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URBAN SPRAWL IN SMALL CITIES, ANALYSIS OF THE MUNICIPALITY OF SÃO PEDRO (SP): POTENTIALS AND CONSTRAINS

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Abstract: Urban sprawl in small cities has led to the occupation of unsuitable areas, resulting in peripheralization and in the occupation of fragile environments. In these occupations, the physical characteristics of the environment are often disrespected. In this context, the present article reports on a case study in the municipality of São Pedro, state of São Paulo, Brazil, which presents and discuss a set of natural factors (geological and geomorphological) conditioning the occurrence of erosion and gravitational mass movements, which are limiting factors for urban sprawl. The methodology employed in this study was based on field work, bibliographic research, and data collection, analysis and GIS-based systematization, which allowed for a spatial reading of the urban sprawl to indicate, from different perspectives, how the phenomenon is manifested. Thus, it was possible to draw up a chart highlighting the areas with the greatest potential for occupation and those with restrictions due to their greater susceptibility to erosion and mass movements. The main identified natural factors of restriction were steepness and soil conditions and law enforced restrictions (environmental protection areas).

Keywords: Urban sprawl; small cities; fragile environments; landslides; erosion; GIS

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INTRODUCTION

The process of urbanization of Brazil's territory intensified in the early decades of the 20th century, concomitantly with the development of industrial production. This situation led not only to an increase in the number of cities but also to a change in the location of residence of the population, most of which moved to urban areas.

In the state of São Paulo, this intensified urbanization was characterized by allowing for the definitive configuration of the Metropolitan Region of São Paulo and by the shift of economic development toward the interior of the state, with clear repercussions on the urban network. Thus, the region of Campinas, encompassing the municipalities of the Piracicaba River Basin, consolidated its status as the most important economic region in the interior of the state, as attested by its accelerated population growth, agricultural and industrial expansion, and the modernization of its tertiary sector.

Urban management instruments such as zoning have being improper to solve urban problems like dispersed urbanization. In urban perimeters, the sprawl occurs due to lack of proper criteria in promoting urban growing. As consequences, urban infrastructure and public services become absent resulting a set of environmental impacts.

All this urban development has led to the occupation of unsuitable areas through territorial sprawl, resulting in peripheralization and in the occupation of fragile environments. In Brazilian Municipalities these occupations often ignored natural environmental conditions like steepness, bedrock, hydrography, and soils. Thus, areas subjected to flood as bottom valleys, as well as areas with erosion-susceptible soils and steep slopes subject to soil and rock landslides are currently occupied, posing risks to the local population.

On the other hand, Brazilian new policies, like 547/2011 Provisional Measure (Brazil, 2011) and 12.608/2012 Law (Brazil, 2012), states the obligation of prepare engineering geological maps for municipalities planning in order to reduce events of landslide and promoting risk management.

This is a big problem for most of Brazilian cities; since this survey usually needs high investments and high qualification professional teams. The problem came bigger in smaller cities, where technical and financial resources are rare.

Moreover, most of Brazilian Municipalities Master Plans are previous of these legal instruments and do not consider the natural environment potential and constrains for planning urban expansion.

Focusing these legal and technical needs, this paper intends to show how the use of basic natural environmental data can be practicable for delimitation and characterization of areas subject to sprawl. Set of data includes rock, soils, steepness and hydrography; and was applied to São Pedro (SP), a small city whose Master Plan don´t consider natural environment conditions to discuss urban expansion.

URBAN SPRAWL IN BRAZIL

According to Santos (1996), the first surge in Brazil's urbanization process took place in the late 19th century, assuming major proportions only in the second half of the 20th century. Driven by industrialization, this process, with its multiple economic and social repercussions, was seen as an urban attraction which encouraged rural to urban migration.

With accelerated urbanization and the instauration of rural exodus, the spatial concentration of the mass of people reached a theretofore inconceivable scale, leading to an ecological, political, economic and social revolution. Thus, the urban dynamics imposed by new urbanization processes often encountered a totally unprepared territory, resulting in consequences for cultural and spatial formation, transforming landscapes into increasingly urbanized refuges and inflicting serious damage to the environment and to life in society.

The production of space urban, intensified by urbanization, follows the same logic as the occupation of Brazilian territory, whereby history has demonstrated that land has always been used intensively and with an immediatist vision, exploiting it to the utmost in an unrestrained quest for profits. For Carvalho (2001), peripheral economies are based on the overexploitation of man – social dumping – and of the environment – environmental dumping – to gain competitiveness, reproducing and exacerbating them in a disorganized manner and with no predictability of the impacts.

Thus, the exploitation of spaces is manifested through the processes of urban sprawl, which, in turn, are founded upon two similar actions, but with distinct social logics. On the one hand is the urban sprawl characterized by compulsive urbanization, which is generated by a portion of the population with higher purchasing power in search of an ideal of nature and tranquility in periurban areas. On the other is the process of urban sprawl caused by the marginalization of poverty, with the excluded population forced to occupy unsuitable areas at the periphery of cities.

According to Valente (1996), the conditions of the environment in these spaces of urban sprawl are generally ignored, such as relief, geological, hydrographic and pedological characteristics inadequate for human occupation. Hence, populations are subjected to the occurrence of catastrophic events such as floods, landslides, loss of soil and urban equipment and intense erosive processes.

Burchell & Mukhjerji (2003) defines sprawl as low density occupation, leapfrog development characterized by unlimited expanses, resulting new land uses in relatively untouched environments. According to Johnson (2001), the most important aspects in urban

sprawl are the creation of large urban gaps and the improper use of land.

The main characteristics of urban sprawl in Brazilian cities are the creation of new housing lots distant from the consolidated city center and its site in the surroundings or proximities of perimeter roads, a phenomenon also observed in small municipalities (Carbonell & Yaro, 2005).

In Limonad (2007) understanding, the form of occupation of the different social classes along urban fringes is characterized by low density peripheral areas and is a worldwide phenomenon. In Brazil, the problem became bigger due to natural environmental condition non consideration in urban plans.

According to Ojima & Hogan (2008), border areas usually concentrate both industrial and residential occupations, usually low-cost, and in most cases do not respect the instruments of urban policy of the neighboring municipality, leading to major environmental impacts.

Therefore, the process of urban sprawl is revealed as an intensifier of spatial complexity and, as Braga & Carvalho (2004) argue, when any system or organism grows, its part differentiate, "becoming organisms that are more complex, more efficient, greater processors of matter and energy, more economically, socially and culturally developed, but also with greater problems: urban impacts, social conflicts, economic and political dysfunctions".

It is crucial to make advances in our understanding of spatial production in small cities, since the process of urban sprawl affects a large portion of the country's municipalities, regardless of their size, resulting in peripheralization and in the occupation of fragile environments. We must break away from the mistaken notion that these cities remain as bastions of environmental preservation.

However, in this scenario, the formation of numerous small cities that multiplied throughout the national territory was significant, either as centers of local importance (given the regional conditions of interconnection with the national economy and the development of specific productive activities), or as locations with notoriously precarious infrastructural conditions (a large part of which emerged due to the laws governing the creation of municipalities and cities in the country).

According to the classification of the IBGE (2000), a small city is defined as one that has a population of up to 100 thousand. On the other hand, the IPEA (2001) classifies small municipalities as those with a total population of less than 50 thousand.

Despite its population's, Brazilian small cities usually have a physical structure that does not meet the real needs of the population, which may, due to unplanned occupation and low investments in infrastructure, lead to low "quality of life" and serious problems in the urban and natural environment. This situation is easily perceived in the municipality of São Pedro, SP.

In this sense, it is necessary to adopt measures of urban planning that allow for adequate and ordered growth in these small municipalities, as well as preservation of the environment in these areas, ensuring a better quality of urban life.

It should be noted that the Constitution of the State of São Paulo (São Paulo, 1989) determines the obligation of Master Plan for all its municipalities, regardless of their size, reaffirming and expanding the ideas of development that are present in the Federal Constitution of 1988. However, what one sees in reality is a lack of local political interest, a paucity of available funds, and minimal practical actions to better deal with urban sprawl in these areas.

In view of the dearth of conceptual and methodological studies about small cities, and the insufficiency of mechanisms of regulation and territorial ordering in these places, we highlight the importance of regional and local studies that can contribute to future analyses of urban sprawl in small municipalities.

STUDIED AREA

The municipality of São Pedro covers an area of 618 square kilometers and is located in the central eastern portion of the state of São Paulo (Middle Tietê River valley), in the region of Piracicaba, 180 kilometers from the state capital (São Pedro, 2008), as illustrated in **Fig. 1**.

Fig. 1 Location of the study area (Fracassi, 2008).

São Pedro, situated in the Paulista Peripheral Depression, has a pluviometric index of 1,175.5 mm/year, temperatures varying from 12 to 32°C, which is considered a dry climate, with a predominance of cerrado biome (São Pedro, 2008).

The Paulista Peripheral Depression, is a depressed erosive strip with portions reaching lengths of 450 kilometers (north/south) and with a mean width of approximately 100 kilometers (narrowing to the north and widening in its central portion) in Parana Basin.

Table 1. Main physical characteristics of the study area

CLIMATE	Tropical Climate with two well defined seasons: DRY-COLD (April to September, with average monthly temperature of 16° to 19°C) and WARM-WET (October to March, with temperatures varying from 22° to 27°C). Mean annual temperatures exceed 22°C. Thermal and rainfall oscillations influenced by altitude and relief.
VEGETATION	Remnants of the original Latifoliate Forest vegetation, restricted locales predominated by steep slopes and Cerrado vegetation. Original vegetation in large part destroyed to make way for pastureland, sugarcane, citrus, reforestation and annual crops.
HYDROGRAPHY	Drainage system reflecting control by regional tectonics with preferential NW – SE direction and secondary N – S and NE – SW directions.
SOILS	Latosol, latosolic quartz sand and hydromorphic soils.
TECTONICS	Heritage of zones with weak foundations. Meso-cenozoic reactivations. Alignment of the mountain range. Oriented drainage systems.
BEDROCK	Corumbataí Formation (argillite, stratified clay-bearing rock and siltites), Pirambóia Formation (fine-grained sandstone and clayey sandstone), Botucatu Formation (fine to medium-grained sandstone with minor clay contents of less than 5%) and Itaquerí Formation (conglomerate sandstone with polymictic pebbles, siltites, argillites and stratified clay-bearing rock). Cenozoic deposits – poorly consolidated sediments with medium-grained sand.
GEOMORPHOLOGY	Based on the geomorphologic division of the state of São Paulo, the study area encompasses three of the five compartments described for the western Paulista plateau (top of the São Pedro mountain range), the peripheral depression (area of the Middle Tietê) and basaltic cuestas. Cenozoic faulting, mainly normal and transcurrent faulting, reflected in the general outlines of the relief and of the regional geomorphology.

In terms of relief, the terrain is relatively even, with differences in height of 20 to 50 meters and, in exceptional cases, higher than 100 meters. The most significant morphological characteristics are expressed in broad horizons and gentle shapes, such as flat-topped hills 550, 650 and 700 meters high, slightly convex, dividing broad valleys, complemented by the flat bottoms of alluvial plains.

Despite the predominance of Paleozoic sediments, there are discontinuous surface areas of intrusive magmatic bodies, usually in the form of diabase sills and dikes that controls parts of the local relief, generating slopes with levels varying according to the homoclinal structure and lithologies resulting from differential erosion.

With regard to the cuestas of the Tietê channel (especially the São Pedro and Itaquerí mountain ranges), these formations exhibit very particular characteristics that reflect tectonic activity, where the exposure of the sandstone to a single lava overflow caused the formation of straight vertical walls. **Table 1** summarizes the main physical characteristics of the study area.

Master Plan of São Pedro

In its chapter II (on the Rural Macro-zone), under article 90, the current Master Plan of the municipality of São Pedro (São Pedro, 2008) subdivides and delimits this zone on the Territorial Macro-zoning Map into zones of interest for urban expansion, urban expansion outside the seat of the municipality, environmental protection and preservation, and rural green zones – RGZ – Corumbataí AEP (Area of Environmental Protection).

According to article 91, the Zone of Interest for Urban Expansion is composed by areas with potential and trend for urban growing, defining new occupation enterprises in the expansion tendencies.

Article 92 states that the Zone of Interest for Urban Expansion definition has the main objectives of propose actions for urban and territorial development, promote urban densification in disperse occupation areas and order new urban occupations.

However the Master Plan doesn´t present the criteria for defining this area and inform that Zone of Interest for Urban Expansion definition is showed in Territorial Macrozoning Map. Observing the map (**Fig. 2**) we note that Urban Expansion Zone limits definition was simple Urban Zone corners connections, without consider other criteria. This is a very common approach in many Brazilian Cities Master Plans.

However, in reality, what one sees is urban sprawl unlike that foreseen in the Master Plan, since, according to the Territorial Macro-zoning Map, there is already a consolidated growth to the southwest of the main urban area of the municipality (Urban Zone outside of the Seat of the Municipality – Z10), while the zone of interest for urban expansion is located to the southeast of the main urban area. An example of a neighborhood situated in Z-10 is Alpes das Águas, which covers an area equivalent to that occupied by the main urban area of São Pedro.

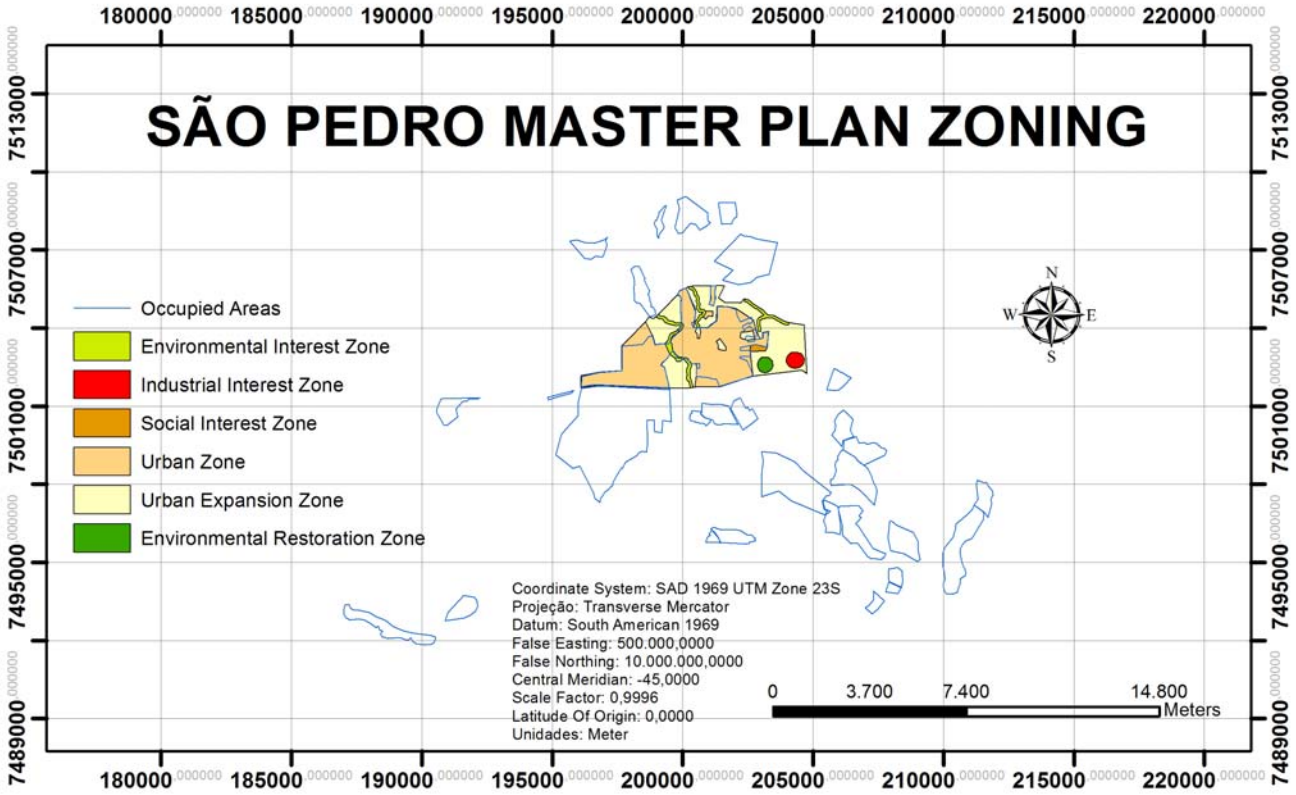

Fig. 2 Territorial Macrozoning Map of São Pedro.

METHODOLOGICAL PROCEDURES

Principles

The surveys required for the characterization of the attributes involved in this analysis included field trips to identify and understand the areas of expansion of the municipality, a bibliographic survey including official documents of the municipality (its Organic Law and respective Master Plan), as well as the collection of data available at the IBGE, the Ministry of Cities, the local city hall, and digital and analogical databases of articles and theses. These are the basic information for studied area characterization in terms of its natural and social environment.

The production of the digital database, the spatial analyses and the creation of thematic charts were performed with computers using the Geographic Information System Spring (SPRING, 1996). The collection of natural attributes and its spatial distribution was essential to provide the basis for data treatment (using algebra map) combining the attributes to establish how its combination results more potential or constrain situations for urban planning.

The natural attributes (hydrography, bedrock, soils, and steepness) were obtained from existing surveys and from the municipality's Master Plan (São Pedro, 2008). The choice of these attributes is justified due to the nature of the municipality's most common natural phenomena, which may act as limiting factors for urban occupation (erosion and gravitational mass movements).

The purpose of GIS is to underpin decisions based on spatial data, proving a selection of priorities. By means of these procedures, it was possible to systematize, relate and observe the data, in order to draw up a chart identifying the different potentials for urban occupation.

Characterization of the attributes

Bedrock

The bedrock of the study area is composed of the following lithostratigraphic units: Alluvial Deposits (sandy alluviums with gravel beds and contributions of fine and coarse ramp colluviums); Botucatu Formation (fluvial sandstone at the base and aeolian sandstone at the top, fine to medium-grained, with occasional conglomerate sandstones bodies at the base); Corumbataí Formation (purplish or reddish siltites and argillites with intercalations of very fine-grained sandstones lens); Itaquerí Formation (post-Serra Geral sediments constituted of banks of sandstones alternating with clayey cement, ferruginous crusts, stratified clay-bearing rock and conglomerates in the basal portion); Pirambóia Formation (fine and medium-grained sandstone with a higher proportion of clay fraction in the lower portion); Serra Geral Formation (a sequence of basaltic overflows (predominantly aphanitic and with associated intrusions, and dikes with intercalations of lenses and sandy layers). **Figure 3** shows the bedrock map for this area (SÃO PEDRO, 2008).

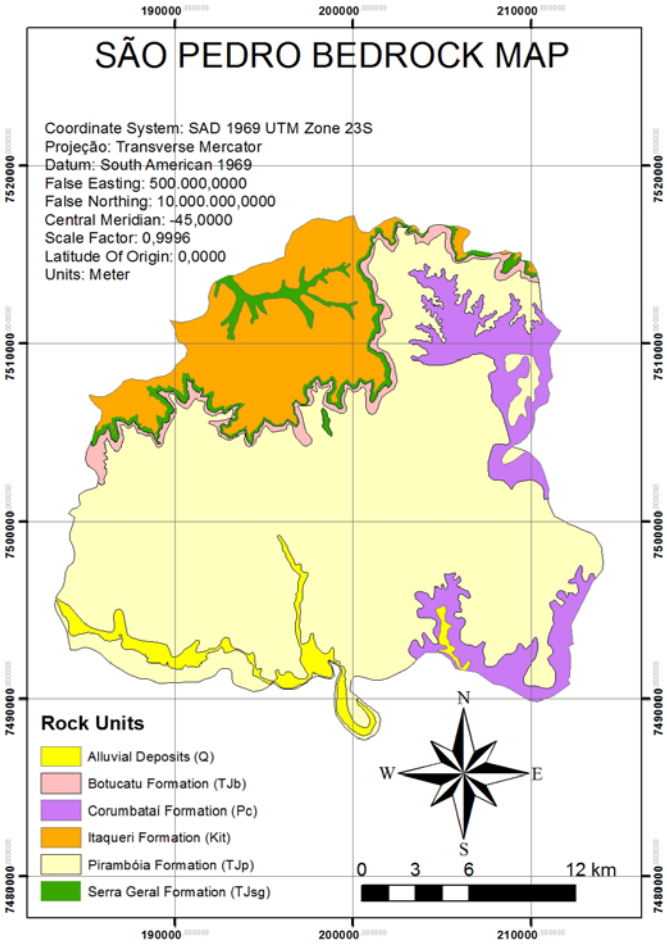

Fig. 3 Bedrock map for São Pedro area.

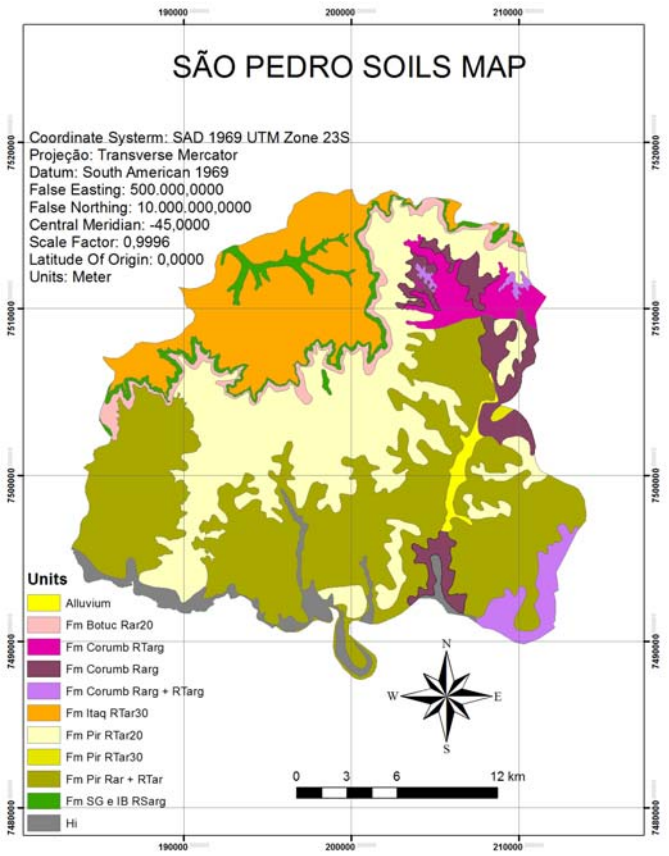

Fig. 4 Soil and sediments units map for São Pedro area.

The analysis of the influence of the units of the substrate on the occurrence of erosive processes took into account the texture and coherence normally presented by the units in the area in their undisturbed state and in an altered condition.

To evaluate the potential for the occurrence of gravitational mass movements, the cohesion and structures of the lithologies in each unit were considered.

Soils and Sediments

Pejon (1992) describes eleven soil units in São Pedro Municipality area. The texture of each unit of soil and its cohesion were the criteria for evaluating the influence of this attribute in triggering processes of erosion and gravitational mass movements. **Figure 4** presents the soil and sediments units' spatial distribution in the study area.

Hydromorphic (HI): According to Pejon (1992), hydromorphic materials present special and important characteristics for geotechnics, such as the level of the water table (normally very close to the surface) and the high quantity of organic matter. Therefore, they are problematic regions from the standpoint of occupation or construction sites.

Botucatu Formation, Residual, 20% Sand (Fm. Botuc Rar20): Pejon (1992) states that this unit is restricted to the areas of escarpments in the São Pedro mountain range with declivities of more than 20%. This unit comprises residual sandy materials of little thickness, with the occurrence of silicified sandstone outcrops of Botucatu Formation.

Corumbataí Formation, Reworked, Clayey (Fm. Corumb RTarg): This unit is composed of thick clayey materials (larger than 5.0 m), of a dark red coloration, related to the lithologies of the Corumbataí Formation, but with contributions of materials originating from other, unidentified, formations (Pejon, 1992). According to Pejon's notes (1992), the mean percentage of clay exceeds 50%, while that of sand is about 15%. Its average density is 1.60g/cm³, and the natural average void index is about 1.30. These values indicate that the material contains a high quantity of voids, and may exhibit collapsible characteristics.

Corumbataí Formation, Residual, Clayey (Fm. Corumb Rarg): This unit is constituted of residual materials of the Corumbataí Formation, with thicknesses varying from 1.0 to more than 5.0 meters. The highest thicknesses present a homogeneous profile, well-structured and of red to yellow coloration. On the other hand, the materials with lower thicknesses show a yellow coloration and retain evidence of the original rock (Pejon, 1992). The granulometric analyses indicate that these materials contain, on average, more than 60%

of clay and less than 25% of sand. According to Pejon (1992), it can be concluded that these materials are highly compact; however, when the package is thicker, they tend to present higher void indices, possibly due to the greater genetic evolution of the profile.

Corumbataí Formation, Residual, Reworked, Clayey (Fm Corumb Rarg + RTarg): This unit, which is associated with the Corumbataí Formation, represents an alternation of residual outcrop materials and reworked materials of little thickness, i.e., less than 2 meters (Pejon, 1992).

Itaquerí Formation, Reworked, 30% Sand (Fm. Itaq RTar30): According to Pejon (1992), this unit is constituted of sandy reworked materials associated to the areas of occurrence of the Itaquerí Formation. Its thicknesses vary from 3 to 4 meters, with less than 30% of fines (silt + sand). This unit is found in a restricted portion at the top of the São Pedro mountain range.

Pirambóia Formation, Reworked, 20% Sand (Fm. Pir RT20): This highly homogeneous unit comprises very sandy and thick materials (> 5.0m), associated with areas of occurrence of the Pirambóia Formation, corresponding, in pedology, to quartz sands. The percentage of sand is higher than 80%, while the clay fraction does not exceed 15%, and that of silt is practically absent, presenting a high natural compactness.

Pirambóia Formation, Reworked, 30% Sandy (Fm Pir RT30): According to Pejon (1992), this unit of reworked materials occurs in higher thicknesses, usually more than 3.0 meters, and is distributed in a small region of the study area.

Pirambóia Formation Residual, Reworked, Sandy (Fm. Pir Rar + RTar): The association of sandy materials of small thicknesses (< 0.3 m) genetically related to the sandstones of the Pirambóia Formation, added to the predominance of the residual over the reworked materials in areas of outcroppings, constitute this unit. These materials present common characteristics with respect to their texture, physical aspects and compaction (Pejon, 1992). As for their texture, they are considered sandy, since they contain more than 70% of sand and only 10% of clay (Pejon, 1992).

Serra Geral Formation and Basaltic Intrusion, Residual, Silty Clayey (Fm. SG IB RSarg): This unit is composed of clayey and silty-clayey materials that result from alteration of the basic magmatites of the Serra Geral Formation and Basaltic Intrusion. Their thicknesses vary from 1.0 to 5.0 m, with the smaller thicknesses containing a higher percentage of silts, and the thicker ones, of clay (Pejon, 1992).

Sandy Alluviums: The last unit of unconsolidated materials corresponds to the alluviums. Pejon (1992) reports that in this region they are mainly sandy, do not cover extensive areas, and are used mainly to extract sand for civil construction.

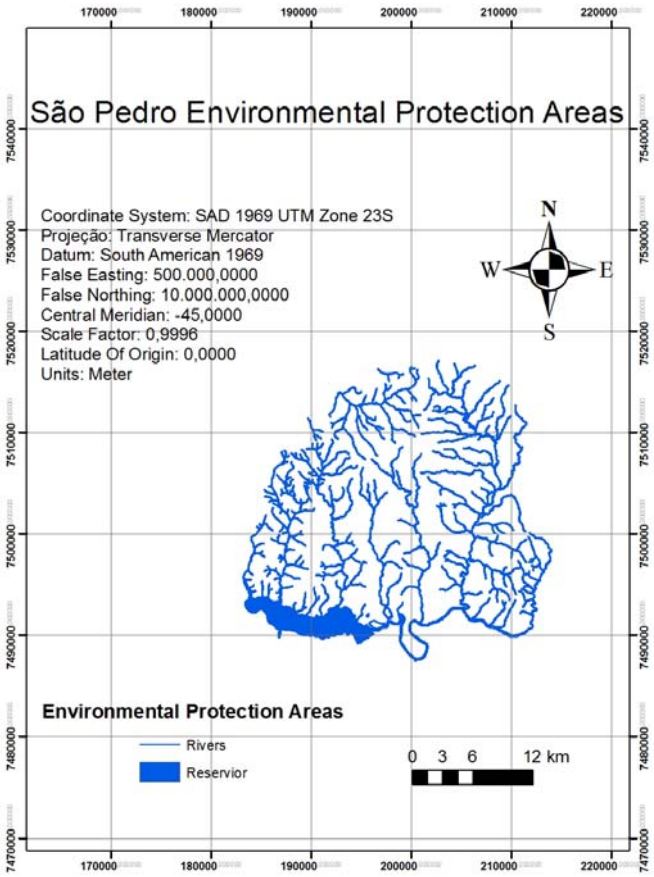

Fig. 5 Map of environmental protection areas in São Pedro.

Hydrology

The hydrography of the study area is part of the Paraná River basin and its drainage occurs over the Paulista Peripheral Depression. As can be observed in **Fig. 5**, the area of the municipality presents a predominantly dendritic drainage pattern, in which the Piracicaba River stands out.

The southwestern part of the study area shows a reservoir on the Piracicaba River created by the Barra Bonita dam.

The consideration of the drainage system in the process played a restricted role in terms of urban sprawl due to the distance of the water bodies, which represent only a minor limiting factor to urban expansion.

Steepness

Most of the terrain is gently hilly, reflecting a predominance of gently sloping land lots, with the exception of the areas of high cuestas located toward the north of the municipality (**Fig. 6**). The limits of the classes of steepness de chosen were 10% (the limit for the onset of erosive processes in lands of the peripheral depression of the Paraná River basin) and 30% (limit imposed by the Forestry Code for land parceling).

Table 2. Classification of the attributes considered

Unit	No Restriction (0)	Low Restriction (1)	High Restriction (2)
Hydrography	>50m		<50m
Steepness	<10%	10-30%	>30%
Substrate	Serra Geral Formation Corumbataí Formation	Pirambóia Formation	Botucatu Formation Itaquerí Formation Alluvial Deposits
Unconsolidated materials	Fm Corumb Rarg Fm Corumb RTarg Fm Corumb Rarg + RTarg FM SG IB RSarg	Fm. Pir RT20 Fm. Pir RT30 Fm. Pir Rar + RTar Hi (Hydromorphic)	Sandy Alluviums Fm. Botuc Rar20 Fm. Itaq RTar30

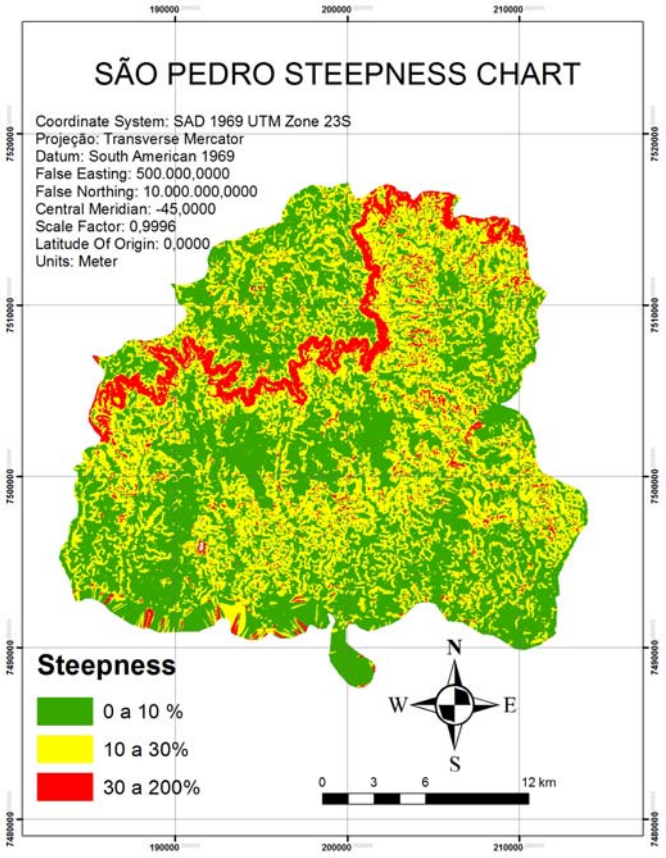

Fig. 6 Steepness chart for São Pedro area.

Attributes Classification

The assessment of the potentialities and limitations of the area's natural environment prioritized the identification of the conditions of the environment that could trigger exogenous processes/phenomena that could cause degradation. Historical records of the area under study indicate that these processes/phenomena are erosive processes and gravitational mass movements (landslides).

Therefore, each of the attributes considered was classified according to its potential contribution to the onset of erosion and gravitational mass movements, according to a scale from zero to two of susceptibility.

On this scale, 0 (zero) represents the absence of any influence in the process, 1 (one) represents a low influence in the process, and 2 (two) represents an attribute condition with a high potential to trigger an erosive process or gravitational mass movement. The classification of the attributes according to this criterion is given in **Table 2**.

To analyze the areas of possible urban expansion in the municipality of São Pedro, the attribute hydrography was considered with the definition of Areas of Permanent Preservation (APP) having a width of 50m starting from the banks of the river bed (a more conservative value than the 30m usually employed for water bodies of the size of those existing in the area – Brazilian Forestry Code), matching the restrictive class of distances smaller than or equal to 50m, and greater distances for areas suitable for urbanization.

Potential Urban Occupation Chart Production

After creating the basic maps and charts presented in the above figures, the final thematic chart was drawn up by adding the sum of the weights and reclassifying the results of this sum.

To this end, the spatial representations of the attributes in matrix form were given values corresponding to their level of restriction. The map algebra consisted of the sum and classification of this result with the generation of a new spatial representation. The operations were performed with a LEGAL algorithm running on version 5.0.4 of SPRING GIS.

RESULTS AND DISCUSSION

The map algebra resulted in a sum of the weights of the attributes under consideration, leading to final values ranging from zero to eight. The value of "0" represented the condition in which the four attributes were favorable for land parceling for urban expansion (no restriction), while "8" represented the condition in which all the attributes indicated restrictions.

The results were classified into the following three categories: 0 to 2 – areas favorable for expansion; 6 to 8 – areas unfavorable for expansion; and 3 to 5 – areas with intermediate conditions between the two extremes.

Based on the above classification, a chart was drawn up indicating the potential for urban expansion based on the limitations and potentialities of the environment,

which took into consideration the susceptibility to the development of erosive processes and gravitational mass movements (**Fig. 7**).

The "without restriction" condition implies a set of attributes of the environment in which one of the attributes classified as restrictive may occur (value 2 – extreme of this class) while the three other attributes are favorable. This is because the unfavorable attribute cannot be a determining factor for the final decision about the occupation of the area. Nonetheless, it should be pointed out that the unfavorable attribute must be analyzed carefully.

In the "low restriction" condition there may be too restrictive and two favorable attributes, indicating that the intermediate situation should also be considered very carefully to ascertain which of the attributes match the unfavorable description and the volume of investment required in works to render these areas feasible.

The "high restriction" classification indicates a set of at least two unfavorable and two intermediate attributes, which implies strong restrictions. This condition makes parceling the land into lots for urban occupation practically impossible, except if massive investments are made in infrastructure and works to stabilize the land lots in order to prevent degradation of the environment.

An analysis of Susceptibility to Urban Sprawl Chart, based on the limitations and potentialities of the environment reveals the following. The areas with intermediate conditions are concentrated in the northeast part of the municipality, above the basalt sandstone cuestas, while the favorable areas are distributed in the northeast, central and southeast regions of the municipality (in the portions with lower relief). Lastly, the areas classified as restrictive for expansion are those located on or at the edges of the cuestas and in the areas of permanent preservation.

In fact, the predominant geomorphologic contexts of the three classes also represent the most marked geological and geotechnical contexts. Hence, the favorable conditions are generally associated with rock units from Pirambóia and Corumbataí Formations and residual and reworked unconsolidated materials of these formations, with medium to fine texture and good cohesion. The intermediate conditions include areas of bedrock of the Pirambóia and Itaquerí Formations and unconsolidated reworked materials from these formations. Lastly, the areas classified as restricted have bedrock and residual materials of the Botucatu Formation (with a very sandy texture). It should also be noted that in situations where the substrate of the Botucatu Formation is silicified and the depth of the residual unconsolidated materials is not great, such areas possess suitable conditions to be classified as favorable.

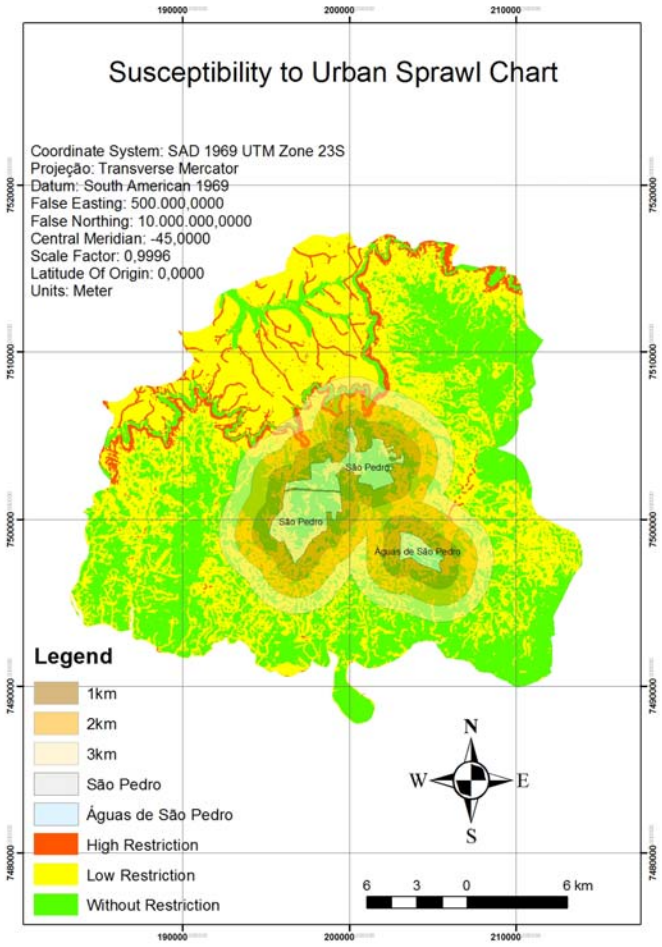

Fig. 7 Susceptibility to Urban Sprawl.

Taking in account the actual tendencies of urban expansion in the area, we consider three expansion buffers involving the urban areas of São Pedro (the main municipality) and Águas de São Pedro (a district of São Pedro). These buffers had one, two and three kilometers from urban limits and show that the expansion areas nearly from urban areas present suitable conditions for urban expansion in all but north area of São Pedro. In more distant areas, the natural conditions are good to urban expansion with exception only for areas up to north of São Pedro.

CONCLUSIONS

The municipality of São Pedro presents a considerable potential of areas suitable for urban expansion intercalated with areas of intermediate and restricted potential. These limiting areas comprise a set of physical factors (geological and geomorphologic) with a high probability for the occurrence of erosion and mass movements, characterizing them as areas of environmental risk.

Therefore, even in areas classified as suitable, urban expansion should be considered carefully, and it is essential that the guidelines for expansion take into account the natural conditioning factors. Hence, it is

crucial for land use planning to be based on the quality and characteristics of the land in order to satisfy certain priorities and/or occupy any terrestrial space.

It should be pointed out that this analysis was based on the conditions of the environment from the standpoint of erosion and gravitational mass movements, which are the most significant dynamic processes in the area in question. It should also be noted that in other realities (different municipalities or contexts of the environment), the selection of the attributes and the definition of the weights for each one may and/or should vary. Considering the buffers around urban areas we observe that only the areas in north of São present high restriction to urban expansion.

Part of the results reported here coincide with the Master Plan of the municipality, which foresees as a zone of interest for urban expansion the area southeast of the urban seat of São Pedro. The analyses of this study, with their aforementioned restrictions, indicated the northeast, central and southeast portions of the municipality as areas with intermediate conditions for urban expansion, and the latter is the same one considered in the Master Plan.

Lastly, it can be stated that this approach enabled aspects of the current legislation and the characteristics of the landscape to be analyzed jointly in evaluating the suitability of land use, thus serving as a strategy applicable to other situations.

REFERENCES

Braga, B. & Carvalho, P.F. (2004) City: space and citizen. In: Giometti, A.B.R. & Braga, R. Citizen Pedagogy: Formation Books*: Geography Education.* São Paulo: Universidade Estadual Paulista. (In Portuguese)

Brazil (2011) Provisional Measure #547/11. Union Official Diary, October 13th 2011. (In Portuguese)

Brazil (2012) #12,608/12 Law. Union Official Diary, April 11th 2012. (In Portuguese)

Burchell, R. & Mukhjerji, S. (2003) Conventional development versus managed growth: the costs of sprawl. American Journal of Public Health. 93 (9).

Carbonell, A. & Yaro, R. (2005) American spatial development and the new megalopolis - Land Lines. Lincoln Institute of Land Policy.

Carvalho, P.F. (2001) Environmental problems in social interest housing and cities. In: Carvalho, P.F. & Braga, R. Environmental management outlook in medium cities. Rio Claro: Universidade Estadual Paulista. (In Portuguese)

Fracassi, P.C. (2008) Urbanization and environmental and social impacts: São Pedro risk areas. Monograph. Rio Claro: Universidade Estadual Paulista. (In Portuguese)

IBGE (2000) 2000 Census. Brazilian Institute of Geography and Statistics. In: http://www.ibge.gov.br. Access: June 2010. (In Portuguese)

IPEA (2001) Brazilian Municipalities Database. Institute of Applied Economy Research. In: http://www.ipea.gov.br/portal/. Access: June 2010. (In Portuguese)

Johnson, M.P. (2001) Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A. 33: 717 - 735. 2001.

Limonad, E. (2007) Disperse Urbanization: another form of urban expression? Formation Journal, 1: (14). 2007.

Ojima, R. & Hogan, D.J. (2008) Urban growing and periurban occupation: spatial distribution of population in new environmental frontiers. In: 4th National Meeting of Post-graduation and Research in Environment and Society. Brasília. (In Portuguese)

Pejon, O.J. (1992) Engineering geological mapping of Piracicaba Sheet (1:100.000 Scale): methodological aspects of surveying attributes. PhD Thesis. São Paulo: Universidade Estadual de São Paulo. (In Portuguese)

Penteado, M.M. (1968) Geomorphology of center-east sector of Paulista Peripheral Depression. PhD Thesis. Rio Claro: Faculdade de Filosofia, Ciências e Letras. (In Portuguese)

Santos, M. (1996) Brazilian urbanization. (3rd ed.). São Paulo: Hucitec. (In Portuguese)

São Paulo. (1989) São Paulo State Constitution. In: http://www.al.sp.gov.br/repositorio/ legislacao/constituicao/1989/constituicao%20de%2005.10.1989.htm. Access. May 2010. (In Portuguese)

São Pedro (2008) São Pedro *Master Plan – #15/08 Law.* Public and Particular Works Department of São Pedro. (In Portuguese)

Camara, G., Souza, R.C.M., Freitas, U.M., Garrido, J. (1996) SPRING: Integrating remote sensing and GIS by object-oriented data modeling. Computers & Graphics, 20 (3): 395-403.

Valente, A.L.S. (1996). Using remote sensing in risk areas definition. 8th Brazilian Remote Sensing Symposium. Salvador. (In Portuguese)