MORPHOMETRIC AND GEOMORPHOLOGICAL ANALYSIS OF HYDROGRAPHIC SISTER BASINS: CARTOGRAPHIC CONTRIBUTIONS TO PLANNING

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ABSTRACT

This article aims to discuss the contributions of morphometric and geomorphological cartography for the analysis of the relief in sister basins. It presents the application of a methodology that proposes the organization of a sequence of cartographic documents: Declivity or Clinographic, Horizontal Dissection, Vertical Dissection, Relief Energy and Geomorphological Detail. The hydrographic basin, a spatial mapping unit, is understood as a system, as well as an integrative functional unit for the analysis of geomorphological dynamics. There for, we applied the cartographic techniques mentioned in sister basins, with the case study of the basins of Piracicamirim and Tijuco Preto rivers, both tributaries of Piracicaba River, located in Peripheral Depression of São Paulo. The results obtained from the analysis of the organized documents contributed to the identification of areas potentially susceptible to the unleashing of denudatory processes, as well as gauged the denudatory features, especially the linear ones. Of particular note were sectors that presented marked denudatory features that were associated to classes with high morphometric potential in areas of pedological/lithological fragility and intense dynamics of land use and occupation, marked by sugar cane monoculture.

Keywords: River basin; morphometric cartography; geomorphological cartography.

ANÁLISE MORFOMÉTRICA E GEOMORFOLÓGICA DE BACIAS HIDROGRÁFICAS IRMÃS: CONTRIBUIÇÕES CARTOGRÁFICAS PARA O PLANEJAMENTO

RESUMO

O objetivo desse artigo é discutir as contribuições da cartografia morfométrica e geomorfológica para a análise do relevo em bacias hidrográficas irmãs. Apresenta a aplicação de uma metodologia que propõe a organização de uma sequência de documentos cartográficos: de Declividade ou Clinográfica, de Dissecação Horizontal, de Dissecação Vertical, de Energia do Relevo e Geomorfológica de detalhe. A bacia hidrográfica, unidade espacial de mapeamento, é compreendida como um sistema, bem como uma unidade funcional integrativa para a análise da dinâmica geomorfológica. Assim, o trabalho aplicou as técnicas cartográficas mencionadas em bacias hidrográficas irmãs, com o estudo de caso das bacias hidrográficas do ribeirão Piracicamirim e do ribeirão Tijuco Preto, ambos afluentes do Rio Piracicaba, posicionados na Depressão Periférica Paulista. Os resultados encontrados a partir da análise dos documentos organizados contribuíram para o apontamento de áreas potencialmente suscetíveis ao desencadeamento dos processos denudativos, bem como aferiu as feições denudativas, sobretudo as lineares. Destacam-se setores que apresentaram marcantes feições denudativas que estiveram associadas a classes de elevado potencial morfométrico em áreas de fragilidade pedológica/litológica e de intensa dinâmica de uso e ocupação da terra, marcada pela monocultura canavieira.

Palavras-chave: Bacia hidrográfica; cartografia morfométrica; cartografia geomorfológica.

INTRODUCTION

For the International Geographical Union (UGI) the geomorphological map must contain morphometric, morphographic, morphogenetic and chronological information (TRICART, 1965). However, the difficulties of gathering such information in a single cartographic document are particularly noticeable, especially when the area surveyed presents great complexity. This fact can make it difficult to read the map, mainly when the purpose of this document is applied to society, in order to subsidize planning.

According to Martinelli (1993), the first geomorphological mappings arose in the early 20th century, with firstly a rigor with the qualitative aspects of the relief forms and later representing the quantitative aspects, expressing better the morphological evolution. Casseti (1994) argues that in order to avoid overloading information in the geomorphological map, which makes it difficult to read, morphometric data can be presented aside, in a specific cartographic representation, which has become common in the geomorphological scientific production.

As dealing with the elaboration techniques, possibilities and restrictions of the morphometric maps, Cunha, Mendes and Sanches (2003) understand them as cartographic representations that aim to quantify the shapes of the relief, which can be analyzed through their geometry. Reviewing the works of Spiridonov (1981) and Dragut and Blaschke (2006) and objectifying the proposition of computational techniques for morphometric mappings, Ferreira (2015) argues that these mappings contribute to the hierarchical evaluation of the potentialities for the development of morphodynamic processes, considering that such informations on relief forms are essential for studies on the evaluation and suitability of land, erosion, risk areas and various fields of local planning.

Emphasizing the production of morphometric maps by geomorphologists, which allowed a quantitative analyses of the attributes of relief forms, Garcia et al. (1993) reinforce that they have been used to identify areas of susceptibility to anthropic use. According to Machado, Cunha and Sato (2010), morphometric maps contribute to the identification of sectors potentially susceptible to morphogenetic action, a fact that makes them useful in environmental planning because they identify spaces in which anthropic interference can dynamize processes of geomorphological and environmental degradation.

Treating of the geomorphological cartography in a post-Second World War, with an emphasis on the Eastern European scientific community, Ross, Matos Fierz and Carvalho (2011) referred the advances of these mappings to the development of technological bases such as aerial photographs, remote sensing and orbital images. In addition, they also referred the advances to the usefulness that Geomorphology started to have from its application as an instrument of economic and social development, contributing to the identification of natural resources and creating subsidies to territorial planning (ROSS, MATOS FIERS and CARVALHO, 2011). For Argento (2012), geomorphological mapping translates into a fundamental chart to be correlated to other information plans and generate environmental scenarios, whether at the urban, rural or local level. The same author, understanding the geomorphological mapping as support to the environmental planning, reinforces that they leave exclusively from the academic context and expand to the level of multidisciplinary association, with possibility of expansion in the specialized job market (ARGENTO, 2012).

Considering the geomorphological indicators for the analysis of environmental sustainability at the first National Symposium on Geomorphology, held at Federal University of Uberlândia (UFU), Chiristofoletti (1996) treated the hydrographic basin as an integrative functional unit for the analysis of geomorphological dynamics. At the opportunity, he mentioned:

> When it is desired to establish geomorphological indicators to analyze environmental sustainability, a relevant concern is to choose the basic space unit for the analytical framework. For certain morphometric variables (topographic

> roughness, strand declivity, etc.), an area bounded by several criteria (administrative boundaries, grid cell, etc.) can be used, because there is no immediate link with the characterization and measurement of the processes. However, when it is desired to link the morphometric characteristics to the process dynamics, it is necessary to use integrative functional units. In this context, hydrographic basins are adequate (CHRISTOFOLETTI, 1996, p. 31, highlights added).

Rodrigues and Adami (2011) understand the basin as a system that comprises a volume of materials (solids and liquids) close to the surface, which can be delimited externally and internally by processes associated with the supply of water through the atmosphere, which interfere in the flow of material and energy of a river or a network of river channels. They reinforce that it includes all spaces of circulation, storage, exits of water and transported material that maintains relations with these channels (RODRIGUES and ADAMI, 2011).

According to Mattos and Perez Filho (2004), the hydrographic basin can be understood as a complex system, formed by subsystems, of which interactions result in the organization of the system as an integrated whole. They emphasize that the delimitation of these subsystems varies according to the objectives of each study. However, regardless of the way in which subsystems are identified, it is important to realize that the basin cannot be understood by the isolated study of each of its components (MATTOS and PEREZ FILHO, 2004).

In dealing with hydrographic basins as planning and environmental zoning units in Brazil, Carvalho (2014) observed that historically these spatial units have been adopted as preferred areas for the planning and management of water resources, and since 1980, the modernization of water management models incorporated the concept of sustainability. Corroborating with Rodriguez, Silva and Leal (2011), the author values the perspective of integration between the management of water resources and environmental management, considering that the planning of the hydrographic basins has been changing conceptually. First, with the focus on water management, then with a basin design as the conjunction of environmental factors and, more recently, with a vision of integrated environmental planning (CARVALHO, 2014).

This way, with the initial presentations about the bibliographic reference of this work made, we retake some considerations that support its objective, as well as its methodological procedures:

- First, to consider that the information overload in the geomorphological map resulted in the specific cartographic representation of morphometric data, a fact that became frequent in the geomorphological scientific production (CASSETI, 1994);

- To understand that these documents aim to quantify the relief forms (CUNHA, MENDES and SANCHES, 2003) and contribute to the hierarchical evaluation of the potentialities for the development of morphodynamic processes (FERREIRA, 2015). In addition, they have been used to identify areas of susceptibility to anthropic use (GARCIA et al., 1993), which make them extremely useful for environmental planning (MACHADO, CUNHA and SATO, 2010);

- To consider the collaboration of geomorphological cartography, especially from the technological advances in the post-Second World War, contributing to the identification of natural resources and creating subsidies for territorial and environmental planning (ROSS, MATOS FIERZ and CARVALHO, 2011). It is a fundamental cartographic document to be integrated with other information plans and generate environmental scenarios (ARGENTO, 2012);

- To treat the hydrographic basin as an integrative functional unit for the analysis of geomorphological dynamics (CHRISTOFOLETTI, 1996);

- To understand the hydrographic basin as a system (RODRIGUES and ADAMI, 2011), consisting of subsystems, in which interactions result in the organization of the system as an integrated whole (MATTOS and PEREZ FILHO, 2004);

- The perspective of integrating water resources management and environmental management, with a vision of integrated environmental planning (CARVALHO, 2014).

Such considerations support the understanding that morphometric and geomorphological cartography contribute with information relevant to territorial and environmental planning. In addition, from the theoretical-methodological point of view, the basin is understood as a system, formed by subsystems. They are, therefore, systems within systems (according to delimitation and hierarchy), which are interdependent. In this perspective:

- The hydrographic basin is understood as a spatial unit of geomorphological and morphometric analysis and mapping;

- Sister basins are understood as subsystems that interact and are part of a system;

- Considering the interdependence of sister basins under the perspective of organization and functionality, the river basin becomes an integrated environmental planning unit.

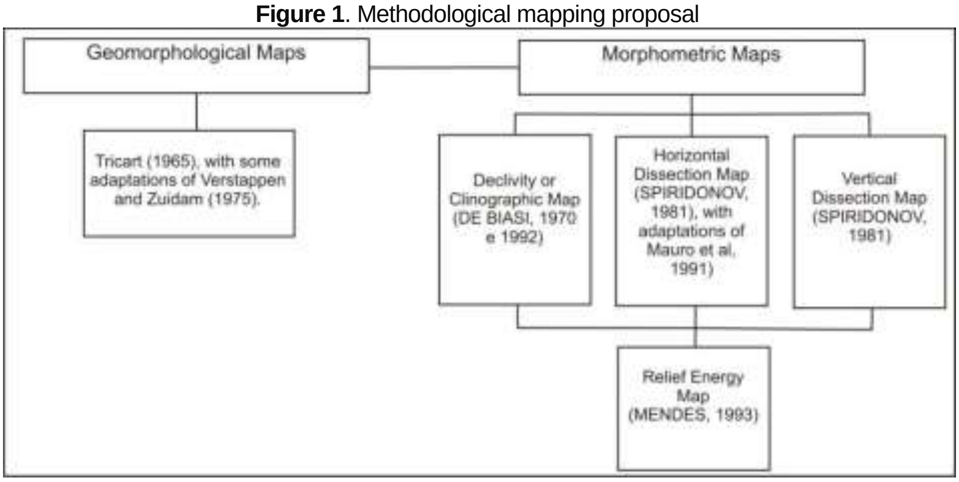
This article aims to present the contributions of the morphometric and geomorphological cartography for the analysis of the relief in sister basins, with the case study of the subsystem basin of Piracicamirim river and the subsystem basin of Tijuco Preto river, both interdependent subsystems and belonging to the system basin of Piracicaba river - SP / MG. Focusing on this objective, we present the technical cartographic procedures of the organized morphometric and geomorphological mappings. These procedures will be followed by a characterization of the basins investigated, as well as by the results derived from the application of the cartographic techniques mentioned.

CARTOGRAPHIC PROCEDURES

The mapping techniques of this work compose a methodological procedure traditionally applied in research carried out by members of the Laboratory of Geomorphology (LAGEO) of São Paulo State University (UNESP), *campus* of Rio Claro. This procedure, which has been developed for near three decades, makes use of morphometric mapping techniques and geomorphological detail mapping, producing a great deal of work with geomorphological analyzes for different environments, which contribute significantly as a subsidy to territorial and environmental planning.

Among the different cartographic techniques frequently used, for this work, we used four different procedures to evaluate the morphometry, as well as the technical procedure of detailed geomorphological mapping. The morphometric documents followed the technical guidelines of De Biasi (1970 and 1992), for the Declivity or Clinographic maps; Spiridonov (1981) with adaptations of Mauro et. al. (1991), for Horizontal Dissection maps; Spiridonov (1981), for Vertical Dissection maps; and Mendes (1993) for the Relief Energy maps. For the geomorphological mapping we adopted the proposal of Tricart (1965), with some adaptations of symbologies proposed by Verstappen and Zuidam (1975). Figure 1 illustrates the methodological mapping proposal.

Figure 1. Methodological mapping proposal



Organization: the authors

Castro and Viadana (2002) emphasize that the study of a basin begins, necessarily, by the topographical map. Its role is also highlighted by Rodrigues and Adami (2011), who still consider it the greatest source of data for surveys and morphometric analyzes, since, with this map, hydrographic basins are delimited, fluvial channel networks are defined and altimetric data are collected, which are the basis for later calculations. For the organization of the mentioned morphometric maps, IBGE topographic maps (1988) were used in a 1: 50,000 scale, which were configured as a Cartographic Base.

Following the proposal of De Biasi (1970 and 1992) for the elaboration of Declivity or Clinographic maps, we used the Cartographic Base and a graduated abacus. The first step was to obtain the values of greater and smaller spacing between the level curves that, used in the formula represented in figure 2, allowed the identification of the limit values of the declivity of the study area.

Figure 2. Calculation to obtain the values of Declivity

$$D = \frac{n \times 100}{E}$$

Source: De Biasi (1992). Organization: the authors

D = Declivity (Percentage)
n = Equidistance (level curves)
E = Spacing (level curves)

After the initial stage, we defined the classes of declivity or clinographic that obeyed to the maximum and minimum limits of slope of the area. Once the classes were defined, we constructed an abacus with the values corresponding to each pre-established class, assigned according to legislation, land use and occupation and area characteristics (DE BIASI, 1992). For the areas inserted in hill tops, isolated space between a single level curve and in the limits of the basin, we used a supplemental abacus, according to adaptations of Sanchez (1993), who suggests that it has half of the altimetric values of the main abacus. The following declivity or clinographic classes were obtained for the area: <2%; 2├5%; 5├12%; 12├20%; 20├30%; ≥ 30%.

For the Horizontal Dissection maps (Spiridonov, 1981), we first delimited all the sub-basins, establishing the area drained by each fluvial course. Then, the areas between the thalweg and the ridge line were classified according to their distance, using a graduated abacus, which demarcates the classes established for the area. In this way, the abacus was displaced on the Cartographic Base trying to delimit the existing classes in each sub-basin, quantifying the distance between the thalweg and the ridge lines. For the definition of horizontal dissection classes, it is necessary to obtain the value of greater and smaller distance between the ridge line and the thalweg of the sub-basins. Spiridonov (1981) recommends that the value of each class corresponds to twice the limit of the previous class, starting from the mappable minimum, which for the scale of this work corresponded to 1 mm in the Cartographic Base, representing 50 m in the ground, up to the maximum identified value, in this case 800 m. This way, the following classes were established: <50m; 50├100m; 100├ 200m; 200├400m; 400├ 800m; ≥ 800m.

Elaborating Vertical Dissection maps, we also used the technical guidance of Spiridonov (1981). The first step, according to the same procedure adopted for the Horizontal Dissection map, consisted of the delimitation of each small sub-basin. Subsequently, we identified the points where the intersections between the thalwegs and each level curve. These points were joined to the ridge lines, respecting the line of greatest fall of the relief, that is, the shortest distance between the thalweg and the ridge line (CUNHA, MENDES AND SANCHEZ, 2003). The vertical dissection classes were established according to the equidistance between the level curves, which depicts the altimetric gap between them, being in this work of 20 m. Therefore, the established classes were: <20m; 20├ 40m; 40├ 60m; 60├ 80m; 80├100m; ≥ 100m.

The Relief Energy map (MENDES, 1993) is understood as an integration map, since it is obtained from the association of information from the Declivity or Clinographic, Horizontal Dissection and Vertical Dissection maps. The technical procedure used is to compile the quantitative relief geometry data provided by the morphometric maps. In this way, the relief energy classes are configured as indices identified by qualitative terms, varying from very strong to very weak (MENDES, 1993). Classes should be formulated from the characteristics of the area of study and the particular interest of the user. For this work, the priority sequence of the mapped morphometric information and the values corresponding to each class followed the parameters acquired respectively in the maps previously elaborated and that are synthesized in table 1.

Table 1. Relief Energy Classes of the Basins of Piracicamirim River and Tijuco Preto River.

Relief Energy	Declivity or Clinographic (%)	Horizontal Dissection (m)	Vertical Dissection (m)
Very Strong	≥ 30	< 50 50 ⊢ 800 ≥ 800	< 20 20 ⊢ 100 ≥ 100
	< 2 2 ⊢ 30	< 50	< 20 20 ⊢ 100 ≥100
	< 2 2 ⊢ 30	50 ⊢ 800 ≥800	≥100
Strong	20 ⊢ 30	50 ⊢ 800 ≥800	< 20 20 ⊢ 100
	<2 2 ⊢ 20	50 ⊢ 100	< 20 20 ⊢ 100
	<2 2 ⊢ 20	100 ⊢ 800 ≥800	80 ⊢ 100
Medium Strong	12 ⊢ 20	100 ⊢ 800 ≥800	<20 20 ⊢ 80
	<2 2 ⊢ 12	100 ⊢ 200	<20 20 ⊢ 80
	< 2 2 ⊢ 12	200 ⊢ 800 ≥800	60 ⊢ 80
Medium	5 ⊢ 12	200 ⊢ 800 ≥800	< 20 20 ⊢ 60
	<2 2 ⊢ 5	200 ⊢ 400	<20 20 ⊢ 60

	<2 2 ⊢ 5	400 ⊢ 800 ≥800	40 ⊢ 60
Weak	2 ⊢ 5	400 ⊢ 800 ≥800	<20 20 ⊢ 40
	< 2	400 ⊢ 800	<20 20 ⊢ 40
	<2	≥800	20 ⊢ 40
Very Weak	<2	≥800	< 20

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Finally, the Geomorphological maps were elaborated through the photointerpretation of stereoscopic pairs of aerial photographs, in the 1: 25,000 scale (BASE, 1995). We adoped the proposal of Tricart (1965), with some adaptations of symbologies proposed by Verstappen and Zuidam (1975). For this work, we mapped the data referring to morphography and morphogenesis and represented the morphometric determinants in the above mentioned morphometric maps. The chronology was evaluated only in relative terms, considering the difficulty of obtaining these data.

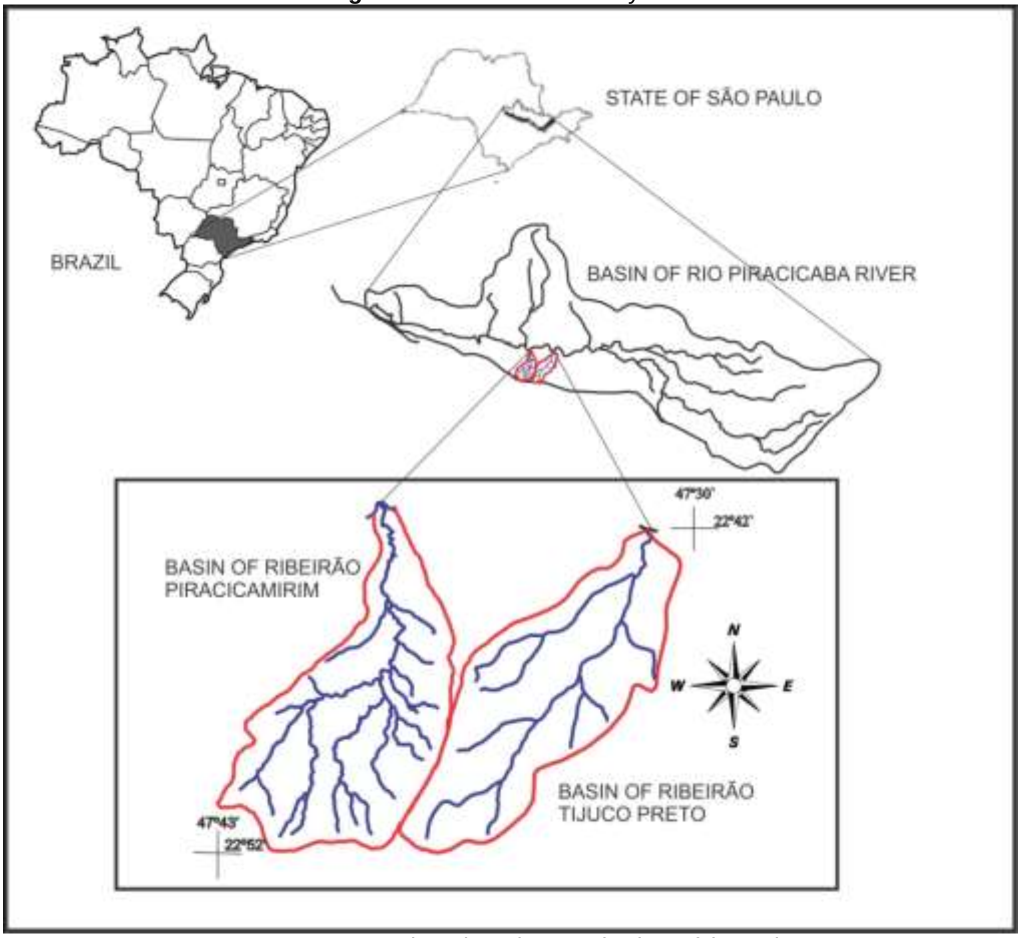
The definition of symbology was also supported in Tricart (1965). It presents a broad concept of symbols, both for the natural features and for the anthropic ones. However, this does not contemplate symbols for the forms of strands. Because of that, we adapted the symbologies present in the orientation of Verstappen and Zuidam (1975), considering the importance of the mapping of these features for the interpretation of the geomorphological picture of the basins.

THE STUDY AREA: LOCATION AND CHARACTERIZATION OF THE SISTER BASINS

The basins of Piracicamirim and Tijuco Preto rivers are located in the interior of the State of São Paulo, with most of its territory in the city of Piracicaba (SP). The first one presents an area of 133.2 km^2, while the basin of Tijuco Preto river has about 85.15 km^2, both of which are direct tributaries of the left bank of Piracicaba river (Figure 3).

As regards the geological constitution, according to the IPT (1981a) emerge in the basins the Paleozoic lithologies of Passa Dois' and Tubarão's Groups and Mesozoic of São Bento's Group. In Piracicamirim basin, Corumbataí's Formation of Passa Dois' Group and Piramboia's Formation of São Bento's Group occupy about 80% of the total area. Corumbataí's Formation, according to Perinotto and Zaine (1996), is constituted mainly by grayish-reddish and purplish siltstones and argillites that decompose in small pellets. Interspersed with these finer rocks, there are very fine sandstone lenses. As for Piramboia's Formation, according to the IPT (1981a), it presents a succession of sandy red and yellow layers, with medium to fine granulation. The clayey fraction presents itself in greater quantity in the inferior part of the formation, where locally occur thick, conglomerative sandstones.

Figure 3. Location of the study area



Source: Forestry Institute (1999). Organization: of the authors.

In the basin of Tijuco Preto river, Itararé's Formation of Tubarão's Group represents about 80% of the outlying lithography in the area. This formation is characterized by the presence of deposits of glacial continental, glacial-marine, fluvial deltaic, lacustrine and marine mainly comprising sandstones; Conglomerates, diamictites, tilites, siltstones, shales, ritimites and rare layers of coal (IPT, 1981b). Vidal Torrado (1994), studying the lithological complexity of the Itararé's Formation, subdivided it into two distinct domains: a domain of diamictites and rocks with a finer texture and a sandy lithology domain. In Tijuco Preto basin there is a predominance of sandy lithology.

On these formations, in both basins, the following classes of soils are found: Argisols, Latosols, Neosols, Gleysols, and Nitosols, with predominance of Latosols and Argisols (EMBRAPA, 2013). For Lepsch (2011), the Argisols are very weathered, but unlike the Latosols and Nitosols, they present a B horizon with clay accumulation. Due to this textural difference, Oliveira et al. (1992) argue that the Argisols present limitations on land use and occupation because they are quite susceptible to erosive processes, especially when combined with the larger relief declivity. Latosols are developed under prolonged conditions in warm and humid tropical environments, with the most typical ones having a not so thick (moderate) A horizon with a diffuse transition to very thick latosol B and it can reach more than 2 meters in depth (LEPSCH, 2011). Oliveira et al. (1992) affirm that the Latosols are very favorable to the tillage because of the great thickness presented by them, however, the fertility can vary a lot, being necessary the use of corrective techniques in the majority of the cases.

These pedological characteristics maintain intrinsic relationships with the relief forms, which includes the studied basins, located in the geomorphological province of Peripheral Depression of São Paulo in Médio Tietê area (IPT, 1981b). According to Ross and Moroz (1997), Peripheral Depression of São Paulo is sculpted in the Paleo-Mesozoic sediments of Paraná's sedimentary basin, presenting modeling associated with the influence of tectonics, lithological variation and morphodynamic processes of paleoclimatic environments (ROSS and MOROZ, 1997).

When referring specifically to Médio Tietê Zone, the cited authors affirm that this corresponds to the area located between Atlantic Plateau to the east, São Paulo Western Plateau to the west and Mogi-Guaçu Depression to the north, where the relief forms are denudational with shaped basically consisting of hills with broad, tabular and convex tops. According to Almeida (1964), Médio Tietê area is covered by a very organized drainage network, in which stand out the Tietê and its two main tributaries, Piracicaba and Sorocaba, being the general pattern of dendritic drainage, with some structural control from diaclases and diabases.

On these physical characteristics the anthropic action has been determining the use and coverage of the land that has in the sugarcane agriculture its greater representativeness, for both hydrographic basins. In addition, we can see the urbanized and urban expansion areas of Piracicaba, Rio das Pedras and Saltinho cities. Ometto (1998), when analyzing the water quality of Piracicamirim river, affirms that, even after the installation of the Sewage Treatment Plant - Piracicamirim, these are very compromised due to the amount of clandestine networks and deposits of waste in their waters that occur in the urban stretch of the river, as well as contamination by chemical inputs from sugarcane plantations. According to Carvalho (1995), Piracicamirim river enters into contact with the urban area in the peripheral district of Ipanema, in Piracicaba city, crossing, shortly after, a neighborhood of self-construction and a cluster of small industries.

In the basin of Tijuco Preto river, these characteristics are also quite expressive, since in the East Middle Basin is found the Batistada district, in Piracicaba city. Already in the transition from the Middle Basin to the Lower Basin, respectively located in the low strand of Tijuco Preto river and its tributary, Ribeirão Batistada, are Vila Tupi and Jardim Bartira districts, both belonging to Piracicaba city. However, as verified by Prochnow (1994), about 63% of the total area of this basin is marked by the presence of sugarcane monoculture, a fact that has been provoking the triggering of erosive processes and the contamination of watercourses.

Given these facts, we can see that there is a disordered occupation in both basins by the urban expansion in the natural areas, causing progressive degradation of the water source areas (figure 4). The implantation of irregular lots and the installation of use and occupation incompatible with the support capacity of the environment, besides deteriorating the water quality, have provoked the unleashing of denudatory processes, indicating the destabilization of the strands. In this way, we emphasize the importance of studies that provide subsidies to the territorial and environmental planning of these areas in order to minimize impacts caused by anthropic action.

Figure 4. Irregular occupation of the urbanized area of Piracicaba on the banks of Piracicamirim river (on the left) and irregular occupation of Vila Tupi district on the banks of Tijuco Preto river (on the right).

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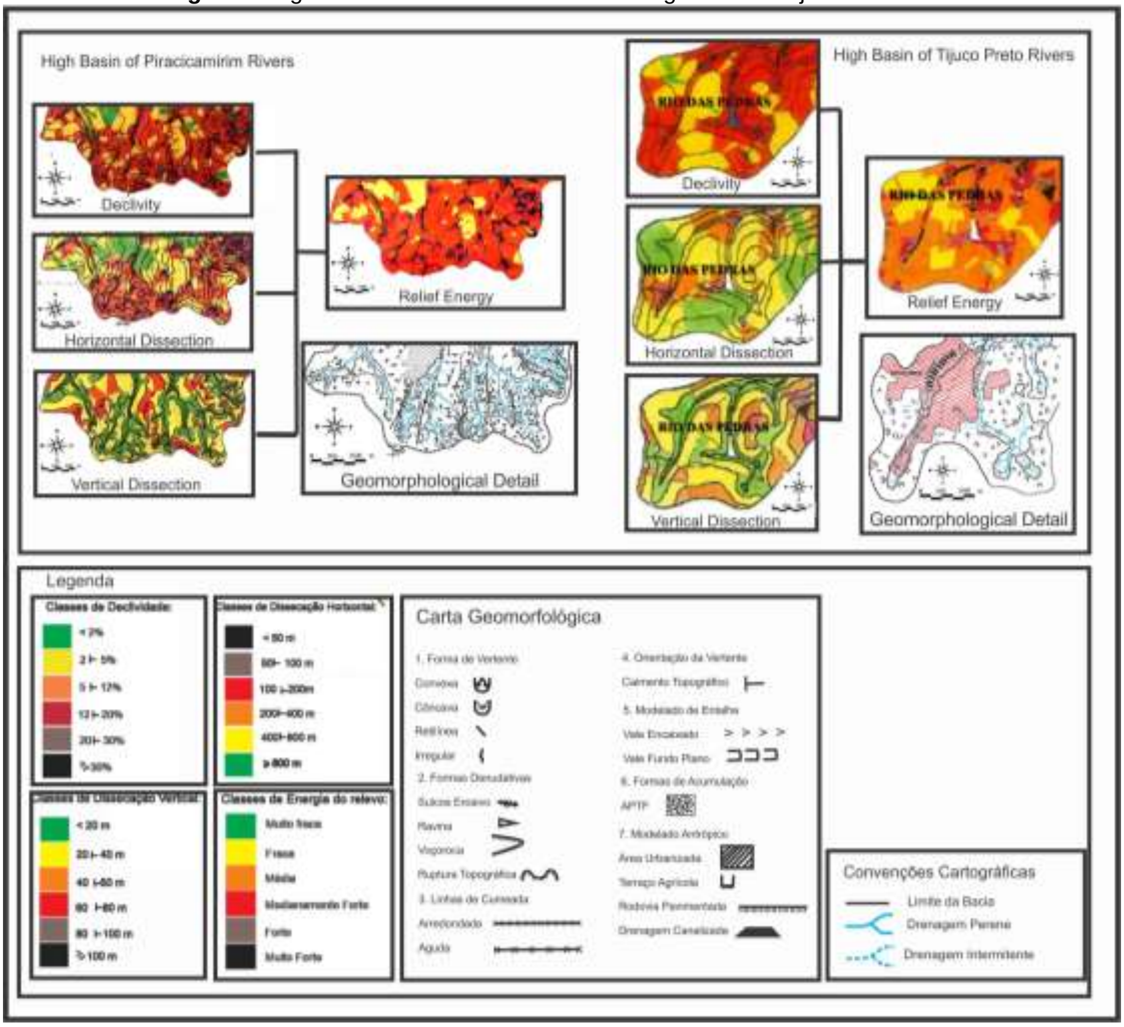
MORPHOMETRIC AND GEOMORPHOLOGICAL ANALYSIS OF HYDROGRAPHIC SISTER BASINS: APPLICATION OF CARTOGRAPHIC TECHNIQUES

In order to organize the interpretation and analysis of the results obtained from the elaborated mappings, the sister watersheds were sectoralized in high basin, east middle basin, west middle basin and low basin.

In the high basin of Piracicamirim (figure 5), the Declivity or Clinographic map shows that the class of 5 ├ 12% is predominant throughout the area. Concomitant to this characteristic, due to the large number of first-order channels, this sector presents the strongest classes of horizontal dissection, predominating the 200 ├ 400 m, but also featured the class of 100 ├ 200 m and <50 m . In relation to vertical dissection, Piracicamirim high basin presents relatively altitudes slightly accentuated, with emphasis on the classes of 20 ├ 40m and <20m.

Figure 5. High basin of Piracicamirim river and high basin of Tijuco Preto river



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When we integrate these characteristics in the Relief Energy map, there is a sector characterized by medium energy class, followed by the medium strong and very strong, the latter in places where the classes of horizontal declivity and dissection are larger. Such morphometric characteristics associated with the Argisols and the sugar cane culture result in denudatory processes quite expressive in this area, as demonstrated in the Geomorphological map. In this one, we verified the record of topographic ruptures, as well as of erosive features of furrows, ravines and gullies, the latter registered in the headwaters of the drains (figure 6). These facts show that this sector presents susceptibility to erosive processes, requiring greater attention regarding the proper use, occupation and management in order to diminish the action of erosive agents.

Figure 6 - Linear erosive features in the high basin of Piracicamirim river.

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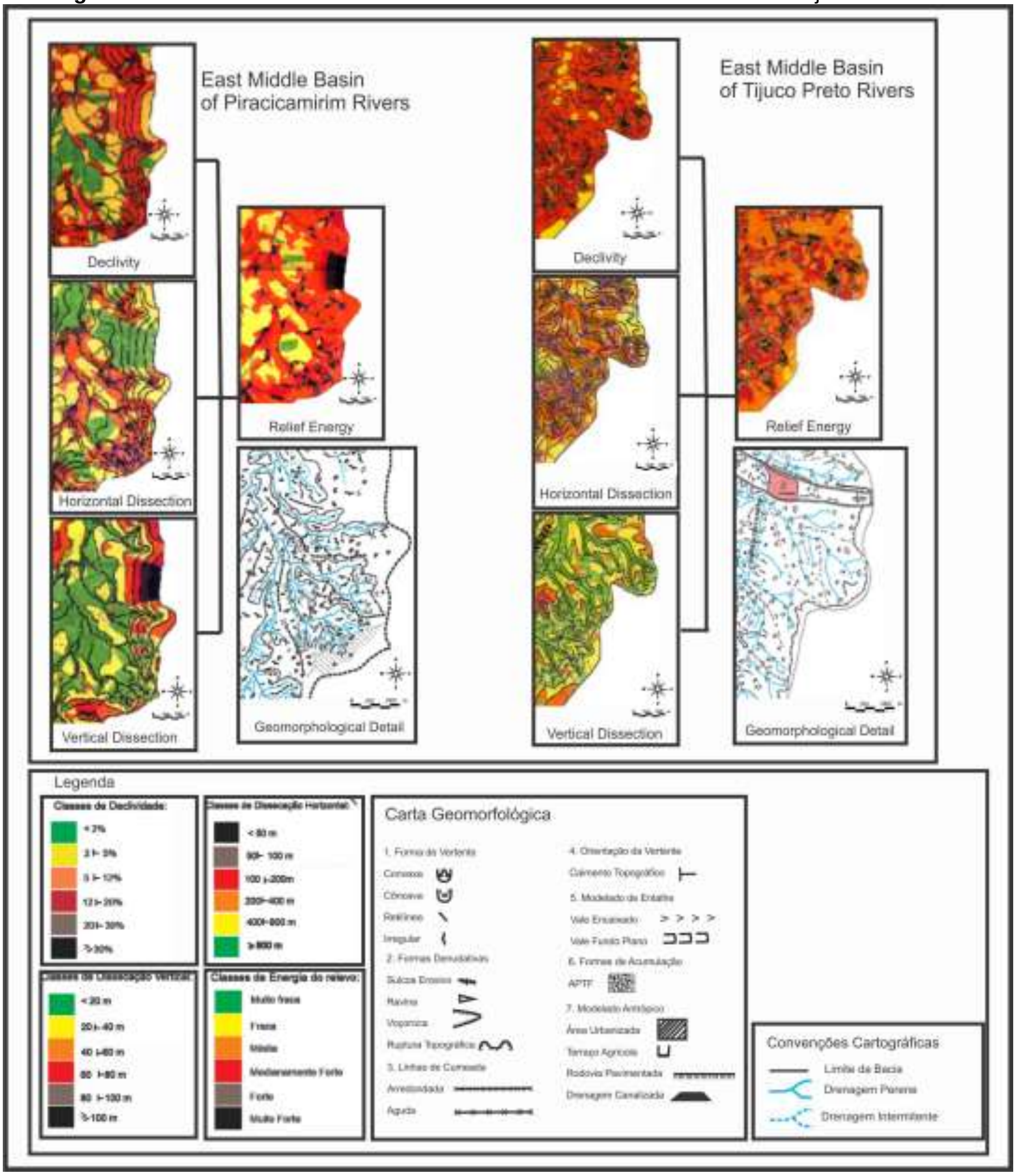
On the other hand, the high basin of Tijuco Preto river (figure 5) presents dominantly the classes of declivity 2 ├ 5% and 5 ├ 12%. The horizontal dissection in this sector is characterized by low value classes, ranging from 400 to 800m and> 800m, as well as the vertical dissection varying, predominantly from <20 to 40m. Such morphometric characteristics will result in predominantly weak and medium relief energy classes. Under these characteristics of the relief are the Nitosols, predominantly, and the Latosols, being the use of the land marked by the sugar cane monoculture and the urban area of Rio das Pedras. Although the morphometric characteristics do not indicate a high potential for the development of denudatory processes, the anthropic actions are responsible for such processes mapped in the Geomorphological map of the basin, which although they are much less accentuated than in Piracicamirim basin, are expressed by the topographic ruptures of strands and erosive furrows.

In contrast to this sector with less pronounced morphometric characteristics, the sector of the east middle basin of Tijuco Preto stands out (figure 7). In this sector, classes of declivity of 5├12% and 12├ 20% predominate, with some areas that exceed 30%. Associated with these declivity classes are those of horizontal dissection that vary widely, however, with a predominance of the class of 200├ 400m, followed by the class of 100├ 200m, 50├100 and <50m, due to the presence of several first order channels which dissect this relief. As for the vertical dissection classes, the lowest ones predominate, varying from <20m to 40m, indicating that this sector presents low relative altitude. Considering these characteristics, the largest energy classes of Tijuco Preto basin are located in this area, varying in medium, average strong, strong and very strong, respectively, in a predominance degree, being that the classes of greater energy (very strong and strong) are located next to the channels of first order.

In addition to the morphometric characteristics presented, the Argisols and Neosols dominate this eastern sector, where we found extensive sugar cane cultivations in the high and medium strands, also expanding to the lower strands, where the riparian forests are found. As a result of this use and occupation of land and physical characteristics, this sector presents frequent denudatory forms, characterized by the numerous topographic ruptures of its strands and by the erosive features of furrows, ravines and gullies (figure 8). In this way, we can observe the incompatibility between the use and management of the land that is made and the physical characteristics, mainly morphometric and pedological.

Figure 7. East middle basin of Piracicamirim river and the east middle basin of Tijuco Preto river



Organization: the authors

Figure 8. Linear erosive features in the east middle basin of Tijuco Preto river

Organization: the authors

The sector of the east middle basin of Piracicamirim (figure 7), although to a lesser degree of intensity than in the sector of the east middle basin of Tijuco Preto, also presents physical characteristics that, together with the use and management of the land, has been triggering denudatory processes that indicate the incompatibility of both. In this case, this sector can be subdivided into two, according to the degree of susceptibility to such processes. First, there is the eastern end of the basin, where the declivity classes are more pronounced, with a predominance of 12-20%. In this, the horizontal dissection varies, predominantly of 100├200m, 50├100m and <50m, respectively, indicating an area severely cut by the first order channels. Vertical dissection shows lower classes, except for a cut where it exceeds 100m relative altitude. These characteristics make this sector, together with the sector of the high basin, present the highest energy classes of the relief of the basin of Piracicamirim river, varying from medium to very strong. With the predominance of the Argisols in this sector, associated with the sugar cane cultivation, we verify, as mentioned before, the development of the denudatory processes of the strands, as demonstrated by the Geomorphological map.

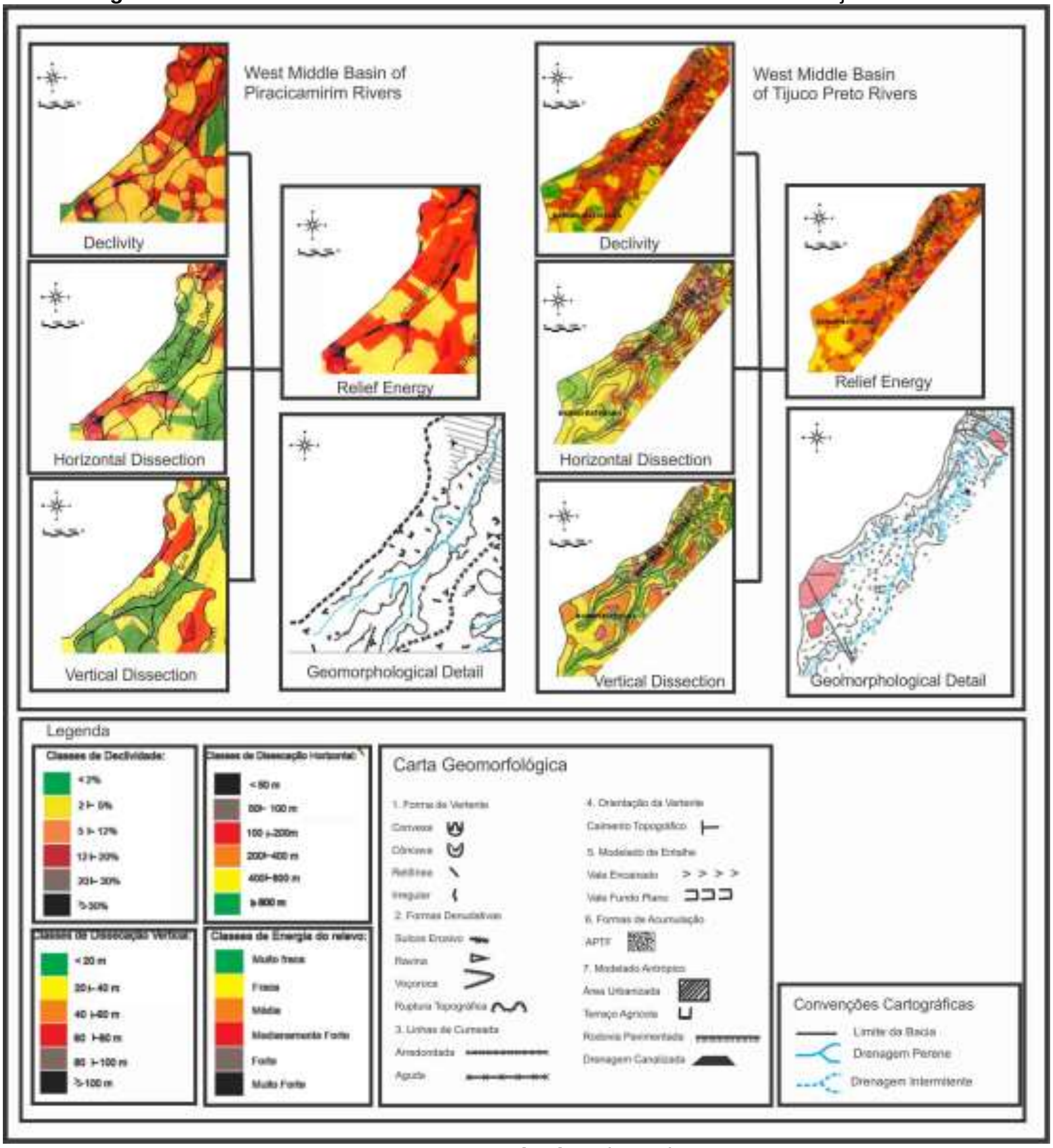
The continuity of the sector of the east middle basin of Piracicamirim presents flatter areas with declivity classes ranging from <2% to 2% 5%. In these, horizontal dissection classes are low, with a predominance of ≥ 800m. However, even with reduced morphometric values, the Geomorphological map points to topographic ruptures, erosive furrows and gullies, which although less frequent than in other sectors of the basin, shows that denudatory processes are dynamized, a fact that is linked to the predominant land use of sugarcane monoculture. In addition, the flat valley bases also demonstrate the existence of a great sedimentary load, related to the dynamics of the strands as well as to the intensity of river processes that develop in the area of springs to the south of the basin.

As for the west middle basin sector (figure 9), in the Tijuco Preto basin, the predominant declivity class is 5├ 12%. The horizontal dissections classes vary considerably, being smaller when close to the sources of the Batistada river, between> 800m and 400 ├ 800m, and larger in the middle course, where the first order channels are more numerous. The predominant vertical dissection is of <20m of relative altitude, with some punctual sectors in the basin interflow, that fall in the class of 80 ├ 100m. As a result of these morphometric characteristics, the west middle basin presents fairly distinct relief energy classes, being low and medium in the upper Batistada course and, average strong to strong, in the medium and low course.

However, as evidenced in the Geomorphological map and field works, such factors of morphometry do not inhibit the erosive processes, since the sugarcane monoculture takes all the interfluvial and drainage head of this fluvial course, leaving only minimal strips of riparian forest, intensifying erosion processes.

The west middle basin of Piracicamirim river basin (figure 9) presents lower declivity classes, 2├5% and 5├12%, with few first order channels, reaching upper horizontal dissection classes only at the springs of Água Branca stream. The relative altitudes in this sector have classes of <20m and 20├40m, with punctual areas, in the basin interflow, where the class is 40├ 60m. As a result of these morphometric classes, the relief energy classes vary from weak to medium. These characteristics associated to the Latosols result in a sector with less accentuated denudatory processes, as demonstrated in the Geomorphological map.

Figure 9. West middle basin of Piracicamirim river and west middle basin of Tijuco Preto river

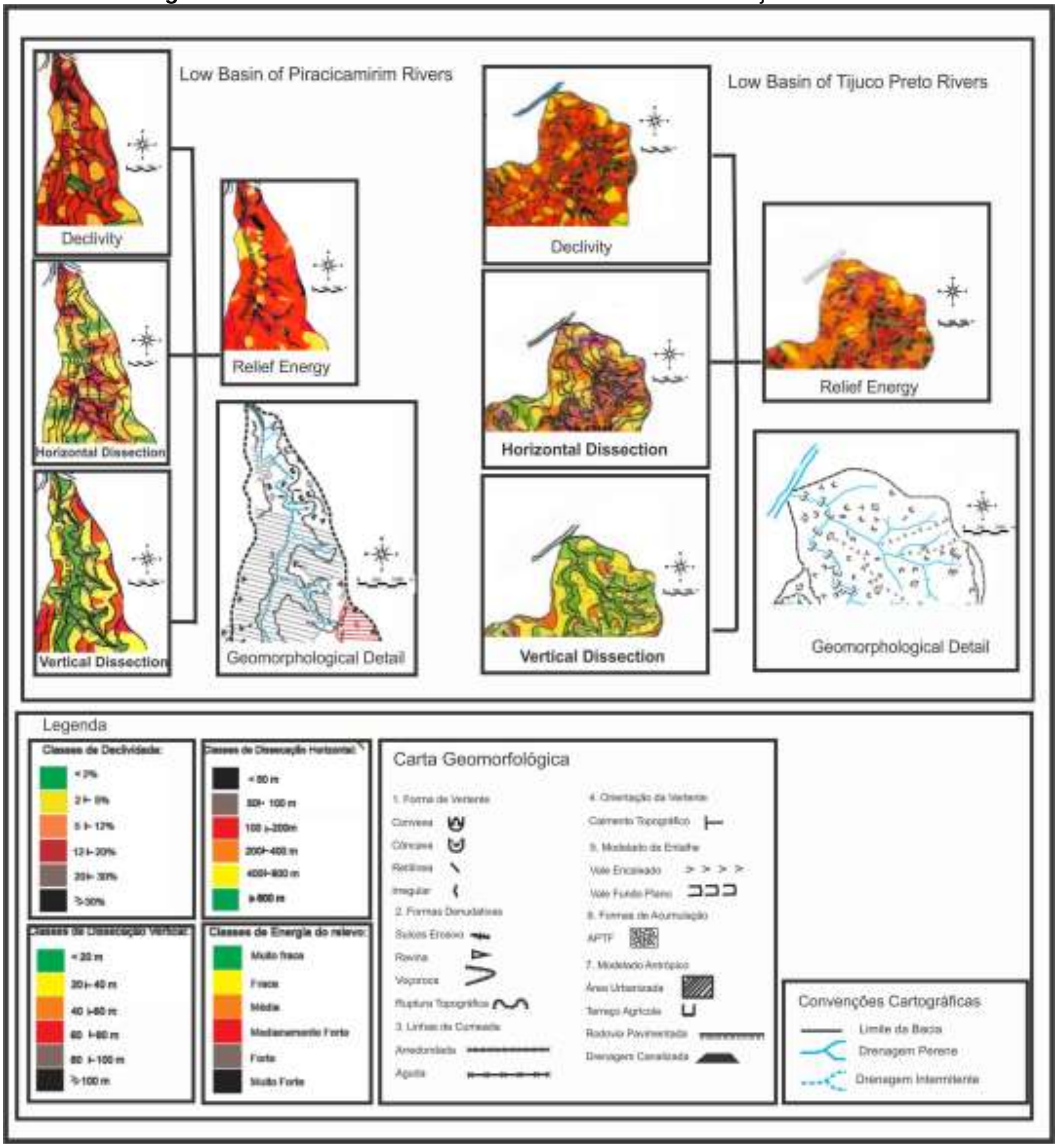


Organization: the authors

Finally, in the area of the low basin of Tijuco Preto river (Figure 10), there are numerous first-order channels, mainly on the right bank, where the strands have higher slopes, ranging from 12% to> 30%, which are progressively reduced according to the proximity of the base level of Tijuco Preto, represented by Piracicaba river. In this sector, the horizontal dissection presents high classes, with narrow interfluves, with predominance of classes 100├200m and 50├100m, respectively. The relative altitudes, indicated by the vertical dissection map, are characterized as low with the predominance of classes <20 m and between 20 and 40 m. As a result the relief energy classes are high, characterized as average strong, strong and very strong.

These characteristics of the relief associated with the anthropic actions and the pedological characteristics make this sector susceptible to the dynamics of erosive processes. The presence of two paved highways, Luiz de Queiroz - SP 304 and old road to Vila Tupi - SP 135, where we can find landfills that deform the topography and strands, there are erosive processes, often associated to the interruption of drainage channels, leading to erosive recovery. In addition, the presence of sugarcane intensifies the erosive processes that contribute to the sedimentation of the river channel. The lithology, as well as the types of soils, help these processes, considering the presence of Itararé Formation and the Argisols associated to the Neosols.

Figure 10. Low basin of Piracicamirim river and low basin of Tijuco Preto river



Organization: the authors

As for the low basin of Piracicamirim river (Figure 10), it presents the average relief energy class resulting from declivities varying from 5 to 12% and low relatively altitudes, with classes of <20m and 20├40m. Only the classes of horizontal dissection are somewhat larger due to the presence of first order channels, especially in the right bank of Piracicamirim river. The use of the land in the low basin is urban, which causes deformations in the relief, fact that is verified in field survey, which causes the strands to be straight and, in some places, the channeling of the central drainage of the basin.

Through the geomorphological map it was also observed that, in this section the valley bases are altered by the engineering works, verifying the construction of urban roads that are parallel to this drainage. Due to these engineering works, according to observations made *in loco*, the valley presents clear signs of erosive recovery that is reflected in its carving on its old deposits. It was also observed the restricted presence of fluvial terrace-like features occupied by urban constructions.

FINAL CONSIDERATIONS

Geomorphological cartography can contribute significantly with subsidies to territorial and environmental planning. However, due to the high and complex amount of information required for the organization of geomorphological mapping, one of the strategies of the geomorphological scientific community was to gather morphometric data into a specific cartographic representation.

Organized traditionally from topographic maps, the morphometric maps allow a quantitative analysis of the attributes of the relief forms. For this work we organized the map of Declivity or Clinographic, which contributed with the quantitative representation, in percentage, of the inclination of the strands; The Horizontal Dissection map, which quantified the distance separating the thalweg from the ridge lines, allowing the analysis of the interfluvial dimensions; The Vertical Dissection map, which quantified the relative altitude between the ridge line and the thalweg, allowing the analysis of the degree of carving performed by the river courses and; Integrating the morphometric information, the Relief Energy map, which allowed the qualitative classification of the relief potential for the occurrence of morphodynamic processes.

In addition to these documents, we also organized detailed geomorphological maps, which enabled the analysis and spatialization of the forms and, deductively, the understanding of the processes involved. There for, when elaborating and analyzing the morphometric maps together with Geomorphological maps, areas potentially susceptible to the unleashing of denudatory processes are pointed out, as well as the occurrence of these, through the features mapped in Geomorphological maps.

The unit of analysis and mapping corresponded to the hydrographic basin, considering it as an integrative functional unit for the analysis of geomorphological dynamics, as well as a system, constituted by the interaction of subsystems. In view of this, the sister basins are understood as subsystems that interact and are part of a system. From this perspective, the river basin system becomes an integrated environmental planning unit.

In this way, this work applied techniques of morphometric and geomorphological cartography with the purpose of analyzing the relief in sister basins, with the case study of the hydrographic basin subsystems of Piracicamirim river and Tijuco Preto river, both belonging to the hydrographic basin system of Piracicaba river. The data acquired through this study contribute to the planning of hydrographic basins according to the analysis of the natural conditions, as well as according to the occupation / anthropic intervention processes.

It can be verified that in certain situations, the morphometric potential of the relief conditions in high-class circumstances, associated to the conditioning of pedological / lithologic fragility, as well as associated with the dynamics of use and occupation, result in significant denudatory features. We can exemplify that with the extreme east sectors of the middle basin of Piracicamirim and the east middle basin of Tijuco Preto. These areas have high drainage density and intermediate to high declivity classes that result in intermediate to high energy classes of relief. They register not so thick soils, represented by the Neosols or soils with a textural difference, with the Argisols. In addition, the lithology presents fragility, mainly for being linked to the sandstones of Itararé's Formation. In these physical conditions the sugar cane monoculture is installed, which creates preferential corridors for the concentration of the rainfall, resulting in linear erosive features, recorded in significant quantities in the Geomorphological maps.

At the same time, we also recorded linear denudatory features in sectors with reduced morphometric potential, with low declivity, extensive interfluvial, reduced notching of river channels, resulting in low energy classes of relief. These conditions are exemplified by the sectors of the east middle base of Piracicamirim and west middle basin of Tijuco Preto, of which the more developed pedological conditions in smoothed relief are not guarantees of the absence of linear erosive features, considering that the dynamics of use and occupation is marked by sugarcane monoculture.

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