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Papers

The Use of Geomorphometric Techniques to Identify Relief Patterns in the Rio Preto Basin, on the Western Plateau of the State of São Paulo

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Abstract
Geomorphological science benefits greatly from technological advances, such as GIS tools available through free software and the improved accessibility to global or quasi-global planialtimetric databases at a semi-detailed scale. Consequently, there is growing use of geomorphometric techniques applied to geomorphological cartography and optimization of mapping routines using semi-automated, digital methods. In this sense, this study applies a geomorphometric classification based on a Digital Elevation Model to compartmentalize the relief patterns of the Rio Preto basin (BRP). We used three main morphometric parameters to define seven landform patterns, namely, drainage density (DD), roughness concentration index (RCI), and relative elevation (RE) - an approximation of relative relief. The global dissection map (DDxRCI) and RE classes were used to create a classification key for the models and relief types based on theoretical and field knowledge. Despite the apparent simplicity and monotony of the predominantly hilly topography characteristic of the Western Plateau of the state of São Paulo, the results demonstrate a diversity in landform patterns, with planated hilltops and gentle hills (65 % of the study area), topographically favorable to the expansion of regional agricultural; steep undulating hills (9 % of the study area), associated with a higher degree of dissection, where morphodynamic processes predominate over pedogenetic processes; valley bottoms (18 % of the study area), where fluvial dissection predominates; and fluvial plains (8 % of the study area), which are quaternary depositional features located on the valley bottoms. In addition to a morphographic characterization of the study area, this study sheds light on certainsome methodological aspects of the mapping and it is intended to be applied to environmental vulnerability assessment in future activities.

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INTRODUCTION

Geomorphological cartography is the area of knowledge that integrates geomorphology and cartography with the aim of representing geomorphological facts according to the genesis of the relief forms and their relationships with the structure and processes responsible for their evolution. Therefore, maps and geomorphological charters are important sources of information on the strengths and weaknesses of the land and provide support for environmental planning and territorial ordinance (CHRISTOFOLETTI, 2007; GUERRA and MARÇAL, 2006; ROSS, 2006; ROSS and MOROZ, 2009; MANTOVANI, 2015; RODRIGUES et al., 2016). This can be seen in the management plans of protected areas, municipal master plans, and the various environmental studies requested during the environmental licensing process. However, despite its great relevance, there is still no consensus as to methodological systems of geomorphological representation adopted in Brazil. The difficulty in adopting methodological standardization that supports a Brazilian system of relief classification, a debate rekindled at the XVIII Simpósio Brasileiro de Geografia Aplicada (2019) (XVIII Brazilian Symposium of Applied Geography) in the city of Fortaleza, is due to the wide variety of elements under consideration (morphogenesis, morphology, morphometry, morphodynamics, morphostructure, and morphochronology) and the complexities intrinsic to the geomorphological systems themselves.

Despite the lack of consensus and methodological standardization, in Brazil there is a gravitation towards the proposals of Jurandir Ross (1992), whose taxonomic organization finds its origins in the work of Jean Tricart and is expanded based on the RADAMBRASIL project (NETO, 2020). In 1997, the state of São Paulo, where the study area of this research is found, received one of Ross's great contributions, together with Isabel Moroz, namely, the “Mapa Geomorfológico do Estado de São Paulo” (Geomorphological Map of the State of São Paulo), at a scale of 1:500,000. This map is organized following the fundamental logic of Tricart, relating the spatialities and temporalities according to orders of magnitude. As such, generalized geomorphological realities correspond to a greater temporality (superior taxa) and have a strong structural tone and morphogenetics. As the map advances in the direction of larger scales (inferior taxa), it approximates to the "present" time and highlights the morphodynamic aspects of the geomorphological realities. According to the proposal of Ross (1992), the relief patterns (3rd taxon) group the models by genetic types (aggradation and dissection) and morphodynamics, deduced from the morphometry (interfluvial dimension and degree of notching). Therefore, when it comes to modeling dissection, the interfluvial distance represents the degree of topographic dissection through fluvial action and/or structural control and the degree of notching corresponds to the depth of the dissections.

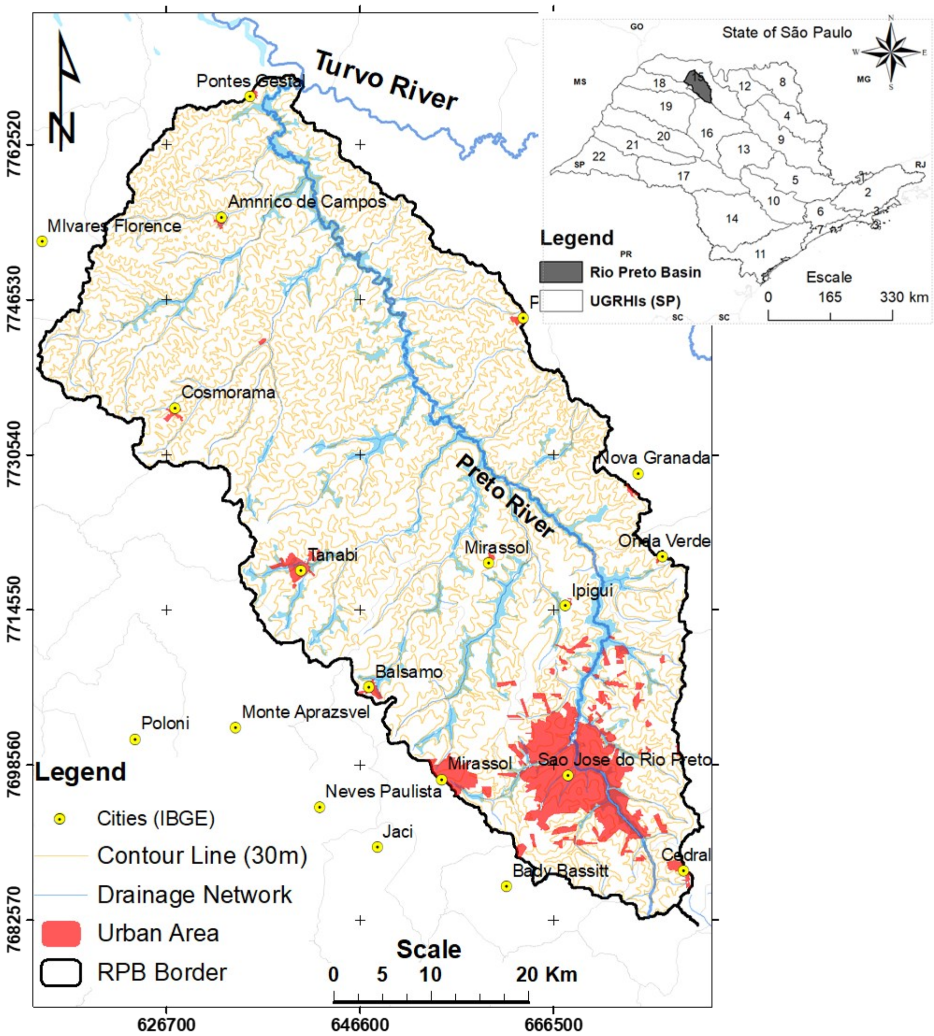
The technological advances in equipment and software and the democratization initiatives of global or quasi-global planialtimetric data, such as the Digital Elevation Models (DEMs) of the Shuttle Radar Topography Mission (SRTM), have favored the use of geomorphometry applied to geomorphological cartography and the consequent optimization of mapping routines. Consequently, it is possible to cite the contributions of Gustavsson (2006); Santos et al. (2006); Evans et al. (2009); Grecu (2009); Pavlopoulos et al. (2009); Silva and Rodrigues (2009); Fonseca et al. (2015); Martins and Rodrigues (2016); Sena Souza et al. (2016); Silveira and Silveira (2016); Diniz et al. (2017); Bortolini et al. (2018); and Nazar and Rodrigues (2019), who produced maps and geomorphological compartmentations based on digital and semi-automated methods in the Geographic Information System (GIS) environment.

This study presents a relief compartmentation of the Rio Preto basin in the Planalto Occidental Paulista (Western Plateau of the state of São Paulo), according to an adaptation of the proposal by Ross (1992), based on geomorphometric analyses, using semi-automated mapping methods that conciliate empirical field knowledge with modern methodologies. In addition to declivity, three main aspects are considered in relief characterization, being drainage density (DD) (equivalent to the interfluvial dimension), the Roughness Concentration Index (RCI) (equivalent to the degree of topographic notching), and the relative elevation (RE), the latter measured as an approximation of relative relief. In a context of great debate regarding the methodologies used in geomorphological mapping, in addition to the central issue of taxonomy and standardization of the inventory of relief forms, we present procedures that remain little explored in the literature, which, due to their simplicity, demonstrate great potential for exploratory use in mapping the 3rd taxon and 4th taxon.

STUDY AREA

The Rio Preto basin (BRP - 2,866 km²), a tributary of the Turvo River, is located in the Unidade de Gerenciamento de Recursos Hídricos "Turvo-Grande" (Turvo-Grande Hydric Resources Management Unit) (UGRHI 15), in the northwest of the state of São Paulo. It contains 16 municipalities, including the municipality of São José do Rio Preto (SP) (Figure 1). According to the classification proposed by Köeppen-Geiger, the regional climate is "Aw" (tropical savanna climate with a dry winter) with a rainy season in the summer, and a clear dry season in the winter, with total rainfall reaching up to 1,800 mm/year (ALVARES et al., 2014; FOREST-GIS, 2015; EMBRAPA, 2021).

Figure 1 - Rio Preto basin (RPB), a tributary of the Turvo River, located in UGRHI 15, highlighting the municipality of São José do Rio Preto, to the southeast.

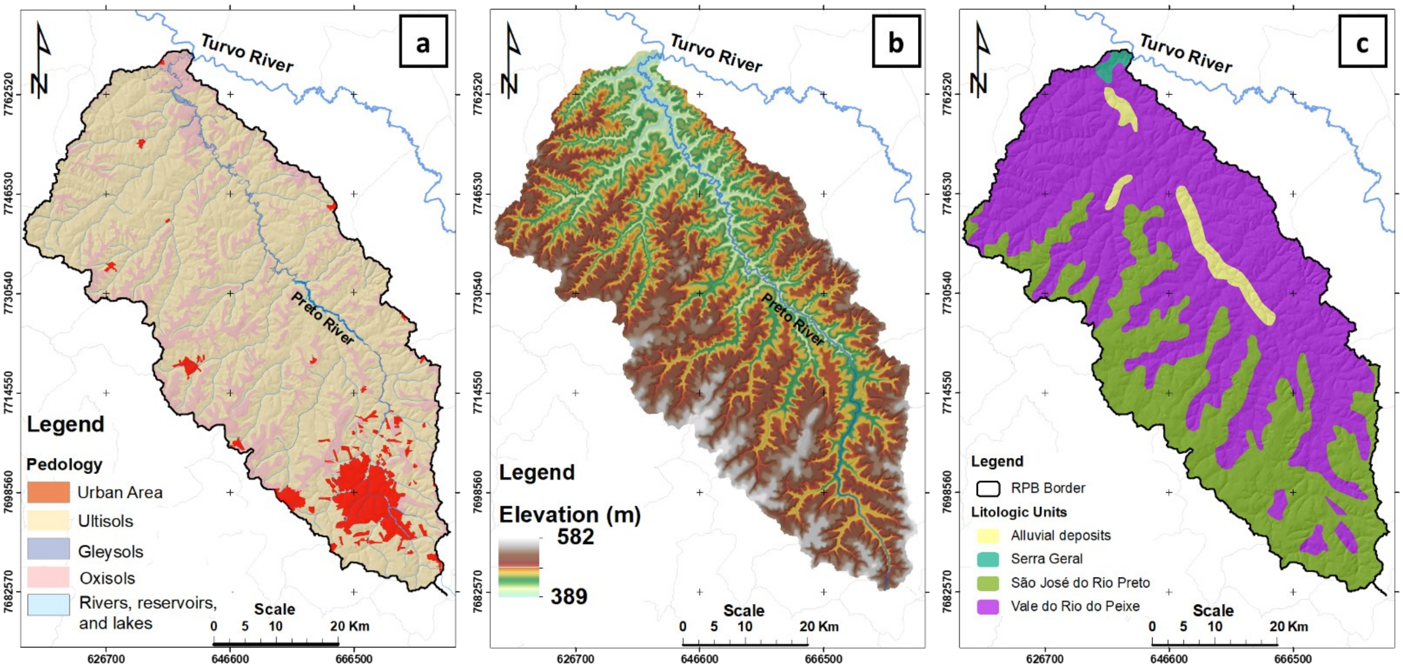


Source: Contour lines generated from the digital elevation mode (SRTM) (NASA, 2009); Municipal headquarters of the state of São Paulo (1:50,000) edited from (ICG, 2010); Drainage network of the state of São Paulo (1:50,000), edited from (DAEE, 2008); UGRHIs (1:1.000.000) (ICG, 2011).

The hypsometric map represents the different altimetric levels of the BRP, between 389 m and 582 m, and records the main slopes controlled by geological variations (Figures 2b and 2c). According to Perrota et al. (2005), the study area has a simple geological composition, whereby in the lowest portion of the basin, close to the mouth of the river, an outcrop of the Serra Geral Formation can be observed, represented at this point by basic rocks interspersed with sandstone. Overlaying the Serra Geral Formation are the predominant geological units in the basin: the Vale do Rio do Peixe Formation, composed of well-selected, very-fine and fine sandstone of continental desert/aeolian formation; and the São José do Vale do Rio Preto Formation composed of poorly selected, very-fine and fine sandstone of intertwined continental desert/fluvial formation. On the main drainage axis, quaternary alluvial deposits of quartzose sand, silt, and clay are observed with local peat formations.

The pedological information was obtained from the soil map of the state of São Paulo, revised and unified by Rossi (2017), at a scale of 1:250.000 (Figure 2a). In most of the BRP, Red-Yellow Acrisols are observed, with Red Latosols on the flat hilltops. In the valley of the Preto River, the occurrence of Haplic Gleysols and Fluvic Neosols can be observed.

Figure 2: a) Pedology; b) Hypsometry; c) Lithology



Source: a) Soil map of the state of São Paulo (1:250.000) (ROSSI, 2017); b) elevation obtained by SRTM with a resolution of ≅ 30m (NASA, 2009); c) Geological map of the state of São Paulo (1:750,000) (PERROTA, 2006); Drainage network of the state of São Paulo (1:50,000), edited from (DAEE, 2008).

The maps of the São Paulo relief date back to Moraes Rego (1932), Monbeig (1949), Ab' Saber (1956), IBGE (1959), and Almeida (1964). However, the more recent geomorphological maps with more detail are from the Instituto de Pesquisas Tecnológicas do Estado de São Paulo (São Paulo Institute of Technological Research) (IPT), signed by Ponçano et al. (1981), Ross and Moroz (1997), Peixoto (2010), and IBGE (2017). The study area is located in the "Bacia Sedimentar do Paraná" (Paraná Sedimentary Basin) (1st taxon) morphostructural unit, which, according to Ross and Moroz (1997), represents an ellipsoidal graben complex filled with sediments, the basement of which is mainly formed of pre-Cambrian crystalline rocks. Advancing another taxon, the study area is contained in the "Planalto Ocidental Paulista" (Western Plateau of the state of São Paulo) (2nd taxon) morphosculptural unit, which covers an area of approximately 100,000 km², around 2/5 of the area of the state of São Paulo. It has relatively simple geology, almost entirely represented by the Bauru Group. The relief is gentle and "monotonous", with a predominance of lightly undulating hills and hillocks, and is extremely favorable to agricultural activities and the layout of communication routes (ALMEIDA, 1964). According to the author, the Western Plateau is the least studied among the provinces of São Paulo, be it for its apparent simplicity or its distance from the capital.

MATERIALS AND METHODS

Compartmentation of the Rio Preto basin relief was carried out in two stages: i) data acquisition, and ii) data processing and geomorphological compartmentation. Data acquisition involved bibliographic/cartographic surveys and fieldwork. The cartographic databases made available by the Companhia de Pesquisas de Recursos Minerais (Mineral Resources Research Compaany) (CPRM) and the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics) (IBGE) were consulted, along with high resolution images available on Google Maps/Earth, using geoprocessing tools to integrate this information. The Digital Elevation Model (DEM) used in the geomorphometric analyses was that of SRTM (Shuttle Radar Topography Mission) at a resolution of 1 arc-second (≅ 30m) (NASA, 2009). The fieldwork was carried out in January 2021 and is part of the empirical investigation, which was essential for understanding the morphographic and morphodynamic characteristics of the study area, and to obtain control points using GNSS (Global Navigation Satellite System), and photographic records.

The geomorphological compartmentation was based on the assumptions of Ross (1992), addressing the taxon that deals with the form patterns (3rd taxon) and the 4th taxon, which represents the individualized forms, indicated, in this case, in the set of form patterns. The morphometric parameters used to classify the dissection models were the declivity and the relative relief, observing the criteria presented by CPRM/IPT (2014) (Table 1).

Table 1 - Relief Patterns (dissection models) and basic parameters

TYPE OF RELIEF	RELATIVE RELIEF (m)	PREDOMINANT DECLIVITY (%)
Hills	40 to 70	< 20
Low hillocks	40 to 50	> 30
Hillocks	60 to 90	20
Low hills	90 to 110	30
High hillocks	60 to 90	30 to 40
High hills	140 to 200	> 30
Mountains	> 300	> 30
Scarps	100	60

Source: Adapted from CPRM/IPT (2014)

This study calculated the relative elevation above the drainage network (RE), mathematically modeled as an approximation to relative relief using the DEM in the GIS environment. As such, we used the Relative Heights and Slope Positions module (BOEHNER; SELIGE, 2006) on the free software SAGA GIS (CONRAD et al., 2015). Boehner and Selige (2006) estimated the altitude above drainage accumulation areas / (AD_M) continuously on the raster matrix, without using discrete data such as drainage lines or crests, following Equation 1. The relative elevations are designated as being the difference between the cells of the raster matrix of inverted elevation zi and the weighted mean of the of the inverted elevation to the sum total zi_i, each being weighted by the square root of its respective contribution area CA_i . The contribution area was calculated using Freeman's multiple flow method (1991). The declivities were calculated based on the DEM in the GIS environment, this procedure being among the most elementary and widely used.

$$AD_M = -1.\left[\frac{\sum_{i=l}^{n} \; zi_i/CA_i^{0,5}}{\sum_{i=l}^{n} \; 1/CA_i^{0,5}} - zi \right]$$

(Equation 1)

The drainage density (DD) and Roughness Concentration Index (ICR) were calculated according to the proposal of Nazar and Rodrigues (2019) (SAMPAIO; AUGUSTIN, 2014). The DD is inversely proportional to the interfluvial distance and, therefore, the higher the DD, the lower the interfluvial distance and the greater the fluvial dissection. The RCI, or the declivity density, corresponds to the different degrees of deepening of the valley in 3 dimensions. Both indices were calculated in the GIS environment, using Kernel Density

Estimation (KDE) (WANDERLEY, 2013) with a radius of 564 m (1 km²) (HORTON, 1945), as discussed by Sampaio and Augustin (2014) and used by Nazar and Rodrigues (2019) and Nazar (2018). After applying KDE, the maps were reclassified on a simple numerical scale (from 1 to 5), (1) being very low, (2) low, (3) medium, (4) high, and (5), very high, respectively (NAZAR; RODRIGUES, 2019).

The DD and RCI indices were multiplied using map algebra, generating a map of global dissection with classes that varied between multiples of 1 and 5. The "DDxICR" map classes were used together with the RE to create a classification key based on the theoretical knowledge and fieldwork of the map executors (Table 2). To identify the aggradation model and the classification key, the contours, the drainage network, and the satellite images were used. For greater operational detail, consult Nazar and Rodrigues (2019).

RESULTS AND DISCUSSION

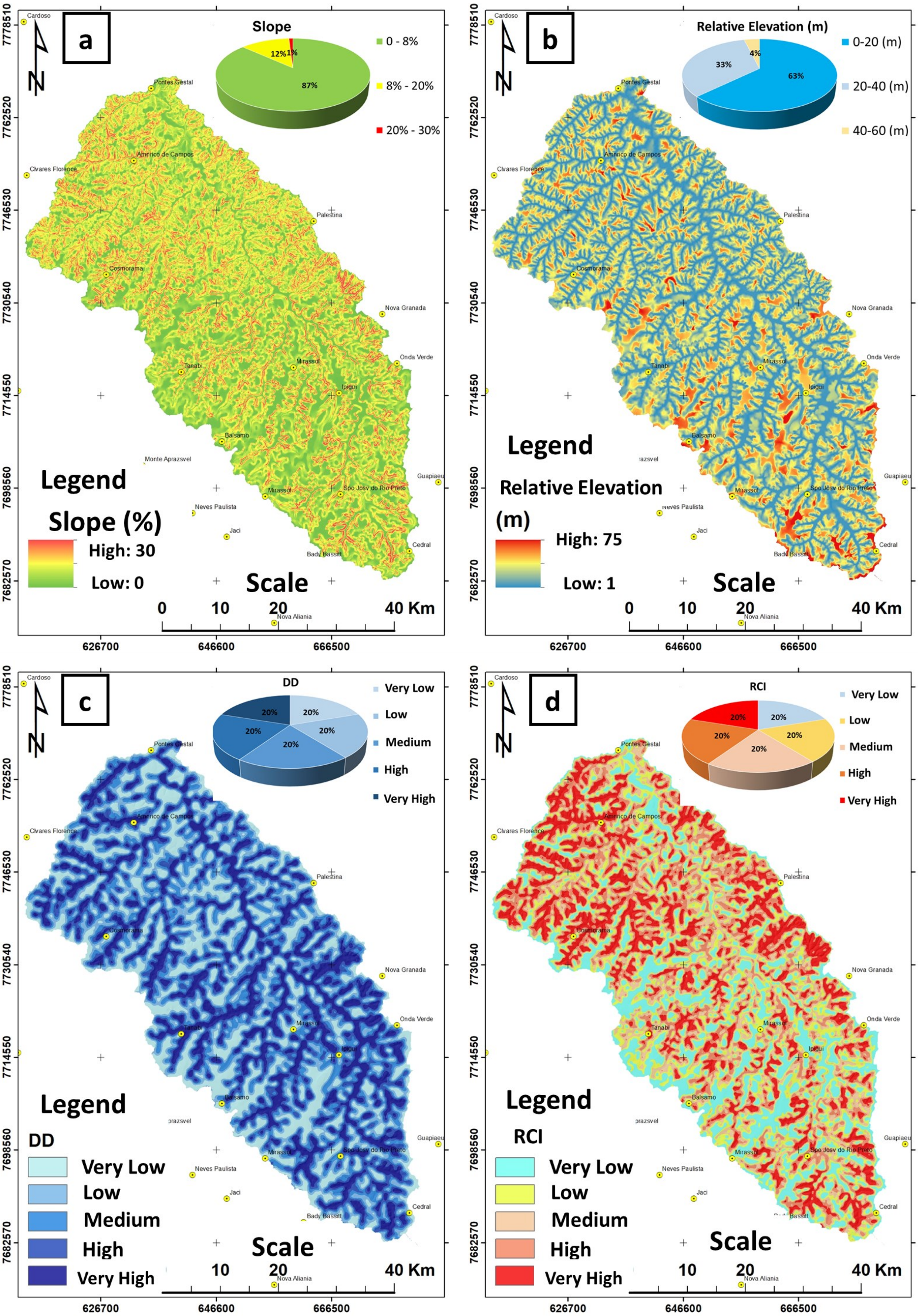
This section presents the maps derived from DEM, namely, the declivity, RE, DD, and RCI maps, and subsequently details the BRP patterns map and its 5 classes produced based on the geomorphometric classification key, according to the previously described methodology.

The declivity was classified as per Table 1. Most of the declivity matrix cells are found in the 0 to 8 % class (87 %), with a mean declivity value of 4 % and a maximum declivity of 33 % (Figure 3a). The RE map, computed using Equation 1, was also classified per Table 1 as an approximation of the spatial distribution of the relative relief in the BRP. Most of the matrix cells are between amplitudes of 0 and 20 m (63 %), followed by the 20 m to 40 m class (33 %). In the study area, the maximum recorded amplitude is 75 m and the mean amplitude value is 17 m (Figure 3b).

Upon comparing the declivity and RE maps, it was observed that the only relief pattern is that of hills (Table 1) (CPRM/IPT, 2014), since they have a relative relief between 40 m and 70 m and predominant declivity <20 %. No combinations were observed between elevations above 40m with declivities above 20 %, as on the low hills and/or hillocks.

The DD and RCI variables reflect the dissection aspects of the BRP in five classes, which vary from very high to very low (Figures 3c and 3d). The maps have a regular distribution of classes due to the applied classification methodology (Quantil) suggested by Sampaio and Augustin (2014), also used by Nazar and Rodrigues (2019).

Figure 3 - Maps computed using DEM. (a) Declivity Map; (b) Relative Elevation Map; (c) Drainage Density Map; and (d) Roughness Concentration Index Map.



Source: Maps computed from the digital elevation model (SRTM) (NASA, 2009).

Relief Patterns of the Rio Preto Basin

There are five relief patterns in the BRP identified based on the classification key presented in Table 2: i) planated relief associated with interfluves (10 %); ii) dissected relief associated with gentle hills (55 %); iii) dissected relief associated with undulating hills (9 %); iv) dissected relief associated with valley bottoms (18 %); and v) fluvial plains and isolated fluvial plains (8 %).

Table 2 - Relief pattern classification key for the Rio Preto Basin (SP)

Index (DDxICR)	ER *(m)*	Nomenclature	BRP (%)
1	>7	Planated relief associated with interfluves **(Int)**	10
2,3,4,5,6,8,9,10,12,15,16	>5	Dissected relief associated with gentle hills **(Dc)**	55
20, 25	>5	Dissected relief associated with undulating hills **(Dco)**	9
3,4,5,6,8,9,10,12,15,16,20,25	≤5	Dissected relief associated with valley bottoms **(Dv)**	18
1,2	≤5	Fluvial plains and isolated fluvial plains **(Apl)**	8

Source: The authors (2021).

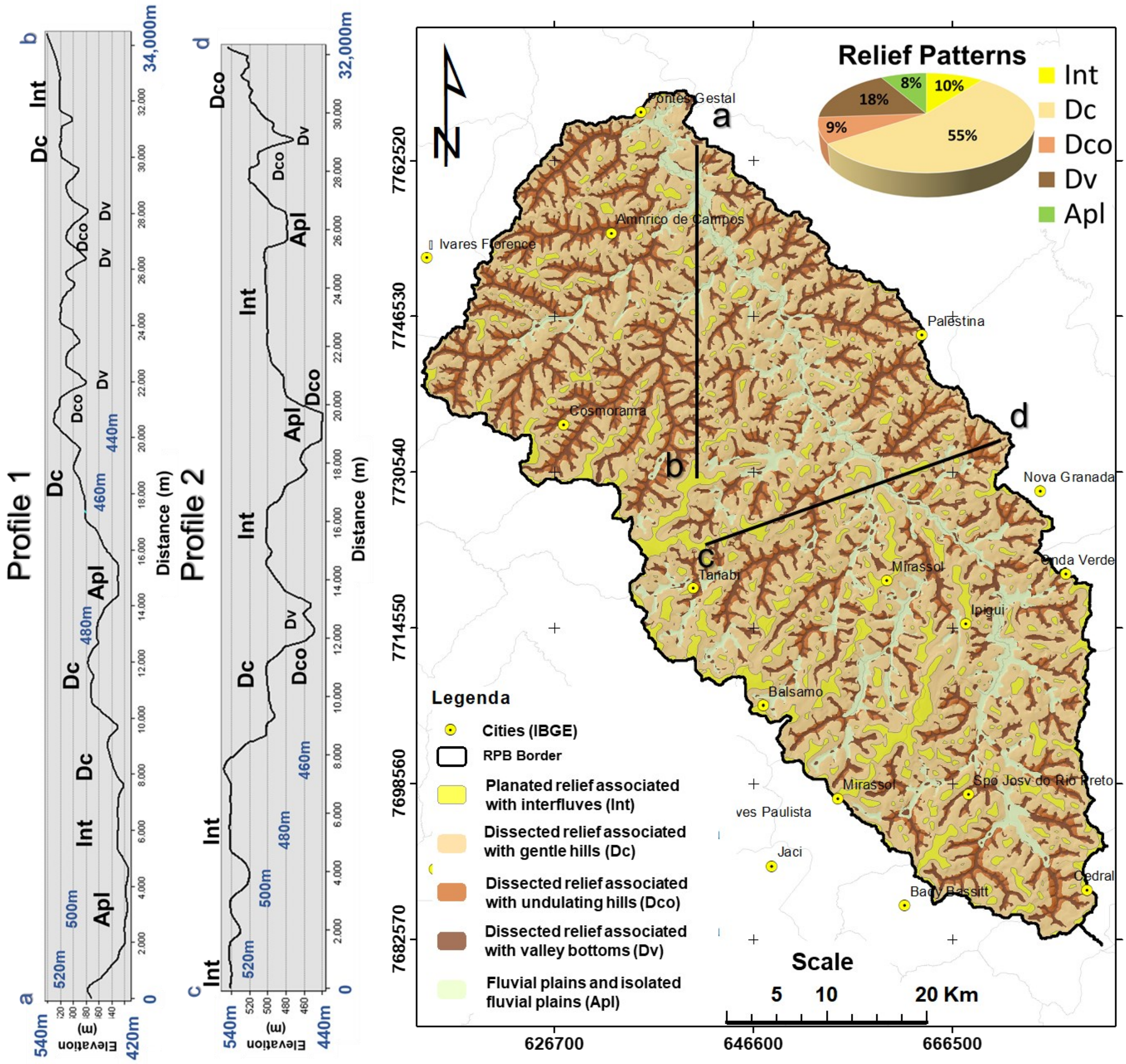
Despite the apparent simplicity and monotony of the hilly relief of the Western Plateau of the state of São Paulo, the map presents a gain in details in relation to the work of Ponçano et al. (1981), Ross and Moroz (1997), Peixoto (2010), and IBGE (2017), which is reflected in the diversity of relief patterns in the BRP.

In general, the relief of the BRP consists of gentle and undulating hills, with convex-concave slopes and rounded and/or planated hilltops with an elongated morphology. The fluvial plains and isolated fluvial plains represent quaternary aggradation areas associated with low-energy environments with relative relief of up to 5 m.

Figure 4 presents the map of relief pattern classes, as presented in Table 2, where two topographic profiles representative of the mapped classes are outlined. In section a-b (profile 1), in “a”, it can be observed that the relief is little dissected and associated with a gentle convex hill (altitude 470 m), close to the mouth of the BRP. The profile crosses the fluvial plain of the Preto River (altitude 420 m), followed by a compartment of gentle hills in the Vale do Rio do Peixe Formation, until reaching the highest altitudes (520 m), and the Vale do Rio Preto Formation, where there are undulating hills interspersed with dissected valleys; finally arriving at “b”, in a planated interfluve at an altitude of 520 m.

In section c-d (profile 2), in “c” there is a more elevated compartment in the Vale do Rio Preto Formation, where the occurrence of a planated interfluve with elongated morphology can be observed at an altitude of 540 m, which extends up to the transitional contact between the geological formations 1.2 km from point “c”. A change in base level can be observed at the contact along with undulating hills and a dissected valley bottom. The lowest altitudes correspond to a fluvial plain of the Preto River (440 m) and continue to the basin borders to the east, where point “d” meets undulating hills.

Figure 4 - Representation of the BRP relief patterns and topographic profiles: profile 1 (section a-b) and profile 2 (section c-d).



Source: Topographic profiles produced from the digital elevation model (SRTM) (NASA, 2009).

Planated relief associated with interfluves

The planated relief forms associated with interfluves have tabular morphology, at times elongated, with low roughness. This class corresponds to 10 % of the area of the BRP, being associated with deep, well-drained soils, mostly Red Latosols. It is important to emphasize that studies on the geosystem dynamic and environmental fragilities of the Western Plateau of the state of São Paulo (PEREZ FILHO; SEABRA, 2004; SEABRA, 2014; QUARESMA, 2008) have found morphogenetic processes associated with pluvial and aeolian erosion. The latter has contributed to the installation of arenization processes as a result of the inadequate dynamic of soil use and occupation with the removal and substitution of native vegetation. Figure 5 represents the planated relief of the hilltops with the notable presence of aeolian erosive processes associated with the sandstone of the area.

Figure 5 - Planated interfluves in the interior of the Rio Preto Basin.

Source: The authors (2021).

Dissected relief associated with gentle hills

This relief pattern occurs in most of the BRP (55 %), on slopes with little dissection, convex curvature, and a gentle gradient. It is mainly observed at the edges of flat hilltops, characterizing a transition from flat relief to a relief of undulating hills or fluvial plains. In this relief pattern, both pedogenesis and morphogenesis processes can be observed, with a predominance of laminar erosion over deep, well-drained Red-Yellow Acrisols (Figure 6).

Figure 6 - Dissected relief associated with gentle hills in the interior of the Rio Preto Basin.

Source: The authors (2021).

The predominant relief patterns in the study area with gentle topography (65 %), namely the planated interfluves and the gentle hills, facilitate agriculture management in the region. According to data obtained from the "Monitoramento da Cobertura e Uso da Terra do Brasil" (Monitoring Land Use and Cover in Brazil) project (IBGE, 2018), most of the BRP consists of agricultural areas, and, according to the Plano Estadual de Recursos Hídricos (State

Plan for Hydric Resources) (COBRAPE, 2020), there are projections for the expansion of these areas. However, the agricultural pressure resulting from the favorable topographic conditions is cause for concern since substitution of the original vegetation may alter hydrological, pedological, and geomorphological processes, and, consequently, the energy/material exchanges, generating instability on the landscape (TRICART, 1977; ROSS, 1994), reducing aquifer recharge and increasing erosive processes.

Dissected relief associated with undulating hills

This relief pattern occurs in 9 % of the BRP and has the highest values of overall dissection (ICRxDD), being frequently located with dissected valleys. In this class, morphogenesis processes predominate over pedogenetic processes. The highest degree of dissection is frequently observed on the lowest third of the slopes, where diffusive processes such as creep are also observed (Figure 7). An association between Red-Yellow Acrisols and Litholic Neosols can also be observed.

Figure 7 - Dissected relief associated with undulating hills in the interior of the Rio Preto Basin.

Source: The authors (2021).

Dissected relief associated with valley bottoms

On the valley bottoms, the relief pattern is more or less dissected (18 %), according to the overall dissection index (ICRxDD) in Table 2, where morphogenesis processes predominate. This relief pattern is observed in the concavities between relative reliefs less than or equal to 5 m. It can present a lesser degree of dissection, as observed in Figure 6, or deeper incisions of a fluvial nature, or as a result of linear erosion, frequently associated with degrees of dissection ICRxDD = 20 and 25 (Table 2), as observed in Figure 8.

Figure 8 - Dissected relief associated with valley bottoms in the interior of the Rio Preto Basin.

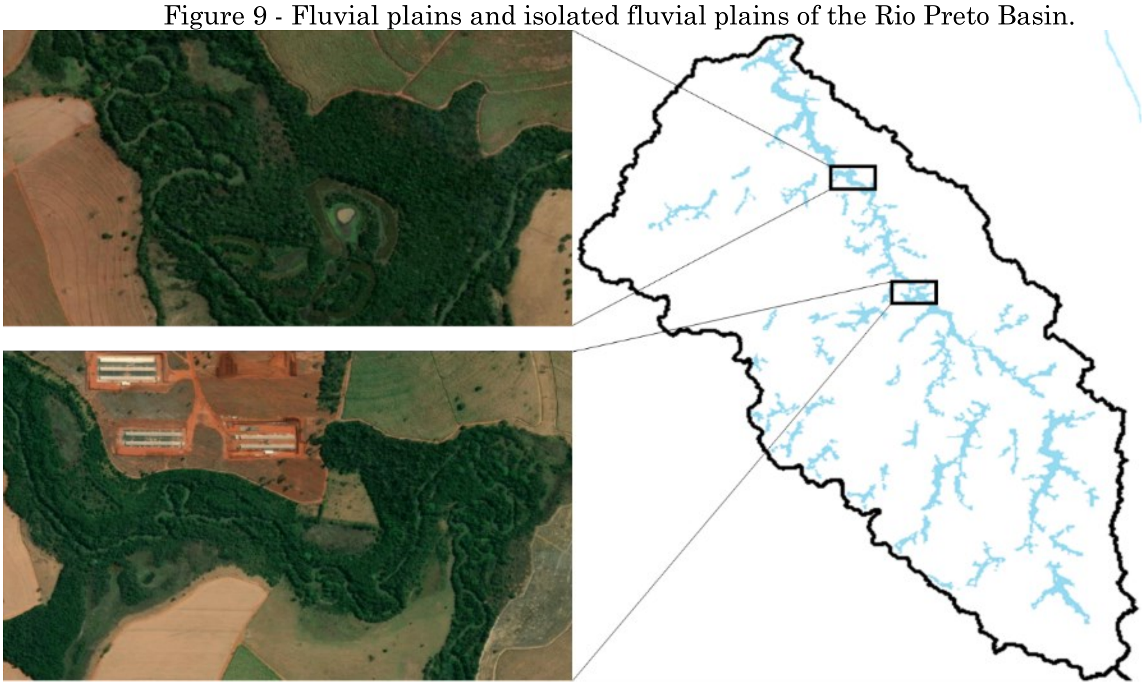
Source: The authors (2021).

The dissection intensity can be considered a first big indicator of the potential fragility of the natural environment, according to Ross (1994), suggesting the need for protection and/or restriction of the use and occupation of these areas.

Fluvial plains

These are quaternary deposition features formed from debris deposited during the flooding of the rivers (8 %). They are planated areas on the valley bottoms and, therefore, associated with low dissection values (Table 2). Satellite images from *Google Earth* reveal important features at the edges of these areas such as abandoned meanders and other paleoforms linked to the fluvial processes produced by flooding and receding events (Figure 9).

Figure 9 - Fluvial plains and isolated fluvial plains of the Rio Preto Basin.



Source: The authors (2021).

The fluvial plains, or flood plains, deserve special attention as they are regions of contact between biomes, which are complex, fragile, and important environments for the equilibrium of physical and biotic environmental systems. Changes in the use and occupation of the BRP may alter these systems, modifying the flooding patterns and increasing sedimentation, etc.

FINAL CONSIDERATIONS

Geomorphological cartography is an important tool for territorial planning given a context of accelerated environmental changes that may alter hydrological, pedological, and geomorphological processes, leading to instabilities on the landscape. In the study, area in particular, agricultural expansion, facilitated by the topographic characteristics of the land, is cause for concern, especially regarding changes in use and cover that could alter aquifer recharge and generate an increase in erosive processes.

This study presents the compartmentation of the relief of the BRP, according to an adaptation of the proposal by Ross (1992), based on geomorphometric analyses, using semi-automated mapping methods that conciliate empirical knowledge from the field with methodological procedures that remain little explored in the literature. The technique enables a reduction in the degree of abstraction due to less use of qualitative information. However, the procedures were complemented with fieldwork, which is essential in any geomorphological research, and demonstrates efficiency by providing more consistent and precise data for mapping.

Five relief patterns (equivalent to Ross's 3rd taxon) were identified based on the classification key that considers the genesis, global dissection, and RE of the relief forms. Most of the study area has planated relief and/or relief associated with gentle hills (65 %), where the expansion of agricultural activities can be observed. The dissected relief associated with undulating hills corresponds to 9 % of the study area, naturally being zones of greater potential fragility, which is inherent to the system itself, resulting from morphodynamic and morphogenetic processes. The dissected areas associated with valley bottoms (18 %) are important areas for the maintenance of regional hydric quality, and, therefore, should be considered places to be conserved. The fluvial plains and isolated fluvial plains correspond to 8 % of the study area and are very fragile environments that are important for the equilibrium of the physical and biotic environmental systems of the BRP.

Finally, we understand that further research is necessary to optimize geomorphological mapping routines through semi-automated methods in the GIS environment, without losing sight of the importance of fieldwork. Moreover, we recommend that different methods for the mapping of relative relief are tested, in addition to different map classification techniques. The map of the BRP relief patterns will be used in the mapping of emerging environmental fragility (ROSS, 1994), which also uses pedology and use and cover maps.

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AUTHORS' CONTRIBUTION

João Paulo de Carvalho Araújo conceived the study, did the fieldwork, analyzed the data and wrote the text. Thallita Isabela Silva Martins Nazar guided João Paulo de Carvalho Araújo, indicating literature, how to proceed in the field, ways to analyze the data and helped to write the text. Francisco de Assis Dourado da Silva contributed writing the text and modeling procedures that required geoprocessing techniques.