Study of the urban expansion of Sao Carlos, Brazil and related increases in environmental degradation

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Abstract: The evolution of the environmental degradation caused by the urban expansion of São Carlos city, in the State of São Paulo, Brazil, during the period 1962 to 2004 was analysed in this study. The methodology used consisted of the identification of both the degraded areas and the areas of urban expansion on aerial photographs for the years 1962, 1978, 1998 and 2000, through photogrammetric techniques. Also, an image from the Ikonos satellite (PSM, 1m) of 2004 was analysed. The types of environmental degradation identified were: erosion, siltation, deforestation of the riparian forest, and abandoned and active mining. Understanding of the nature of the expansion of the urban area allowed conclusions to be made that the environment degradation occurred because of inadequate land use in the majority of the areas. Land division into lots was introduced in places where the environment was fragile with regard to urbanization and no precautions were taken to minimize or to prevent the damage caused. Existing natural drainage in the urban area was altered, which caused the deforestation of the riparian forest and an increase of the speed of the water, mainly in the rainy seasons. These degradation effects could have been prevented if there had been management and control of the urban expansion, both the responsibility of the planning agency of the city. The results of this mismanagement are: silting of stream channels, deforested spring areas, erosional gullies next to buildings, unreclaimed abandoned mining workings, active mining workings expanding towards the urban area, amongst other problems of great impact on the environment and the health of the population.

Résumé: L'évolution de la dégradation environnementale provoquée par l'expansion urbaine de la ville de São Carlos, dans l'état de São Paulo, Brésil, pendant la période 1962 à 2004 a été analysé dans cette étude. La méthodologie utilisée a compris l'identification des secteurs dégradés et des secteurs de l'expansion urbaine sur les photographies aériennes pendant les années 1962, 1978, 1998 et 2000, par des techniques photogrammétriques. En outre, une image du satellite d'Ikonos (PSM, 1m) de 2004 a été analysé. Les types de dégradation environnementale identifiés étaient : érosion, envasement, déboisement de la forêt ripicole, et carrière abandonnée et active. L'arrangement de la nature de l'expansion du secteur urbain a permis à des conclusions d'être faites que la dégradation d'environnements est produite en raison de l'utilisation de la terre insatisfaisante dans la majorité des secteurs. La division de terre dans les parcelles a été présentée dans les endroits où l'environnement était fragile en ce qui concerne l'urbanisation et aucune précaution n'a été prise pour réduire au minimum ou empêcher les dommages. Le drainage naturel existant dans le secteur urbain a été changé ce qui a causé le déboisement de la forêt ripicole et une augmentation de la vitesse de l'eau, principalement dans les saisons des pluies. Ces dégradations pourraient avoir été empêchées s'il y avait eu gestion et commande de l'expansion urbaine, les deux sur la responsabilité de l'agence de planification de la ville. Les résultats de cette gestion mauvaise sont : envasement des canaux de drenage, secteurs déboisés de sources d'eau, erosion à côté des bâtiments, carrière abandonnés, carrière actifs augmentant vers le secteur urbain, entre d'autres problèmes de grand impact sur l'environnement et à la santé de la population.

Keywords: environmental urban geotechnics, land use, regional planning, photogrammetry, remote sensing, environmental impact.

INTRODUCTION

The problem of environmental degradation has been occurring for a long time, and is directly related to the increased capacity of Man to modify the environment. In this context, the increase and the diversification of environment exploitation has resulted from an intensification of the urbanization process that entails increasing use of resources including energy, water and agricultural products, as well as basic materials for the construction, such as sand, clay, stone and wood, all of which are extracted from the environment (Carvalho & Prandini, 1998).

The lack of the knowledge about geological-geotechnical characteristics of the environment and of the planning for the urban occupations underlies many geotechnical, social and economic problems, including for example erosion, silting and flooding that threaten the well being of people, as well as property and the urban infrastructure.

For decades diverse authors have been studying and debating this subject, among them Lal (1990), Morgan (1995), Hudson (1995), Conacher & Sala (1998), Brown & Quine (1999), Ebbett (2004). Barrow (1991) considers the main causes of degradation of soils to be human activities that contribute to natural risks, including construction on flood plains, removal of vegetation, alteration of stream hydrographs, intensive agriculture, draining of land. This is exacerbated by the pressure exerted by population growth for the space and materials for construction, including the inappropriate use of existing degraded areas, coupled with the negligence of the population to appreciate the environmental impacts of this growth.

In the Brazil, studies by Seixas (1984), Weissberg (1989), Bauer (1989), Bertoni & Lombardi Neto (1990), Cunha (1991), Barroso et al. (1996), Amorim (1997), Bitar (1997), Disperati (1998), Zuquette et al. (2004), among others, have highlighted concerns about environmental degradation. Almost all these studies concern geological-geotechnical problems caused by unplanned urban expansion, including the occupation of unsuitable areas, that have resulted in negative impacts on the urban landscape and the quality of life. The inappropriate use of the environment has impeded the implementation of urban plans and caused the environmental degradation, including the creation of situations of geological risk such as flooding and landslides. Such geological processes are accelerated by human action, such as for example: the construction of steep cuttings, increase in run-off due to increased imperviousness of the land, insufficient or badly constructed drains and the removal of vegetal covering. Of particular concern is an expansion in the construction of informal housing in areas prone to mass movements as this is liable to increase the frequency and size of the unstable area, thus causing bigger problems in the future.

Studies of environmental degradation require knowledge of the relationships between the elements that constitute the environment as well as an understanding of the effects of different forms of human activity. In the city of São Carlos, where this study was done, rapid and irregular urbanization as in the majority of the cities in Brazil, has aggravated the environmental problems.

The environment degradation observed by Gonçalves (1986), Aguiar (1989), and Gaspar (2000) in the city of São Carlos- SP include the discharge of domestic sewage directly to streams of the city, the deposition of garbage in unsuitable places, lack of restoration of former stone and sandstone mines, excessive soil erosion due to the deforestation associated with the division of land or other environmental changes. The aim of the study was to discover how urban occupation has influenced in the evolution of the present environment degradation in the city. The application of photogrammetric techniques for studying the evolution of degraded areas was tested, and the use of Ikonos satellite images (PSM, 1m) was evaluated.

STUDIED AREA

General Characteristics

The City of São Carlos occupies an area of 1,140.90 km^2 in the central region of the State of São Paulo, (see Figure 1) between longitude 47º30’ and 48º30’ west Longitude and latitude 21º30' and 22º30' south. It is boardered by the cities of Ibaté, Itirapina, Dourado and Luis Antonio. (see Oliveira, 1996).

The area studied is 160 km², which corresponds with the watershed of the rivers Monjolinho and Feijão together with the sub-basin of the Água Fria stream. The city has a total population of 192,923 inhabitants, of whom 183,369 are in the urban area and 9,554 in rural parts (Ibge, 2001).

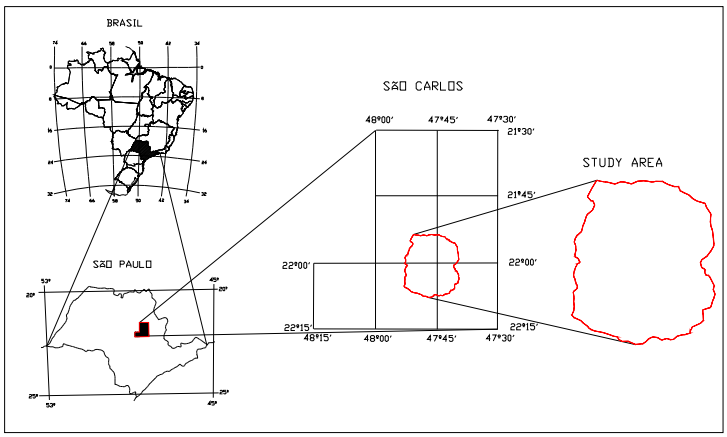

Figure 1. Location of the studied area.

According to Gonçalves (1986), the region of the State of São Paulo, which includes the City of São Carlos, is part of a geomorphologic province of "basaltic cuestas and sandstone", located between provinces of Plateau Occidental and the São Paulo Peripheral Depression. Geologically the Plateaux of São Carlos are represented by the Botucatu Formations (São Bento Group), region below the cuestas; Serra Geral (São Bento Group), in the narrow region of the cuestas (scarp slopes); Itaquerí Formation (Bauru Group), on the dip slope of the cuestas, where the bigger part of the urban centre is located. The soils can be divided into two main groups: Red-Yellow Latossol, in the higher parts of the study area, and Deep Quartzose Sands, below the cuestas (Gonçalves, 1986).

São Carlos is located on the watershed between the basins of the Rivers Mogi-Guaçu and Tietê. Because of its high location the majority of the water courses that drain the urban area of São Carlos originate from springs located in the city (Oliveira, 1996). The main streams that drain the area urban are the Monjolinho, Mineirinho, Gregório, Tijuco, Medeiros, Lazarini, Água Quente and Água Fria streams, within the catchment of the Monjolinho River, that flows east-west across the area.

According to Tolentino (1967) andGonçalves (1986), using the Köpen systematics, the climate of the São Carlos Plateaux can be classified as transitional between Cwa.i (tropical climate with humid summers and dry winters) and

Aw.i (hot climate of dry winter). According to Oliveira (1996), the annual average rainfall is 1,512 mm and the average relative humidity is 66%. According to Gonçalves (1986), the predominant original vegetation was the *cerrado*, that it is characterized by herbaceous scrub rather than forest.

METHODOLOGY

Photogrammetric Techniques

The photogrammetric technique was used to identify environmental degradation see on aerial photographs for the years 1962, 1978, 1998 and 2000. These were respectively at scales 1:24,000, 1:35,000, 1:8,000 and 1:30,000. The Ikonos satellite image (PSM 1m) was used to update the information to the year 2004.

Measurement of the Density of Urban Occupation

The urban occupation density was measured using a 300 x 300m mesh applying the following classification:

- without urbanization
- < 20% occupation
- 20 to 50%
- 50 to 70%
- 70 to 100%

Analysis of the Increases in Environmental Degradations

The information from the photo interpretation and the occupation density measurement was overlain to analyse the increases in environmental degradation. This allowed verification of how much the urban occupation influenced the increases in environmental degradation.

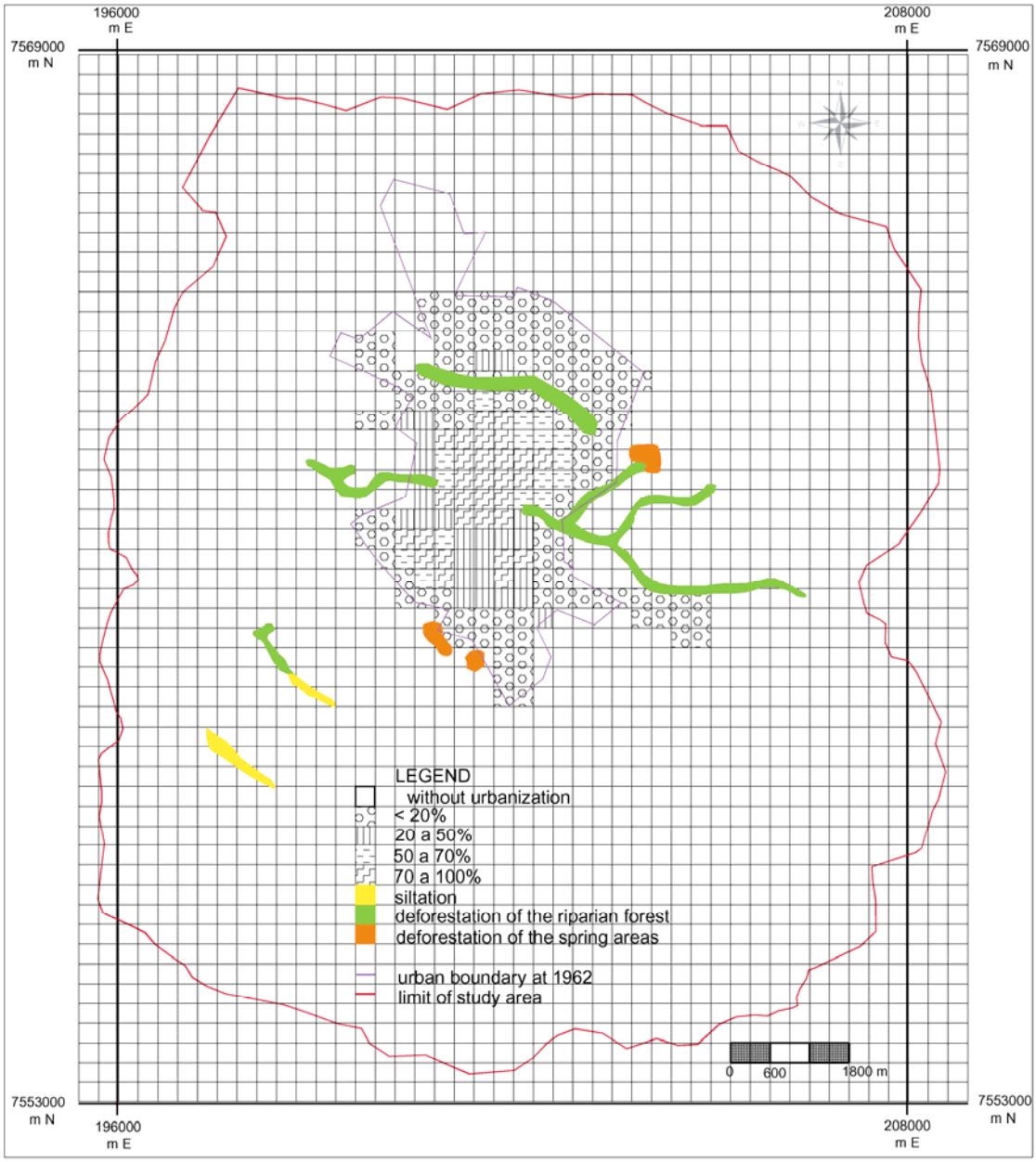

Figure 2. Urban occupation of the studied area and environment degradation (1962).

RESULTS

Figure 2 represents the situation of the city in the year 1962. It shows areas of deforestation in areas of springs and the riparian forest of the Gregorio and Tijuco Preto streams, located in the central area. The straightening of these streams in connection with road construction is a cause of flooding in the central part of the city during periods of intense rain. These events have caused socio-economic damage to the population and the public administration. Also some points of silting existed in the Água Quente and Água Fria Streams, to the west of the urban area.

After 16 years (1962-1978), the city had expanded to the area presented in Figure 3. The greatest growth is in the southwest, where the environment presents greater restrictions to the occupation. The presence of the Botucatu Formation, the occurrence of steep slopes (>15%) and the area of recharge of the Botucatu Aquifer form a set of environmental elements that are sensitive to the occupation, because of the risk of contamination of groundwater and initiation of erosive processes. An increase in deforestation and silting in Água Fria and Água Quente streams, situated in this same region, and also of erosive processes in the areas adjacent to urban occupation were observed.

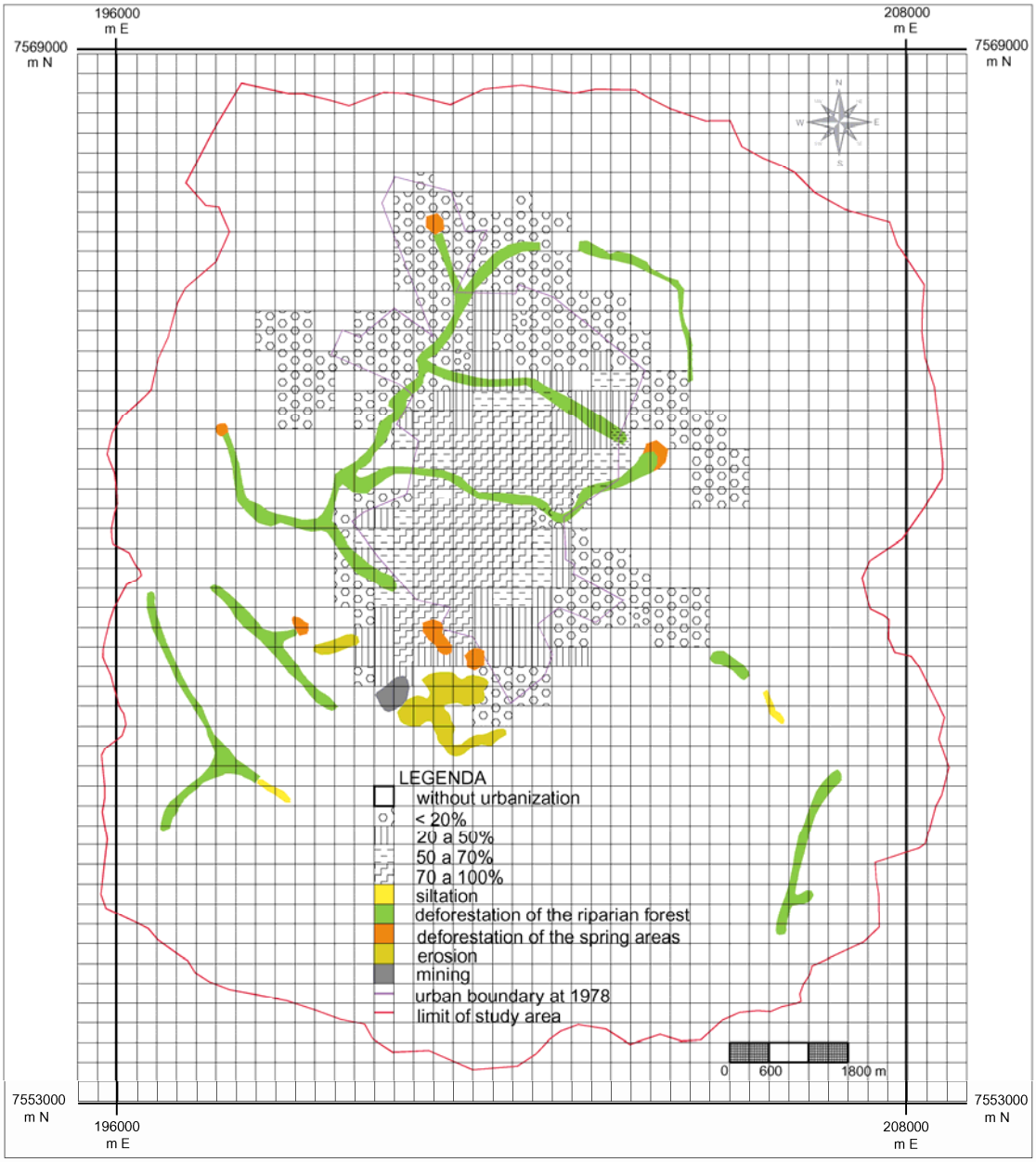

Figure 3. Urban occupation of the studied area and environment degradation (1978).

During the next 20 years (1978-1998), the city underwent unplanned expansion resulting in an increase in deforestation of the riparian forest and spring areas (Figure 4). The Monjolinho Stream, which bounds the city to the north and west, was subject to great deforestation because of the intensification of the urbanization. Erosion became more serious, in the south-western region of the city, where the Botucatu Formation occurs. This process was exacerbated by steep slopes in sandy soils, intensification of informal occupation and lack of urban infrastructure. There was also an increase in mining and quarrying activities where the Botucatu and Serra Geral Formations were respectively exploited for sand and basalt.

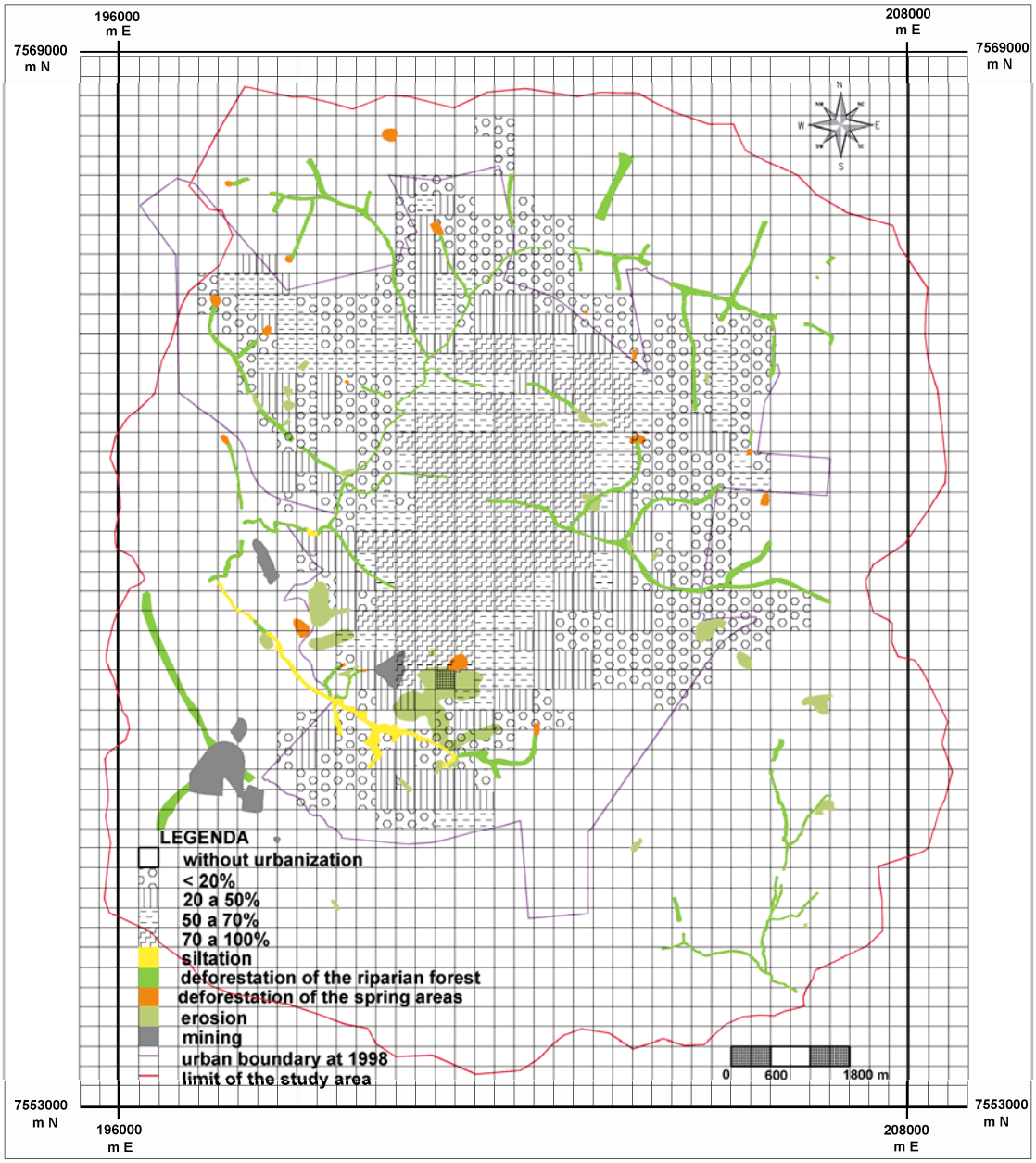

Figure 4. Urban occupation of the studied area and environment degradation (1998).

Figure 5 shows that the city continued to growth continued, mainly to the north-west in the 2 year period of 1998 to 2000. This region of the city is the preferred one for urban expansion, due to the characteristics of the environment, including low declivities (<5%) and soils with average permeability favourable to the installation of a sewerage system. However, the presence of some springs must be considered in order to prevent contamination or their demise. The existing spring areas in the urban area had suffered more deforestation, as had the riparian forest, due to of land division and construction of basic infrastructure.

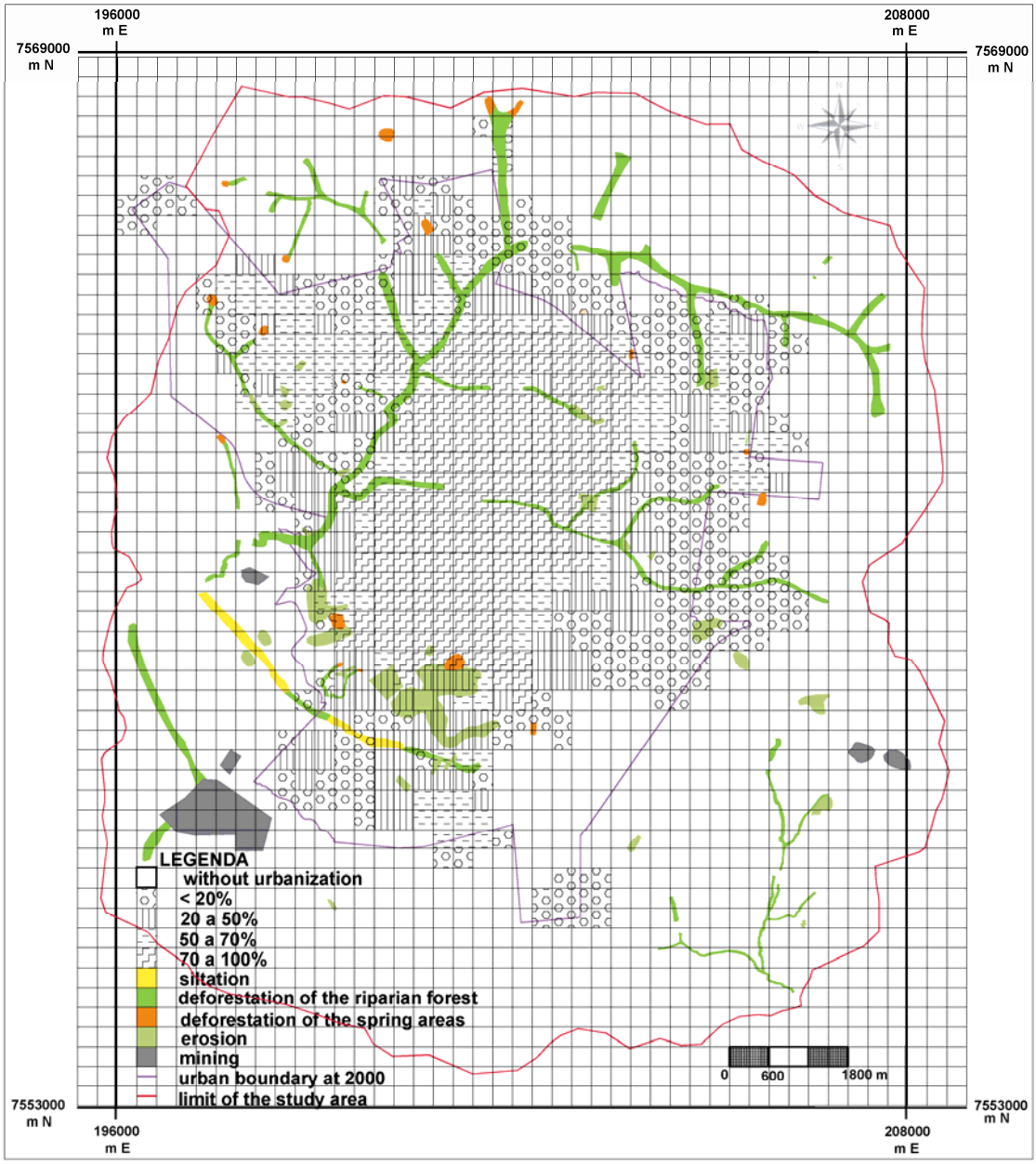

Figure 5. Urban occupation of the studied area and environment degradation (2000).

From Figure 6 it can be observed that intense urbanization occurred during the 4 years (2000-2004). The creation of land divisions in the north, northwest and east regions caused deforestation of spring areas and riparian forest, many times beyond the limit allowed in urban areas (30 meters) and, in other cases, the total deforestation of the riparian forest accompanied canalization of the drainage. These factors are liable to contribute to the pollution of streams, incidence of flooding and the demise of streams. There was also an increase in mining areas and the continued presence of abandoned mining areas.

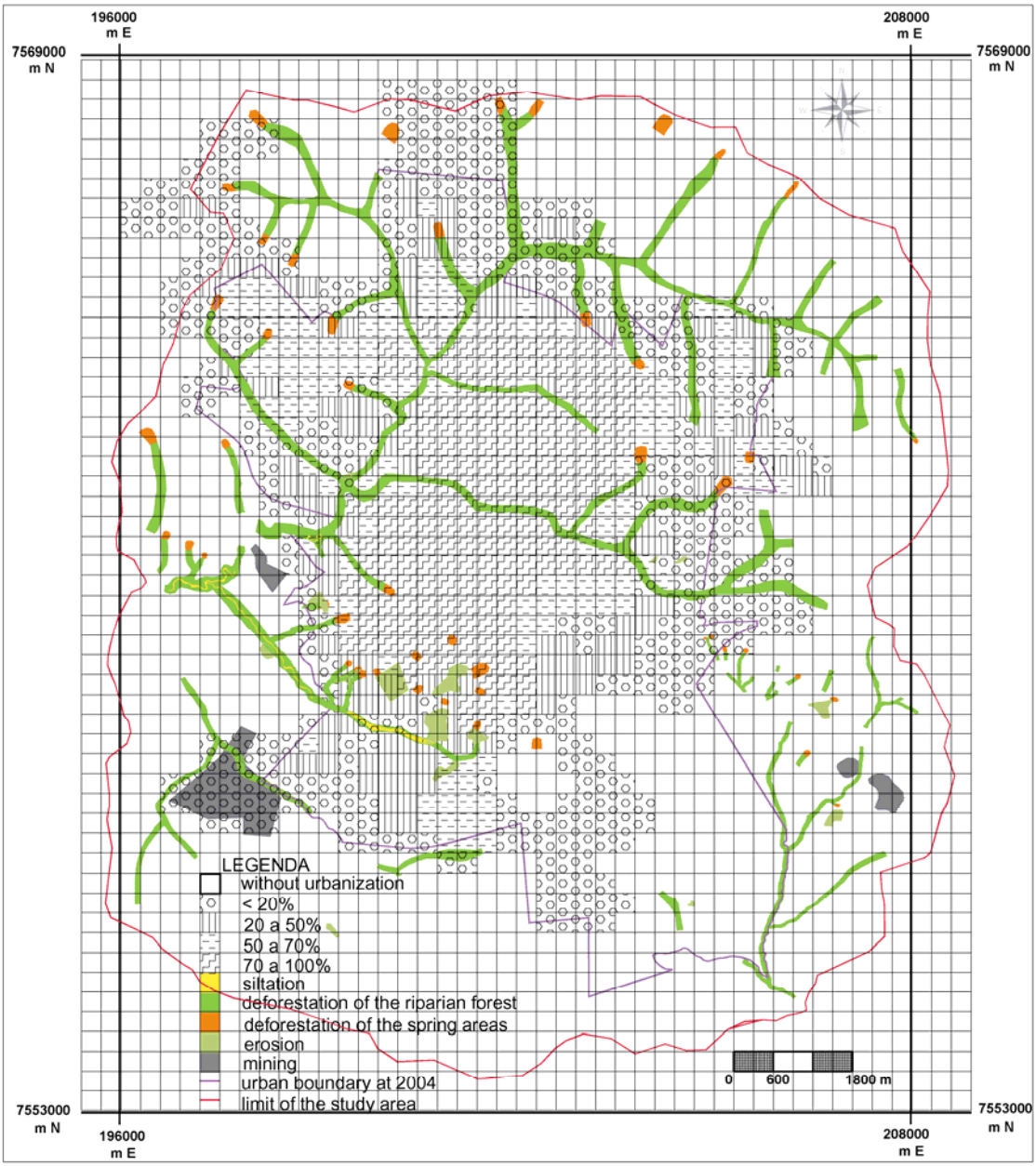

Figure 6. Urban occupation of the study area and environment degradation (2004).

Analysis of the Results

The study allowed the main adverse environmental impacts in the city to be identified as erosion, silting, abandoned mining, deforestation of the springs areas and riparian forest. These problems are caused by unplanned urban expansion. Table 1 presents the dimensions of the degraded areas in the year 2004.

Table 1: Areas degraded identified in the city of São Carlos in 2004.

Type of degradation	Dimension
Erosion	15 areas = 490,000m^2
Deforestation of spring areas	51 spring areas
Deforestation of riparian forest	101,0 km
Silting	5.91 km = 40,000m^2
Mining	17.0 km^2

The number of deforested spring areas corresponds to 56.7% of the existing total in the study area, what it represents high risk to the pollution and the demise of streams. The extension of deforestation of riparian forest showed that 67.3% of the existing streams in the city have lost protection. The consequences of this degradation include a reduction in evapo-transperation, an increase of the amount of the runoff, changes in the level of the groundwater, increased soil erosion and increase in siltation of streams, as well as an increase in flood risk and the pollution of superficial and underground waters.

The degradation observed in the region west of the city, where sandy soils occur, were associated with the increase in the urbanization, and of reduced infiltation. The sandy soils has high coefficient of permeability (around 10^{-2} to 10^{-3}cm/s), such that infiltration of pluvial waters is rapid. However, the imperviousness of the surface has caused an increase in runoff, mainly in regions with high declivities (>15%). This fact, aggravated by the deforestation of the riparian forest, has resulted in erosive processes to begin, while also increasing the occurrence of flooding and contamination risk to groundwater.

Gully erosion has resulted from urban expansion on sandy soils, whose thickness (>2m) and highly erodable character has resulted in a situation of high fragility to the occupation process, mainly due to the lack of drainage construction and erosion control measures.

The deforestation of the riparian forest, independent of the lithology, always causes damage to the environment. In the argillaceous soil case, the superficial flow intensity is increased, thus increasing the occurrence and severity of flooding. In sandy soil, where the permeability is higher and the superficial flow is less, the main problems are erosion and siltation.

In the central region of the city, where the Gregorio Stream flows, the deforestation of the riparian forest, associated with a narrowing of the stream channel, low ground slope angles and low permeability of the argillaceous soil, causes periods of flooding of the area. In the case of the Água Quente Stream, to the west of the city, due to the Botucatu Sandstone and sandy soil of that area, associated with the deforestation of the riparian forest, several problems of erosion and silting are caused.

It can be observed that the geological-geotechnical characteristics of the area have not been considered in the São Carlos city urbanization process, and the environment has been degraded, sometimes in an irreversible way. The greatest example of degradation includes the erosion where the Botucatu Sandstone occurs, due to inadequate installation of land divisions, as well as its expansion. The existing degradations in the city could have been prevented if the environmental factors had been considered in the planning of the area.

CONCLUSIONS

From this study it is concluded that the process of urbanization in the city of São Carlos did not consider the environment characteristics of the area and that this has resulted in environmental degradation of various types.

The most serious form of degradations were caused by the intense and inappropriate occupation. The lack of planning to direct the urban occupation in a period of 42 years (1962-2004) has caused problems of erosion and siltation. Affected areas are situated on the Botucatu Formation outcrop and in areas of high declivity, presenting restrictions to occupation. The deforestation of spring areas and riparian forest caused the loss of small streams in the city leading to a barren landscape. The lack of the riparian forest increased the vulnerability of streams to erosion and siltation thus increasing the flooding risk in the centre of the city.

The photogrammetric techniques contributed to the identification and analysis of the increase of environmental degradation. However, the different scales of the aerial photographs had made it difficult to determine the arears of degradation because it is an urban area. Among the scales used, the most useful in that it presented greater detail was 1:8,000. The Ikonos image (PSM, 1m) for the year 2004 allowed updating of all environment degradation areas and types.

The impacts to the environment caused by diverse human actions in the city, have been reflected by the deterioration of the quality of life of the population. Deforestation has modified the microclimate of the city, initiated erosive processes, the siltation of streams, the increased surface water flow and reduced infiltration, and associated flooding. These degradation features are the cause of economic and social damage to the population.

Despite the urbanization process having occurred without considering the existing environmental conditions, there is still time to recoup some degraded environments and to plan for the protection of residual undamaged areas. Many challenges need to be faced to solve the problems, including the development of information systems that link environmental management, the economy and the evaluate degradation impacts. However, society needs to be mobilized for the establishment of viable environment recovery and protection projects.

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REFERENCES

AGUIAR, R. L. 1989. *Geotechnical mapping of the urban expansion area of São Carlos, SP.* Dissertation (Geotechnic Engineering). São Carlos, São Carlos Engineering School, São Paulo University (in Portuguese).

AMORIM, D. A. de**.** 1997. *Survey of erosions and mining of the Basin of the High River Jacaré-Guaçu, proposals for recovery.* Dissertation (Environmental Engineering Sciences). São Carlos, São Carlos Engineering School, São Paulo University (in Portuguese)**.**

BARROSO, J. A. et al. 1996. Preliminary environmental diagnosis from geotechnic geologic mapping. Study of case: oceanic region of Niterói. In: *Geotechnical Cartography Brazilian Symposium*, 2º and Environment and Geotechnic Regional Meeting, I. Anais... São Carlos. 87-93 (in Portuguese).

BARROW, C.J. 1991. *Land Degradation*. Cambridge University Press.

BAUER, A. M. 1989. Planned mining and whitewashing of areas. In: VALVERDE, F. M.; KIYOTANI, M.A.; AKINAGA, R. M. (orgs.) *International Conferences about Mining in Urban Areas*. Anais... São Paulo. 51-54 (in Portuguese).

BERTONI, J.; LOMBARDI NETO, F. 1990. *Soil Conservation*. 2. Ed. São Pualo: Ícone (in portuguese).

BITAR, O. Y. 1997. *Evaluation of the recovery of areas degraded for mining in the Region Metropolitan of São Paulo*. Thesis (Mineral Engineering). São Paulo, São Paulo University (in Portuguese).

BROWN, A. & QUINE, T. 1999. *Fluvial processes and environmental change***.** British Geomorphological Research Group Symposia Series. 426 p.

CARVALHO, E. T. & PRANDINI, F. L. 1998. Urban areas. In: OLIVEIRA, A. M. dos S., BRITO, S. N. A. de (ed). *Engineering Geology*. São Paulo: Engineering Geology Brazilian Association (in Portuguese).

CONACHER, A. J. & SALA M. (editors). 1998. *Land degradation in mediterranean environments of the world*: Nature and Entent, Causes and Solutions. Chichester: Wiley. 492 p.

CUNHA, M. A. (coord.). 1991. *Occupation of Hillsides*. São Paulo: Technologics Researches Institute (in Portuguese).

DISPERATI, A. A. 1998. Air photographs of small format for recovery of degraded areas. In: DIAS, L.E. & MELLO, J.W.V.de. *Degraded areas recovery*. Viçosa: UFV, Soil Department; Brazilian Society for Recovery Degrated Areas. 251p (in Portuguese).

EBBETT, E. 2004. *Soil Deterioration on the Continent of Africa*: Possible locations for an information and support centre. Simon Fraser University. URL: http://www.sfu.ca/geog/geog355fall00/ejebbett/index.htm. Consultada em 01/02/2004.

GASPAR, W. J. 2000. *Analysis of the erosive process of the social land division Antenor Garcia.* Proposal for expansion of the quarte. Dissertation (Urban Engineering). São Carlos, São Carlos Federal University (in Portuguese).

GONÇALVES, A. R. L. 1986. *Environmental Geology area of São Carlos*. Thesis (Geosciences). São Paulo, São Paulo University (in Portuguese).

HUDSON, N. 1995. *Soil Conservation*. London England: Redwood Books.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. 2001. Web Site of Statistic and Geography Brazilian Institute.htm. Consultated in 02/11/2001 (in Portuguese).

LAL, R. 1990. *Soil erosion and land degradation*: the global risks. *Advances in Soil Science*, **7**, 129-172.

MORGAN, R.P.C. 1995. *Soil Erosion and Conservation***.** 2nd ed. Longman.

OLIVEIRA, C. H. 1996. *Environmental planning in the City of São Carlos (SP) with emphasis in the public areas and green areas*: diagnosis and proposals. Dissertation (Ecology and Naturals Resoucers). São Carlos, São Carlos Federal University (in Portuguese).

SEIXAS, B.L.S. 1984. *Beddings of the handling and the conservation of the ground***.** Salvador: Center Editorial and Didatic of the Bahia Federal University. 275p (in Portuguese).

WEISSBERG, I. 1989. *Geochemistry aspects of the environmental impact of the mining in the Amazônia***.** Serra of the Carajás, Pará. Dissertation (Geosciences). São Paulo, São Paulo University. 220p (in Portuguese).

ZUQUETTE, L. V., PEJON, O. J., COLLARES, J. Q. dos S. 2004. Land degradation assessment based on environmental geoindicators in the Fortaleza metropolitan region, state of Ceará, Brazil**.** In: *Environmental Geology***, 45**, 408-425.