The landscape effects on water quality parameters: understanding relationships to improve water resources management planning

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Abstract. Although it is well known that the water quality is dependent on many factors, among them the catchment's landscape characteristics, there are not enough research in tropical climate regions that could support aquatic environment quality management through the catchment's land-use management, most studies being leaded in temperate regions. This research attempted to investigate the relations between the land-use and the stream water in the Juquery River Basin, part of the more important public water supply system in the São Paulo Metropolitan Region. Remote sensing images were analyzed within a GIS environment and used to calculate land-use class area and runoff estimation, in order to relate to water quality parameters sampled in the field. The land-use map is an official data obtained from visual interpretation of IKONOS images. The runoff estimation was obtained from TOPODATA image analyzed in GIS environment. The water quality parameters considered are ammonia, pH, and faecal coliforms sampled at the effluents connection with the Juquery channel. Statistical analysis was performed to examine the water quality parameters. Ammonia discharge was significantly related to regenerating forest, human disperse occupation, forest, bare ground and urban area; pH was related to all this land-uses and also anthropic fields and silviculture; and faecal coliform was influenced by disperse human occupation, forest, bare ground, and urban area. The digital elevation model used showed an important rule in those analyses.

Palavras-chave: land-use, water quality, water resources management, runoff, catchments basin

1 - Introdução

Pollutants originated by human activities from punctual or diffuse sources can reach streams and impair the stream water quality. Punctual sources are generally easily identifiable, but the complex interactions among all physical, chemical and ecological factors make diffuse pollution more difficult to be detected and managed (Sliva & Williams, 2001).

Along the literature research has been made in order to identify the land-uses that are responsible for the greatest diffuse pollutant inputs in streams. Generally, researches try to find a positive or negative correlation between the amount of certain pollutants/nutrients in the stream water and some specific land-use area (or its proportional area in the catchment), but methods vary greatly. Sliva & Williams (2001) compared the water quality correlation with the land-use classes of all the catchment area or only of a 100m buffer zone around the streams; Houlahan & Findlay (2004) estimate the critical distance from where land-uses have a more powerful impact on stream water quality; King *et al* (2005) take into account the land-use effect on the benthonic communities along a stream. Instead of considering all land-use types coverages within a catchment, Zampella *et al* (2007) consider the anthropic and non-anthropic area. Wente(2000) uses a runoff model to create a weighted proximity measure where land-uses next to the streams are considered to have a greater influence on the water quality.

Most of these studies point urban and agricultural/cattle-raising areas as the greatest sources of diffuse pollution in the catchments. Presence and intensity of some relationships depend on numerous ecosystems characteristics and differ among the references cited. Most researches were performed in temperate or cold climate. Very few researches on this point have been leaded in tropical climate regions, including Brazil (Ometo *et al*, 2000; Vetorazzi, 2006). Considering some findings that show great differences in the results even when relatively close different "eco-regions" where studied (Herrlihy *et al* 1998) efforts to understand the phenomena in tropical regions are of great importance.

This research attempts to quantify the influence of the land-use on the water quality of the Juquery River, which is of major importance for the São Paulo Metropolitan Region water supply maintenance, looking for a model to easier future water resources management.

The Juquery River is actually a channel which flows to the Paiva Castro Reservoir, part of a water supply system that is responsible for a half of all the water consumed in São Paulo – the Cantareira System. Water arrives at the channel from subterranean tunnels linked to other reservoirs within the system. Its basin is part of the protected areas created in the 1970s by the São Paulo State Government in order to assure water production to the metropolis[1]. These areas are called Water Sources Protection and Recuperation Areas (APRM in Portuguese). Since then occupation should be controlled, some activities should be avoided or even banned from the area, and deforestation should be restricted. However, from 1996 to 2003, more than two decades after the APRM creation, the Juquery basin has been suffering intense urbanization and deforestation, compromising the water quality of the Cantareira System (Instituto Socioambiental, 2006).

A norm from the Federal Environmental Council determines that streams must be classified taking into account their principal use[2]. Juquery River is classified into Class I, designated for human consumption, aquatic environment protection, recreation, or vegetable cultures irrigation. Several strict limits for water quality parameters are imposed by this norm, but a decade ago Giatti (2000) verified that almost none of the water quality parameters established has been maintained. The sanitary agency charged of distributing the water (SABESP) reports increasing spends on the efforts to archive the legal norms on water supply quality due to contamination of the Juquery channel water body.

Knowing each local land-use class potential to cause environmental degradation or promote conservation/restoration can be crucial in landscape management. Decision support tools, implemented in several GIS software, can be used to handle this kind of data and analyze them with another ecological processes and social aspects (like human communities resources needs and growing rates), so that landscape planning can be done in order to archive specific environmental and social goals. This study meant to analyze some methods to access water quality parameters using spatial analyses to verify if this investigation is possible using InSAR remote sensing data and GIS tools to easier the management and monitoring processes.

2 – Material and Methods

2.1. Study site

Being one of the biggest metropolitan agglomerations in the world, São Paulo faces difficulties on providing more than 20 million inhabitants with potable water. Due to its upland localization, water bodies are not as copious as downstream in the Tietê River Basin, the principal basin in the State (Nucci *et al*. 1976, *apud* Giatti, 2000). Also, this is the most industrialized and populated area in Brazil, and for centuries the water bodies have been used as a discharge way for industrial or residential wastes (Esteves, 1988).

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1 State law number 898 from december 18th 1975 and 1172 from november 17th 1976. The first establishes rules for the land-use in key areas for water sources protection in the São Paulo Metropolitan Region. The second one delimitates the protected areas created. São Paulo State Government.

2 Resolution number 357 from march 17th, 2005. About water bodies classification. Conselho Nacional do Meio Ambiente – CONAMA. Brazilian Environment Ministry.

The Juquery channel basin is located very close to the highly occupied and vertical core of the metropolis, only a few kilometers from São Paulo city (Figure 1). The basin has approximately 336km^2, 76% of which is located in Mairiporã municipality, with almost 60.000 inhabitants (Instituto Socioambiental, 2006).

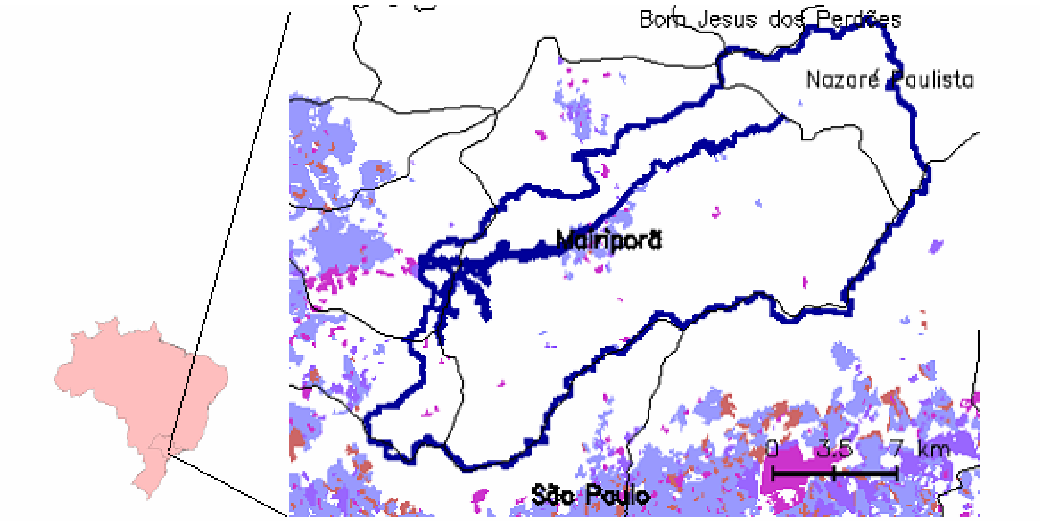

Fig 1 Image showing approximately the Juquery Basin location. The thick line represents the Juquery channel catchment. Colored areas show dense urban occupation. The Juquery channel and the Paiva Castro Reservoir are also represented (thick lines inside the catchment).

2.2. Water Sampling for an exploratory analysis

We sampled water in 7 points along the Juquery channel from May 2009 to April 2010, obtaining a total of 9 samples for each point, which were analyzed for *Faecal* coliform, dissolved oxygen, pH, water conductance, phosphate, nitrate, and ammonia. Sampling points location were chosen always just downstream of the main tributary streams, to determine the relative inputs of each sub-basin in the system, as in Rhodes *et al* (2001).

Faecal coliform analysis were performed as described in American Water Works Association (2005, method 56). PH and conductance measures were done by a handheld YSI (model 63/100 FT). Dissolved oxygen was evaluated trough Winkler's method (Golterman et al, 1978). Ammonia and nitrate concentrations were determined as described in Koroleff (1976) and Mackareth *et al*(1978).

2.3. Spatial Analysis

The first step was to delineate the catchment area for each sample point – the sub-basins of interest. A Digital Elevation Model (DEM) of the area and an image containing the end point of the basin of interest, in our case the sample points, were used as inputs in a module in IDRISI software to obtain this delineation. The DEM used was generated through TOPODATA, a non optical (InSAR) image derived from SRTM (Shuttle Mission Radar Topographic Mission – SRTM[3]) data, modified from 90m pixel to 30m pixel by Valeriano (2008). The sampling points collected by a GPS receptor were used as "seed images": the software's tool delineates, through the altitude information (DEM), the catchment area of

3 SRTM is an international project spearheaded by the American National Geospatial-Intelligence Agency (NGA) and the American National Aeronautics and Space Administration (NASA). SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000, and obtained elevation data on a near-global scale to generate the a complete medium-resolution digital topographic database of Earth. More information: http://www2.jpl.nasa.gov/srtm/

those specific points. The result of that analysis was seven image files comprising the 7 sub-catchments of interest within the Juquery channel Basin.

The land-use map from EMPLASA (Metropolitan Planning Agency), made through interpretation of IKONOS (1m pixel) images (optical remote sensing) from 2003 was imported in the GIS database and used with the sub-basins delineated to calculate the area of each land-use class per basin.

Since we had no water flow data, the RUNOFF module in IDRISI was performed to estimate each sub-basin flow on each sampling day. This operation attempted not to calculate the exact flow in each sampling point, since the permeability and evapotranspiration data, for example, were not available, but to allow us to do comparisons of discharge between sub-basins and sampling days. This module requires as input a DEM and optionally a rainfall and a permeability map. The DEM used was again the TOPODATA derived DEM. Rainfall data were obtained from the São Paulo State's Center for Agro-meteorological Information (CIIAGRO) and is a mean of the recorded rainfall of a three-day period before each sampling day in three meteorological stations next to the basin area (Bom Jesus dos Perdões, Nazaré Paulista and São Paulo stations), since there is no data collected within the basin area. Images were created containing, as all pixel values, this rainfall means. These images were used as precipitation images for each sampling day.

RUNOFF module assumes that each pixel in the image receives the precipitation established in the precipitation image and simulates the water accumulation per pixel through time considering that water flows from the higher pixels to the lower ones, using for that the DEM altitude value of each pixel. Figure 2 resumes the RUNOFF module function.

Each sub-basin runoff was then used to calculate total comparative discharge of all pollutants analyzed.

Figure 2 summarizes all the spatial analysis performed. The results were further used in the regression analysis.

2.4. Statistical Analysis

R[4] was used to perform statistical analysis on the water quality data and its relationships with spatial and other environmental data. A factorial ANOVA without replication as described in Sokal & Rohlf (1995) and Zar (1996) were performed on the water quality data, one factor being the sample point and the other sampling day, against the null hypothesis that there were no differences in samples accounted to any of these factors. We chose this ANOVA delineation since the sampling effort was not so large and sampling days seemed to cause interferences that could hide land-use effects. However, in the cases where not all sampling points had records (lost samples, pollutant concentration bellow the test's detection limit), no data of any sampling point of that parameter in that sampling day could be used.

Linear regression models were tested as fitting models for the relation between land-use classes percentage in the sub-basin catchments and the stream water parameters analyzed (the pollutant's discharge and pH value) downstream. Since sample points were all located in the Juquery River the land-use areas considered were cumulative, eg., land-use area that modeled the regression of the point 2 water quality data was the Sub-basin 1 area *plus* the Sub-basin 2 area.

4 The R Project for Statistical Computing. http://www.r-project.org/

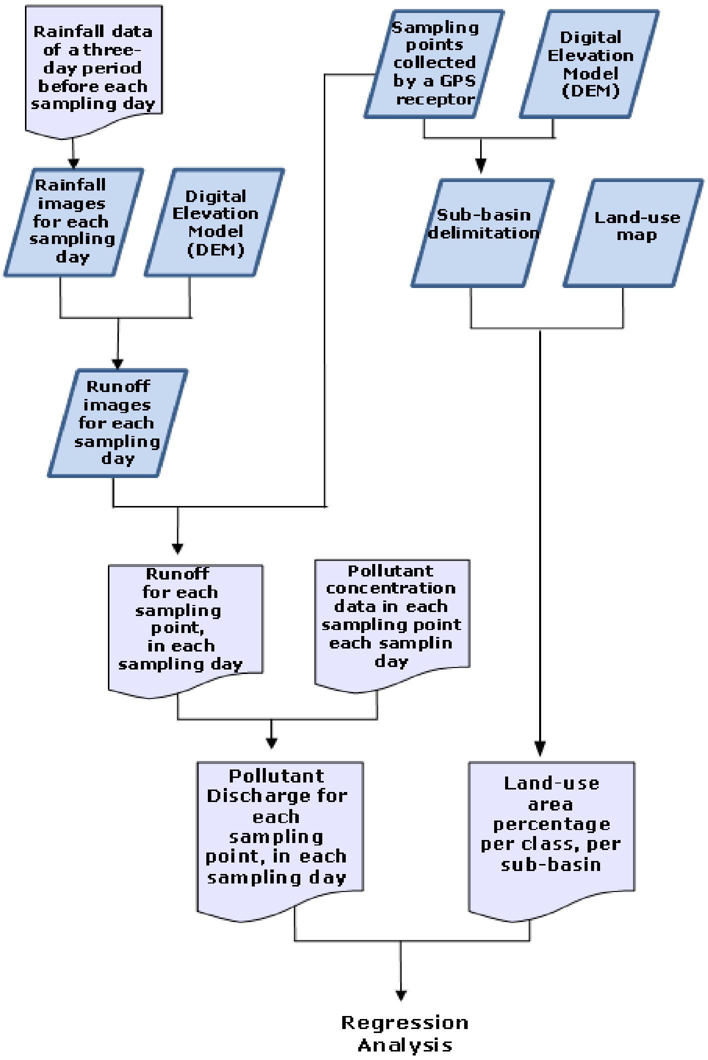

Fig 2 *Scheme showing all spatial analysis that yielded the data further used for the linear regression*

3. Results and discussion

Spatial analysis showed that, although deforestation has been intense in the past few decades (Instituto Socioambiental, 2006), forested land covers more than 54% of the whole basin. Disperse human occupation has 13% of the total area; regenerating forest has 10.2%; anthropic fields, 9%; silviculture 8.4%; urban area 1.8%. All other land-use classes had less than 1% of the basin area. This conserved landscape is probably conditioned by the hilly landscape found in the area where no ordinary crops, like sugar-cane or soy, now extensively planted in São Paulo State, can be cultivated, and no dense residential buildings can be built. Only small farms and livestock were found, occupying little area. Figure 3 shows the sub-basins delineation obtained for each water sampling point. Figure 4 resumes the percentage of the ain land-use within sub-basins.

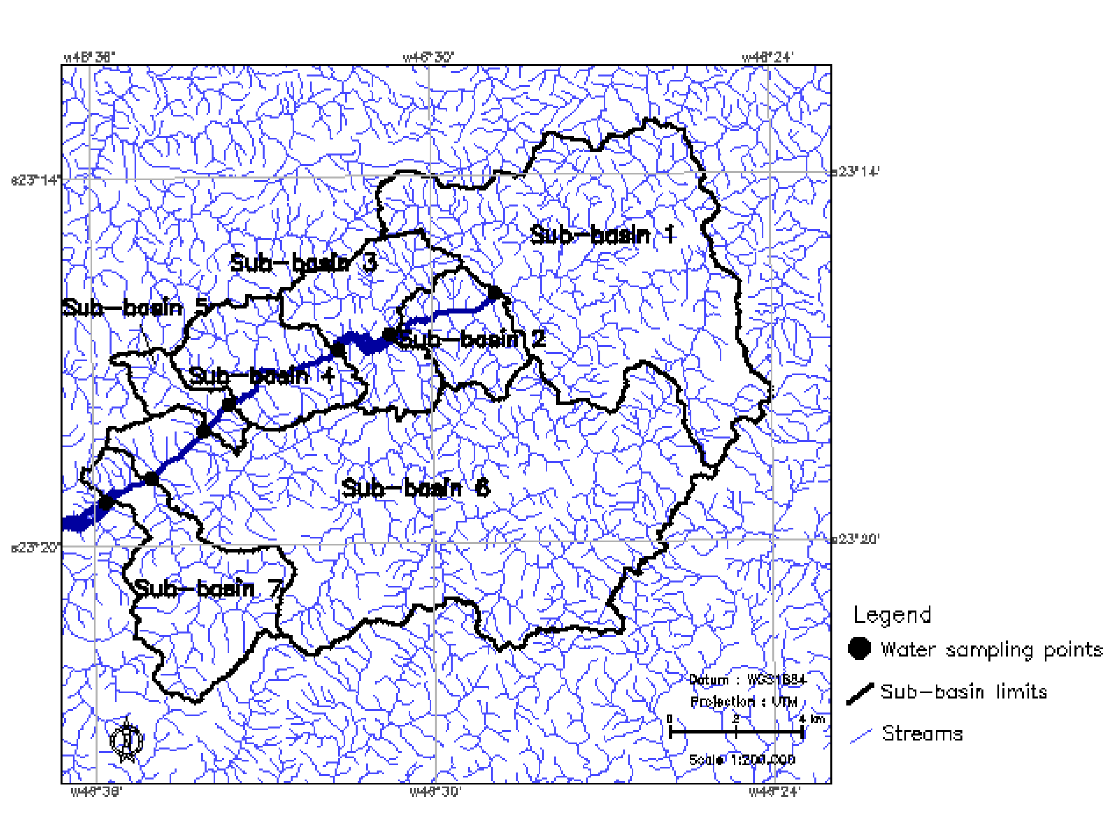

Fig 3 Land-use distribution within sub-basins. Sub-basin limits extracted by WATERSHED module in IDRISI after topological correction and arc smoothing. The water sampling points were used as seed images for the watershed module, so that they become the ending points of each sub-basin. Juquery is the thicker river in the figure, where sampling points are placed

Graphics of the water quality parameters results, by sample point and by day, are shown in figure 4. This graphics were done to allow a visual analysis of the interaction among these two factors, and support the factorial ANOVA results: of all the parameters analyzed, ammonia, pH and faecal coliform were the only that differed significantly among sample days ($p<0.01$ in all cases) and sub-basins ($p<0.01$ for ammonia and pH and $p<0.02$ for faecal coliform). The graphics for these parameters, indeed, show additional effects of both factors over them, allowing right assumptions about the ANOVA results. Dissolved oxygen and conductance differed only among sampling days, and nitrate samples were all statistically equal, so further tests to identify relationships between land-use areas and water quality did not consider these parameters.

All water quality norms for Class I water bodies were reached except for faecal coliform and dissolved oxygen. For faecal coliform the 200 colonies/100ml limit was not respected in 28% of the samples, and the sample point 1 (just at the beginning of the channel) was the only one with no over-limit samples. For dissolved oxygen the minimum of 6ml/L was not reached in 40% of the samples, and all the sampling points have shown under minimum values.

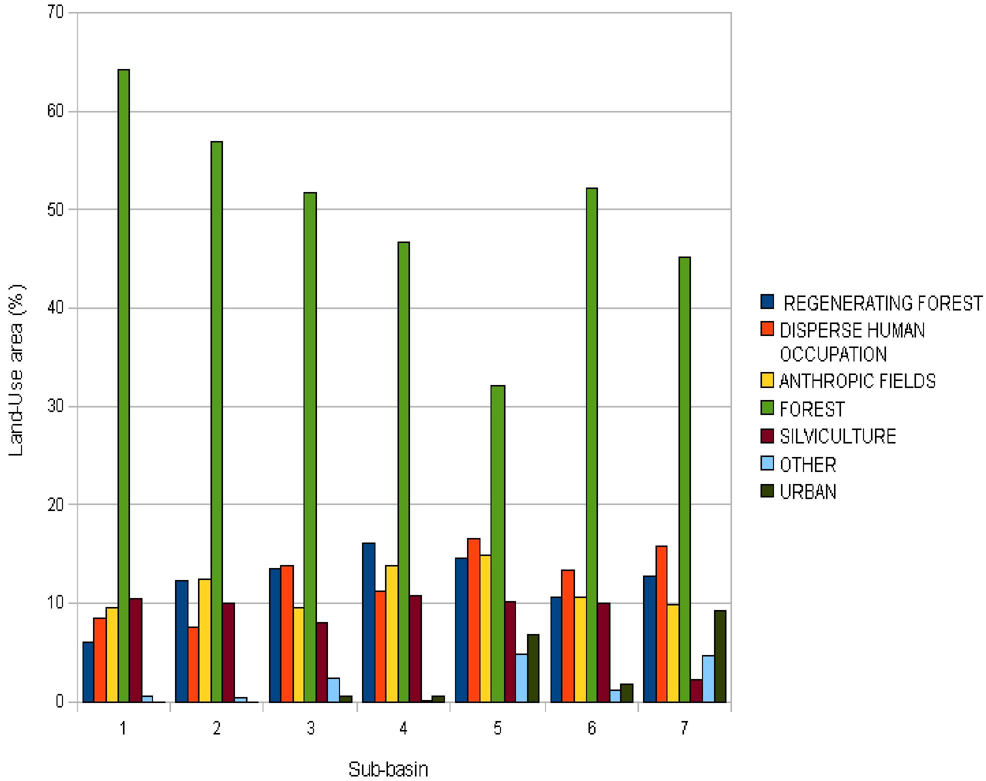

Fig 4 Land-use distribution within sub-basins. All land-uses with less than 1% in area are included in the class "OTHER"

The linear regression tests showed that faecal coliform were significantly and positively related to disperse human occupation, bare ground, and urban area, and was negatively related to the basin's forest area; ammonia was positively related to regenerating forest, disperse human occupation, bare ground and urban areas, whereas negatively related to forest. The pH values were higher when regenerating forest, disperse human occupation, anthropic fields, exposed soil, wet-land, and urban areas were more extensive, and water pH was more acid when forests and artificial mono-species forests were more abundant. Table 1 resumes these statistical relationships found.

Table 1 Linear regression analysis results

Water Parameter	Regenerating Forest	Disperse Human Occupation	Anthropic Fields	Forest	Silviculture	Bare ground	Urban
ammonia[1]	p=0.0499 $\beta=4.634^{03}$ $r^2=0.1185$	p=0.00802 $\beta=6.989^{03}$ $r^2=0.2057$	ns[3]	p=0.0175 $\beta=-2.314^{03}$ $r^2=0.1689$	ns	p=0.00552 $\beta=1.171^{05}$ $r^2=0.223$	p=0.0248 $\beta=1.216^{04}$ $r^2=0.1523$
pH	p=0.000148 $\beta=0.14073$ $r^2=0.3578$	p=0.000538 $\beta=0.14893$ $r^2=0.3081$	p=0.00114 $\beta=0.4615$ $r^2=0.2779$	p=0.000236 $\beta=-0.05723$ $r^2=0.3402$	p=0.00130 $\beta=-0.5127$ $r^2=0.2726$	p=0.00105 $\beta=2.30870$ $r^2=0.2814$	p=0.00271 $\beta=0.26833$ $r^2=0.2416$
Faecal coliform[2]	ns	p=0.0248 $\beta=1.471^{09}$ $r^2=0.1198$	ns	p=0.0469 $\beta=-4.794^{08}$ $r^2=0.09515$	ns	p=0.0154 $\beta=2.562^{10}$ $r^2=0.1381$	p=0.0406 $\beta=2.743^{09}$ $r^2=0.01007$

1 Ammonia discharges calculated in $kg.day^{-1}$ **2** Faecal coliform calculated in $colonies.day^{-1}$ **3** Non-significant regression

The influence of urban area and human disperse occupation on faecal coliform is reasonable since only 20% of the residences are served by the sewage collection municipal service in Mairiporã (Instituto Socioambiental, 2007). We can point out that probably the residences not served by sewage collection do not have either cesspool or concrete cesspit for individual sewage discharge control.

4. Conclusions

The TOPODATA was crucial for sub-basin delimitation and runoff calculation. The land-use map obtained from IKONOS images showed to be satisfactory to this work specific aims, due to its high spatial resolution. The availability of both saved time and efforts to achieve the desired goals.

The water quality parameters sampled along the Juquery channel showed an increased pollutant contribution of each catchments basin from the beginning to the end of the channel, the Paiva Castro reservoir.

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