Follow-up of environmental impacts upon water sources of São Carlos, Brazil

Carlos Wilmer Costa, Francisco Antônio Dupas, Reinaldo Lorandi and Erica Zanardo Oliveira

Abstract

An understanding of the interrelationship between the characteristics of natural and man-made environments is essential to avoid heavy economic and social burdens on society resulting from environmental deterioration. Irreversible human changes can be avoided using land use models, which can examine the impacts of alternative land use regulations and future urbanization on the environment Much of the population of medium-sized Brazilian cities is concentrated in densely populated urban areas. In this context, the use of Geographical Information Systems have a great value for land management, allowing the diagnosis and characterization of the areas that have suffered the consequences of land use for urban development and helping in the proposition of alternatives to minimize the generated impacts. In this paper, a simple spatially explicit model was used to explore potential areas for urban expansion in São Carlos city, Brazil. Orbital images of the satellite ALOS sensor AVNIR-2 were used to diagnose the urban area of the city and a comparison is made with the Master Plan. This way, Municipal Zone Management, urban sprawl, topography, geology, hydrography, pedology, infrastructure and land use were analyzed in an integrated way, each of them serving as the "background" to the other. This analysis has drawn criticisms and considerations for further alternatives. Another approach of interest refers to the expansion of the urban sprawl on the watershed of Feijão Rivers. The basin is the main source of surface water supply to the city of São Carlos, and is an important recharge area of the Guarani Aquifer System (GAS), therefore, they shall be preserved to serve as future water reserves.

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1. Introduction

Urban development and population growth, together with socio-economic, technological and climatic changes are the main and most likely driving forces which will shape future and affect water resources (Weatherhead and Howden 2009; Seto et al. 2012; Terreno, 2013).

Urban development in South America is more intense in peripheral areas where precarious settlements are formed, being constituted by local inhabitants. Considering the 5,564 cities in Brazil, rare are those where a considerable amount of the population is not settled precariously; rivers, floodable valleys and hills are regarded as obstacles to be overcome, therefore earthworks and waterways are constructed in an attempt to minimize spatial loss for land use. Such model is strengthened by two elements constitutive of our cultural policy: No distinction between public and private, factual and legal. This model of urbanization is the result of a market aimed at an immediate profit, expanding city boundaries in a fragmented way, from initiatives of land owners and land negotiators moved by private interests to the detriment of social welfare, disregarding the guidelines for city development defined in the Municipal Master Plan, regulations for land use and Permanent Preservation Areas (APPs). Moreover, urban planning is carried out for the formal city, while informal cities are analyzed solely in their trends of land use (Rolnik 2009; Sperandelli et al., 2013; Costa et al., 2012; Costa et al., 2013).

Day after day, decisions on land planning and water management shape the standards of urban development, while decisions on the use of urban land influence hydrological systems. However, such connection is commonly ignored, or merely recognized, especially by politicians with inadequate background. Schueler et al. (2009) alerts that the difficulties faced by city administrators for the implementation of an integrated planning are the result of a limited institutional capability to cope with complex and interdisciplinary issues. To make matters worse, the omission or the noncompliance with legal regulations of land use and occupation by the executive power on municipal, state and federal spheres and the negligent use of water resources may hinder the quality and quantity of this resource.

According to Carneiro (2008), disarticulation is evident among water resource management tools and land-use planning, thus reflecting some delegitimization of city planning and urban legislation, marked by high levels of informality and illegality concerning land use.

Consequently, Rural and Urban Zone Mangement, proposed in the Municipal Master Plans, are tools applied internationally for the management of land use, reflecting positively in the water resources (Carter et al. 2005; Lerner and Harris 2009; Peng et al., 2014). However, no practical ways of measuring the consequences of these zone managements can be found in local scale (Nielsen-Pincus et al. 2010). Conway and Lathropet (2005) warn that, even from a holistic approach of watersheds management, it is uncertain whether regulation strategies, and spatial planning, applied at a specific moment, will be effective for protecting local resources in the future, especially for those watersheds subject to urbanization.

Rawashdeh and Saleh (2006) considers mapping an essential tool, as it would assure a suitable and balanced spatial development; the constant data update would enable a systematic monitoring of landscape, offering more appropriate technical and management tools to public agencies. According to Mukundan et al. (2013) and Badwi et al. (2014) the creation of scenarios overlapped with environmental variables in information plans enables the analysis of the further impacts of the actions to be taken assuring their effectiveness and efficiency. Presently within the regional planning, there is great interest in developing land use change models that focus on available potential urban areas to be occupied.

We can observe in São Carlos that, fast urban development indices combined with inadequate disposal of solid waste and intense use of land for agribusiness activities in watersheds used as water sources, have caused negative impacts on regional ecology and contamination of surface and groundwater resources. Such water sources are sensitive aquifer recharge areas and due to their proximity to the city should be maintained or preserved in order to serve as water reservoirs (Zuquette 1981; Lorandi 1985; Gonçalves 1986; Aguiar 1989; Nishiyama 1991; Tundisi et al. 2007; Zuquette et al. 2009; Cunha et al., 2011).

Through a land-use scenario or a simple spatially explicit model, the present study aims at analyzing the expansion of the urban city of São Carlos-SP in the year 2006 comparing it with the Municipal Master Plan in force since 2005 and attributes of: topography, geology, hydrography, pedology, infrastructure and land use. With such data collection, it is our expectations to be able to point out limitations and suggest due corrections and adequacies in order to assist the city spatial planning, highlighting the vulnerability of urban water sources.

2. Materials and Methods

For the database, we used images of the Advanced Land Observing *Satellite –ALOS (A*VNIR-2), 2006, bands 3, 2, and 1 with 10-meterresolution. According to Zuquette (1987) scales smaller than 1:100,000 represent general scales, from 1:100,000 to 1:25,000 regional scales and from 1:25,000 to 1:10,000 semi-detailed scales. In this case, scales 1:50,000 were used to represent the region. The information plans of the georeferenced digital database were performed using Idrisi software (version Selva). Table 1 shows the topographic, geological and pedological studies and the Municipal Zoning maps.

Table 1. Used maps.

Maps	City	Reference	Source	Scale
Topographic	São Carlos Corumbataí Ibaté Descalvado	SF-23-Y-A-I-1 SF-23-Y-A-I-2 SF-23-V-C-IV-3 SF-23-V-C-IV-4	IBGE (1971)	1:50,000
Geological	São Carlos	Rock substract Map	Zuquette (1981) Muro (2000)	
Pedological	São Carlos Descalvado	SF-23-Y-A-I SF-23-V-C-IV	IAC (1981) IAC (1982)	
Municipal Zoning	São Carlos	-	São Carlos (2005)	

2.1 Location and preliminary recognition of the study area

São Carlos, in the southeast region of Brazil and central area of the state of São Paulo, has latitude and longitude co-ordinates between 22°00’ and 22°30’ S and 47°30’ and 48°00’ W, and is 230 Km away from the São Paulo, capital city. The study area is located in the important recharge area of the Guarani Aquifer System (GAS), one of the world's largest aquifer systems and is an important source of fresh water. However, according to São Paulo (2009), taking into account surface water minimum flows and groundwater potential flows, this area already consume more than 60% of the water available (Figure 1A).

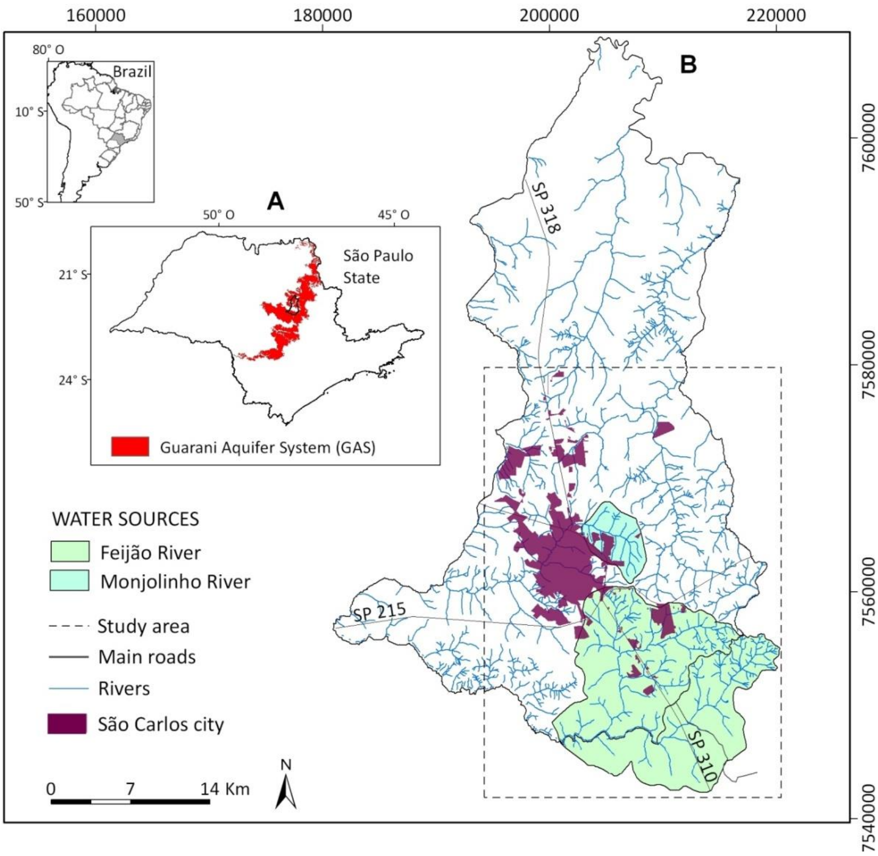

Figure 1 (A and B). Study area.

The study area involves a polygon determined with the purpose to include all the urbanized area and the urban expansion, as well as the watersheds of Monjolinho and Feijão Rivers, which serve as the main sources of water supply (Figure 1B).

Due to its singular features and to the water good quality and flow rate, Feijão River is regarded as the most important source of water for the city of São Carlos and region (Costa et al., 2013; Machado & Dupas, 2013; Machado et al., 2014). Its source is in the São Carlos plateau, flowing along the Botucatu Formation in its middle and upper course. Its watershed borders the cities of São Carlos, Analândia and Itirapina. The watershed is located in the Corumbataí Area of Environmental Protection (State decree No. 20.960 of 1983), whose purpose is to protect water (rivers, swamps and reservoirs) and land ecosystems in the central region of the state of São Paulo, involving areas of the cities of São Carlos, Itirapina, Brotas, Rio Claro and Corumbataí.

Vegetation consists of semi deciduous riparian forest, namely, Cerradão and Cerrado. Soares et al., (2003) has already noted the reduction and further disappearance of the vegetation due to the development of the region. The author argues that the vegetation has been reduced to forest belts, mainly due to agribusiness and land subdivision.

The area between the Occidental Plateau and the Cuestas has altitudes varying from 775 to 1,020 meters. Gonçalves (1986) states that the highest peaks of the São Carlos plateau, are formed by the Itaqueri Formation, whose base corresponds to an altitude of about 800 meters. The rivers at the bottom of the valley, as well as the east and west areas of the plateau are formed by eruptive rocks from the Serra Geral Formation. Just below, in extensive areas north and south of our study area outcrops of the Botucatu Formation, responsible for the flat terrain surface, can be observed.

Sandstones of the Botucatu Formation supplied the source material of the Quartzite Sands which cover this Formation, mainly south and southeast of our study area where the water source of Feijão River is located. The residual soil is excessively drained, essentially quartzite (>70%) and with greater perviousness, around 10^{-3} to 10^{-2} cm/s, classifying the area as a water recharge for the Botucatu Aquifer. The compact massive basalt of the Serra Geral Formation covers about 90% of the Botucatu Formation and behaves as an impermeable substrate. Its argillaceous residual material has coefficient of permeability lower than 10^{-6} cm/s. The Itaqueri Formation consists of fluviolacustrine sandstone, behaving as a free aquifer (Zuquette 1981; Lorandi 1985; Gonçalves 1986; Aquiar 1989; Nishiyama 1991; Muro 2000) (Table 2).

Table 2. Characteristics of the main units found in the study area.
Source: Zuquette (1981), Nishiyama (1991) and Muro (2000).

	Residual Soil		
Characteristics	Itaqueri	Serra Geral	Botucatu
Texture	Sandy	Argillaceous	Sandy
Thickness	0 to 2 m	< 2 m up to 5 – 10 m	< 2 m
Granulometry	Fine Sand: 60 to 80% Medium Sand: 2 to 20% Silt: 5 to 28% Argillaceous: 10 to 63%	Fine Sand: 10 to 35% Silt: 20 to 45% Argillaceous: 25 to 60%	Medium Sand: 70 to 80% Fine Sand: 2 to 20% Argillaceous: ≤ 10%
Coloration	Reddish	Reddish to Brownish	Reddish
Coefficient of permeability	10^{-5} to 10^{-2} cm/s	10^{-6} to 10^{-3} cm/s	10^{-3} to 10^{-2} cm/s

2.2 Methods

To facilitate the organization and understanding of the work structure, Figure 2 shows the general flowchart of the methodology applied. The maps were generated with the Mercator Transverse Universal Projection – UTM, horizontal Datum from Córrego Alegre, vertical Datum from Imbituba-SC Tide-Gauge Station and Central Meridian 45º W.

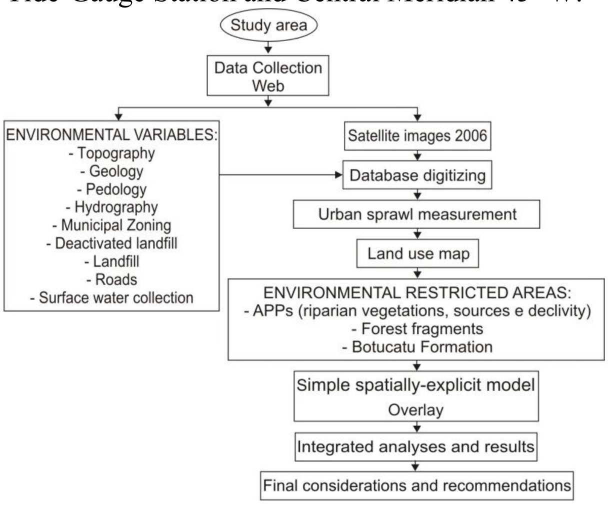

Figure 2. Method’s general flowchart.

A simple model was developed to verify the potential of the areas available to urban expansion in the city of São Carlos. Such modeling is valid because there are territory planning regulations that restrict the urban sprawl in some places and, at the same time, prepare places for future development. In Brazil, land use planning is guided through the municipal zoning, contained in the master plan. The zoning defines the best land use for the soil, but it rarely take into account the environmental consequences, especially the impacts on watersheds that are used for water supply. The omission of public authorities regarding the environmental impacts is, partially, due to a lack of studies in map format, which model the behavior of urban sprawl and the interrelationship with the characteristics of natural environments.

For the elaboration of a spatial model in GIS which represents the complexity of the natural and anthropic environment each of the elements were stored in different layers. This way, Municipal Zone Management, urban sprawl, topography, geology, hydrography, pedology, infrastructure and land use were analyzed in an integrated way, each of them serving as the "background" to the other. So that the integral land planning could be performed, a diagnosis of the current situation was made (2006) and future alternatives recommended, in compliance with the Master Plan.

Traditionally, a major part of geo-spatial information was in analogue format, that is, in paper. Recently, this information is available in digital format on the web for import and manipulation in a GIS. The first step was an attempt to gather information regarding the study area: topographic, geological, pedological and Municipal Zone Management maps were combined with satellite images.

Satellite images were submitted to standard techniques of image processing. Making use of the methodology proposed by Jansen (2009), an on-screen digitizing of the urban sprawl was processed manually from the false color composition. In this study case, urban sprawl refers to residential, commercial and industrial areas, including paved roads, streets, markets, parking-lots, etc. (Jat et al. 2008).

Next, in order to elaborate an overview which could represent the city sprawl, as well as to point out its limitations, suggest due corrections and adequacies to the Municipal Zone Management, areas with environmental restrictions for urban purposes were delimited, that is, Permanent Preservation Areas (APPs) along river banks and sources, forest belts, areas with declivity higher than 30% and areas comprising the Botucatu Formation, as describe below.

APPs along river banks and sources were delimited on the basis of the Brazilian Forestry Code instituted through Law No. 4.771/65 of September 15th, 1965 (Brasil 1965) which, according to Article 2 defines along rivers or any watercourses: 30 meters for watercourses smaller than 10-meter-wide; (c) in water sources a minimum radius of 50 meters. Topographic maps were elaborated for the ranges of interest, in this case, taking into account the restrictions suggested in the Municipal Master Plan (São Carlos 2005), which does not authorize areas with declivity higher than 30% for urban purposes. Forest belts were removed from the map of land use whereas coverage and field observation was performed in order to document the soil current situation, encompassing riparian and hillside vegetation, remainings of Cerrado and Cerradão.

According to Zuquette (1981), Gonçalves (1986), Nishiyama (1991) and Zuquette et al. (2009) soil vulnerability could be defined as the capability the referred soil has, when receiving a load of contaminant, either superficially or deeply, to carry such contaminants to the aquifer. In this study context, topographic, geological and soil maps (Table 1) combined with soil perviousness data, as well as granulometry and thickness (Table 2), classified a few areas where the Botucatu Formation emerges as more vulnerable to pollution than other lithologies. Another important factor is that the soil water storage capacity can achieve extremely high values and, combined with the local geology, leads us to conclude that it is an area of direct recharge for the Guarani Aquifer System (GAS).

3. INTEGRATED ANALYSES AND RESULTS

The current scenario, in compliance with the Master Plan, establishes that the expansion of the urban sprawl on the basis of commercial, industrial and residential developments, is projected for the Northwest, East, North and Southwest regions, comprising a Southwest/Northwest corridor along Washington Luis (SP 310), Thales de Lorena P. Jr. (SP 318) and Luiz A. de Oliveira (SP 215) highways. Consequently, the Master Plan, through the Municipal Zone Management, defines Zones 1, 2, 3A, 4A and 4B as suitable areas for the urban sprawl while Zones 3B, 5A, 5B, 6 and 7 are regarded as unsuitable (São Carlos, 2005) (Figure 3).

With a view to perform a critical analysis, highlighting limitations in the current regulation of land use by means of the Municipal Master Plan, as well as suggest due corrections and recommendations, the current situation of the urban sprawl was assessed (2006) aiming at finding alternatives. The areas foreseen in the APPs along river banks and sources, as defined by the Brazilian Forestry Code (Brasil 1965), areas with declivity higher than 30% (Brasil 1979; São Carlos 2005), as well as areas comprising forest belts and the Botucatu Formation were considered unsuitable for urban development, as, according to Zuquette (1981), Gonçalves (1986),

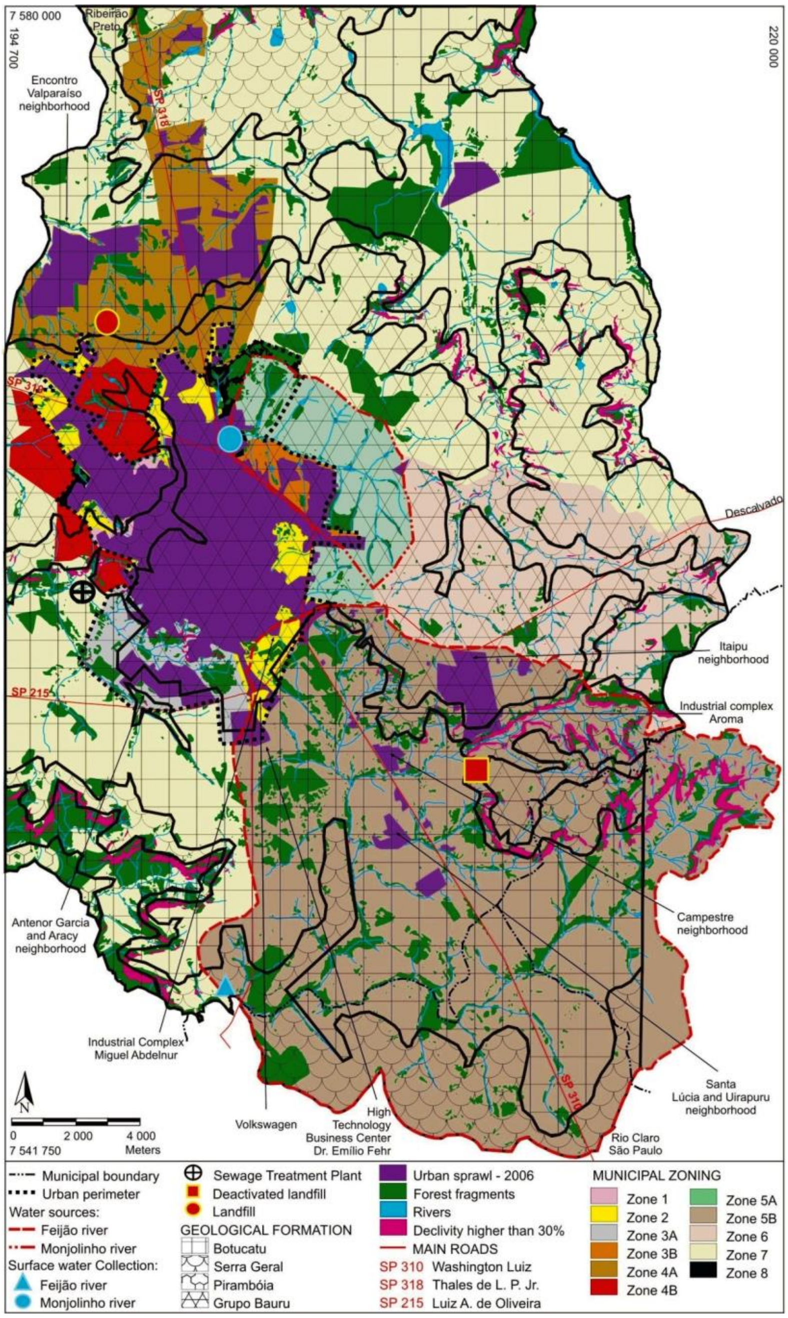

Figure 3. Summary of suitable and unsuitable areas for urban sprawl of the city of São Carlos.

Nishiyama (1991) and Zuquette et al. (2009) they are essential for the recharge system of the GAS. According to this study context, urbanization would be allowed on the Botucatu Formation as long as pollution vulnerability issues were carefully considered.

A comparative study between the areas of each existing zone removed from the Master Plan carried out in 2005 (São Carlos 2005) and the areas in fact occupied in 2006, enabled to perform analyses and diagnoses of the situation soon after the Master Plan was performed and, in an integral way, defines the prognosis of how city planning will effectively be in the future concerning development and preservation of urban water sources by means of information of land use and coverage, infrastructure, geology and topography.

This way, Figure 3 and Table 3 bring a summary of the fully urbanized or partially urbanized areas in suitable and unsuitable locations for urban development. Analyses were performed in suitable zones (1, 2, 3A, 4A and 4B) with total area of 125.7 Km² and unsuitable (3B, 5A, 5B, 6, 7 and 8) with total area of 1015.2 Km².

Table 3. Summary of the urban sprawl (2006) based on the Municipal Zone Management with total area of 1140.9 Km².

	Zones	A	B	C*	D
Suitable	1	16.0(12.7)	15.3(95.	0.2(1.3)	0.5(3.1)
	2	32.9(26.2)	23.9(72.	2.0(6.1)	7.0(21.3)
	3A	15.7(12.5)	6.0(38.2	5.5(35.0)	4.2(26.8)
	4A	47.0(37.4)	10.1(21.	20.6(43.8	16.3(34.7
	4B	14.1(11.2)	0.6(4.3)	2.1(14.9)	11.4(80.9
Total		**125.7(100**	**55.9(44.**	**30.4(24.2**	**39.4(31.3**
Unsuitable	3B	6.3(0.7)	5.3(84.1	0.3(4.8)	0.7(11.1)
	5A	[23.0(2.3)	[0.5(2.2	[-]	[-]
	5B	[120.3(11.	[7.1(5.9	[-]	[-]
	6	61.4(7.0)	0.1(0.2)	12.9(21.0	48.4(78.8
	7	799.6(91.	3.2(0.4)	179.0(22.	616.7(77.
	8	4.6(0.5)	1.9(41.3	1.4(30.4)	1.3(28.3)
Total		**871.9(100**	**10.5(1.2**	**193.6(22.**	**667.1(76.**

Note: A – Total area in Km² (%); B – Urban area in Km² (%); C – Unsuitable areas for urbanization in Km² (%); D – Available areas for urbanization in Km² (%). *PPAs along river banks and sources, declivity higher than 30%, Forest belts, geology of the Botucatu Formation and others; [-] 5A e 5B were not considered due to being water sources; 5B refers to the area belonging to the city of São Carlos.

This study did not consider vacant urban areas and underused properties that could make a better use of the available services and infrastructure. A way for promoting and making the referred areas available for land use would be the application of a tool foreseen in the law, that is, the progressive territorial urban property tax (IPTU).

The Induced Land-Use Zone – Zone 1 offers the best infrastructure conditions, besides unoccupied lots and vacant or underused properties (São Carlos 2005). Considering an area of 16 Km² (12.7% of the total), 95.6% is already urbanized, 1.3% is unsuitable for urbanization, therefore, only 3.1% or 0.5 Km² is available for urbanization. This implies that very few areas are still available for urbanization.

The Conditioned Land-Use Zone –Zone 2 has a total area of 32.9 Km² (26.2% of the total). Of this amount, 72.6% is already urbanized, 6.1% is inadequate and 21.3% or 7 Km² refers to areas available for urban use. It should be noted that these areas are disperse and situated northwest, west, and southeast of the central urban sprawl.

The Recovery and Controlled Land-Use Zone – This Zone is featured by the presence of irregular land subdivisions, areas with high declivity and susceptible to erosion, silted waterways and precarious infrastructure. Zone 3A has an area of 15.7 Km² (12.5% of the total). Of this amount, 38.2% is already urbanized, 35% is inadequate and 26.8% or 4.2 Km² refers to areas available for urban use. Situated south of the urban sprawl, where Antenor Garcia and Cidade Aracy neighborhoods are located, this area is considered environmentally fragile, having isolated forest belts and areas with declivity higher than 30%. Moreover, it is worth noting that Água Quente and Água Fria streams, according to Lorandi (1985), are born in the Botucatu Formation and that such lithology partially covers the south border of this zone being overlapped by Quartzite Sands excessively permeable and highly erodible. Gonçalves (1986) expresses his concern with the region's occupation once it was considered a recharge area of the GAS, representing an important supply of water. In spite of such features, in the Municipal Master Plan it is considered an area for mixed land use aimed at attracting commerce and services. Due to this, the urban expansion in this zone will potentiate problems related to riparian vegetation, flood, erosion and silting of the rivers draining the area, as already mentioned by Pons et al. (2007), resulting in the decrease of the quantity and quality of the water of these resources.

The Recovery and Controlled Land-Use Zone – Zone 4A has an area of 47.0 Km² (37.4% of the total). Of this amount, 21.5% is already urbanized, 43.8% is inadequate and 34.7% or 16.3 Km² refers to areas available for urban use. Located northwestern of the urban sprawl this zone is featured by a strong tendency for urban development. It is worth mentioning that it may be an option for the expansion of the urban sprawl to the southern side of the water source aimed at the maintenance of the quantity and quality of the water from Feijão River.

This zone is home to the municipal landfill. According to Muro (2000) recharge areas of the aquifer are not suitable for waste disposals or landfills. In view of the above, it is essential to consider the slurry generated in the landfill, which is settled in loose material from the Botucatu Formation, 5 to 10 meters deep and close to water source of Galdino stream, south of the Encontro Valparaíso land subdivision between the existing urban areas.

The Recovery and Controlled Land-Use - Zone 4B has an area of 14.1 Km² (11.2% of the total). Of this amount, 4.3% is already urbanized, 14.9% is inadequate and 80.9% or 11.4 Km² refers to areas available for urban use. However, southernmost, two rivers will drain over the areas comprised by the Botucatu Formation and other formations, besides having declivities higher than 30%. Such features prevent urban expansion southernmost of the referred zone, being a revision of the current Master Plan essential for the correction of these boundaries.

Next we analyzed inadequate areas for urban expansion. A criticism results from the fact that the Recovery and Controlled Land-Use Zone – Zone 3B is situated in the source of Monjolinho River, being the development of the area restricted to the urban expansion central line (São Carlos, 2005). Zone 3B has an area of 6.3 Km² (0.7% of the total). Of this amount, 84.1% is already urbanized, 4.8% is inadequate and 11.1% or 0.7 Km² refers to areas available for urban use.

As a general rule, this zone gathers the tributaries of Monjolinho River, which has gradually been taken by the urban sprawl, evidencing an noncompliance with the Brazilian Forestry Code (Brasil, 1965), the Municipal Master Plan (São Carlos 2005) and the Water Resources Act (São Paulo 1997), resulting in severe damages to the quality of these sources. Besides violating the laws in force and impairing future water supplies, deforestation in the watershed is intense with the consequent use of the land for pasture, poultry farming and urban expansion. This scenario may soon condemn the water source due to the disposal of urban rainwater and domestic and industrial wastewater. It is important to mention that the preservation of the sources depends on the adoption of policies against urban expansion in areas inside the water source as well as an environmental monitoring of the watershed.

The Protection and Restricted Land-Use Zones – 5A and 5B pose restrictions to the urban development, having as main guidelines the protection and recovery of the quality and the quantity of surface water for public supply (São Carlos 2005). Suitable and available areas for urbanization in the referred zones will not be considered in this study. In addition to being of great importance to the city water sources they pose restrictions to urban development.

Zone 5a is regarded as an area of protection and preservation of Monjolinho River. Moreover, this zone comprises water sources of Gregório stream. Having water sources located in the plateau region, the watershed of upper Monjolinho drains part of the urban area. The water collection takes place near the campus of the Federal University of São Carlos. Zone 5A has an area of 23 Km² (2.3% of the total) being 2.2% already urbanized. New settlements northwest and southernmost this zone are being established, due to their proximity to a state highway (SP 215) bypassing the lower border of the urban sprawl, east-west direction. It is worth noting that such urban settlements imply new openings for urban expansion in water source areas, suggesting a monitoring by authorities in order to restrain their progress.

Zone 5B is regarded as an area of protection and preservation of Feijão River. Only 120.3 Km² (11.9% of the total) of the 222.7 Km² of the watershed area belong to the city of São Carlos. The remaining 102.4 Km² belong to the cities of Analândia and Itirapina. Of the 120.3 Km² of the water source belonging to the city of São Carlos, it turns out that 5.9% of the Zone 5B is already urbanized. The water collection takes place close to its mouth, in the affluent Jacaré-Guaçu River.

According to Zuquette (1981), Gonçalves (1986), Nishiyama (1991), Muro (2000) and Zuquette et al. (2009), the most important aquifer in the region is in the sedimentary geology units, being the Botucatu Formation (GAS) the main reservoir. In the mapped portion, the south sector appears as the main recharge area, where Feijão River, in its medium course, flows northwest-southwest and east-west upon unconsolidated sand sediments in the Botucatu Formation.

The surface and groundwater in these sources, as well as in Monjolinho River, is highly vulnerable to contamination, therefore considered unsuitable for urban development, going against the laws in force and the results of scientific studies already performed in the area.

However, as public roads are an encouragement to land development, Figure 3 shows the creation of new urban settlements along Washington Luiz highway (SP 310) interrupting the water course in the southwest/northwest direction. The same happens north of the water source due to its proximity to Luiz Augusto de Oliveira highway (SP 215). These urban settlements suggest a new urban expansion front, thus implying the need of monitoring by authorities in order to restrain their progress. Moreover, it is a fact that the Industrial Complex Miguel Abdelnur, the Technology Science Park and a High Technology Business Center – the CEAT "Dr. Emílio Fehr", according to the Municipal Master Plan, are part of Zone 2. As a matter of fact, they are situated inside Feijão source, exceeding, inclusively, the urban perimeter.

This situation contributes to increase problems such as punctual pollution, caused by disposal of industrial wastewater in the water bodies, as well as diffuse pollution caused by rain water, reflecting in the decline of the quantity and the quality of ground and surface water of the referred sources.

The Subsistence Agricultural Zone –Zone 6 has an area of 61.4 Km² (7% of the total). Of this amount, 0.2% is already urbanized, 21.0% is inadequate and 78.8% or 48.4 Km² refers to areas still not taken by the urban sprawl.

The Predominantly Agricultural Zone – Zone 7 features agricultural production. The areas covered by Zone 7 are situated north and south of São Carlos. The study area of the referred zone has 799.6 Km² (78.7% of the total). Of this amount, 0.4% is urbanized, 22.4% is inadequate and 77.2% or 616.7 Km² refers to areas still not taken by the urban sprawl.

Zone 8 incorporates the University Campuses contiguous to the existing urban areas (UFSCar - Federal University of São Carlos and USP – University of São Paulo). Zone 8 has an area of 4.6 Km² (0.5% of the total). Of this amount, 41.3% is already urbanized, 30.4% is inadequate and 28.3% refers to areas available for the extension of the university campi. These areas are located north and east of the urban sprawl.

4. FINAL CONSIDERATIONS

The disorderly growth of the city induces detrimental consequences of varied socio-environmental compartments. To minimize such incidents, if applicable, it is essential that the laws in force meet the needs of the population. However, when laws are not followed, the communities usually penalized are those dependent on natural resources, for instance, in cases of water shortage. Implications in the pace of disorderly urban development may affect surface and/or groundwater sources with several and varied degrees of impacts, this way preventing the accomplishment of industrial projects, urban development and population growth.

The Participatory Master Plan foresees that the entire city land may be made available for residences; commerce and industries or mixed purposes, as long as in compliance with restrictions of activities generating impact and disturbances. This way, the Master Plan restricts, although does not forbid the use of Zones 3B, 5A and 5B for urban purposes, due to being areas of protection and preservation of water sources of Monjolinho and Feijão Rivers.

According to the Water Resources Act and the Municipal Master Plan, Zones 3B, 5A and 5B are to be protected as they are water sources. However, it seems a fact that since 2006 the urban sprawl has grown reaching areas of the water sources, suggesting an inadequate monitoring from the municipal administration. It also evidences pressures and private interests of land owners to the detriment of the population welfare.

The total amount of suitable areas for urban development is 125.7 Km²; of this amount 55.9 Km² (44.5%) is already taken by the urban sprawl. Unsuitable areas for urban development total30.4 Km² (24.2%), therefore the remaining 39.4 Km² (31.3%) is available for urbanization (Table 3). These figures show that even disregarding inadequate areas, 31.3% is available for the urban sprawl.

We must highlight that even if considered adequate for urban expansion, use of the referred area shall be carefully considered due to its geology features hindering urban use and due to being a water source of high importance to the region. Such variables combined with topography, low density of vegetation coverage and high drainage network, make the region environmentally susceptible.

It is essential to highlight that Costa (2013) foresees an increase of 93.6% of the urban sprawl in São Carlos for the year 2050, that is, the size of the city will double in 40 years. Thus, land planning of new areas should start immediately. In an aggressive scenario, it seems a fact that, many times, the local government is reckless concerning the increase of the urban sprawl and the use of the soil in surrounding areas, therefore failing in the integration of urban and rural areas.

The absence of preservation of current surface water sources (quality and quantity), in combination with unlimited exploitation and groundwater contamination, may soon lead São Carlos to a scenario of severe water shortage. According to Costa (2013), from 1989 to 2009 the collection of surface water in the city of São Carlos decreased 20.5%, while groundwater exploitation increased 684.2%. This scenario evidences a change in the model for water resources exploitation, which was previously based on surface sources and now appears dependent on the exploitation of groundwater sources due to its abundance, exploitation easiness and lower costs of groundwater treatment, which, definitely, contributes and reinforces degradation, pollution and disregards the preservation of surface water sources.

In São Carlos, as in any watershed or region, water must be regarded as a human right.

References

AGUIAR, R. L. (1989) Geotechnical mapping of the urban expansion area of Sao Carlos - SP: Contribution to the planning. M.S. thesis, Universidade de São Paulo, São Paulo, Brazil (in Portuguese).

BADWI, I., EL-BARMELGY, M., OUF, A. (2014). Modeling and Simulation of Greater Cairo Region Urban Dynamics Using SLEUTH. J. Urban Plann. 0 0:0, (2014). Doi: http://dx.doi.org/10.1061/(ASCE)UP.1943-5444.0000193

BRASIL. Law No. 4.771. Brazilian Forestry Code. September 15th, 1965.

BRASIL. Law No. 6.766. Parceling of the Urban Land. Dezember 19th, 1979.

CARNEIRO, P. R. F. (2008). Flood control basins in metropolitan considering the integrated planning of land use management of water resources. Case Study: Iguazu river basin / Saratoga in the metropolitan region of Rio de Janeiro. Doctoral thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil (In Portuguese).

CARTER, N.; KREUTZWISER, R. D., LOE, R. C. (2005). Closing the circle: linking land use planning and water management at the local level. Land Use Policy, 22(2) 115–127 (2005). doi:10.1016/j.landusepol.2004.01.004.

CONWAY, T. M., LATHROP, R. G. (2005). Alternative land use regulation and environmental impacts: assessing future land use in an urbanizing watershed. Landscape and Urban Planning 71(1), 1-15 (2005). doi: 10.1016 / j.landurbplan.2003.08.005.

COSTA, C. W., DUPAS, F. A., CESPEDES, J. G., SILVA, L. F. (2013). Monitoring of urban sprawl, future scenarios of population growth and consumption of hydric resources in the city of São Carlos, SP, Brazil. Geociências (São Paulo. Impresso), 32(1): 63-80 (in Portuguese).

COSTA, C. W., DUPAS, F. A., PONS, N. A. D. (2012). Regulamentos de uso do solo e impactos ambientais: avaliação crítica do plano diretor participativo do município de São Carlos, SP, Brasil. Geociências (São Paulo. Impresso), 31: 143-157 (in Portuguese).

CUNHA, R. C., DUPAS, F. A., PONS, N. A. D., TUNDISI, J. G. (2011). Análise da influência das variáveis ambientais utilizando Inferência Fuzzy e zoneamento das vulnerabilidades. Estudo do caso da bacia hidrográfica do ribeirão do Feijão, São Carlos – SP. São Paulo, UNESP, Geociências, (30) 3: 399-414.

CWP. Center For Watershed Protection. (2003). Impacts of impervious cover on aquatic systems, CWP ed., Ellicott City, USA.

GONÇALVES, A. R. L. (1986). Environmental Geology of São Carlos. Doctoral thesis, Universidade de São Paulo, São Paulo, Brazil (in Portuguese).

IAC. Instituto Agronômico de Campinas. (1982) Pedological maps, SF.23-Y-A-I.; SF.23-V-C-IV.

IBGE. Instituto Brasileiro de Geografia e Estatística. (1971) Topographic maps, SF 23-Y-A-I-1; SF-23-Y-A-I-2; SF-23-V-C-IV-3; SF-23-V-C-IV-4.

JANSEN, J. R. (2009). Remote sensing of environment: A perspective on land resources. Parentêses ed., São José dos Campos, Brazil.

JAT, M.K., GARG, P.K., KHARE, B. (2008). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation 10(1), 26-43 (2008). doi:10.1016/j.jag.2007.04.002.

LERNER, D.N., HARRIS, B. (2009). The relationship between land use and groundwater resources and quality. Land Use Policy, 26(1), 265–273 (2009). doi:10.1016/j.landusepol.2009.09.005.

LORANDI, R. (1985). Soil characterization of Carlos urban and suburban areas. Doctoral thesis, Universidade de São Paulo, São Paulo, Brazil (in Portuguese).

MACHADO, F. H., SILVA, L. F., DUPAS, F. A., MATTEDI, A. P., VERGARA, F. E. (2014). Economic assessment of urban watersheds: developing mechanisms for environmental protection of the Feijão river, São Carlos - SP, Brazil. Brazilian Journal of Biology, 74: 677-684 (2014). Doi: http://dx.doi.org/10.1590/bjb.2014.0073

MUKUNDAN, R., PRADHANANG, S. M., SCHNEIDERMAN, E. M., PIERSON, D. C., ANANDHI, A., ZION, M. S., MATONSE, A. H., LOUNSBURY, D. G., STEENHUIS, T. S. (2013). Suspended sediment source areas and future climate impact on soil erosion and sediment yield in a New York City water supply watershed, USA. Geomorphology, 183: 110-119 (2013). doi:10.1016/j.geomorph.2012.06.021.

MURO, M. D. (2000). Favorable areas for waste sanitary landfills: 1:50,000 scale zoning Chart of São Carlos region, SP, Brazil. M.S. thesis, Universidade de São Paulo, São Carlos, Brazil (in Portuguese).

NIELSEN-PINCUS, M., GOLDBERG, C. S., POCEWICZ, A., FORCE, J. E., WAITS, L. P., MORGAN, P., VIERLING, L. (2010). Predicted effects of residential development on a northern Idaho landscape under alternative growth management and land protection policies. Landscape and Urban Planning, 94(3 and 4), 255-263 (2010). Doi:10.1016/j.landurbplan.2009.10.011.

NISHIYAMA, L. Mapeamento geotécnico preliminar da quadrícula de São Carlos – SP. São Carlos, 1991. Dissertação (Mestrado em Geotecnia) - EESC, Universidade de São Paulo, São Carlos.

PENG, J.; MA, J., YUAN, Y., WEI, H.; PANG, W. (2014). Integrated Urban Land-Use Zoning and Associated Spatial Development: Case Study in Shenzhen, China. J. Urban Plann. 0 0:0 (2014). Doi: http://dx.doi.org/10.1061/(ASCE)UP.1943-5444.0000245.

PONS, N. A. D., PEJON, A. J., ZUQUETTE, L. V. (2007). Use of geoprocessing in the study of land degradation in urban environments: the case of the city of São Carlos, state of São Paulo, Brazil. Environmental Geology, 53(4), 727-739 (2007). Doi: 10.1007/s00254-007-0685-y.

RAWASHDEH, S. A., SALEH, B. (2006). Satellite monitoring of urban spatial Growth in the Amman área, Jordan. Journal of urban planning and development, 132(4), 211-216 (2006). Doi: 10.1061/(ASCE)0733-9488(2006)132:4(211).

ROLNIK, R. (2009) La democracia em el filo de La navaja: limites y posibilidades para la implementación de uma agenda de reforma urbana em Brasil. Eure, 25(104) 5-28, (in Spanish).

SÃO CARLOS. Plano Diretor Municipal de São Carlos. Texto extraído do site oficial da Prefeitura Municipal de São Carlos/SP. http://www.saocarlos.sp.gov.br/index.php/utilidade-publica/plano-diretor.html. Accessed 04 January 2012.

SÃO PAULO. Lei n° 9.866. Dispõe sobre diretrizes e normas para a proteção e recuperação das bacias hidrográficas dos mananciais de interesse regional do estado de São Paulo. São Paulo, SP, 28 de novembro de 1997.

SÃO PAULO. Situação dos recursos hídricos no Estado de São Paulo: ano base 2007. Secretaria do Meio Ambiente; Coordenadoria de Recursos Hídricos. São Paulo: SMA/CRH, 149 p., 2009.

SCHUELER, T., FRALEY-MCNEAL, L., CAPPIELLA, K. (2009). Is Impervious Cover Still Important? Review of Recent Research.

Journal of Hydrologic Engineering. 14(4), 309-315 (2009). Doi: http://dx.doi.org/10.1061/(ASCE)1084-0699(2009)14:4(309).

SETO, K., C., GÜNERALP, B.; HUTYRA, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. PNAS - Proceedings of the National Academy of Sciences of the United States of America. 109 (40): 16083-16088 (2012). Doi: 10.1073/pnas.1211658109.

SPERANDELLI, D. I., DUPAS, F. A., PONS, N. A. D. (2013). Dynamics of Urban Sprawl, Vacant Land, and Green Spaces on the Metropolitan Fringe of São Paulo, Brazil. J. Urban Plann. Dev., 139(4), 274–279 (2013). Doi: http://dx.doi.org/10.1061/(ASCE)UP.1943-5444.0000154.

TERRENO, C. G. (2013). Integration of Simulations Models in Planning for Local Sustainable Development. The Case of Río Ceballos in Cordoba´s Metropolitan Area. In: The 13th International Conference on Computers in Urban Planning and Urban Management. Utrecht, Netherlands: Conference proceedings, Session 3 - Simulation: Urban Modelling 1, p. 1-15.

TUNDISI, J. G., TUNDISI, M. T., DUPAS, F. A., SOUZA, A. T. S., SHIBATTA, O. A. Uso atual e potencial do solo no município de São Carlos, SP – base do planejamento urbano e rural. Instituto Internacional de Ecologia. FAPESP – Relatório final de projeto de Políticas Públicas – Processo 98/10924-3, 2007.

WEATHERHEAD, E. K., HOWDEN, N. J.K. (2009). The relationship between land use and surface water resources in the UK. Land Use Policy, 26(1), 243–250 (2009). Doi:10.1016/j.landusepol.2009.08.007.

ZUQUETTE, L. V. Mapeamento geotécnico preliminar na região de São Carlos. São Carlos, 1981. Dissertação (Mestrado em Geotecnia) – EESC, Universidade de São Paulo.

ZUQUETTE, L. V.; PALMA, J. B.; PEJON, O. J. (2009). Methodology to assess groundwater pollution conditions (current and predisposition) in the São Carlos and Ribeirão Preto regions, Brazil. Bulletin of Engineering Geology and the Environment, 68(1) 117-136 (2009). Doi: 10.1007/s10064-008-0173-y.