva and Cavalcanti (2007), the landscape is an object of geoecological investigation, serving as a basis for the planning of the territory, because, from the potential of natural resources, it is possible to formulate strategies for the use of its landscape units. The authors emphasize that the landscape must be conceived as an integrated system, since the isolated components do not have integrative properties.

Several articles repeatedly published on landscape compartmentalization and vulnerability assessment to soil loss are based on the geosystemic approach (influenced by the General Systems Theory) in order to understand the structure and natural processes at work. The works of integrated environmental analysis began to gain strength from the second half of the 20th century, with emphasis on authors from the Soviet school, such as Sotchava (1977), and from the French school, for example, Bertrand (1971) and Tricart (1977).

Since then, several authors, in Brazil and around the world, have relied on these concepts for the elaboration of landscape subdivisions of watersheds and other territorial units, although most of them are carried out from adaptations of the methodologies of the mentioned classic authors, such as Oliveira and Marques Neto (2015), Marent and Portilho (2017), Arias-García, Gómez-Zotano and Delagado-Peña (2017), Nicolau (2018), Lima and Corrêa (2019) and Oliveira, Viadana and Pereira (2019).

Cavalcanti's approach (2013, 2014) is entirely based on researchers from the Soviet school, whose proposal is the search for a naturalistic synthesis with the cartographic differentiation of landscapes. Another outstanding perspective is the Geoecology of Landscapes by Rodriguez, Silva and Cavalcanti (2007), who have guided authors in Brazil, such as Trombeta and Leal (2016), Miranda et al. (2018) and Faria e Silva (2020).

In other publications that do not directly mention the classical authors, geosystemic concepts are somehow applied, since there is integration of landscape components to identify territorial homogeneities, as it can be noted in the publications by Gülçin and Yilmaz (2020) and Carlier et al. (2021). The compartmentalization of Carlier et al. (2021), for example, is based on the European Landscape Convention, a treaty of the year 2000, with iterations of grouping from physiographic units and land cover for statistical classification of Irish landscapes.

Although there is a variety of landscapes compartmentalization methodologies, it is observed that studies involving the geosystemic bias have not presented major methodological innovations, in many cases, they are replications and adaptations of models based on the classics. However, from a procedural point of view, improvements have, in fact, occurred due to the advancement of geotechnologies available for collecting, processing and analyzing geographic information. Geoprocessing software and WebGIS are increasingly useful in generating accurate cartographic products.

Based on the above, this article presents a case study dedicated to identify and characterize landscape scenarios in the Uberabinha river basin, located in the state of Minas Gerais (Brazil). Thus, the objective is to detect, through multiple scales, internal landscape units, taking into account the entirety of the basin as well as the local particularities. By means of this diagnosis, it is possible to find the natural vulnerabilities of each of the delimited units.

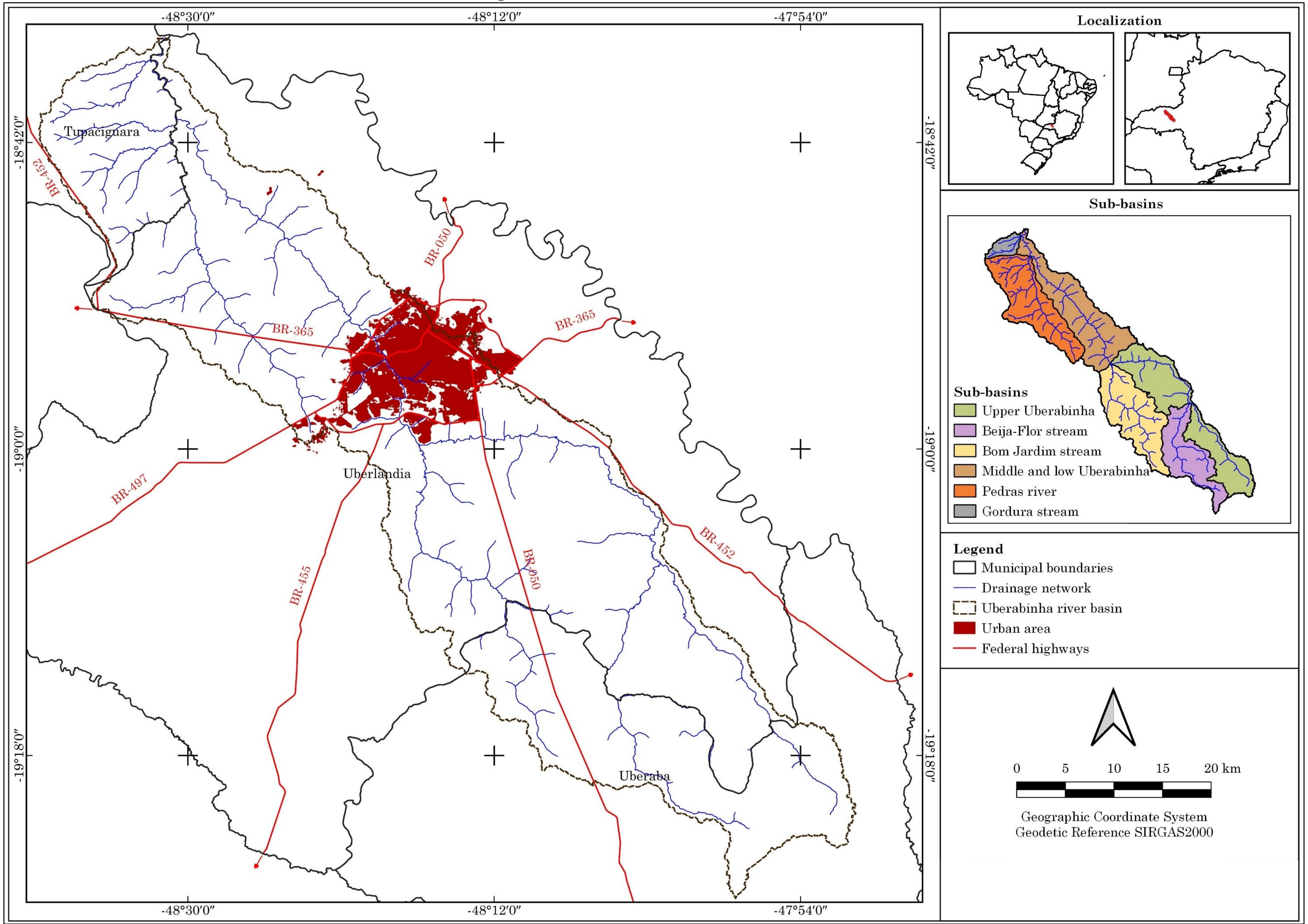
In this context, with the use of geoprocessing techniques, this article aims to identify internal specificities of the study area from the assumptions of classic authors from the French school: Bertrand and Bertrand (2009) and Tricart (1977). The proposal contemplates the identification of the geofacies of Bertrand and Bertrand (2009) by means of the thematic map and geoecological profiles that are supported by the geohorizons defined by the authors. The geofacies were selected as geomorphological components for the survey of vulnerability to soil loss, by Crepani et al. (2001), based on Tricart (1977).

Seeking for an integrated approach that meets the studies of watersheds, the conceptions on the theory of geosystems of authors from the French school may contribute to the identification improvement of internal heterogeneities. Their methodologies can be conceived as support for the development of updated methodological procedures. The results may provide subsidies for decision-making in the context of environmental planning of watersheds.

STUDY AREA

The area defined for study is the Uberabinha river basin, whose main river is an affluent from the left bank of the Araguari river (statewide), which in turn flows into the Paranaíba (federal). This basin, whose total area is 2,189.42 km^2, is located in the Intermediate Regions of Uberlândia and Uberaba (IBGE, 2017), covering part of three municipalities: 20% in Uberaba, 70% in Uberlândia and 10% in Tupaciguara (ROSA, 2017) (Figure 1). It is an important source that serves the public supply from the city of Uberlândia, whose estimated population is 706,597 inhabitants (IBGE, 2021).

Figura 1 – Localization of the Uberabinha river basin.



Elaborated by the Authors (2021).

METHODOLOGICAL PROCEDURE

The methodology initially included a survey of natural aspects, land cover and use, as well as the determination of vulnerability to soil loss. The work was developed by means of bibliographic references, making thematic maps and elaborating geoecological profiles.

The vector files of the Brazilian territory and the drainage network are from IBGE (2020) and IGAM (2012), respectively. The digital elevation model used to delimit the Uberabinha river basin is the Alos Palsar (2021). The tools for obtaining it are "Fill sinks (Wang & Liu)", "Channel network and drainage basins" and "Upslope area", all from SAGA software, integrated with QGIS 3.18.3 with GRASS 7.8.5.

Thematic maps were also made in QGIS 3.18.3 with GRASS 7.8.5 from vector and raster files obtained free of charge from specialized electronic addresses. The sources of the geology theme are Pacheco et al. (2017) and Rosa, Ferreira and Brito (2019). The hypsometry and slope were generated using Alos Palsar (2021) image. The elevation intervals were established in the image properties, while the slope was obtained using the "Slope" option, with the classes being sliced in the raster properties.

Still in relation to the themes, the soil map was elaborated through the vectorization of the soil image from EPAMIG (1980). The rainfall was obtained from interpolated data from rainfall stations located in and around the study area. These data are made available by the HidroWeb portal (ANA, 2021). The order of the channels corresponds to information from the attribute table of the IGAM (2012) vector file. The land cover and use maps were obtained with the image from the MapBiomas Collection 6 Project (2021).

However, other maps were prepared based on specific methodologies, such as the compartmentalization of geosystems and vulnerability to soil loss, based on authors from the French school of geosystemic studies: Bertrand and Bertrand (2009) and Tricart (1977). The geosystems correspond to the geomorphological compartments, while the geocomplexes were organized by morphometric aspects. For the delimitation of the geofacies, elevation intervals were defined using the "r.reclass" tool of QGIS 3.18.3 with GRASS 7.58.5. For the vulnerability to soil loss, the "Raster Calculator" of the above-mentioned software was used.

The methodological perspective used for the compartmentalization of geosystems is part of the GTP system (Geosystem-Territory-*Paysage*), by Bertrand and Bertrand (2009). In this multiscale methodology, the geosystem is the naturalistic input, associated with geological time, and can be identified as a large area relatively homogeneous from a physiographic point of view. Each geosystem can be compartmentalized in geofacies from the observation of even more homogeneous portions and other smaller units in the geofacies can also be represented, the geotopes.

Bertrand and Bertrand (2009) still consider the vertical perspective (geohorizons) to be important in landscape analysis, which can be portrayed through geoecological profiles. Thus, four profiles were drawn that contemplate a synthesis of the terrestrial reality of each geocomplex. Santos, Ruchkys and Travassos (2021) emphasize that the profiles favor horizontal and vertical readings and the interpretation of correlations between the landscape components. For Cavalcanti (2014, p. 37), the profiles can be called type-sections and constitute a model whose aim is to "characterize the landscape variations along the landform gradient".

The geoecological profiles were developed in QGIS 3.18.3 with GRASS 7.8.5. Initially, the transects were traced with vector files of the line type and the profiles were generated using the "Profile tool" plugin. Then, all tracks corresponding to land cover and use, soils, geofacies, geology and vulnerability to soil loss were added to the print composer.

Regarding Tricart, his methodological assumptions known as "ecodynamics" (TRICART, 1977) served as a basis for Crepani et al. (2001) to establish degrees of vulnerability to soil loss (Table 1). For Tricart (1977), the areas where pedogenesis predominates would be the stable environments, the portions of greater instability (morphogenesis) would correspond to the strongly unstable environments and, finally, the lands in which there is a balance between pedogenesis and morphogenesis are called intergrades.

Table 1 – Scale of vulnerability to soil loss.

LANDSCAPE UNIT	AVERAGE			DEGREE OF VULNERABILITY	DEGREE OF SATURATION			
					RED	GREEN	BLUE	COLORS
U1	↑	3.0		VULNERABLE	255	0	0	
U2		2.9			255	51	0	
U3		2.8			255	102	0	
U4	V	2.7			255	153	0	
U5	U	2.6		MODERATELY VULNERABLE	255	204	0	
U6	L	2.5	S		255	255	0	
U7	N	2.4	T		204	255	0	
U8	E	2.3	A		153	255	0	
U9	R	2.2	B	MEDIAN STABLE/VULNERABLE	102	255	0	
U10	A	2.1	I		51	255	0	
U11	B	2.0	L		0	255	0	
U12	I	1.9	I		0	255	51	
U13	L	1.8	T		0	255	102	
U14	I	1.7	Y	MODERATELY STABLE	0	255	153	
U15	T	1.6			0	255	204	
U16	Y	1.5			0	255	255	
U17		1.4			0	204	255	
U18		1.3		STABLE	0	153	255	
U19		1.2			0	102	255	
U20		1.1			0	51	255	
U21		1.0	↓		0	0	255	

Source: Crepani et al. (2001, p. 22).

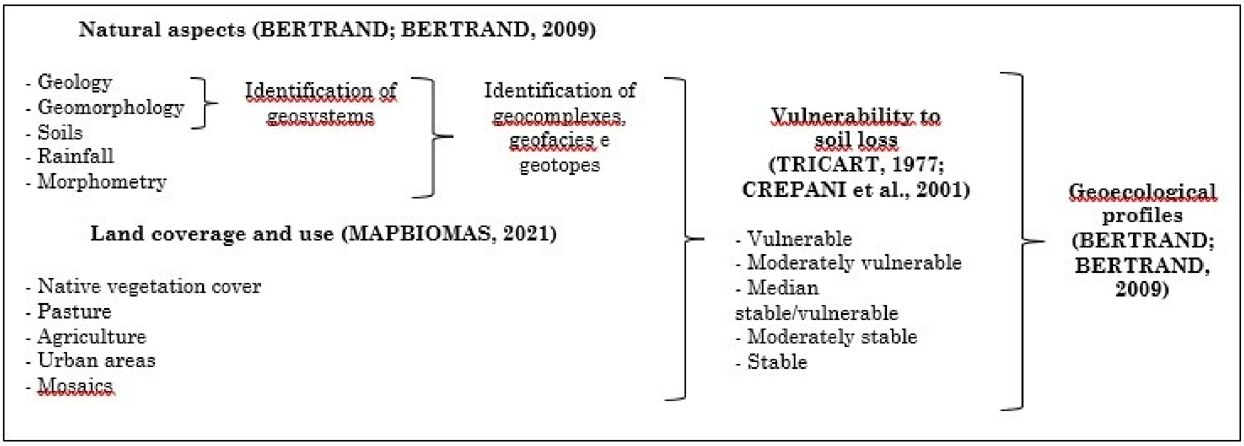
Based on the scale by Crepani et al. (2001), the physiographic variables have different vulnerability values. Thus, the work contemplated the indication of the values in the attribute table of each variable from the geology, geofacies, soils, rainfall as well as land cover and use components. Subsequently, the vector files were converted to raster and overlapping on the QGIS 3.18.3 with GRASS 7.8.5 "Raster Calculator" in order to extract the arithmetic mean. The result indicates the degree of vulnerability from the following equation:

$$V = \frac{(Geol + Geof + Sol + IP + CUT)}{5}$$

Where:
V = Vulnerability
Geol = Vulnerability for the Geology theme
Geof = Vulnerability for the Geofacies theme
Sol = Vulnerability for the Soils theme
IP = Vulnerability for the Rainfall Intensity theme
CUT = Vulnerability for the Land Cover and Use Theme.

After the natural aspects survey, the land cover and use as well as the vulnerability to soil loss, geoecological profiles were prepared to represent the identified geocomplexes (Chart 1). It is a schematic characterization capable of representing the variations of the physiographic components along a topographic section (CAVALCANTI, 2014), based on the geohorizons of Bertrand and Bertrand (2009).

Chart 1 – Schematic aspects of the methodological procedure.



Elaborated by the authors (2021).

RESULTS

Natural Aspects

The Paraná Sedimentary Basin is the predominant geotectonic context in the Uberabinha river basin, whose rocks present in the study area were formed in the Cretaceous Period (Mesozoic). However, in the final stretch of the main river, rocks from the Brasília Orogen (Neoproterozoic) emerge. These regional basement rocks correspond to the mica schists of the Araxá Group (SEER; MORAES, 2017).

The rocks from the Lower Cretaceous are the basalts from the Serra Geral Formation (São Bento Group) and of the Upper Cretaceous are the sandstones from the Marília Formation (Bauru Group). It is noteworthy that sandstones from the Botucatu Formation (not mappable) are occasionally found under the mica schists or in the form of intertrap lenses with the basalts (PACHECO et al., 2017).

In the Cenozoic, there were peneplanation processes, landform dissection and formation of lateritic covers. In the Paleogene, the planing originated the "South American Surface" under arid conditions. In the Neogene, under humid climate, this Surface experienced the "Old Cycle" process, forming the plateaus. Finally, in the Quaternary, the "Paraguaçu Cycle" exhumed the rocks of the Neproterozoic, (KING, 1956; MOREIRA; PEREZ FILHO, 2020).

In view of the above, it is observed that the Uberabinha river basin has two large geomorphological compartments. The first, located in the upper course and Bom Jardim basins, is a plateau. The higher portions (the pediplanes) are the remnants of the "South American Surface". The rest of the basin corresponds to a dissected plateau, associated with the "Old Cycle and, to a lesser extent, the "Paraguaçu Cycle", with exposure of the Araxá Group.

In order to emphasize the presence of the mentioned compartments and observing the hypsometry and slope maps of Figure 2, it is noted that the elevation of the plateau, for the most part, is above 900 m. The slope classes in the plateau are: 0% to 3% (flat), 3% to 8% (smooth undulating) and 8% to 20% (undulating). On the plateau, there are classes 20% to 45% (strong undulating) and greater than 45% (mountainous) in the most dissected valleys.

Regarding the soil classes in the study area (Chart 2 and Figure 2), Latosols are predominant, they can be found in the plateau and upland. However, some soil classes are found only in one of the geomorphological compartments. Red-Yellow Latosols are present in the plateau, while Cambisols and Neosols are restricted to the upland, especially on hillsides with a higher slope (EPAMIG, 1980; SANTOS et al., 2018).

Chart 2 – Soil classes of the Uberabinha river basin.

CXbe1 – HAPLIC CAMBISOLS Tb typical Dystrophic
CXbe2 - HAPLIC CAMBISSOLS Tb typical Dystrophic + LITHOLIC NEOSSOLS Dystrophic
GXbd1 – HAPLIC GLEISOLS Tb typical Dystrophic
GXbd2 – HAPLIC GLYSOLS Tb typical Dystrophic + HAPLIC ORGANOSOLS
LVAd1 – RED-YELLOW LATOSOLS typical Dystrophic
LVd1 – RED LATOSOLS typical Dystrophic
LVd2 – RED OXISOLS typical Dystrophic + RED-YELLOW ARGISOLS typical Dystrophic
LVdf1 – RED LATOSOLS typical Dystroferric
LVdf2 – RED LATOSOLS typical Dystroferric + HAPLIC CAMBISSOLS Tb leptic Eutrophic
LVef1 – RED LATOSOLS typical Eutroferric
LVef2 – RED OXISOLS typical Eutroferric + HAPLIC CAMBISSOLS Tb typical Eutrophic

Source: Adapted from EPAMIG (1980) and Santos et al. (2018).

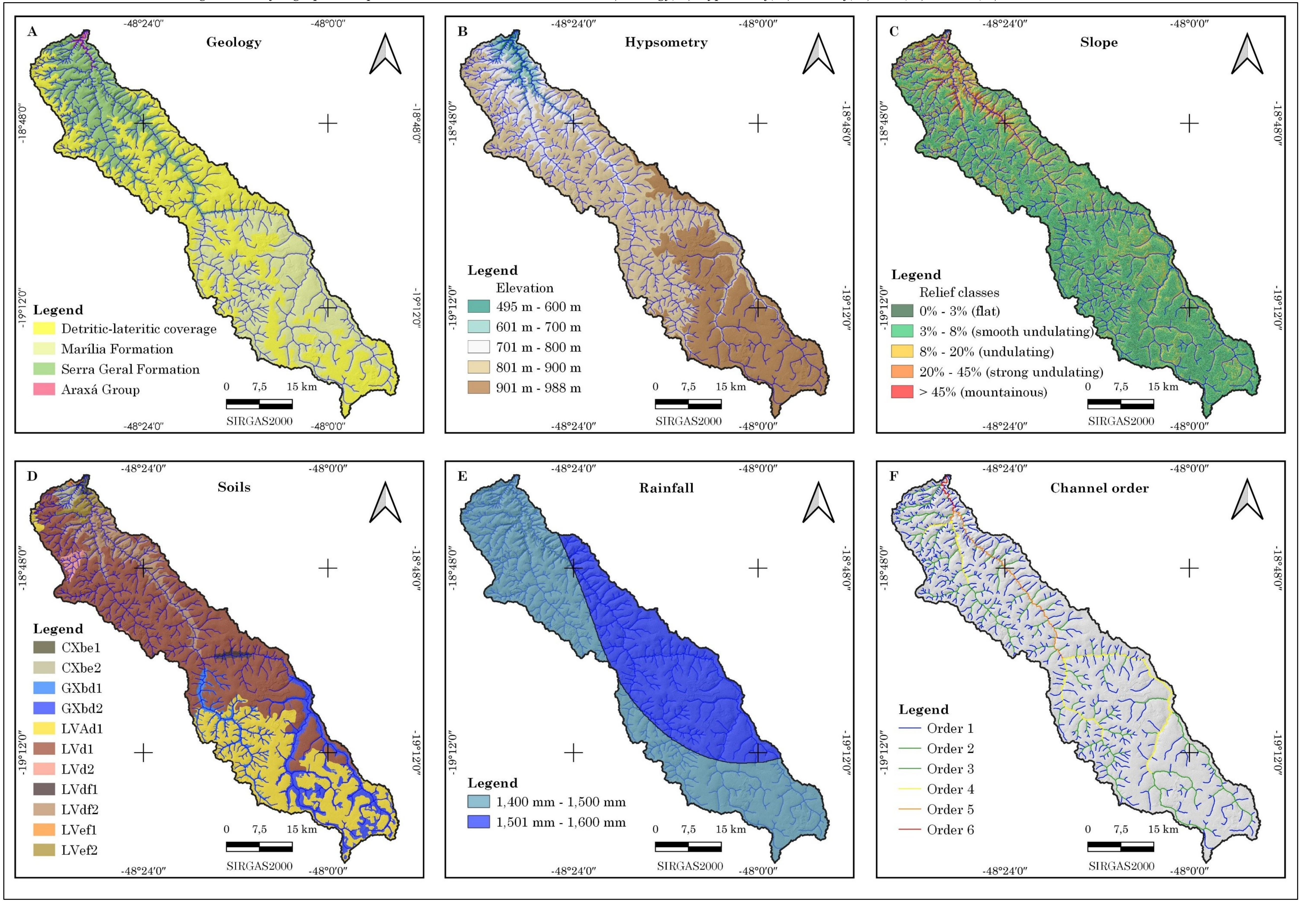
The vegetational phase associated with soils comprises the three phytophysiognomic formations found in the "Domínio dos Cerrados" (AB'SABER, 2012): forest, savanna and grassland. The forest formation encompasses the deciduous tropical forest, subdeciduous, lowland hydrophilic phases, as well as the subdeciduous "tropical cerradão". The subdeciduous tropical cerrado phase is part of the savanna formation and the lowland hydrophilic field is part of the grassland formation.

Regarding the climatic conditions, the Uberabinha river basin is located in the Tropical Zone of Central Brazil (IBGE, 2002). Average temperatures exceed 18°C most of the year and the dry period varies from 4 to 5 months. The average annual rainfall ranges from 1,400 mm to 1,600 mm, with two well-defined seasons: rainy and hot summer and dry winter.

Another important component for identifying geomorphological compartments is morphometry. Feltran Filho and Lima (2007) identified that the portions with the lowest density of rivers are in sedimentary terrain, from flat to gently undulating topography. In more undulated areas and with more embedded channels, with basaltic substrate, the number of channels is increased.

When it comes to Strahler's (1952) channel hierarchy, the final stretch of the Uberabinha river is of order 6. The final stretches of the upper Uberabinha river, the Beija-Flor and Bom Jardim streams and the Pedras river are of order 4. In addition to the hierarchy of the channels, the maps of the described components of the Uberabinha river basin contribute to the analysis of the physiographic aspects (Figure 2).

Figure 2 – Physiographic components of the Uberabinha river basin. A) Geology; B) Hypsometry; C) Declivity; D) Soils; E) Rainfall; F) Order of channels.



Elaborated by the authors (2021).

Based on Bertrand and Bertrand (2009), the two geomorphological compartments identified (plateau and upland) can be considered as two geosystems: the Plateau Uberlândia-Uberaba and the Dissected Upland of the Triângulo Mineiro.

The Plateau Uberlândia-Uberaba geosystem can be further divided into two geocomplexes: Planned Surfaces Very Little Dissected and the Planned Surfaces Little Dissected. This compartmentalization is due to the fact that there is a lower power to generate first-order channels in the upper Uberabinha and Beija-Flor stream sub-basins (very little dissected) when compared to the Beija-Flor stream (little dissected).

In the Dissected Upland of the Triângulo Mineiro, two other geocomplexes are noticeable when analyzing the physiographic components: Little Downgraded Levels and Downgraded Levels and Deep Valley. The difference is due to a very noticeable change in elevation and slope, where the rocks of the Araxá Group are found in the last geocomplex.

Each geocomplex is further divided into geofacies, which can be repeated among them, even if they differ to some degree. The etchplaned degraded pediplan, the homogeneous dissection modeled, the plains and river terraces and the notches of varied incisions as well as the structural dissection are considered as geofacies. In each geofacie there are also examples of the smallest homogeneous units considered by Bertrand and Bertrand (2009), the geotopes (Figure 3).

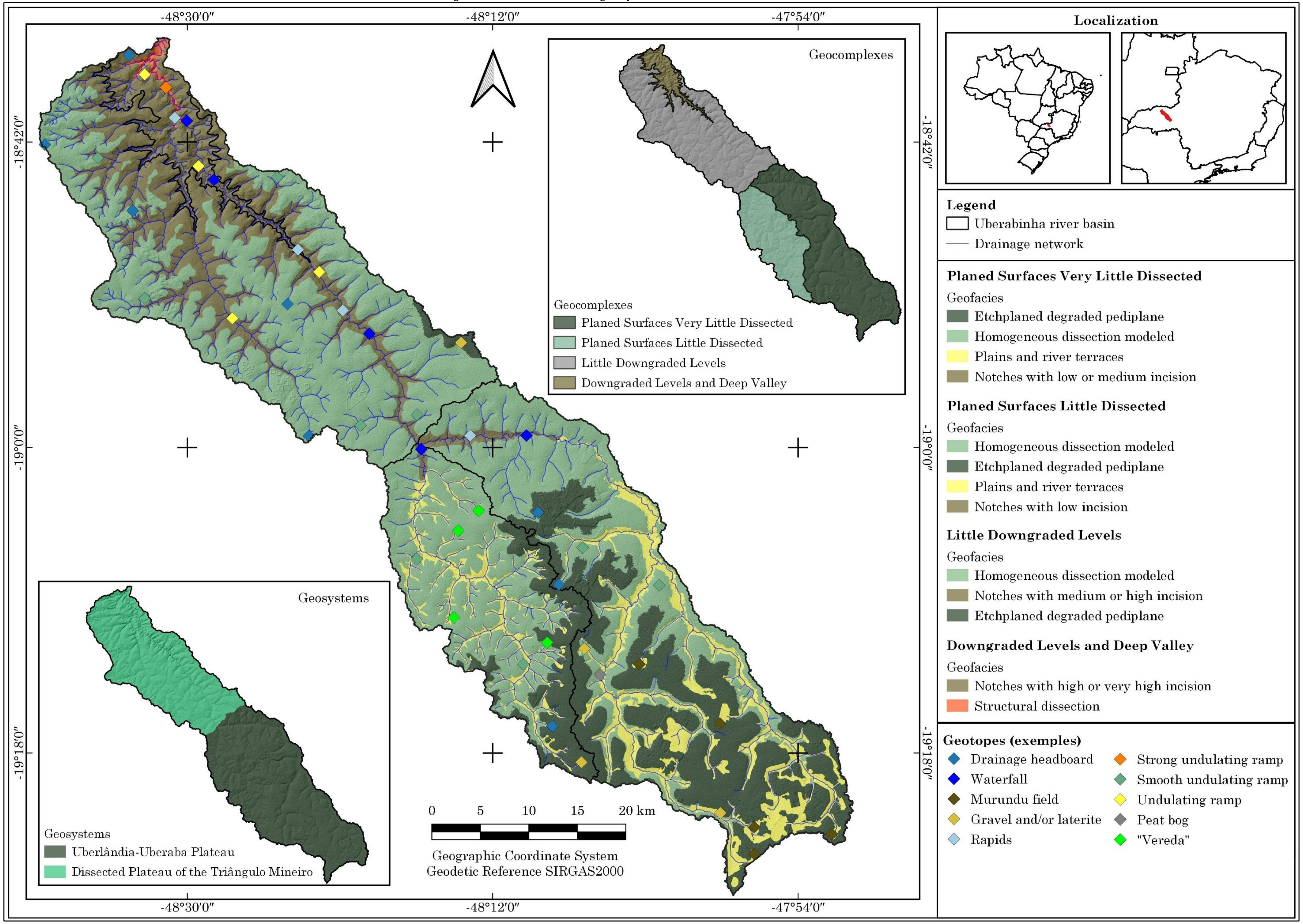
Land cover and use

In the 1960s, the Uberabinha river basin had significant native vegetation cover. However, due to government incentives, the first changes to natural spaces occurred in the 1970s with the rise of forestry and agriculture (SCHNEIDER, 1996). In this context, the growth of the city of Uberlândia, located in the middle course, was intensified by the expansion of industries and the consolidation of transport infrastructure.

According to the calculation of areas carried out from the images of the MapBiomas Project (2021) since the 1980s, the classes of land cover and use are the same, but different areas of occupation over the period 1985-2020 (Table 2). The data corroborate the indication that the natural areas have been converted into anthropic occupations, which indicates a continuous appropriation of the natural resources of the Uberabinha river basin.

The study area lost 11.34% of native vegetation cover (forest, savanna and grassland formations) between 1985 and 2020. In 1985, vegetation occupied 26.93%, while in 2020 it was present in only 15.59 % of the basin. Over these 35 years, soybeans, which represented a paltry 0.45% of occupation in 1985, became the largest class of land use in 2020, 24.97%. Pasture has decreased considerably, but it is still a relevant form of occupation, with 39.61% in 1985 and 17.64% in 2020. The urbanized area more than doubled the occupation.

Figure 3 – Subdivision of geosystems in the Uberabinha river basin.



Elaborated by the authors (2021).

Table 2 – Areas and percentages of land cover and use in the Uberabinha river basin.

Classes	**Periods, areas and percentages of occupancy**											
	1985		**1992**		**1999**		**2006**		**2013**		**2020**	
	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
Forest formation	251.68	11.50	178.23	8.14	132.58	6.06	128.54	5.87	115.3	5.27	116.61	5.33
Savanna formation	176.61	8.07	160.63	7.34	119.65	5.46	117.86	5.38	117.23	5.35	103.26	4.72
Wetland	91.29	4.17	79.77	3.64	74.98	3.42	72.46	3.31	70.64	3.23	70.25	3.21
Grassland	161.11	7.36	128.79	5.88	103.55	4.73	104.40	4.77	117.21	5.35	121.21	5.54
Pasture	867.32	39.61	827.42	37.79	774.62	35.38	623.97	28.50	460.67	21.04	386.16	17.64
Soybean	9.88	0.45	62.13	2.84	92.95	4.25	379.16	17.32	335.05	15.30	546.61	24.97
Coffee	14.02	0.64	0.67	0.03	2.68	0.12	1.79	0.08	0.79	0.04	2.71	0.12
Sugar cane	0.02	0.00	0.02	0.00	0.02	0.00	0.06	0.00	59.95	2.74	114.27	5.22
Mosaic of agriculture and pasture	309.81	14.15	314.09	14.35	216.29	9.88	227.94	10.41	310.42	14.18	332.56	15.19
Forest plantation	108.74	4.97	133.03	6.08	111.84	5.11	106.88	4.88	101.71	4.65	97.28	4.44
Urban area	60.64	2.77	83.24	3.80	97.92	4.47	109.3	4.99	122.93	5.61	133.76	6.11
Other non-vegetated areas	19.48	0.89	5.28	0.24	4.59	0.21	4.09	0.19	6.44	0.29	8.32	0.38
Water	4.31	0.20	6.13	0.28	5.71	0.26	5.27	0.24	5.35	0.24	5.31	0.24
Other temporary crops	114.51	5.23	209.99	9.59	452.04	20.65	307.7	14.05	365.73	16.70	151.11	6.90
Total	2,189.42	100.00	2,189.42	100.00	2,189.42	100.00	2,189.42	100.00	2,189.42	100.00	2,189.42	100.00

Source: Adapted from MapBiomas (2021).

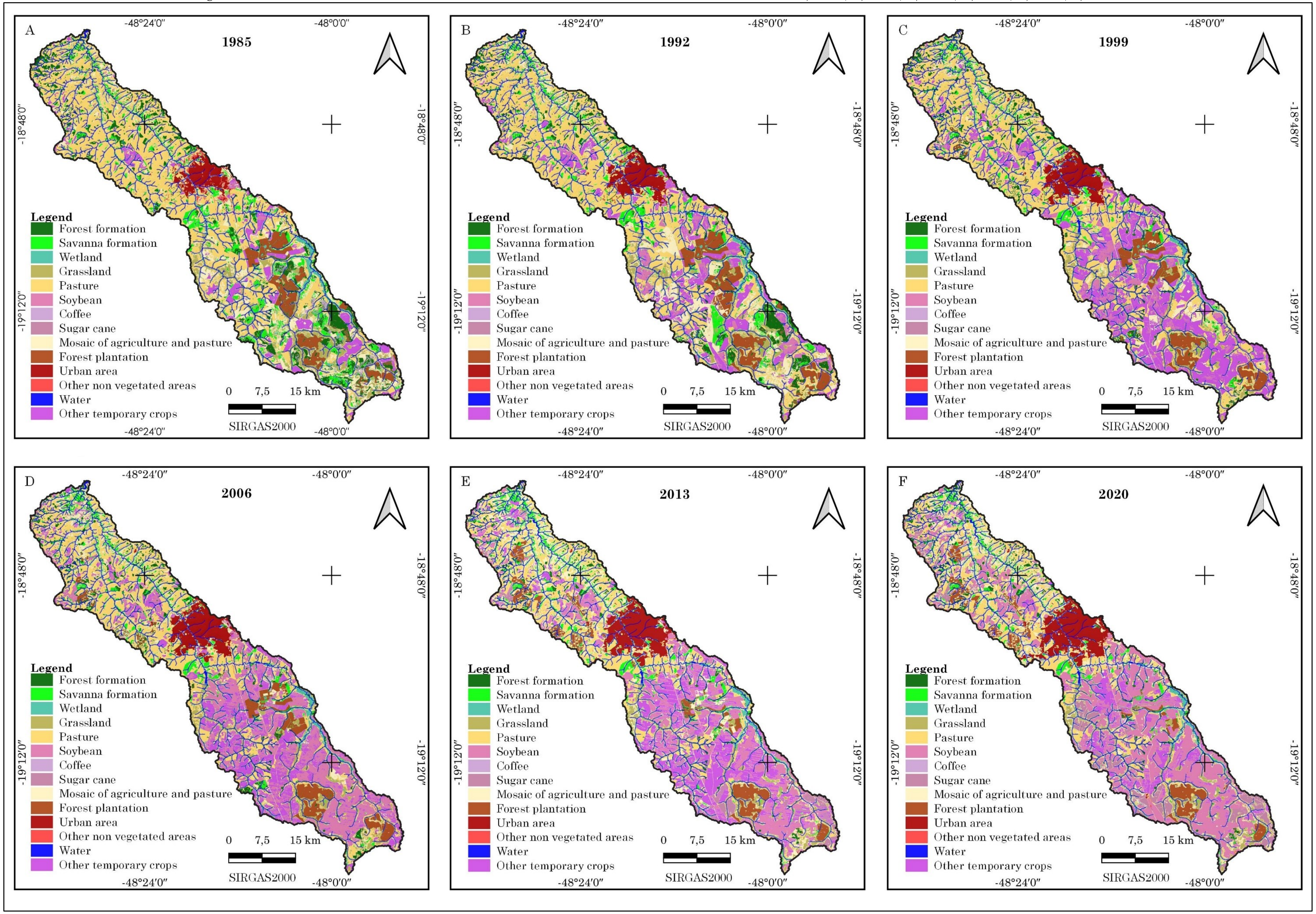
Soc. Nat. | Uberlândia, MG | v.34 | e63507 | 2022 | ISSN 1982-4513

The gradual decrease in native vegetation cover has been caused by different forms of appropriation of the basin's territory. In Uberlândia-Uberaba Plateau, technified agriculture advances over wetlands. In the Dissected Upland of the Triângulo Mineiro, the portion in which the relief has greater undulation contributed to a lower incentive for mechanized agriculture. Agricultural areas in the Upland are more restricted than in Plateau.

Thus, there are two large social groups that interfere in the use of land in the basin: farmers capitalized in Uberlândia-Uberaba Plateau, linked to agribusiness; and small farmers and ranchers in the Dissected Upland of the Triângulo Mineiro. Both of the groups can be identified by land use classes in the form of maps (Figure 4).

Other forms of occupation, such as the refractory clay mining in Plateau and the Small Hydroelectric Power Plants (SHPs) in the Upland, are located occasionally in the basin.

Figure 4 – Evolution of land cover and use in the Uberabinha river basin between 1985 and 2020. A) 1985; B) 1992; C) 1999; D) 2006; E) 2013; F) 2020.



Elaborated by the authors (2021).

Vulnerability to soil loss

Vulnerability to soil loss was obtained by assigning vulnerability values (1.0 to 3.0) to physiographic variables pertaining to geology, geofacies, soils, rainfall intensity and land cover and use (Chart 3). Values were based on indications by Crepani et al. (2001) from the tendency that each variable has in relation to stability/vulnerability to soil loss.

Chart 3 – Vulnerability values of the physiographic variables.

Physiographic components	Physiographic Variables	Vulnerability values
Geology	Detritic-lateritic covers (laterites)	1.4
	Marília Formation (sandstones)	2.4
	Serra Geral Formation (basalts)	1.5
	Araxá Group (micaschists)	2.0
Geofacies	Etchplaned degraded pediplane	1.0
	Homogeneous dissection model	2.0
	Plains and river terraces	3.0
	Notches with low incision	1.5
	Notches with low or medium incision	2.0
	Notches with medium or high incision	2.5
	Notches with a high or very high incision	3.0
	Structural dissection	3.0
Soils	Cambisols/Neosols	2.5
	Gleysols/Organosols	3.0
	Latosols/Argisols	1.0
Rainfall intensity	175,00 mm – 214,28 mm (1.400 mm – 1.500 mm)	1.7
	187,50 mm – 228,57 mm (1.500 mm – 1.600 mm)	1.8
Land cover and use	Forest formation	1.4
	Savanna formation	1.7
	Wetland	3.0
	Grassland	1.9
	Pasture	2.8
	Soybean	2.7
	Coffee	2.5
	Sugar cane	2.5
	Mosaic of griculture and pasture	2.6
	Forest plantation	2.1
	Urban área	-
	Other non-vegetated areas and other temporary crops	2.7
	Water	-

Source: Adapted from Crepani et al. (2001).

The geology presents, for the most part, moderately stable areas, while the geofacies vary according to the environment. The vulnerability values of the geofacies were assigned according to the two predominant slope classes. The exceptions are the plains and river terraces, as they present environmentally fragile terrains (Table 4). Regarding soils, the study area has a predominance of developed soils, so stability values were assigned in most classes.

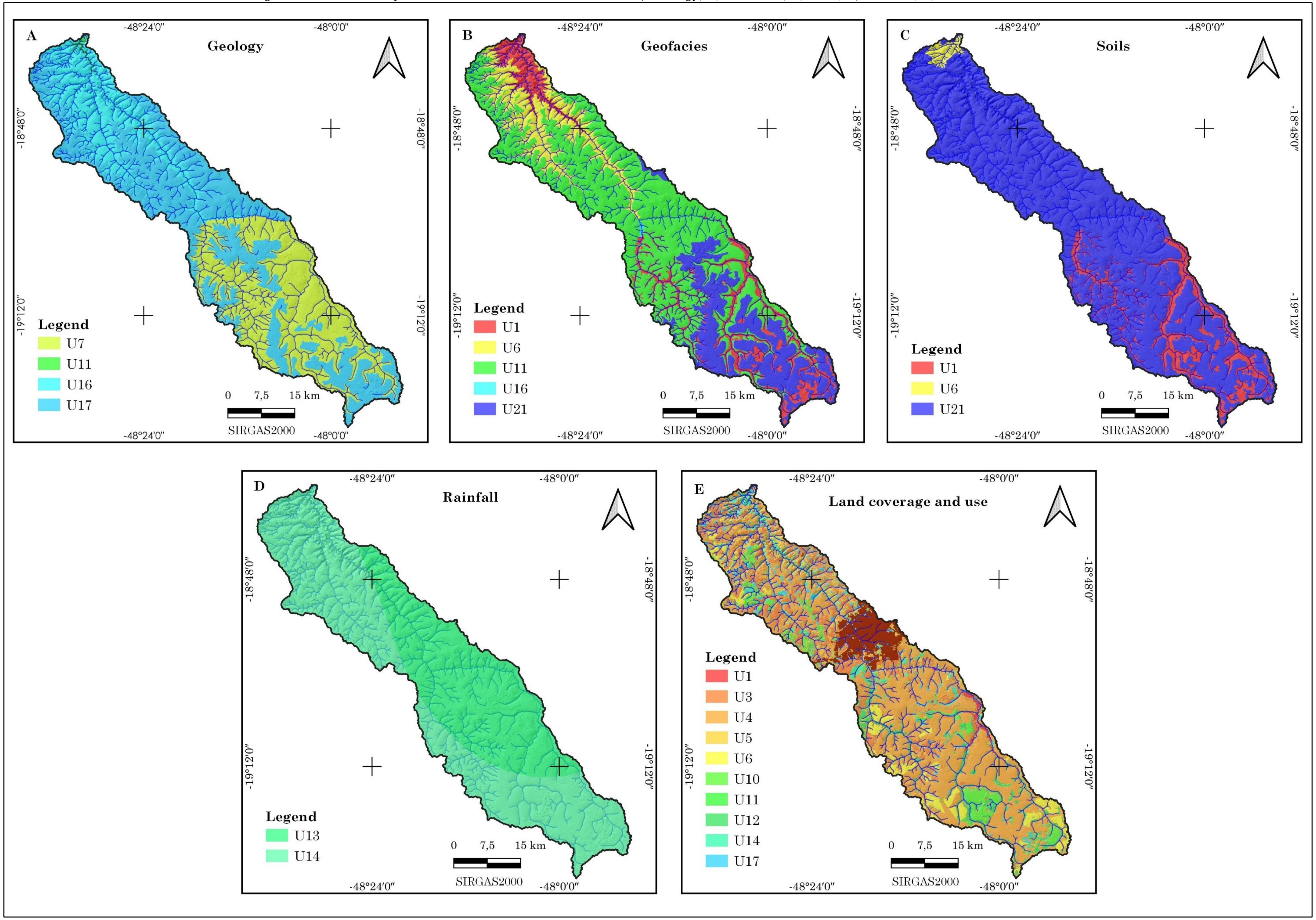
Chart 4 – Predominant slope classes by geofacies.

Geofacies	Predominant slope classes	Vulnerability values
Etchplaned degraded pediplane	0% – 3% e 3% – 8%	1.0
Homogeneous dissection model	3% – 8% e 8% – 20%	2.0
Plains and river terraces	3% – 8% e 0% – 3%	3.0
Notches with low incision	3% – 8% e 8% – 20%	1.5
Notches with low or medium incision	8% – 20% e 3% – 8%	2.0
Notches with medium or high incision	8% – 20% e 20% – 45%	2.5
Notches with a high or very high incision	20% – 45% e >45%	3.0
Structural dissection	20% – 45% e >45%	3.0

Source: Adapted from Crepani et al. (2001).

The rainfall was presented based on the rainfall intensity definitions by Crepani et al. (2001), defined in classes, minimum and maximum (both in mm/month). The Uberabinha river basin has seven to eight months of rainy season. Thus, in order to obtain the maximum rainfall intensity, the highest average annual precipitation value within a class (interval) was divided by seven and, conversely, to obtain the minimum, the lowest average annual precipitation value was divided by eight. of the same class (Figure 5).

Figure 5 – Vulnerability units of the Uberabinha river basin. A) Geology; B) Geofacies; C) Soils; D) Rainfall; E) Land cover and use.



Elaborated by the authors (2021).

From the definition of vulnerability values in the physiographic components, the thematic maps were superimposed and the arithmetic mean was extracted to obtain the landscape units. Then, the values in the classes of vulnerability to soil loss by Crepani et al. (2001) were added as well as the areas and percentages of occupation in each geocomplex of the Uberabinha river basin were calculated (Table 3).

Table 3 - Areas and percentages of vulnerability by geocomplex.

Geocomplex	Degrees of vulnerability	km²	%
Planed Surfaces Very Little Dissected	Moderately vulnerable	169.11	20.17
	Moderately stable/vulnerable	238.11	28.40
	Moderately stable	416.39	49.,66
	Stable	6.64	0.79
	Waterproofed área	8.25	0.98
	Total	838.50	100.00
Planed Surfaces Little Dissected	Moderately vulnerable	69.35	17.44
	Moderately stable/vulnerable	143.02	35.96
	Moderately stable	184.39	46.37
	Stable	0.93	0.23
	Waterproofed área	0.00	0.00
	Total	397.69	100.00
Little Downgraded Levels	Moderately vulnerable	0.00	0.00
	Moderately stable/vulnerable	225.24	26.62
	Moderately stable	495.49	58.56
	Stable	0.00	0.00
	Waterproofed área	125.43	14.82
	Total	846.16	100.00
Downgraded Levels and Deep Valley	Moderately vulnerable	2.64	2.47
	Moderately stable/vulnerable	81.04	75.69
	Moderately stable	23.39	21.85
	Stable	0.00	0.00
	Waterproofed área	0.00	0.00
	Total	107.07	100.00

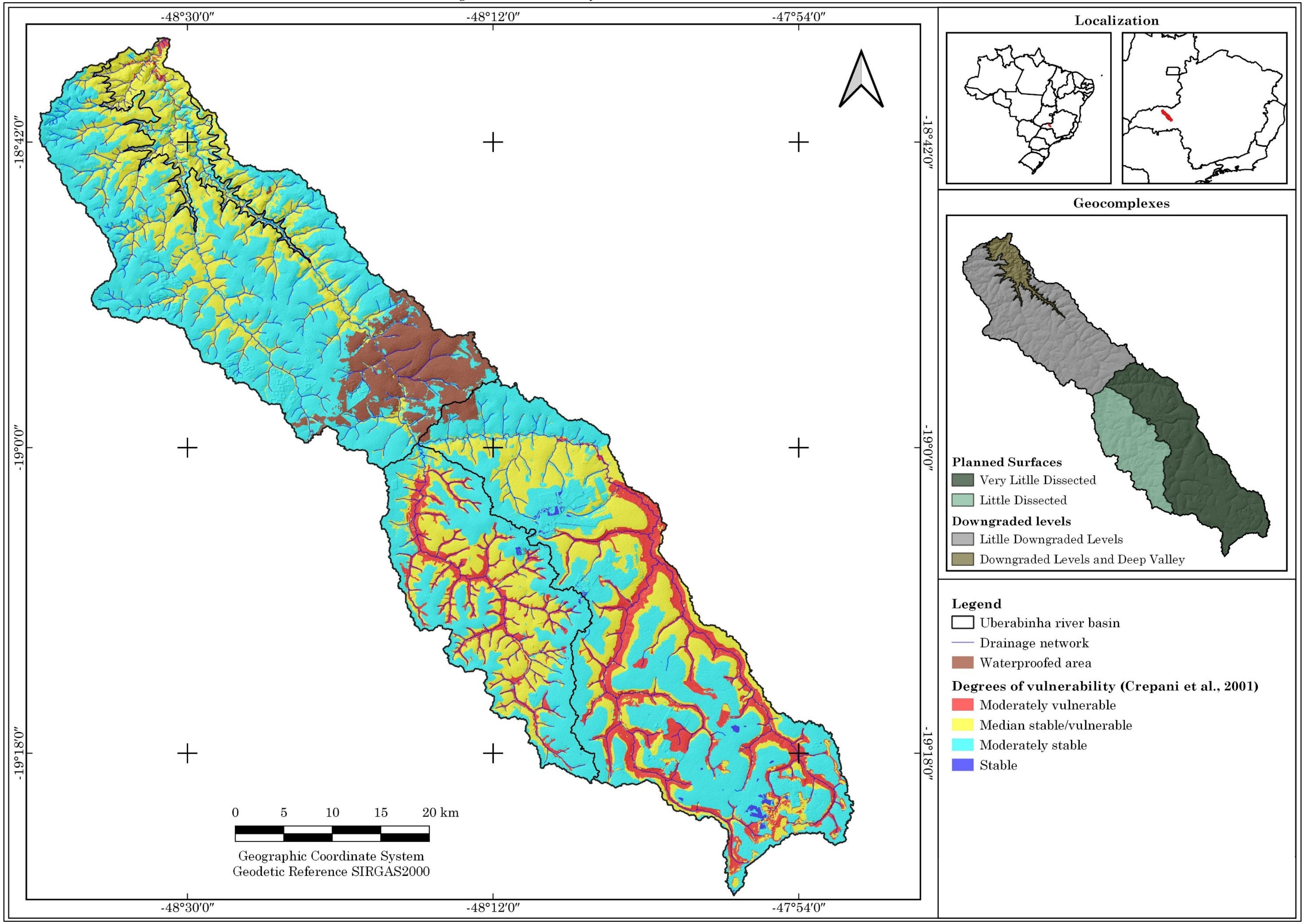
Source: Adapted from Crepani et al. (2001).

The results indicate that moderately stable areas stand out in all geocomplexes. With the exception of the Downgraded Levels and Deep Valley, whose mentioned class is the second in occupation area, the other geocomplexes present moderately stable terrains as predominant terrains. This condition indicates that the variables tend to be relatively stable for the most part.

As an example, the presence of laterites in pediplans and models of homogeneous dissection, in addition to Latosols in the Planed Surfaces Very and Little Dissected geocomplexes, contributed to the fact that the moderately stable areas are significant. The basalts in homogeneous dissection models and the Latosols in the Downgraded Levels also defined the predominance of areas established as moderately stable.

The moderately stable/vulnerable class is also representative in geocomplexes. This result derived from the average of some variables that tend towards stability (soils) and others towards vulnerability (land use). The moderately vulnerable terrains are in the portions of hydromorphic soils in the Uberlândia-Uberaba Plateau in areas of the Downgraded Levels and Deep Valley. Stable areas are quite restricted, associated in a combination that includes pediplanes (Figure 6).

Figure 6 – Vulnerability to soil loss in the Uberabinha river basin.

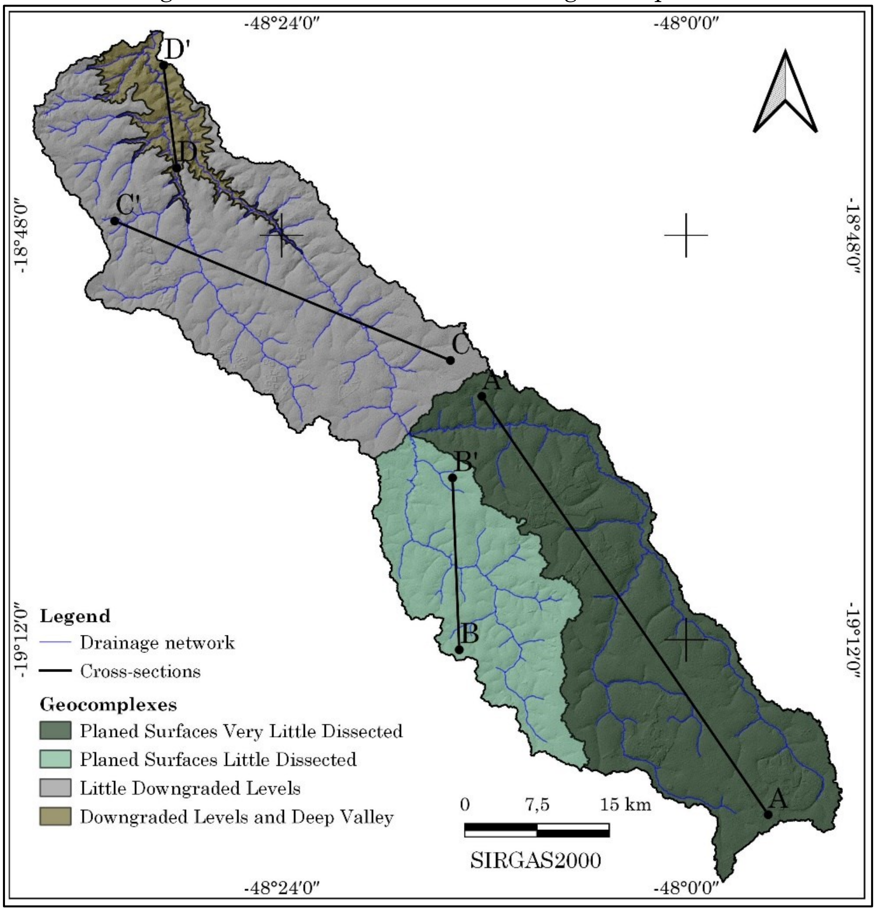


Elaborated by the authors (2021).

Geoecological profiles

The geoecological profiles constitute a representative scheme of integrated analysis of the landscape. In this sense, four transects were established, one in each geocomplex, in order to obtain a synthesis of the terrestrial reality in a vertical perspective (geohorizons) (Figures 7).

Figure 7 – Location of transects in geocomplexes.



Elaborated by the authors (2021).

Profiles A – A' and B – B', with a length of just over 54 km and 18 km respectively, have similar characteristics. In geology, both sandstones and lateritic covers are widely represented. Only in the profile A – A', in the section that crosses the Uberabinha river, the basalts are outcropping. In the wide dividers, especially in A – A', pediplanes are predominant, while smooth hillsides represent the modeled, best represented in the B – B' profile.

Still in profiles A – A' and B – B', the most representative soils correspond to Latosols. Only on the plains and river terraces Gleysols and Organosols can be found. In this context, the two profiles located in the Uberlândia-Uberaba Plateau corroborate the natural aspects described above: in general the relief is planed or smooth-undulated, which favors pedogenetic processes to the detriment of morphogenetic ones. Thus, mechanized agriculture is the main occupation.

The profile C – C', of just over 38 km, passes the basalts in the channel of the watercourses (notches), as well as in the medium and low hillsides (modeled of homogeneous dissection). The detritic-lateritic covers are found in the higher areas. Although the relief is more undulated than in the plateau, Latosols are still the main class in this geocomplex. Land use is the component with the greatest variation in the profile, in which the urbanized area, agriculture and pasture are considered the most expressive.

Finally, the profile D – D', with a length of just over 11 km, demonstrates a difference in relation to the other geocomplexes. Basalts are found on most hillsides, in more incisive notches. The mica schists outcrop in the Uberabinha river channel and final stretches of other drainages, in structural dissection. The soil classes depend on the relief, in which Latosols, Cambisols and Neosols, as well as the land use, vary from pastures to vegetation cover, according to the slope.

Regarding vulnerability to soil loss, it is observed that in the plateau transects (A – A' and B – B') moderately stable areas occur mainly in the broad topographic divides. However, the wetlands are considerably vulnerable, which are pointed out in the river valleys and their adjacencies.

In upland transects, there is a greater difference in vulnerability classes. While in the C – C' profile there is an intercalation between moderately and moderately stable/vulnerable areas, in the D – D' profile the moderately stable/vulnerable areas are predominant (Figure 8).

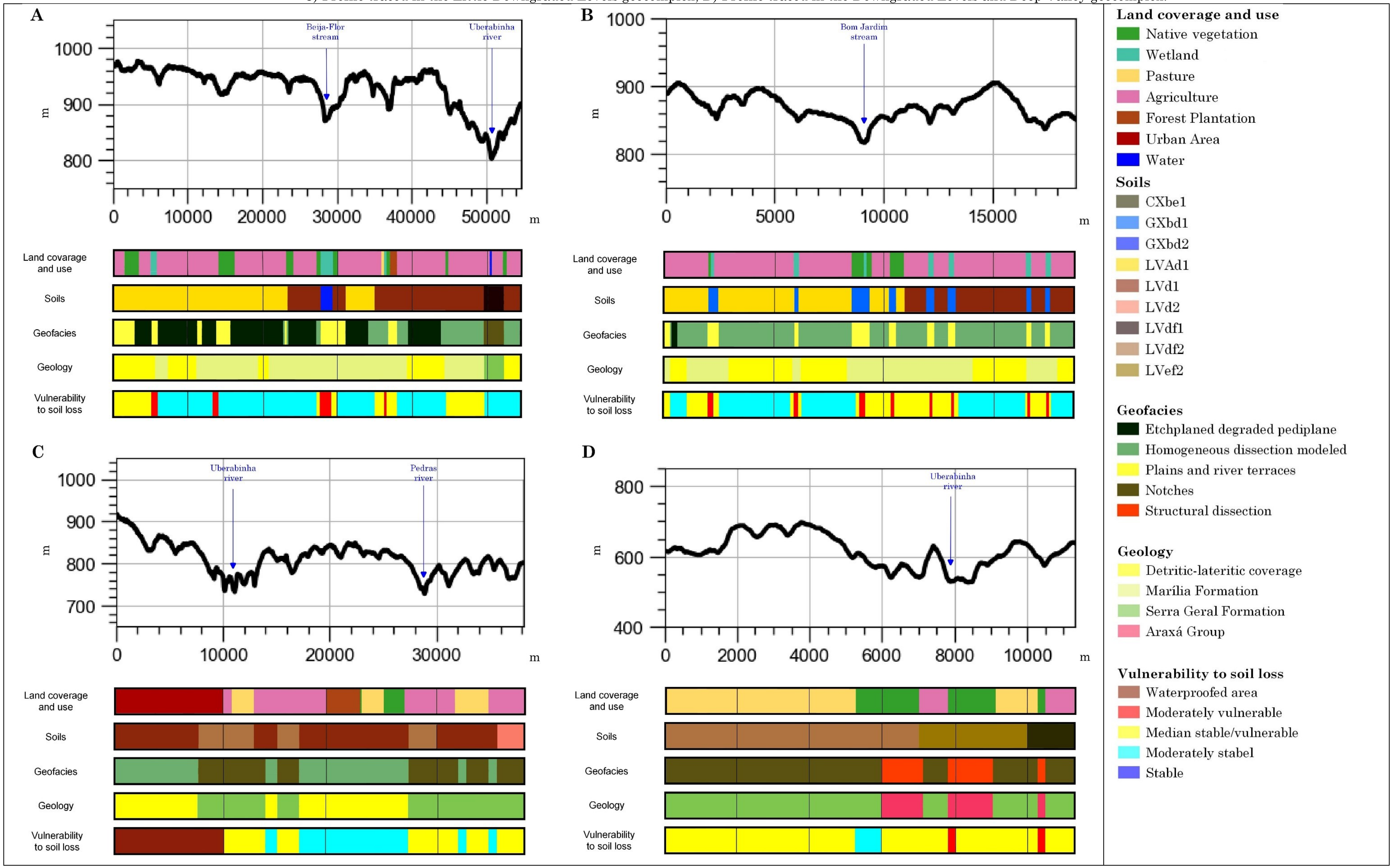
FINAL CONSIDERATIONS

Good environmental quality, which includes a series of aspects closely linked to quality of life, requires a balanced association of actions subordinated to the weaknesses and potential of the environment. In this context, we seek to minimize the impacts of economic actions on nature by means of procedures that aim to identify the natural characteristics and ways of using the resources available in the territories. The integrated diagnosis of physiographic components and land uses, through landscape compartmentalization, provides important information to environmental planning and management instruments.

The watersheds have been adopted for the understanding and application of such premises. It is essential to recognize that the watersheds are internally heterogeneous, as they are configured as a set of spatially differentiated landscapes. In this perspective, the article presented a compartmentalization of the landscape regarding the Uberabinha river basin built on the geosystemic conception of the French school. This basin has internal specificities that justify the compartmentalization of the landscape in a multi-scale way. Mapping of physiographic components, land cover and use, and vulnerability to soil loss demonstrated this perspective.

Given the above, it is expected that this analysis of the Uberabinha river basin may contribute to the proposal of guidelines for planning and environmental management, since its exploitation has shown to be ecologically predatory, a condition not very different from most Brazilian hydrographic basins.

Figure 8 – Geocological profiles. A) Profile traced in the Planed Surfaces Very Little Dissected geocomplex; B) Profile traced in the Planed Surfaces Little Dissected geocomplex; C) Profile traced in the Little Downgraded Levels geocomplex; D) Profile traced in the Downgraded Levels and Deep Valley geocomplex.



Elaborated by the authors (2021).

ACKNOWLEDGEMENTS

The first author thanks the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for granting the doctoral scholarship.

REFERENCES

AB'SÁBER, A. N. **Os domínios de natureza no Brasil**: potencialidades paisagísticas. 7. ed. São Paulo: Ateliê Editorial, 2012. 158 p.

ALOS PALSAR. **Imagens Alos Palsar 2011, resolução espacial 12,5 m**. Available: https://search.asf.alaska.edu/#/. Accessed: Oct. 20th 2020.

ARIAS-GARCÍA, J.; GÓMEZ-ZOTANO, J.; DELGADO-PEÑA, J. J. Classifying landscape in endorheic basins: a methodological approach for the implementation of the European landscape convention. **European Journal of Geography**, v. 8, n. 2, p. 55-77, fev. 2017.

AGÊNCIA NACIONAL DE ÁGUAS. **Sistema de Informações Hidrológicas**. Available: http://www.snirh.gov.br/hidroweb/serieshistoricas. Accessed: Sep. 20th 2021.

BERTRAND, G. Paisagem e geografia física global: esboço metodológico. **Cadernos de Ciências da Terra**, n.13, 1971. (Trad. Paysage et géographie physique globale: esquisse méthodologique, 1968).

BERTRAND, G.; BERTRAND, C. **Uma geografia transversal e de travessias**: o meio ambiente através dos territórios e das temporalidades. (Translation: Messias Modesto dos Passos). Maringá: Ed. Massoni, 2009. 332 p.

BRASIL. **Mapeamento do uso e cobertura da terra do Cerrado**: Projeto TerraClass Cerrado 2013. Brasília: MMA, 2015. 67 p. Available: http://www.dpi.inpe.br/tccerrado. Accessed: Feb. 15th 2019.

CARLIER, J.; DOYLE, M.; FINN, J. A.; Ó HUALLACHÁIN; MORAN, J. A landscape classification map of Ireland and its potential use in national land use monitoring. **Journal of Environmental Management**, v. 289, p. 1 – 12, 2021. https://doi.org/10.1016/j.jenvman.2021.112498

CAVALCANTI, L. C. S. **Cartografia de paisagens**: fundamentos. São Paulo: Oficina de Textos, 2014. 95 p.

CAVALCANTI, L. C. S. **Da descrição de áreas à teoria dos geossistemas**: uma abordagem epistemológica sobre sínteses naturalistas. 216 f. Tese (Doutorado) – Federal University of Pernambuco, Recife, 2013.

CREPANI, E. *et al.* **Sensoriamento remoto e geoprocessamento aplicados ao Zoneamento Ecológico-Econômico e ao ordenamento territorial**. São José dos Campos: INPE, 2001. 124 p.

EMPRESA DE PESQUISA AGROPECUÁRIA DE MINAS GERAIS. **Mapa de reconhecimento dos solos no Triângulo Mineiro**. Serviço Nacional de Levantamento e Conservação dos Solos. 1980. Available: http://library.wur.nl/WebQuery/isric/21562. Accessed: May 5th de 2016.

FARIA, K. M. S.; SILVA, E. V. Dinâmica das paisagens antropogênicas na microrregião do Vão do Paraná (GO). **Revista Geográfica Acadêmica**, v. 14, n. 2, p. 141-152, 2020.

FELTRAN FILHO, A.; LIMA, E. F. DE. Considerações morfométricas da bacia do rio Uberabinha - Minas Gerais / Morphometric considerations of the Uberabinha river basin - Minas Gerais. **Sociedade & Natureza**, v. 19, n. 1, 1 nov. 2007.

GÜLÇIN, D.; YILMAZ, K. T. Mapping landscape potential for supporting green infrastructure: the case of a watershed in Turkey. **Land**, v. 9, p. 1 – 13, 2020. https://doi.org/10.3390/land9080268

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Arquivo vetorial do território brasileiro**. Disponível em: https://mapas.ibge.gov.br/bases-e-referenciais/bases-cartograficas/malhas-digitais. Accessed: Dec. 20th 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Divisão regional do Brasil em Regiões Geográficas Imediatas e Regiões Geográficas Intermediárias**. Rio de Janeiro: IBGE, 2017. Available: https://www.ibge.gov.br/apps/regioes_geograficas/. Accessed: May 6th 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Mapa de clima do Brasil escala 1:5.000.000**. Rio de Janeiro: IBGE, 2002. Available: https://geoftp.ibge.gov.br/informacoes_ambientais/climatologia/mapas/brasil/Map_BR_clima_2002.pdf. Access: Feb. 1st 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Uberlândia**: população estimada. Available: https://cidades.ibge.gov.br/brasil/mg/uberlandia/panorama. Accessed: Sep. 20th 2021.

INSTITUTO MINEIRO DE GESTÃO DAS ÁGUAS. **Rede de drenagem de Minas Gerais em formato *shapefile***. Belo Horizonte: Igam, 2012. Available on: http://idesisema.meioambiente.mg.gov.br/. Access on: Sep. 19th 2019.

KING, L, C. A. Geomorfologia do Brasil Oriental. **Revista Brasileira de Geografia,** Rio de Janeiro. v. 18, n. 2, p. 147-266, 1956.

LIMA, E. M.; CORRÊA, A. C. B. Compartimentação da paisagem em bases geossistêmicas do alto curso do rio Canhoto, Planalto da Borborema, Nordeste do Brasil. **GeoUERJ**, n. 35, p. 1-19, 2019. https://doi.org/10.12957/geouerj.2019.38012

MAPBIOMAS. **Coleção 6 da série anual de mapas de cobertura e uso de solo do Brasil**. 2021. Available: http://mapbiomas.org. Accessed: Sep.15th 2021.

MARENT, B. R.; PORTILHO, S. Unidades de paisagem na bacia hidrográfica do Ribeirão Preto, Serra do Gandarela-MG. **Geousp – Espaço e Tempo** (Online), v. 21, n. 1, p. 138-155, abr. 2017.

https://doi.org/10.11606/issn.2179-0892.geousp.2017.116477

MIRANDA, L. C.; SILVA, E. V.; GORAYEB, A.; RABELO, F. D. B. Zoneamento Geoecológico como Instrumento para o Planejamento e Gestão Ambiental da Ilha do Príncipe. **Revista Eletrônica Casa de Makunaima**, v. 1, p. 131-144, 2018. https://doi.org/10.24979/makunaima.v1i1.517

MOREIRA, V. B.; PEREZ FILHO, A. Das superfícies de aplainamento aos pulsos climáticos holocênicos: a evolução da paisagem em relevos de chapada. **Sociedade & Natureza**, v. 32, p. 176-195, 23 mar. 2020. https://doi.org/10.14393/SN-v32-2020-46867

NICOLAU, R. F. Vulnerabilidade da paisagem à perda de solos da bacia hidrográfica do rio do Peixe - Goiás. **Caminhos de Geografia**, v. 19, n. 66, p. 285–296, jun. 2018. https://doi.org/10.14393/RCG196620

OLIVEIRA, C. S.; MARQUES NETO, R. Características estruturais dos geossistemas da bacia hidrográfica do ribeirão Pari/MG. **Revista de Geografia**, v. 1, p. 1-12, 2015.

OLIVEIRA, T. A.; VIADANA, A. G.; PEREIRA, A. A. Fragilidade ambiental e dinâmica geossistêmica: mapeamento da paisagem na bacia hidrográfica do rio Lourenço Velho, sul do estado de Minas Gerais-Brasil. **Caminhos De Geografia**, v. 20, n. 71, p. 504–516, ago. 2019. https://doi.org/10.14393/RCG207146666

PACHECO; F. E. R. C.; SERRANO; P. M.; CAXITO; F. A.; MOURA; C. D.; QUINTÃO; D. A. **Geologia da Folha Uberlândia SE.22-Z-B-VI**: escala 1:100.000. Belo Horizonte: CODEMIG/UFMG, 2017, 37 p.

QGIS.org, 2022. QGIS Geographic Information System. QGIS Association. http://www.qgis.org

RODRIGUEZ, J. M. M.; SILVA, E. V.; CAVALCANTI, A. P. B. **Geoecologia das paisagens**: uma visão geossistêmica da análise ambiental. 2. ed. Fortaleza: Edições UFC, 2007. 222 p.

ROSA, R. M.; FERREIRA, V. O.; BRITO, J. L. S. Mapa de reconhecimento geológico da bacia do rio Uberabinha (MG): procedimento experimental utilizando coeficientes de concordância. **Caminhos de Geografia**, v. 20, n. 70, 2019, p. 507-518. https://doi.org/10.14393/RCG207042721

ROSA, R. M. **Unidades de paisagem e zoneamento**: subsídios para o planejamento ambiental na bacia do rio Uberabinha-MG. Thesis (Master's degree), Federal University of Uberlândia, Graduate Program in Geography, 2017, 118 p.

SANTOS, D. J.; RUCHKYS, U. A.; TRAVASSOS, L. E. P. Perfil Geoecológico do Parque Nacional da Serra do Gandarela, Minas Gerais, Brasil. **Sociedade & Natureza**, v. 33, p. 1-10, 2 fev. 2021. https://doi.org/10.14393/SN-v33-2021-57012

SANTOS, H. G. *et al.* **Sistema Brasileiro de Classificação de Solos**. Brasília: Embrapa, 5ª ed., 2018.

SANTOS, R. F. **Planejamento ambiental**: teoria e prática. São Paulo: Oficina de Textos, 2004.

SEER, H. J.; MORAES, L. C. **Geologia regional do Triângulo Mineiro**. Belo Horizonte: CODEMIG/UFMG, 2017, 123 p.

SCHNEIDER, M. O. **Bacia do rio Uberabinha**: uso agrícola do solo e meio ambiente. Thesis (Doctorate in Physical Geography), Faculty of Philosophy, Letters and Human Sciences, University of São Paulo, 1996, 157 p.

SOTCHAVA, V. B. O estudo de geossistemas. **Métodos em questão**, IG-USP, São Paulo, n. 16, 1977, 51 p.

STRAHLER, A. N. **Hypsometric (area-altitude)**: analysis of erosional topography. Geol. Soc. America Bulletin, 63(10), 1952, p. 1117-1142. https://doi.org/10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2

TRICART, J. **Ecodinâmica**. Rio de Janeiro: IBGE, SUPREN, 1977. 97 p.

TROMBETA, L. R; LEAL, A. C. Planejamento ambiental e geoecologia das paisagens: contribuições para a bacia hidrográfica do córrego Guaiçarinha, município de Álvares Machado, São Paulo, Brasil. **Revista Formação (online)**, v. 3; n.23, p. 187-216, 2016.

AUTHORS' CONTRIBUTION

Rafael Mendes Rosa conceived the study, determined the methodology, prepared the maps and geoecological profiles and wrote the results. Vanderlei de Oliveira Ferreira prepared the abstract, introduction, final remarks and revised the methodology as well as the results, including adaptations to the preliminary version of the study.