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URBAN WATERSHED STUDIES IN SOUTHERN BRAZIL

Cristiano Poleto* and Gustavo Henrique Merten

Hydraulic Research Institute, Federal University of Rio Grande do Sul, Brazil

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Abstract: One of the greatest problems observed in Brazilian urban watersheds are concerned to the amount of solid residues, domestic sewerage and sediments that are disposed in the rivers and streams that drain those areas. This project aims to present these problems through a study of case taken in an urban watershed in Porto Alegre city, Southern Brazil. For this study, different procedures were used, such as field surveys, interviews with the inhabitants, satellite images, sediment samples, flow measures and morphology assessment of part of the local fluvial system to check the degree of instability of the channel. In 2005, it was verified that 42.57% of the watershed was impermeable, considering the paved streets, the residential and commercial buildings and stone pavements. As there was no sewer treatment, most of this sewerage was directly disposed into the stream and the TOC has reached 20% (m/m). Moreover, the occupation of riparian areas, a great amount of soil exposed in the watershed, the non-paved streets and a great volume of solid residues were causing the instability in the channel, silting the stream bed. The metals (Zn, Pb and Cr) selected for this study are most frequently found in high concentrations in urban areas. The results suggest the occurrence of a high enrichment of the fluvial sediment by these metals. The concentrations of these elements vary temporally during storms due to the input of impervious area runoff containing high concentration of elements associated to vehicular traffic and other anthropogenic activities. Then, it is possible to conclude that the contamination of the urban watershed is reflected in the results obtained in the fluvial suspended sediments.

Keywords: Urban watershed; socioeconomic conditions; river morphology; fluvial suspended sediments; urban dusts; metals

* Correspondence to: Cristiano Poleto, Tel.: +55 51 8454 1677; Fax: +55 51 3308 7509.
E-mail: cristiano_poleto@hotmail.com

INTRODUCTION

One of the greatest problems verified in Brazilian urban watersheds is regarded to the quantity of solid residues, domestic sewage and sediments, which are thrown in the rivers and streams that drain those areas. Thus, as the rivers pass by urban areas, they receive loads of pollution causing modifications in the water quality, in the fluvial morphology and in the hydrological system.

Pollutants can form complexes with fine sediments and can also contribute to the eutrophication of the rivers. In addition, the increasing amount of sediments causes the silting of the channel, reducing its outflow capacity, leading to floods and channel instability.

Great complex questions related to socioeconomic and cultural conditions of the populations and also aspects concerning the lack of governmental policies for investments in infrastructure and urban basic sanitation result in the enhancement of watershed problems.

Generally, periphery urban areas in developing countries have a limited infrastructure and low-income inhabitants. The impacts in water resources are more severe, mainly because of the absence of sewage treatment systems, trash collection or non-paved streets, which are important sources for the production of sediments in urban watersheds. On the other hand, there is also the socioeconomic and cultural component, which is closely related to the absence of environmental knowledge.

The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce water infiltration into the ground, and accelerate runoff to ditches and streams (USGS, 2003). The sediments are an important part of this process because their presence into the rivers not only cause sedimentation process problems but they mainly cause the contamination of the water due to the presence of pollutants found associated to sediments. Horowitz (1991) clearly shows that as suspended sediment concentrations increase, the percentage of suspended sediment-associated trace elements also increases.

The sediments contaminated by heavy metals have been considered as one of the biggest environmental problems. While many metals are required nutrients, others are toxic to living organisms (Dahl, 2005). In this sense, studies on the quality of sediments have an important focus in environmental assessments, protection and management of aquatic ecosystems.

There are many causes that can increase the production of sediments in urban areas; however, the most important ones are related to little vegetal covering, the lack of urban infrastructure (paved streets, sewer and draining system), the absence of a rigid control on civil labor and the lack of work to store the sediments deriving from the pavements (restrainer boxes).

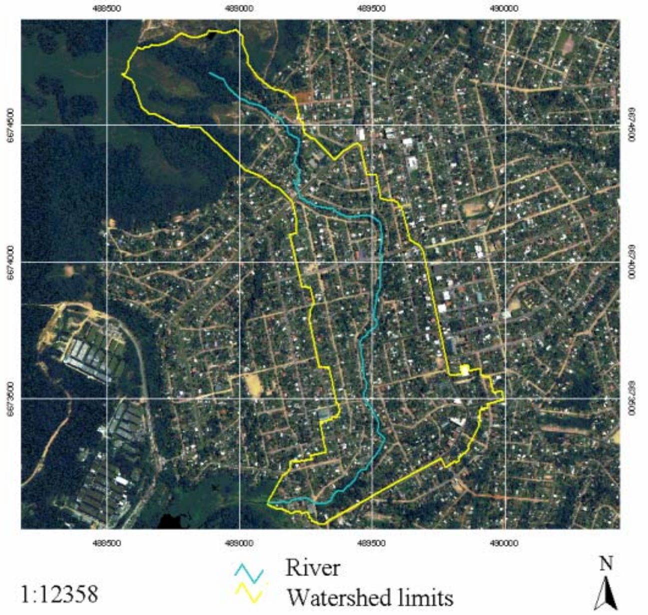

Fig. 1 Watershed limit and its stream.

This work aims to present a study of case, analyzing the impacts of the urbanization on the instability in the course of water, the physical and social characterization of this watershed, the conditioning factors for the degradation of the fluvial system and the concentrations and distribution of three metals in this area.

OBJECT OF INVESTIGATION

The urban watershed is located in Porto Alegre city, capital of the Rio Grande do Sul state, southern Brazil, with an area of approximately 0.83 km^2. The study area and its limits can be observed in **Fig. 1**.

The topography of this area is softly waved, consisting of a first grade watershed, whose geologic formation is composed by granite.

The climate is subtropical with the average annual temperatures ranging from 14–20°C, but during summer and winter the thermometer can reach extremely high or low temperatures, respectively, with cold winters and regularly well-distributed rains, varying between 1,200–2,000 mm/year.

The physical characterization of the watershed was made using field surveys, as it was verified the conditions of the fluvial system that drains the watershed, the existent urban infrastructure (streets, houses, systems of pluvial and wastewater drainage conditions) and the main sources of sediments production in the area.

To measure the use of soil over the last five years, it was used a QuickColor® image from the satellite QuickBird, which is composed by three of the four individually spindle multispectral bands with the panchromatic band, resulting in bands with a spatial resolution of 0.60 m, taken in December 2002 and May 2005.

The socioeconomic survey was based on a questionnaire applied to 659 houses in the watershed under study (although there were a total of 1,733 houses, the sample was only 38.03%). The questions intended to assess socioeconomic, cultural and environmental perception aspects.

To verify the instability of the fluvial stream, bathymetries were taken in one part of its section, next to the watershed outlet, 12.75 m length and 7.20 m width, from October of 2003 to January of 2005.

METHODS

Collection of Suspended Sediment, Urban Dust and Background Samples

The collections of suspended sediment samples started in 2003, still with a training staff and equipment test stage, and finished in the end of 2006. As most of the load of sediments in this area is carried through during the outflows generated by precipitations, the collections of suspended sediment samples were accomplished during rainy days, in the section located in the outlet of the studied area, in two points of the transversal section, at 0.60 m and 1.20 m on the left edge of the stream, with an US DH-81 sampler.

The samples were collected in 20 liter polypropylene gallons, and they were stored for 24 hours to be later centrifugated, facilitating the concentration of the sediments. The centrifuged samples were dried at maximum temperature of 40ºC per approximately seven days. The dry samples were transferred to polypropylene bottles of 50 mL and they were frozen, avoiding contact to metal implements so that the samples could not be contaminated, according to a procedure suggested by Horowitz (1991), Mudroch *et al.* (1997) and Poleto & Gonçalves (2006).

Collections of urban dust samples (47 samples per km²) in main diffuse sources of the urban environment (represented by paved and non-paved streets) had been taken, beyond the area with remaining vegetation, in some points of the bed river and in its margins. This sampling searched for representative areas (composed samples) and it was conducted to cover the entire watershed.

To obtain background values, the collection of samples were accomplished in the soil of the region next to the stream (inside the studied area). The place that presents fragments of the original vegetation has still little human alterations. Some samples were obtained from different points of this area, dividing it in three regions. After that, the samples were separated according to their respective areas of collection, joined and homogenized in order to get three compounding samples that could represent the place.

All the gallons, baskets and glassware involved in the collection procedure and concentration of the sediments for posterior freezing were washed with distilled water and stayed in nitric acid solution of 14% (v/v) for 24 hours and they were later rinsed with deionized water.

Characterization of Suspended Sediments and Background Samples

Mineralogical analyses were made to verify if the samples obtained with background values presented similar mineral characteristics as the fluvial suspended sediment samples and the mineral kinds.

Acid Digestions of Suspended Sediment, Urban Dust and Background Samples

During these analyses, it was studied 25 fluvial suspended sediment samples. In relation to the background samples, it was digested three compounding soil samples (after bolted), and later applied a grain sized factor of correction to the results, enabling the equalization of the concentrations with the ones obtained in the studies of the suspended sediments.

The total concentrations of metals were determined by acid digestion (HCl – HF – HClO4 – HNO3) for total destruction of the minerals aggregated to the sediments (Horowitz *et al.*, 2001; Poleto & Teixeira, 2006).

The analytical reagents and the extracting solutions used for the analyses are Merck®, which have a high degree of pureness. The water used for the dilutions is a Milli-Q type (extra-pure) because simple distillated water could present organic complexes of metallic ions. All the glassware involved in the procedures had been washed with distilled water and stayed in nitric acid solution of 14% (v/v) for 24 hours and later rinsed with deionized water.

Studied Metals

The selected elements are some of the most frequently found in high concentrations in urban area studies. Thus, Zinc (Zn), Lead (Pb) and Chromium (Cr) were determined during total acid digestions.

RESULTS AND DISCUSSION

Physical characteristics of the watershed

In **Table 1** the results concerning the use of the soil's temporal evolution in the watershed are presented.

It was verified significant modifications that have occurred over the last three years, such as the reduction of the area with riparian zones from 5.15% in 2002 to 3.57% in 2005. The reduction of the riparian zone along these three years is due to illegal occupation of this area, which should be under permanent preservation, according to the Brazilian Forest Code (Act 4771, of 1965).

Table 1. The soil uses from 2002 to 2005

Categories	2002		2005	
	Area (km²)	Area (%)	Area (km²)	Area (%)
Impervious areas	0.32	37.93%	0.35	42.57%
Uncovered soils	0.08	9.51%	0.15	18.56%
Unpaved streets	0.05	6.40%	0.05	6.13%
Bush or trailing vegetation	0.15	18.52%	0.10	12.55%
Remaining vegetation	0.11	12.92%	0.09	10.58%
Riparian zone	0.04	5.15%	0.03	3.57%
Grassed areas	0.08	9.58%	0.05	6.04%
Total area	**0.83**	**100%**	**0.83**	**100%**

The field surveys showed that families occupying these areas have a highly prominent poverty condition and were then forced to live in those areas.

The surveys have demonstrated that 15% of the houses in the watershed are located in this section from 10 to 15 meters of the margins of the stream, whose area should be under permanent preservation. This condition presents some implications. Firstly, the risk that these people suffer from living in such places where there are under constant floods. Secondly, the negative impacts on the fluvial environment caused by the withdrawal of the riparian zone and by the direct discharge of domestic effluents and solid residues into the stream.

Along with the withdrawal of the riparian zone and the occupation of the areas next to the channel, an increase in the susceptibility to erosive action of the flowage next to the margins also has occurred. It contributed to the instability of the channel. In the ecological point of view, the withdrawal of the riparian zone also represents a problem as it alters the water temperature with all the implications caused by this effect.

Areas with remaining vegetation represent 10.58%, while the bush or trailing vegetation corresponds to 12.55% of the watershed. The stream has an extension of 1,918 m, and only 69.50% of its total length represents a riparian zone, as it was analyzed with the aid of satellite images.

Other uses of the soil in the watershed have demonstrated that in 2005, 42.57% of the area was impervious (**Figs 2** and **3**), considering paved streets, sidewalks, residential and commercial constructions.

The high percentage of impervious area reflects in modifications of the hydrograph, in which the rain tends to present smaller periods of concentration and higher peaks of outflow. Moreover, in Calhoun *et al.* (2003) studies, it was observed that the urbanization has reduced the baseflows and has increased stormflows.

Environmental perception

Through interviews, it was assessed the population's environmental perception level regarding the importance of the water resources to them. The results have showed that the river is perceived as a drawback, an ugly and polluted yard where trash is thrown.

The valleys are an undervalued and ownerless land, and it is the place the invaders occupy. These ideas are

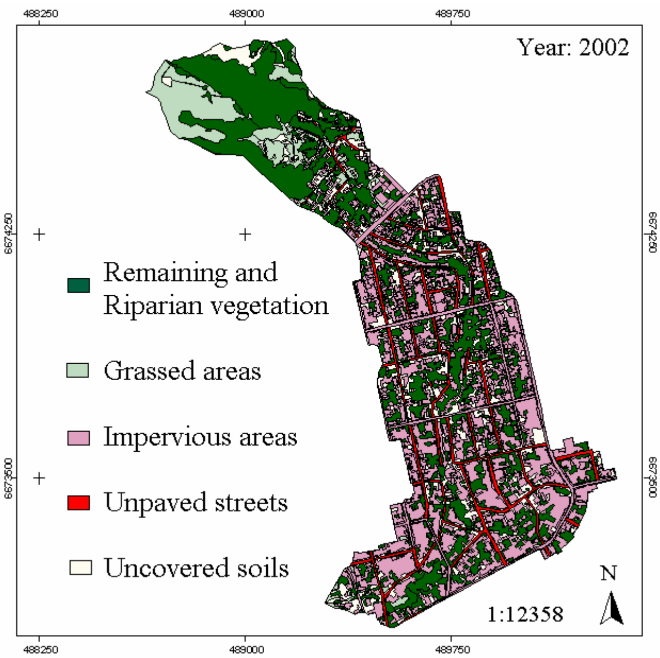

Fig. 2 Urban watershed soil uses in 2002.

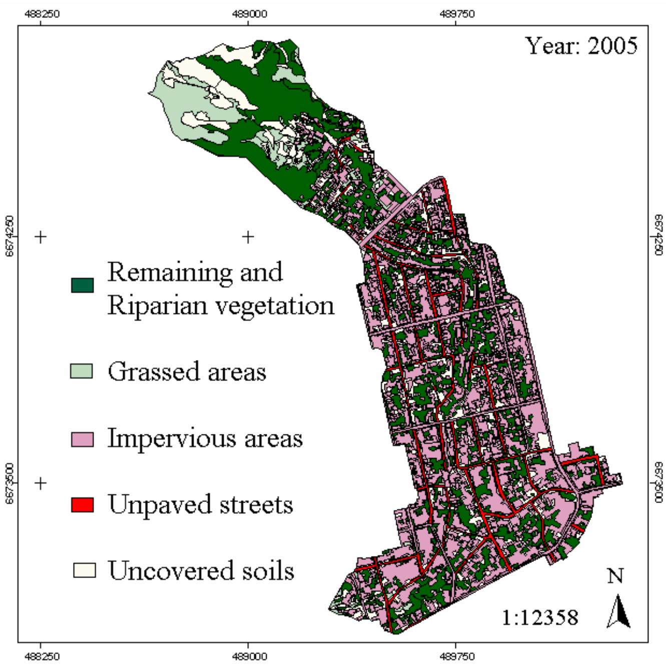

Fig. 3 Urban watershed soil uses in 2005.

expressed through the habit of littering or seeing people throwing trash in the stream.

This situation is mainly due to people who are conditioned to mind only about their own survival for they are extreme poor. Then, it is possible to observe that in poor urban areas, where the population has their survival as their main challenge, the environmental matters present very small importance. Thus, it is expected that little or no attention should be given to water resources.

Socioeconomic Data

The urban watershed has a population of approximately 4,901 inhabitants, which is considered a high occupation rate when compared to other demographic densities of Rio Grande do Sul state. The watershed has 1,733 constructions, among which 90% are residential, 4% commercial and 6% are both, being characterized as a residential area.

According to the World Health Organization (WHO), people who survive with less than US$100.00 per month are considered poor. Thus, more than 22.1% of the inhabitants of the watershed are in this group. Income distribution is shown in **Fig. 4**.

The group surveyed presents well-distributed age patterns in all age groups, as shown in **Fig. 5**. In **Fig. 6,** the schooling of the population represents a very low scholarship level. It shows that 42% of them have not even finished Elementary School. Another aspect also evidenced in this watershed is that the lowest scholarship rates are associated to inhabitants of areas next to the stream. The most inadequate types of housing and basic sanitation were identified in these areas, as well.

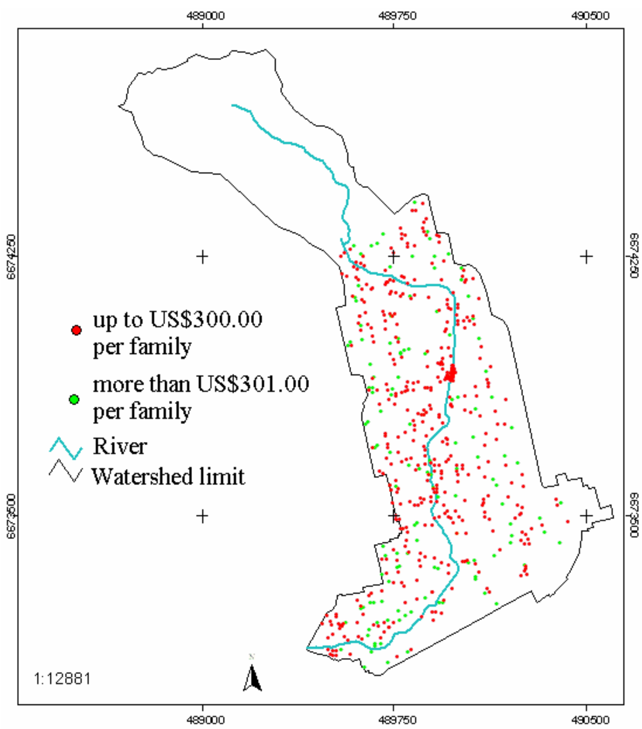

Fig. 4 Local income.

Basic infrastructure

Through surveys in the basic urban infrastructure, it was evidenced that 31% of the streets are paved (asphalt or parallelepipeds) and 69% are unpaved. Unpaved streets were considered a greatest source of available sediments to be carried into the stream, as the constant presence of erosion ridges along the streets was reported, especially where the ground is more sloped.

The potable water supply reaches approximately 100% of the population; however, a domestic sanitary sewer system does not exist. In **Fig. 7** different destinations given to domestic sewer is observed.

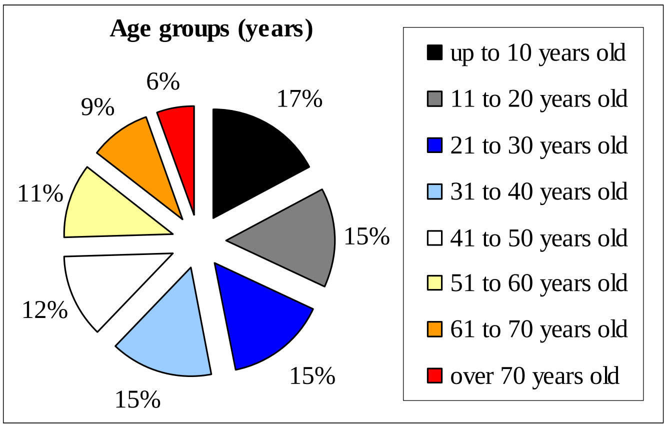

Fig. 5 Age group of the local population.

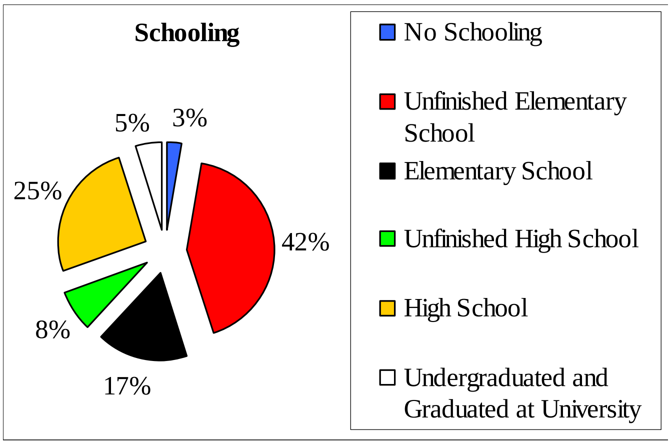

Fig. 6 Scholarship of the local population.

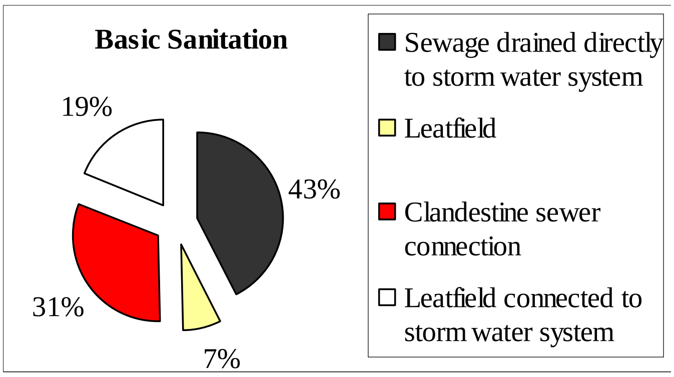

Fig. 7 Basic Sanitation in the Urban Area.

In other words, 31% of these sewers are clandestine, launching the domestic sanitary sewer *in natura* into the stream, 43% of direct bonding with the pluvial water drainage canalization, ending up in the channel, 7% built leatfields, and the 19% left built leatfields and channeled them with the pluvial water drainage canalization in order to avoid maintenance. Consequently, most part of the sewer also runs into the river. This condition consists in one of the biggest source of TOC contaminating the fluvial system.

Impacts caused in the fluvial system

During field surveys, some impacts caused in the fluvial system due to urbanization were reported. One of these impacts is related to water quality, which is endangered by the sewer drainage and trash. They maintain the suspended sediments collected in the river with high concentrations of TOC (**Fig. 8**) and low concentrations of dissolved oxygen (an average of 2.6 mg/L in dry weather).

Through bathymetries made in a section of the channel its instability can be observed. Comparing **Fig. 9** to **Fig. 10**, changes in the channel can be seen, e.g. its narrowing process in some points provoked by the rising of quotas.

The occupation of riparian zones, the great amount of exposed soil in the watershed, the unpaved streets and a great volume of solid residues are causing the instability of the channel. The increase of sediments in the water has been bigger than the outflow capacity to carry them, characterized by the stream bed silting. In many points, the collimation of these banks is occurring and it is promoting their stability inside the stream bed.

According to a field survey it was verified that approximately 3% of the irregularly occupation of the land has fluvial erosion problems (**Fig. 11**). This index can be considered small, but these problems occur in the stream margins, and the material used for leveling it generally has low cohesion and/or it is made of civil construction solid residues. This material is easily carried into the stream because of rain. Although the inhabitants rebuild these embankments, the erosion of these materials will end up in the stream again.

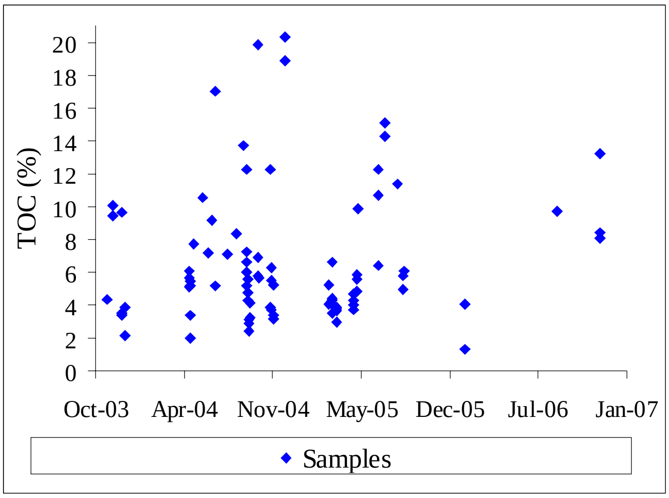

Fig. 8 TOC (%) in suspended sediment samples.

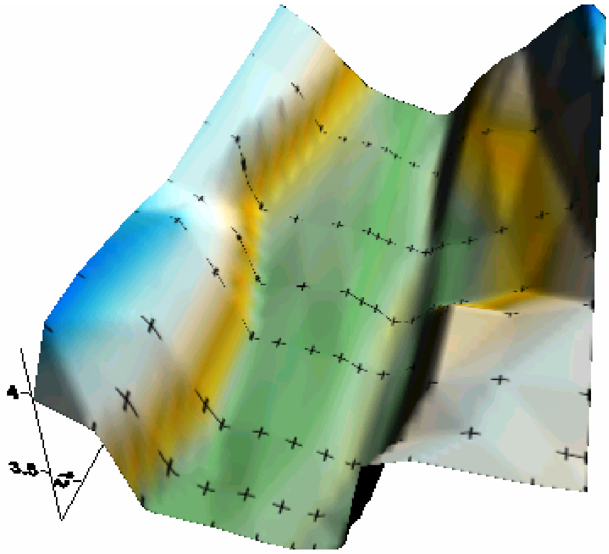

Fig. 9 Bathymetries made in part of the stream next to the watershed outlet: October, 2003.

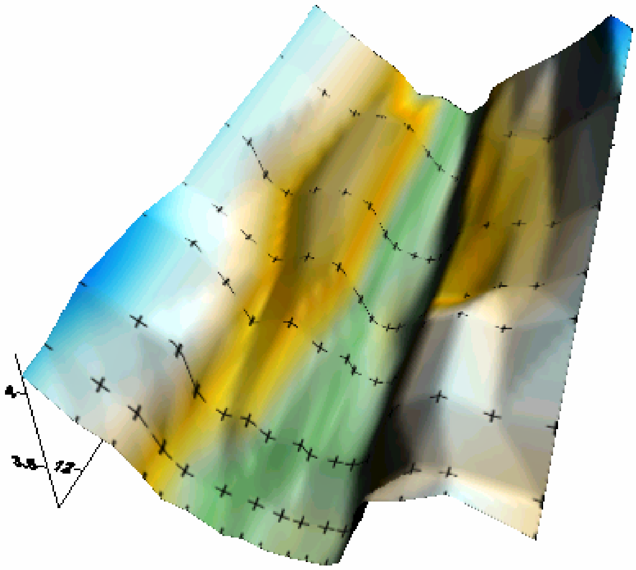

Fig. 10 Bathymetry made in part of the stream next to the watershed outlet: January, 2005.

Fig. 11 Fluvial erosion of the margins.

Fig. 12 Banks formed by solid sediments and residues in the central part of the stream bed.

Fig. 13 Solid residues accumulated in the watershed outlet after a rain event.

The group of sediments from streets, the embankments and also solid residues carried into the stream during the rain increases the instability of the channel, generating mixed banks of sediments and solid residues to the stream bed (**Fig. 12**).

The percentage of solid residues collection in the city reaches 99%. Only in areas very close to the stream this service is not offered, although there are some sites with big collecting boxes. However, it does not avoid a great amount of solid residues from being thrown inside the stream, and it is more visible after a period of rain (**Fig. 13)**.

Assessment of Potential Environmental Risks from Sediments

The annual sediment discharge is approximately eight tons. To assess the metal concentration in the sediment, and thus enable a first analysis on possible ecological impact to the environment, it is commonly used tools as guidelines or background concentrations. Therefore, for tudies on the concentrations of Zn, Pb and Cr in suspended

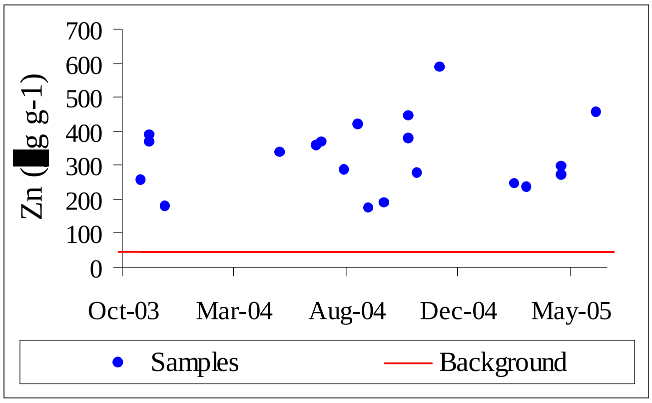

Fig. 14 Frequency of Zn concentrations in the fluvial suspended sediments compared to the background values (red horizontal line).

sediment samples, it was used the background concentrations as the own watershed limit. Zn, Pb and Cr contents of suspended sediments were greater than in the soils of the watershed, as shows Dong *et al.* (1983) studies.

The results of Zn studies have shown that 100% of the suspended sediment samples have their concentrations above the reference value (background), as presented in **Fig. 14**.

The concentrations found in the samples presented an average of 326.16 µg/g and a standard deviation of 108.64. It was greater than what was found in studies accomplished in urbanized areas in Hawaii by De Carlo *et al.* (2004). These results suggest that a high enrichment of the local sediment with Zn is occurring. Guéguen *et al.* (2000) found similar concentrations in Poland and they considered the place was very contaminated.

Concentrations of Pb (**Fig. 15**) in the analyzed suspended sediment samples have an average of 52 µg/g, and all samples have exceeded the background value. In another study in Australia, the researches (Simonovski *et al.*, 2003) found concentrations three times higher than the background value and they considered that the area was contaminated by industrial activities.

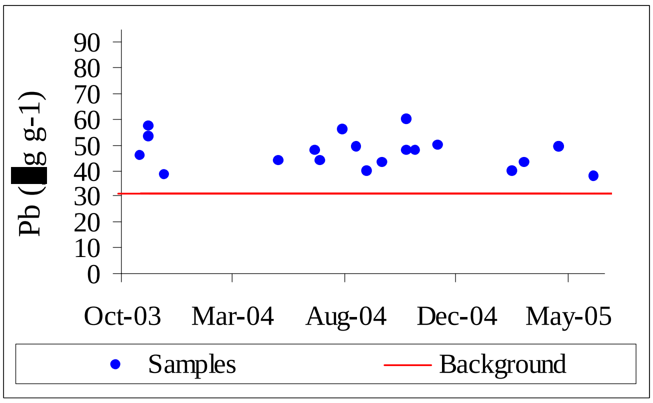

Fig. 15 Frequency of Pb concentrations in the fluvial suspended sediments compared to the background values (red horizontal line).

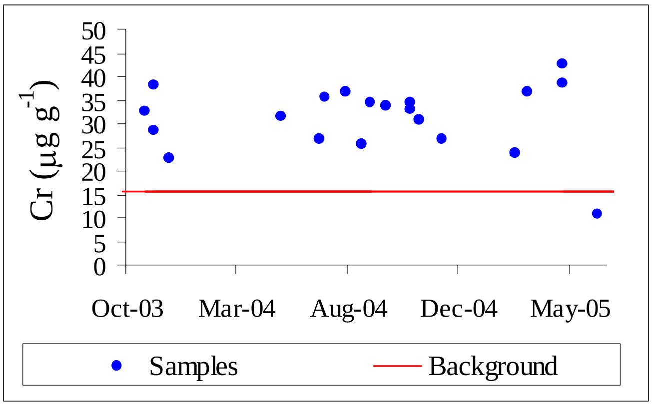

Fig. 16 Frequency of Cr concentrations in the fluvial suspended sediments compared to background values (red horizontal line).

The average of Cr concentration in the samples presented 30.34 μg/g and a standard deviation of 7.51. As observed in **Fig. 16**, most of the samples' concentration has exceeded the local background (its average is the double of the background limit). The higher values can be consequence of the urbanization but they are lower than the values presented by De Carlo *et al.* (2004) in fluvial sediment studies in Hawaii (392 e 469 μg/g).

The urban dust samples were collected and the same three metals were analyzed, and their distribution in the urban watershed can be observed in **Figs 17**, **18** and **19**.

Zn appeared in high concentrations in all the area (almost homogeneous distribution), so it is almost impossible to distinguish the different values presented in **Fig. 17**.

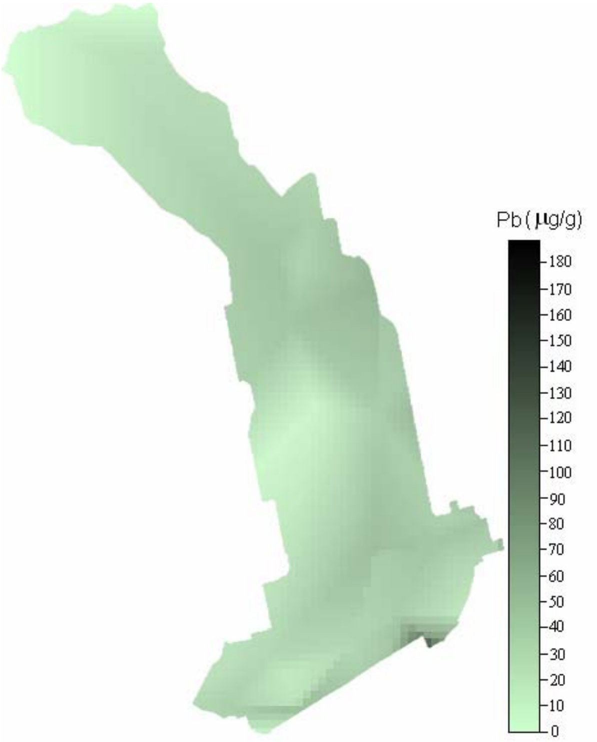

Fig. 18 Distribution of Pb concentrations in the urban watershed.

The peaks of Pb concentrations appeared on paved streets and downstream. **Figure 18** presents the distribution of Pb. It occurs because during the storms the metals associated to dusts in the streets are led to the stream.

Concentrations of Cr (**Fig. 19**) are higher in paved streets and in more urbanized areas, as well as Pb. Many car repairs in the middle area of the watershed can be observed.

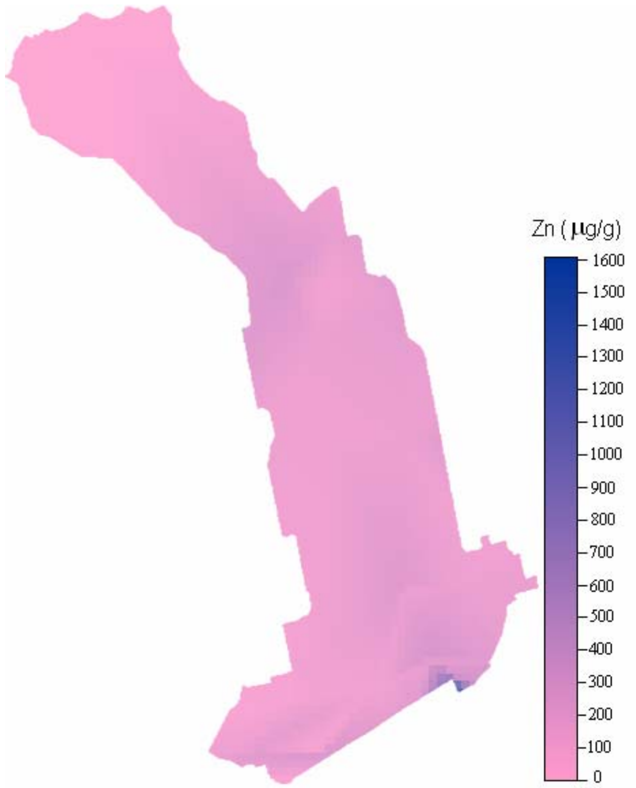

Fig. 17 Distribution of Zn concentrations in the urban watershed.

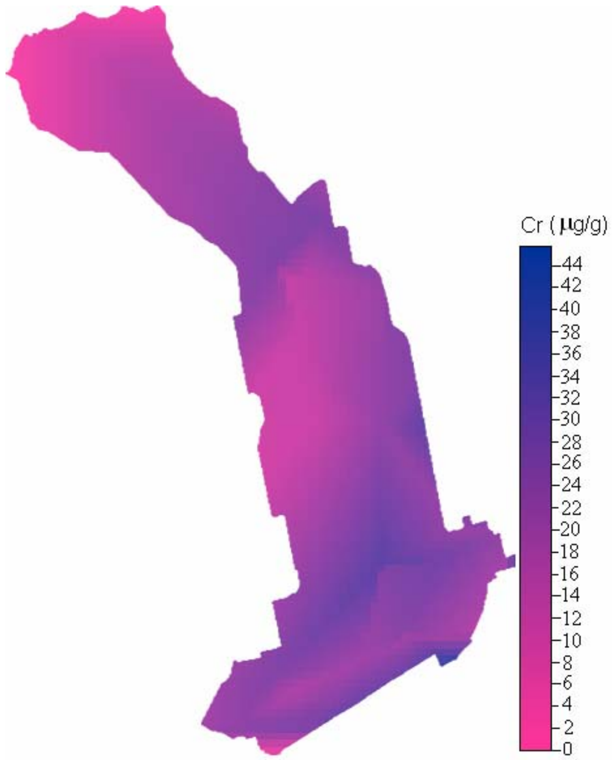

Fig. 19 Distribution of Cr concentrations in the urban watershed.

The diffuse sources of pollutants have strong influence in the results of the fluvial suspended sediment contamination. It can be observed in **Table 2** three main sediment sources in this urban watershed presenting the most concentrations of these metals on paved streets.

Table 2. Average concentrations (µg/g) of Zn, Pb and Cr in urban dusts in the three main sources of sediments

Metals (µg/g)	Paved streets	Unpaved streets	Stream
Zn	377.64	139.95	201.73
Pb	79.66	36.45	49.78
Cr	35.19	20.41	23.52

This result is similar to other studies, as De Miguel *et al.* (1997), Charlesworth *et al.* (2003) and Taylor (2007). Paved streets are shown as the main source of metals and other contaminants.

Conclusions

The instability caused by the urban watershed in the fluvial system is due to a group of factors. One of them is the absence of public policies related to investments in basic infrastructure, such as the pavement of streets, popular set of houses and sewer treatment stations, without mentioning the socioeconomic and cultural situation of the population who live in this densely occupied area, mainly characterized by low income and little or no schooling people.

The socioeconomic characteristics and the existing infrastructure conditions in the studied area show that this watershed is very representative for the existent conditions in most of Brazilian peripheries. Therefore, it is possible to infer that the results obtained through the diagnosis of the damage caused to the fluvial system can be applied in other fields presenting similar characteristics as the present study.

Concentrations of Zn, Pb and Cr in fluvial suspended sediments have presented signals of anthropogenic enrichment two or more times higher than the background values, even this watershed being considered a non-industrial area. Therefore, the results suggest that a high enrichment of local sediment because of these metals is occurring.

The concentrations of these elements vary temporally during storms due to input of streets runoff containing high concentration of elements associated to vehicular traffic and other anthropogenic activities. In general, they have their most concentrations on dusts from paved streets but they are carried out to the channel during the storms. Then, it is possible to say that the contamination of the watershed is reflected in the results obtained in fluvial suspended sediments.

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