Delimitation of physiographic units using remote sensing data and GIS for territorial planning in the São José dos Campos region, São Paulo State, Brazil

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Abstract. This paper shows the results of physiographic compartmentalization of the region covered by the topographic sheets of São José dos Campos and Jacareí, São Paulo State, in Brazil. It is inserted in the Sedimentary Basin of Taubaté limited by Crystalline Basement of Serra do Mar and Mantiqueira. According to the geomorphological division of the State of São Paulo is part of the Atlantic Plateau Province in the zone Middle Paraíba do Sul Valley. As materials were used topographic maps in scale 1:50,000, geological map in 1:100,000 scale, geomorphological map in 1:250,000 scale of Paraíba do Sul Valley, image Landsat-5 of band 4 and morphometric data obtained by TOPODATA system. The realization of physiographic compartmentalization followed the recommendations of the logical interpretation method. In this method, the study of texture, form and structure of the features follows the steps photoreading, photoanalysis and photointerpretation. As results the units located in the region of mountains (units 1, 2, 3, 16 and 19) have potential to mass movements, as creep, landslides and debris flow. These units are geologically located in the region of Crystalline Basement that has high textural density, high slopes, high amplitudes and angular tops. It is recommended for the areas that follow the directions of the Forest Law Brazilian, which establishes that areas with slope more than 45° and mountains top that needs having forest. The units located in the region of mounds and hills

(units 4, 5, 7, 9, 12, 14, 15, 17) may be located both in the domain of Crystalline Basement or in the sedimentary rocks (Taubaté Group). The geological process that can occur is linear erosion, as erosive furrows and gullies. For these units the mainly characteristics are the medium slopes, medium textural density and rounded tops. As these units have the pasture as main land use, it is recommended the reconstitution of the vegetation and restoration of forest fragments. The units inserted in the region of floodplains and fluvial terraces (units 10, 11, 12, 13 and 18) are both in the domain of sedimentary rocks or sediments of quaternary (sands, gravels, silts, clay and peat). The geological processes that occur in these areas are mainly flood, siltation and fluvial erosion. These areas have as main land use mining and rice culture that can initiate or speed these geological processes. The products of remote sensing and GIS are efficient to territorial planning as seen in this work. Thus, this methodology can be employed in other places because uses tools of low cost that can help in the environmental planning mainly in the decision-making.

Keywords: physiographic compartmentalization, logical interpretation method, territorial planning

1. Introduction

The population growth and increasing demand for natural resources have caused an intense appropriation of elements of the environmental system, often devoid of proper planning. Human activities on the Earth's surface they are directly related to the elements of the physical environment, increasing the occurrence of geodynamic processes such as landslides, floods, siltation, flooding, and others (Corrêa 2013).

According to the same author, the lack of knowledge of the limits on the physical environment becomes an aggravating factor in this scenario, since the study and recognition of the elements that constitute it can help mitigate the environmental problem primarily around the major urban centers and places of intense agriculture activity (Corrêa op. cit). Fernandes-da-Silva et al. (2010) complement, pointing out that data about the physical environment (such as rock and soil types, relief, vegetation and natural processes) are essential to formulate and to implement successful strategies for environmental management. For this assessment, the remote sensing provides a powerful tool for environmental evaluation in support of land-use planning (Dai et al. 2001).

For Oliveira (2004), the Physiographic Compartimentalization is the method used to group the elements of the physical environment according to their similarities and differences. It is performed by the analysis of the elements of the physical environment, which may be of geological or geomorphological nature, and identifying local aspects of these elements, i.e., their

forms of occurrence (Vedovello and Mattos 1993, 1998). Zaine (2011), Silva et al. (2010) and Cardoso et al. (2009) corroborate this assertion, stressing that for the compartimentalization to be performed should have as reference mainly the textural properties (relief, shape and drainage structure) of the analyzed environment.

In the proposal of Zaine (2011), that follows the recommendations of the logical interpretation method (Soares and Fiori 1976), the studies of texture, shape and structure of features follows the steps of photoreading, photoanalysis and photointerpretation. According Soares and Fiori (1976), the photoreading corresponds to the recognition of texture elements of interest in image. In the photoanalysis, is performed the association and order of parts of image analyzed and the photointerpretation analyses the image, aiming the discovery and evaluation by inductive, deductive and comparative methods of the meaning, function and relationship of objects corresponding the images. As this work used orbital images, the considerations of Veneziani and Anjos (1982) and Soares et al. (1978) were required.

The photoreading it is based in techniques identification and process of obtainment of orbital image or aerial photography , as spatial resolution, spectral resolution and the solar angle, beyond the recognition of texture elements of interest in image (Soares and Fiori 1976; Soares et al. 1978).

This paper shows the results of physiographic compartmentalization of the region covered by the topographic sheets São José dos Campos and Jacareí, São Paulo State, in Brazil. The area it is characterized by several fragile geoecosystems and by an intense intervention of anthropic activities. The proposal is to realize the physiographic analysis following the propositions Fernandes-da-Silva et al. (2010) and Zaine (2011).

2. General features of the study area

The study area is located in the State of São Paulo, called Middle Paraíba do Sul Valley (Figure 1). Understands the 1:50,000 topographic sheets of São José dos Campos (SF-23-YD-II-1) and Jacarei (SF-23-YD-II-3), bounded between parallels 23°00'S and 23° 30'S and meridians 46° W and 45°45'W. In general, according to Köppen, the climate of the area in question permeates between the CFA (oceanic subtropical) and Aw (seasonal tropical with a dry season in winter) (Kottek et. al. 2006). Regarding the geological context, the Paraíba Valley is inserted in the Sedimentary Basin of Taubaté limited by Crystalline Basement of Serra do Mar and Mantiqueira, which consists mainly of gneiss and granite sequences (IPT 1978). The Sedimentary Basin of Taubaté consists in fulfilled sediments from the Tertiary and in the study area comprises the Resende, Tremembé, São Paulo, Pindamonhangaba Formations and quaternary sediments (IPT 1978).

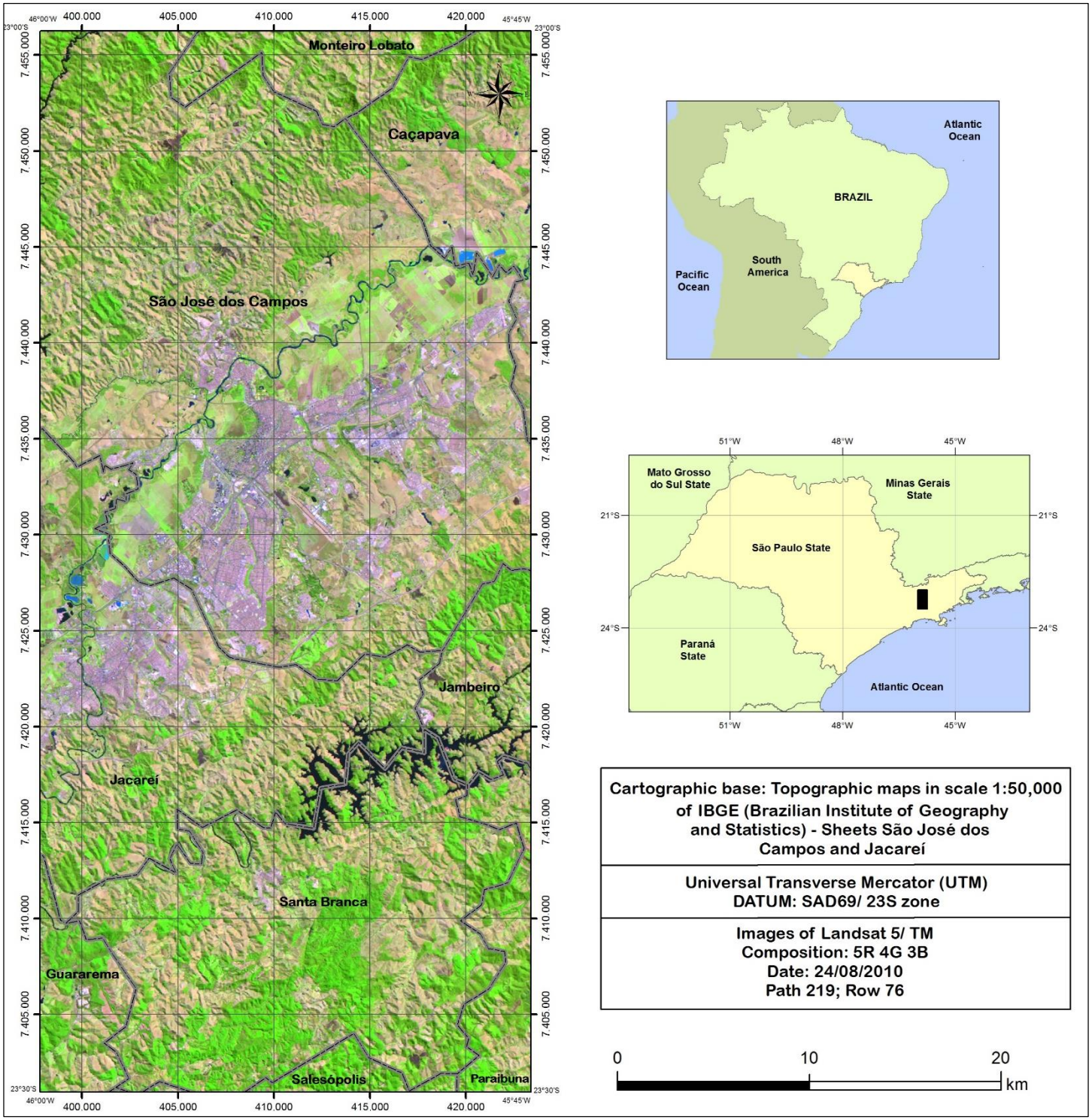

Figure 1. Location of study area

Linked to these geological formations, the area in question, according to the geomorphological division of the State of São Paulo (IPT 1981) is part of the Atlantic Plateau Province in the zone Middle Paraíba do Sul Valley.

For the same author, the Middle Paraíba do Sul Valley is an area divided into a region of hills developed on Precambrian crystalline rocks, known as Crystalline Hills, and in a region called Sedimentary Hills, located in the Sedimentary Basin of Taubaté and Flood Plain, where are allocated the quaternary sediments originated from neo-morphodynamics of the Paraíba do Sul River.

3. Methodology

As materials were used topographic maps in scale 1:50,000 (IBGE), geological map in 1:100,000 scale (IPT), geomorphological map in 1:250,000 scale of Paraíba do Sul Valley (Florenzano and Csordas 1993) and image Landsat-5 of band 4, dated from 08/19/87 with path 219 and row 76. The respective image has suffered two digital processing in SPRING 5.1.8 software: linear contrast and Linear Filtering Highlight. According Florenzano (2008), with these processes drainages, faults, joints and other linear features in the image they are highlighted. The geological and geomorphological maps they were used to help field surveys as well as support the analysis of photointerpretation, one of the steps of Physiographic Compartimentalisation. About morphometric data, represented by maps of slope and hypsometric, stress that were prepared from the data obtained by TOPODATA system (Inpe 2008) in the software Acgis 10.1.

From the above steps, the realization of physiographic subdivision followed the recommendations of the logical interpretation method (Guy, 1966; Soares and Fiori, 1976). In this method, the study of texture, form and structure of the features follows the steps photoreading, photoanalysis and photointerpretation. According to Soares and Fiori (op.cit.), photoreading comprises the step of recognizing the texture elements of interest in the image. The photoanalysis, in turn, makes the association, ordering of parts of the image is analyzed, the image interpretation of image analysis aimed at the discovery and evaluation by inductive, deductive, comparative methods of meaning, function, and relationship of objects corresponding to images. In the present study, the orbital sensing images they were used, so the propositions of Veneziani and Anjos (1982) and Soares et al (1978) were necessary. This step followed the propositions of the analysis framework performed by Zaine (2011) (chart 1). This method aims to obtain a geological-geotechnical map, sectioned in various terrain units, that includes characteristics concerning to the relief, geology and land use, in which information are summed and presented by the integrated analysis according the logic method proposed by Soares and Fiori (1976). The chart elaborated by Zaine (2011) considers the analysis of textural density (corresponding to the elements of

drainage and relief), the analysis of shape and relief characteristics, the analysis of geological structures (structural elements) and the complementary analysis (land use and geological process occurring in the area).

Finally, the step of photointerpretation it was based in the assimilation of the results obtained from photoanalysis, by the identification of meaning of the shapes and characteristics of the delimited units in the context of its function in the environment (Fernandes-da-Silva et al. 2010; Soares and Fiori 1976; Soares et al. 1978).

Regarding the geological-geotechnical characterization, the frame proposed by Zaine (2011) gathers the results obtained by the previous steps with the data of fieldwork. In this work, the geological-geotechnical characterization was performed by textural properties and spectral of images. The analysis performed in this step followed the guidelines of item “Applications”, "Analysis of textural density”, “Analysis of forms and relief characteristics” proposed by Zaine (2011).

4. Results and analysis

In the study area, it was found 19 physiographic units, which are distributed over floodplains, Médio Paraíba Depression and Morpho-Sculptural Units of Atlântico Plateau, Mantiqueira Hills, Paraitinga/ Paraibuna Plateau and Plateau Middle Paraíba Valley (Ross and Moroz 1997) (Figure 2).

For the unit 1 (Mica schists, quartz mica schists, quartzites and quartz schists in hills relief) the process of photoanalysis and photointerpretation displayed that the textural density of drainage elements and relief is high, thus by the method of Zaine (2011) the permeability intergranular is low. The forms of slopes in this unit ranging from concave to straight, whose slope values are high. So the potential to mass movements and the relationship runoff/ infiltration is high, according the chart of Zaine (2011) in the item “Aplications”, that indicates a favorable region to geological processes of mass movements mainly landslides and creep.

The unit 2 (Migmatites in hills relief) has high relief density and drainage, so according the chart of Zaine (2011) the permeability is low and the relationship runoff/ infiltration is high. The local amplitude are high, allied to slopes that ranging from concave to straight, whose slopes are high. Therefore, following the item “Applications” in the chart of Zaine (2011), the potential to gravitational movements is high and the processes that can occur are mass movements. Compared with the unit 1 the migmatites tend to form soil profiles deeper with boulders and rocky blocks.

Analysis of textural density	**Classes**			
Elements of analysis	Elements of drainage and relief			
Analysis criteria	Density of drainage elements	Low 0 to 5/10 km²	Medium 5 to 30/10 km²	High > 30 km²
	Density of elements relief	Low	Medium	High
Property to be interpreted	Permeability (intergranular)	High	Medium	Low
Aplications	Relationship runoff/ infiltration	Low	Medium	High
Analysis of forms and relief characteristics	**Classes**			
Elements of analysis	Slopes, tops, valleys, slope ruptures, ridges and scarps			
Analysis criteria	Local amplitude	Small 0 to 100 meters	Medium 100 to 300 meters	Big > 300 meters
	Slope	Low 0 - 15%	Medium 15 - 30%	High > 30%
	Forms of slope	Convex	Concave	Straight
	Forms of valley	Open	----------	Closed
	Forms of top	Planed	Rounded	Angular
Property to be interpreted	Resistance to natural erosion	Low	Medium	High
Aplications	Depth of the bedrock	Deep	Intermediate	Shallow to outcropping sub
	Thickness of unconsolidated materials	Thick	Intermediate	Thin to nonexistent
	Degree of excavability	Low resistant	Medium resistant	Very resistant
	Potential to linear erosion (induced)	Medium to high	Medium to high	Medium to low
	Potential to mass moviments	Low	Medium to high	High
Types of relief according proposed by the IPT (1981)		**Flooplains and fluvial terraces**	**Mounds, hilllocks and hills**	**Mountains**

Chart 1. Chart of photoanalysis and photointerpretation according Zaine (2011)

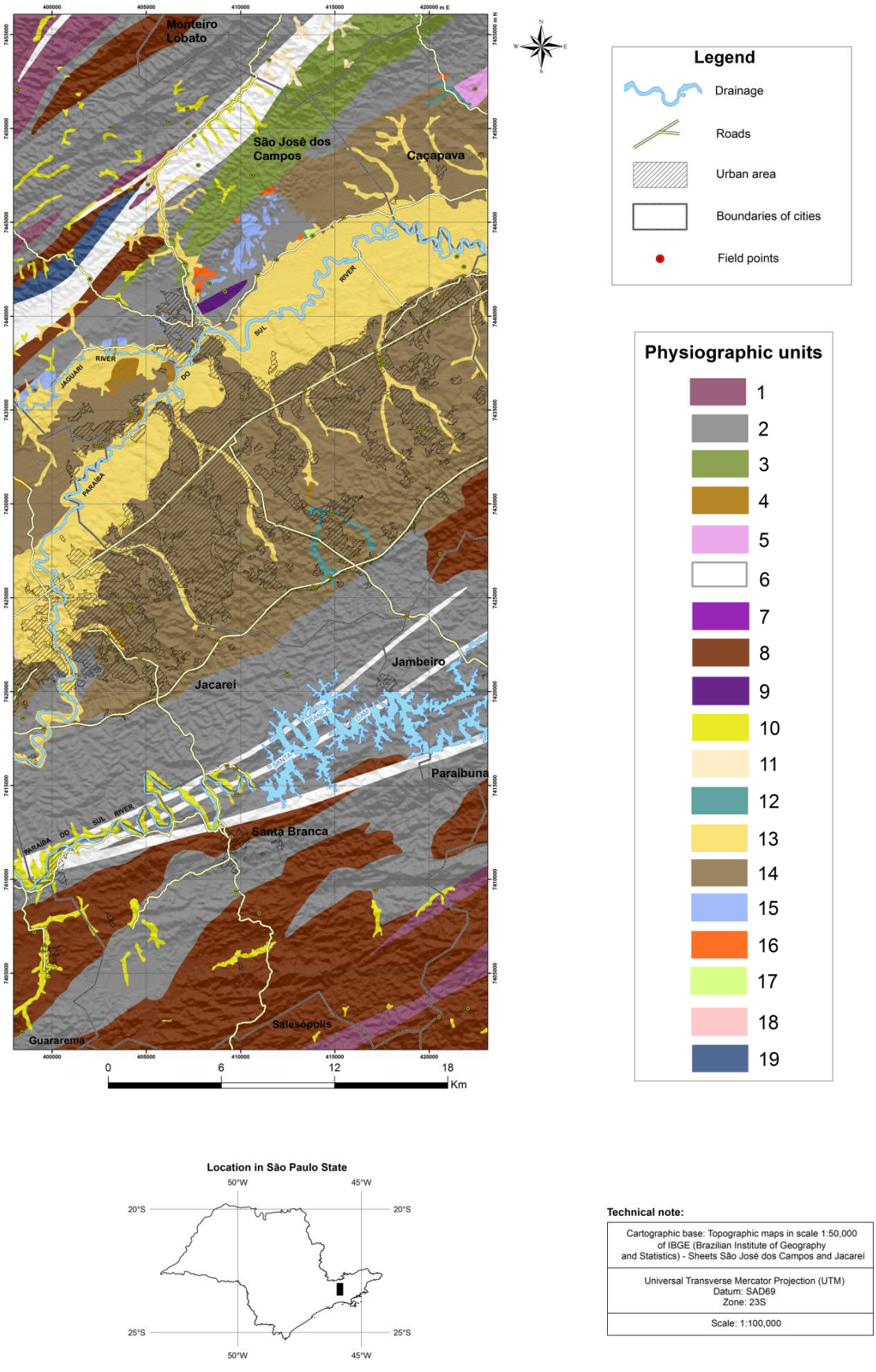

Figure 2. Physiographical units of study area

In the unit 3 (Migmatites in mountains relief) the process of photointerpretation showed that the textural density is high thus the density of relief and drainage is high. Therefore, the permeability is low and the relationship runoff/ infiltration are high. About the analysis of relief and its characteristics, this unit has high local amplitude, straight and high slopes, beyond angular tops. This way for the geotechnical characteristics of this unit it is found a high potential to gravitational movements mainly bearing blocks and landslides due the boulders in the soil profile.

The unit 4 (Migmatites in hilllocks relief) the density of drainage and relief are medium, thus the permeability as well the relationship runoff/ infiltration are medium, according the propositions of Zaine (2011). This way, the values of slope and local amplitude are medium whose slopes are concaves and the form of tops are rounded. About the geological-geotechnical properties of this unit the potential to linear erosion ranges from middle to low, as well the potential to gravitational movements, due to the more developed soil to be associated to slopes with middle values.

About the unit 5 (Migmatites in mounds relief) the process of photointerpretation showed that the density of drainage and relief are medium, as well the local amplitude and the slope. In this way according the chart of Zaine (2011), the permeability and the relationship runoff/ infiltration are medium. The forms of slopes ranging from concaves to convex and the forms of tops they are plane or rounded. About the geological-geotechnical properties the potential to linear erosion ranging from medium to high while the probability in occur gravitational movements is medium.

For the unit 6 (Cataclastic rocks in hills relief) the textural density is high due to the high density of drainage and relief. So according the chart of Zaine (2011) in the item “Applications” there is a low permeability and a high relationship runoff/ infiltration in the unit. The local amplitude and the values of slope are high with forms of slopes concave-straight with rounded tops. The potential to linear erosion ranging from medium to high as well the probability to gravitational movements.

In the unit 7 (Cataclastic rocks in mounds) the density of drainage and relief are medium, that induce a permeability and relationship runoff/ infiltration to medium values. The forms of slopes ranging from concave or convex whose values of slopes and local amplitudes are medium, with rounded or straight tops. According the chart of Zaine (2011) the potential to gravitational movements is medium, however the potential to linear erosion ranging from medium to high.

In the unit 8 (Granitic rocks in hills) the high density of drainage and relief, according Zaine (2011), in the item “Applications” induces to region a high relationship runoff/ infiltration. In this way, with the forms of slopes concave and convex and its high values, the unit can shows mass movements throughout its length.

In relation to the unit 9 (Granitic rocks in mounds relief), the textural density is medium, due to the medium density of relief and drainage. Therefore, the permeability and the relationship runoff/ infiltration are medium, according the propositions of the item "Applications" in the chart of Zaine (2011). The local amplitude and the values of slope are medium, in which shows concave forms with form of tops rounded. The potential to linear erosion and gravitational mass are medium.

The unit 10 (Quaternary sediments in hills relief) is present along all study area and although be locate in hill relief, presents as small floodplains with low slopes and local amplitudes and open valleys, however restricted. The geological process that more occur is the fluvial erosion with the undermining of riverbanks, beyond siltation and flood.

The unit 11 (Quaternary sediments in mountains relief) is distributed as small floodplains with low slopes, beyond low local amplitudes and open valleys, although restricted. The mainly geological processes that occur in this unit are fluvial erosion, the undermining of riverbanks, siltation and flood. However, the velocity of the process it can be differentiated in each unit due, the unit 11 be located in a mountain relief, in which the slopes are straight and with high values; so the entrainment of sediments tends to be more intense and faster, that enable the formation of flood waves in beds in drainages.

In the unit 12 (Quaternary sediments in hillocks relief) the textural density is medium due the medium density of relief and drainage. Therefore, the permeability and the relationship runoff/ infiltration are medium, according the prepositions of the chart of Zaine (2011). The local amplitudes and slopes are low, in which the valleys are open with forms of slopes convex to concave. Thus, the potential to linear erosion is medium to high.

In the unit 13 (Quaternary sediments in floodplains) the step of photointerpretation showed low density of drainage and relief, thus low textural density. This way the permeability is high and the relationship runoff/ infiltration is low. The analysis of relief shows low local amplitude and low values of slopes, with open valleys and plain surfaces. According the propositions of Zaine (2011) the potential to linear erosion is high. The fluvial erosion and flood occurr in this unit. This place has urban areas with big cities, as São José dos Campos and Jacareí and engineer works they are frequently performed to mitigate the problem of flooding. However, the disorderly occupation, mainly in the areas nearest to Paraíba do Sul River aggravates the problem of flood, since there is no adequate infrastructure for housing.

About the unit 14 (Conglomerates, sandstones, siltstones, mudstones and shales of Taubaté Group in hillocks relief) the photointerpretation activities showed medium to high density of drainage and relief. Thus the relationship runoff/ infiltration ranging from medium to high while the permeability ranging from medium to low. The local amplitude and slope are medium, with forms of slopes concave and closed valleys. About its geological-

geotechnical characteristics, the potential to linear erosion and to gravitational movements is medium.

The unit 15 (Conglomerates, sandstones, siltstones, mudstones and shales of Taubaté Group in hills relief) shows medium density of drainage and relief, so according the method of Zaine (2011) the permeability and the relationship runoff/ infiltration are medium. About the forms and characteristics of relief, the local amplitude and the slope have medium values, the forms of slope are concave, and the tops are rounded. About its geological-geotechnical characteristics the potential to linear erosion and gravitational movements ranging from medium to high. In the fieldwork were observed linear erosion (as gullies and ravines) and creeping.

In the unit 16 (Conglomerates, sandstones, siltstones, mudstones and shales of Taubaté Group in mounds relief) the textural density is medium and the relief density, that indicates the dissection and roughness of the terrain is medium. Thus, the permeability and the relationship runoff/ infiltration are medium. About the analysis of forms and relief characteristics, the local amplitude and the values of slopes are medium. The form of top it is plane. According the method of Zaine (2011) the unit has medium to high potential to linear erosion and gravitational movements, as landslides.

About the unit 17 (Conglomerates, sandstones, siltstones, mudstones and shales of Taubaté Group in fluvial terraces) the textural density is low due by low density of relief and drainage. The permeability and the relationship runoff/ infiltration are low. About the forms and relief, they were observed by the step of photointerpretation low local amplitudes and slopes. The form of the tops are rounded and the particular features of relief they are the fluvial terraces. By the method of Zaine (2011), about the geological-geotechnical characteristics, the potential to linear erosion of this unit ranging from medium to high. They were observed gullies in the fieldwork in some isolated points. The potential to gravitational movements is low, since the slopes have low values.

In the unit 18 (Conglomerates, sandstones, siltstones, mudstones and shales of Taubaté Group in floodplains) the textural density is low due the low density of relief elements and drainage. Thus, the permeability is high and the relationship runoff/ infiltration are low. The local amplitude as well as the slope have low values. In this way, the tops are plane and the particular features of relief are the floodplains. Therefore, the geological-geotechnical characteristics of this unit display a high potential to linear erosion and a low potential to gravitational movements.

Finally, in the unit 19 (Granulites and charnockites in hills relief) the textural density is high due the high density of drainage and relief. In this way, according the prepositions of Zaine (2011) the permeability is low. In the analysis of forms and relief characteristics were observed high local amplitude and high values of slope. The forms of slope are straight with closed

valleys besides rounded tops. In this unit, the potential to gravitational movements is high and the potential to linear erosion ranging from medium to low.

In general the units located in the region of mountains (units 1, 2, 3, 16 and 19) have potential to mass movements, as creep, landslides and debris flow. These units are geologically located in the region of Crystalline Basement that has high textural density, high slopes, high amplitudes and angular tops. As specific features, these units have oriented ridges that difficult the anthropic action. It is recommended for these areas that follows the directions of the Forest Law Brazilian, which establishes that areas with slope more than 450 and mountains top that needs having forest (Brazil 2012).

The units located in the region of mounds and hills (units 4, 5, 7, 9, 12, 14, 15, 17) may be located both in the domain of Crystalline Basement or in the sedimentary rocks (Taubaté Group). The geological process that can occur is linear erosion, as erosive furrows and gullies. For these units the mainly characteristics are the medium slopes, medium textural density and rounded tops. As these units have the pasture as main land use, it is recommended the reconstitution of the vegetation and restoration of forest fragments.

The units inserted in the region of floodplains and fluvial terraces (units 10, 11, 12, 13 and 18) are both in the domain of sedimentary rocks or sediments of quaternary (sands, gravels, silts, clay and peat). The geological processes that occur in these areas are mainly flood, siltation and fluvial erosion. These areas have as main land use mining and rice culture that can initiate or speed these geological processes. The region of Paraíba do Sul Valley it is very important in relationship the mining of sands in national context. In 1999, the Department of the Environment of the State of São Paulo established the environmental zoning for sand mining that divides the floodplain of River Paraíba do Sul in areas for protection and conservation of forest (Department of the Environment of the State of São Paulo 1999). Thus, it is very important to follow these guidelines so that geological processes they are minimized.

Fernandes-da-Silva et al. (2010) using the same methodology called the physiographic units "Basic Compartimentalization Units" – BCU's where each unit it was analyzed by tectonic discontinuities, bedrock lithology, soil profile, slope steepness and water table depth through remote sensing techniques. In similar way, Cardoso et al (2009) with the same terminology ("Basic Compartimentalization Units" – BCU's) perfomed the Physiographic Compartimentalization through the analysis and identification of textural elements of relief and drainage with remote sensing images. Fontes and Pejon (2008) using the technique known as the "Ottobasin Method" performed the compartimentalization through physical environmental atributes. Variables as rock substrate, landforms, unconsolidated material and slope they were used for making the compartimentalization in which the homogeneity of

each basin and interbasin was evaluated. In this article, the units it was called of "Physiographic Units" and its characterization was performed by the variables pointed in the chart 1. The method it is based in the textural elements of relief and drainage, and the obtainment of geotechnical data is performed by the correlation with inferences from informations of other nature (Vedovello, 2000). The main advantage of this method is the development a single cartographic product from the integration of physical environmental elements in "Basic Compartmentalization Units" – BCU's. This compartmentalization technique with field descriptions facilitates the establishment of physiographic characteristics and enables to extend the considerations to the various compartments (Oliveira, 2004).

5. Conclusion

The products of remote sensing and GIS are efficient to territorial planning and this methodology it can be employed in other places because uses tools of low cost that can help in the environmental planning mainly in the decision-making.

In the physiographic compartimentalization the environmental and anthropic elements (soil, relief, geology, geomorphology and land-use) they can be analyzed in an integrated to identify different units that can concrete limits in the space and can be used for different purposes such as environmental planning.

The process of physiographic compartimentalization produced 19 units distributed along of Crystalline Basement and the Taubaté Sedimentary Basin. The remote sensing techniques based in the photointerpretation provided satisfactory results for this study area.

It was observed that the São José dos Campos region has high fragility to geological processes due its geoenvironmental characteristics. This way is important evaluate the weight of each geoenvironmental variable in the installation of new enterprises, once the type of impact may be variable.

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