Delimitation and Analysis of Environmental Protection Areas in the Paraíba do Sul River Basin in Brazil

[a]Jussara de Oliveira Ortiz, [a]Sergio Rosim, [b]Manoel Jimenez Ortiz, [a]Joao Ricardo de Oliveira Freitas, [a]Rodolfo Morais, [c]Fernando Regis Siqueira

[a] INPE, Av. Dos Astronautas, 1758, Jd da Granja, São José dos Campos, SP, Brasil; [b]Geopixel, R. Euclides Miragaia, 433, Edificio Crystal Center, São José dos Campos, SP, Brasil; [c]ICMBIO, Av. Olivio Gomes, 100, Santana, Pq da Cidade, São José dos Campos, SP, Brasil.

ABSTRACT

This work establishes a semi-automatic methodology to define and evaluate the Environmental Protection Areas (EPA), in the Paraíba River Basin, Brazil, taking account the land use and the water quality. The development of this work started from the water capitation point of Guaratingueta city located on the stream that runs through the city. From ASTER GDEM data the drainage network and the basin catchment was automatically extracted. Landsat images for the dates of 1989, 2001 and 2014 were digitally classified and the land uses were mapped, considering the area of permanent protection (APP) for drainage, respecting the limits indicated by Brazilian forest code. Scenes from the RapidEye satellite were used to answer questions of classification, due to good image definition. The study showed that in 1989, the total area classified as APP, 37.59% were anthropized, reaching 37.98% in 2001 and 36.98% in 2014. In a few years it was possible to associate data from water quality, measured directly at the capitation. In 2001 the water quality data showed that the intensive use of fertilizers drained into the Guaratingueta stream by rice paddies was seriously affecting the water supply of the municipality. In 2008 measures for water quality at the capitation point showed that the water resources were still impacted by agricultural activities from the rice fields. So, this work indicates the need for revitalization of the APP inside the EPA Guaratingueta in order to meet the law, protect watersheds and also avoid large investments in water treatment arriving for public consumption.

Keywords: Environmental Protection Area; Area of permanent protection; satellite images**;** drainage network**.**

1. INTRODUCTION

Environmental degradation has affected all forms of life on the planet and its protection is a matter of survival. The several forms of pollution are among the leading causes of negative impacts that our environment is suffering.

According to the Glossary of Ecology Brazil [1] pollution is defined as any adverse change in the environment caused by waste products, residues and by-products from overcrowding and inadequate human activities.

There are some legal instruments available to protect the human environment from pollutants and the creation of Conservation Units (CU) is one of those resources used by the Brazilian Government. According to the National System of Conservation Units (NSCU), Law number 9985, of July 18th, 2000, UC is a territorial space and its environmental resources, including jurisdictional waters, with significant natural features, legally instituted by the Government for the purposes of conservation and limits defined under special administration regime, to which appropriate guarantees protection applied.

Areas protected by NSCU are divided into two groups with specific features: full protection and sustainable use units. In particular, the Environmental Protection Area (EPA) will be addressed in this work, and are inserted into the latter category. In Brazil, there are several EPA, for example, Campos do Jordao, Serra do Mar and Paraíba do Sul River that is the study area.

In terms of international environmental reserves, Canada is a country that holds vast expanses of intact natural areas, and is well known for its magnificent natural scenery and rich wildlife. The Government of Canada plays a central role in conservation of natural resources and biodiversity, protecting habitat of national ecological importance [2].

In Australia, the National Reserve System (NRS) forms the network of natural security in face of threats of climate change. They form a protection against the impacts of climate change, providing refuges for species to survive and adapt, reducing the risk of extinction of native species. Many areas protected by NRS are centers of scientific research,

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providing important data on how native species are dealing with changes in their environment. This information is the basis for future adaptation strategies [3].

In Brazil, when it decrees the creation of an EPA, a key aspect is to fulfill the conservation of forest remnants, ensure the protection of water resources and ensure sustainability of the nature of human action in the region. Under this context, the aim of this study was defined.

Through the Chico Mendes Institute for Biodiversity Conservation-ICMBio, headquarters in São José dos Campos, State of São Paulo, which is the agency responsible for implementing the plan for management of Protected Areas of the Watershed of the River Basin of southern Paraíba (PAW), the Image Processing Division - DPI at National Institute for Space Research - INPE was asked to supervise the work of geoprocessing of this management plan that aims to identify and refine the delineation of the PAW.

This study considers the water capitation point, responsible for water supply of the city, which is inserted in an EPA and it has to be protected so that the water resources that are available for the population are in adequate conditions of consumption.

It is understood that the quality level of the captured water is inversely proportional to the government investment to make the water suitable for consumption. To know the water situation in terms of quality, this paper proposes to evaluate the use and occupation of land inside the area and its influence on the watershed region, which defines EPA.

The methodology of this paper proposes to automate the delineation of the watershed from the water capitation point, classify digital remote sensing images to map land use classes and to define digitally permanent protection areas around the rivers also to identify the land use inside the APPS, as established by the Brazilian forest Code.

2. DESCRIPTION OF THE STUDY AREA

This paper analyzes the EPA Guaratinguetá, located in the basin of the Paraíba do Sul River, São Paulo, Brazil, as shown in Figure 2.1 below. The study area is situated between the geographical coordinates W 45º 26' 27" & S 22º 47' 03" and W 45º 12' 38" & S 22º 41' 00".

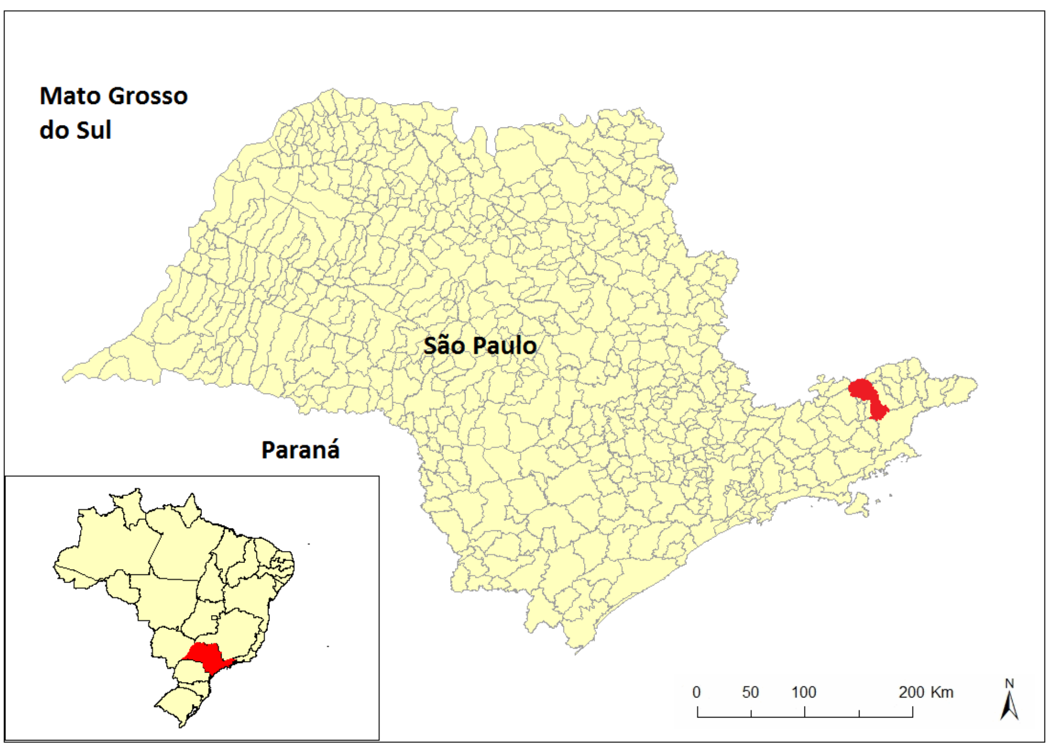


Figure 2.1. – Location of the EPA Guaratingueta

3. MATERIAL AND METHODS

This work is based on the use of GIS techniques and remote sensing, which can highlight the automatic generation of watershed and drainage, automatic generation of the drainage network, supervised automatic classification of satellite images and spatial operations such as the generation of buffers and intersections of information plans.

The water capitation point, which is responsible for the water supply of the city, is presented as starting point for all calculations and processes of this work.

3.1. Material

Regarding to the supervised classification process in this paper LandSat 5, LandSat 8 satellite images were used to identify and analyze what are the elements in terms of land use inside the EPA, their amount and location. The image of RapidEye Satellite was used as support in the multitemporal classification process due to its higher spatial resolution.

Images from the Landsat 5, Landsat 8 and RapidEye satellites, for the years 1989, 2001, 2014 and 2011 respectively were used. Each satellite has the following spectral characteristics:

- ✓ Landsat 5: In Table 3.1 the following spectral characteristics of the imaging instrument TM.

Table 3.1. Spectral characteristics of the satellite LandSat 5.

Landsat-5	Bands	Wavelength
	Resolution	
	(micrometers)	(meters)
Band 1 – Blue	0.45 – 0.52	30
Band 2 – Green	0.52 – 0.60	30
Band 3 – Red	0.63 – 0.69	30
Band 4 – Near Infrared (NIR)	0.76 – 0.90	30
Band 5 – SWIR 1	1.55 – 1.75	30
Band 7 – SWIR 2	2.08 – 2.35	30

- ✓ Landsat 8: Below are the spectral characteristics of the imaging instrument OLI

Table 3.2 Spectral characteristics of the satellite LandSat 8.

Landsat-8	Bands	Wavelength
	Resolution	
	(micrometers)	(meters)
Band 1 – Coastal aerosol	0.43 – 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 – Near Infrared (NIR)	0.85 – 0.88	30
Band 6 – SWIR 1	1.57 – 1.65	30
Band 7 – SWIR 2	2.11 – 2.29	30
Band 8 – Panchromatic	0.50 – 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30

✓ RapidEye: below, the spectral characteristics of the imager instrument on this satellite

Table 3.3. Spectral characteristics of the satellite RapidEye.

RapidEye	Bands	Wavelength
	Resolution	
	(micrometers)	(meters)
Band 1 – Blue	0.40 – 0.51	6.5 / 5.0
Band 2 – Green	0.52 – 0.59	6.5 / 5.0
Band 3 – Red	0.63 – 0.685	6.5 / 5.0
Band 5 – Red-Edge	0.90 – 0.73	6.5 / 5.0
Band 4 – Near Infrared (NIR)	0.76 – 0.85	6.5 / 5.0

Those images have been gathered from the site from Brazilian Ministry of Environment [4] in partnership with INPE.

For the process of generating the boundaries of watershed and drainage network was used as the data source the Global Digital Elevation Map (GDEM) from satellite ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) with 30 meter spatial resolution was used to extract the altimetry information. The GDEM is available for download at no charge from NASA (American Space Agency).

In addition to satellite images, water capitation point was located and made available by the Chico Mendes Institute for Biodiversity, of the Brazilian Ministry of the environment [5].

Enabling the use of these data, the use of some of the systems and libraries, developed at DPI/ INPE, was required:

✓ TerraLib [6] is an open-source GIS software library. TerraLib supports coding of geographical applications using spatial databases, and stores data in different DBMS including MySQL, PostgreSQL and other databases. The TerraLib is available from the Internet as open source, allowing a collaborative environment and its use for the development of multiple GIS tools. Its main aim is to enable the development of a new generation of GIS applications, based on the technological advances on spatial databases.

✓ The TerraView [7] is an application built on the library geoprocessing TerraLib, having as main objectives:

- Introduce to the community an easy geographic data viewer with query capabilities to analyze these data.
- Demonstrate the use of TerraLib.

✓ The TerraView handles vector (points, lines and polygons) and raster (grids and images) data, both stored in DBMS relational or geo-relational market, including ACCESS, PostgreSQL, MySQL, Oracle, SQLServer and Firebird.

✓ TerraHidro is a distributed hydrological system created to develop water resource applications. It uses regular grid Digital Elevation Model (DEM) as the surface and relief structure for drainage extraction. TerraHidro is a plugin of the geographic visualizer TerraView that loads and stores data in the geographical library, TerraLib. This approach has allowed TerraHidro project team of designers and programmers keep focused on the development of system functionality of TerraHidro. TerraView main goal is to make available to the GIS Community an easy geographic data viewer with resources that include database queries and data analysis, exemplifying the use of the TerraLib library [8]. Figure 3.1., shows the relationship between Terralib, Terraview and TerraHidro.

✓ The SPRING [9] is a Geographic Information System (GIS) and it is a step by step of data georeferencing. It supports raster and vector geometries format and allows integration of data from different sources such as remote sensing, another GIS, through functions of image processing, spatial analysis, numerical modeling of terrain and query the database spatial data.

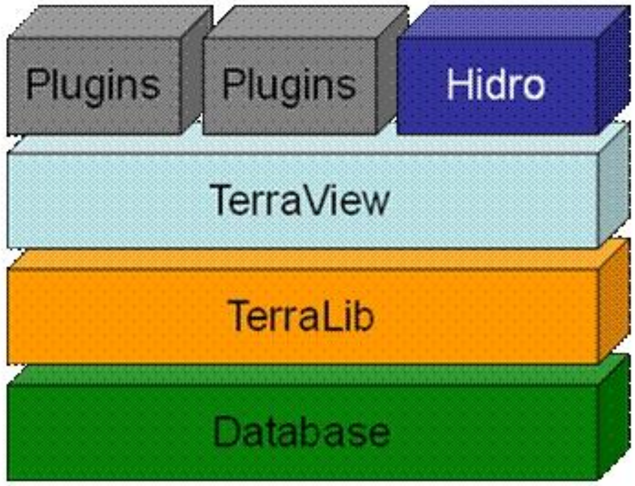


Figure 3.1. - Relationship between Terralib, Terraview and TerraHidro

3.2. Methodology

The methodology employs several types of input data: satellite images from Landsat 5, Landsat 8 and RapidEye; the grid of altimetry ASTER GDEM, topographic maps, scale 1:50.000, and the water capitation point that was located in the field and water samples to identify the water quality. With these data, the methodology can be structured in 4 stages: the first responsible for generating the delimitation of the contribution area, that is the watershed and the creation of the drainage network; the second is responsible for the delineation of the drainage and spring rivers APP; the third is responsible for the land use classification in different dates, from the satellites images; and the fourth for crossing APP with land use classification, producing the tables with the results to be analyzed.

Phase 1

The TerraHidro [8] extracts drainage networks from surface and elevation data model representation and delimits hydrographic basin based on these drainages. These two elements, drainage and basin, are basic elements present in most water resource applications. The Figure 3.2 presents the steps used by TerraHidro to execute these tasks and after each task is described.

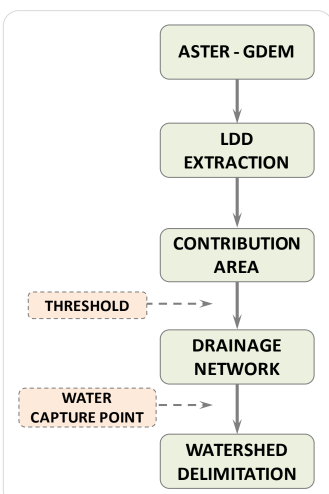


Figure 3.2. TerraHidro tasks sequence to define drainage networks and watersheds.

First task is the definition of local flow, called of Local Drain Directions (LDD) [10]. For each grid cell of DEM the LDD is defined considering the steepest downstream regarding the 8 grid cell neighbors. At the end of task, a new grid is created with the same number of columns and rows of DEM and same resolution. Each grid cell has a code indicating the water flow from this cell.

The next task is the creation of the grid called contribution. The user wants to work only with representative drainages regarding his application, not with drainages of all LDD grid. Each cell of the grid of contribution areas receives a value that is the amount of the area of all cells that participate of a path arriving in the this cell. Figure 3.3 presents this concept.

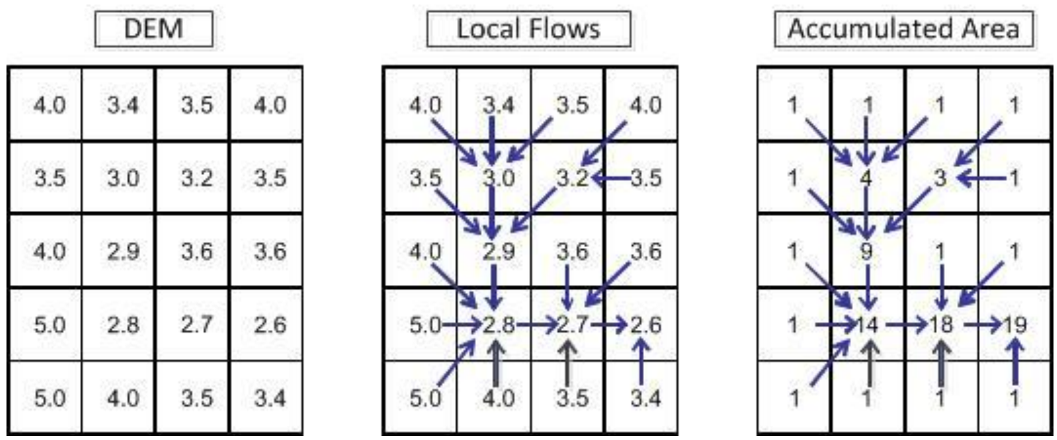


Figure 3.3. Contribution area processes.

At this point the user can define the drainage network more adequated at your proposal. Using a thresold value. The value of each cell of the contribution area grid is compared with the thresold value. If the value of contribution area grid is equal or gathers than the threshold value the cell is selected with a drianage network cell. At the end of processes a new grid is created, defining the draiange network.

Other task of the TerraHidro is the watershed delimitation for drainage segments or for isolated points. A segment is a drainage path between water springs and junctions, between junctions, or between junctions and mouth of the drainage. A watershed point is a location defined by the user on a location containing drainage. The drainages and the watersheds can be converted to vectorial representation. In this work the watershed was delimitated form isolated point that is the pickup point of water of a city.

In the context of this work, one pickup point was inserted into TerraHidro, and it was associated with the position of the nearest drain. From it, using the grid LDD, the TerraHidro delimited area of contribution to the capitation point, defining thus the EPA.

Then four drainage networks were defined, from the choice of four different thresholds; these are empirical thresholds to define the drainage density values, according to the grid values of contribution area. These values can be changed so that drainages are generated with different densities, allowing the user to choose the one that suits best to your needs. For this study the objective was to use these four densities to evaluate the influence of these on the final result, and the following thresholds were used: 100, 300, 600 and 1.000.

Drainages that were generated through TerraHidro for the chosen four thresholds were superimposed and compared with the topographic map scale 1: 50000, in order to identify which of the drainage generated showed the best agreement with the map.

Phase 2

The water capitation point at APA Guaratingueta, which supplies the city, is in Guaratingueta.river. This, in turn, according to the Brazilian Forest Code in force (Law Number. 12651, May 25th, 2012), falls into the category of rivers with less than 10 meters wide, and therefore has by the law to preserve a minimum range of 30 meters of riparian vegetation from the average riverbed in the areas of environmental preservation.

The APA is Sustainable Use Unit, aimed at reconciling nature conservation with sustainable use of natural resources; the activities involving the collection and use of natural resources are permitted provided that practiced to ensure the sustainability of renewable resources and environmental ecological processes.

At Spring system, through the functionality of Buffer, the APPs of drainage were delimited, making the whole area of contribution from the water capitation point.

Phase 3

At this stage three semiautomatic classification processes were performed using the method Battacharya. Each classification has used a particular year and a sensor that are shown in Table 3.4.

Table 3.4. - Table showing dates, satellites and resolutions used in the work.

Data da Imagem	Satelite	Sensor	Resolução Espacial
24/09/1989	LandSat 5	TM	30 m
09/09/2001	LandSat 5	TM	30 m
14/04/2014	LandSat 8	OLI	30/15 m

The following themes were mapped in the process of digital classification: Water, High Growing Natural Vegetation, Low Growing Natural Vegetation, Grassland, Agriculture, Bare Soil and Urban Area.

The entire classification process was aided by RapidEye satellite images (Figure 3.4.), due to its spatial resolution of 5 meters which allowed a better detail of the study area.

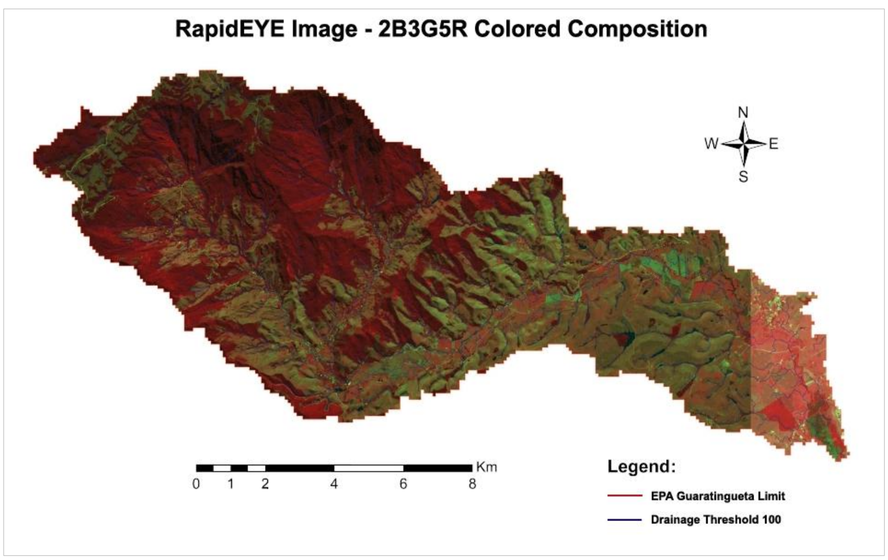


Figure 3.4. RapidEYE Image, colored composition 2B3G5R.

The classification process was performed in Spring GIS using a digital method of supervised classification, which means that there is need for user interaction. The adopted algorithm works in targeted areas. Examining a large number of unclassified pixels and divides them into a number of classes based on natural groupings present in the segmented image.

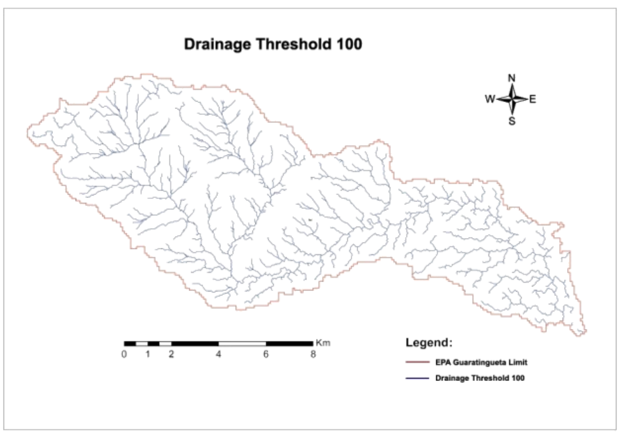
The classification process can be briefly described as follows: first, a threshold percentage of acceptance is chosen. This threshold is used to calculate distance of Battacharya [11] a region created by the segmentation process that can be separated from the center of a class and still be considered to belong to this class. The measurement of distance is used in this Battacharya to measure statistical classifier separability between a pair of spectral classes, namely measures the average distance between the probability distributions of spectral classes. Interactively, the classifier removes all regions with a distance of Battacharya above the threshold of acceptance.

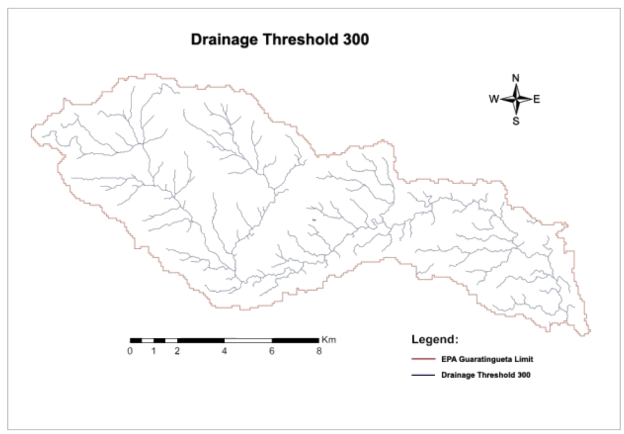
Phase 4

The plan resulting from step 2 was crossed with the land use maps generated from step 3; the results are presented for each land use class inside the APP. At the end of this process, the analyzes were carried out with the results as can be seen in the next section.

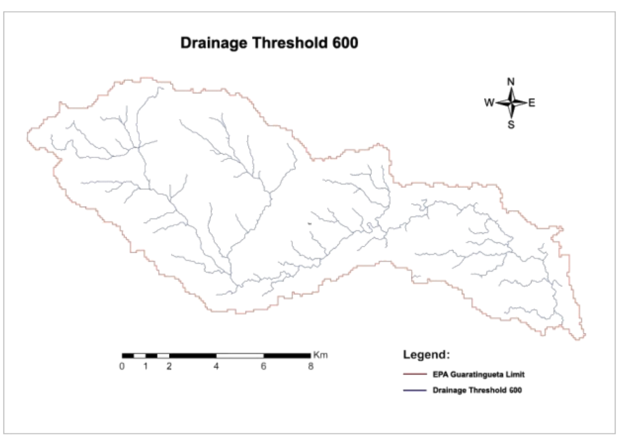
4. RESULTS AND ANALYSIS

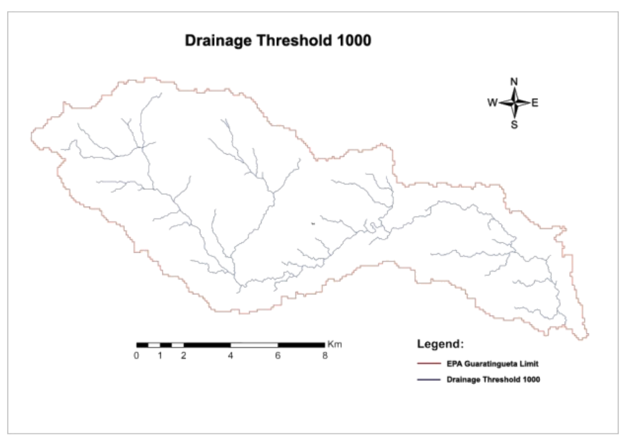
Initially, the results from steps 1, 2 and 3 were presented and after from step 4. As described in step 1, the drainage for the four tested thresholds, 1000, 600, 300 and 100 were generated. The contribution area of the Guaratingueta River was delimeted as it can be seen in Figures 4.1. (a, b, c, and d).





(a) (b)





(c) (d)

Figure 4.1 Drainage Network and limit of the APA for the four selected thresholds.

Observing figure 4.1, there is a difference in drainage density in each of the thresholds used. The threshold 100 is the one closest to the present drainage network in the topographic map, scale 1: 50000 and this one has been adopted as standard for making adjustments in drainage.

After completion of the adjustments, the procedure of generating the buffer on the drainage was performed by generating the APPS of drainage and springs, following the legal guidelines of the Brazilian Forest Code, presented in section 3.2.

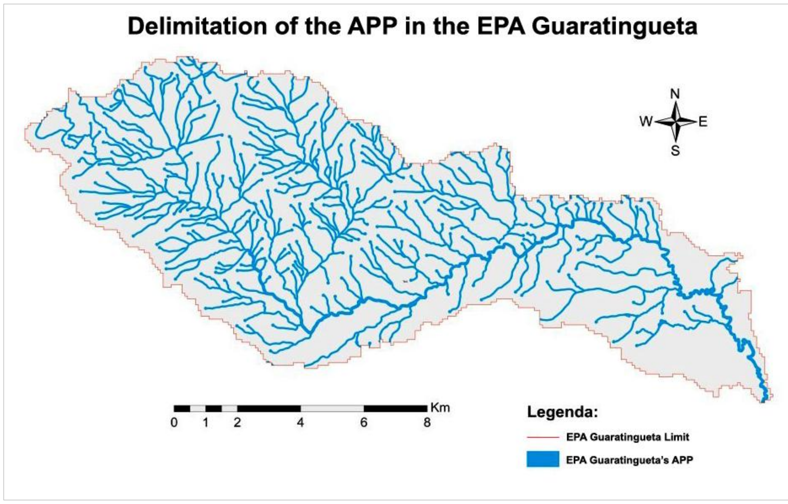
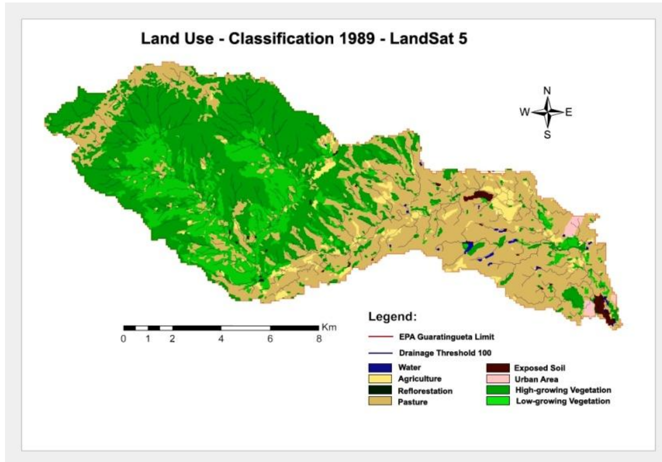


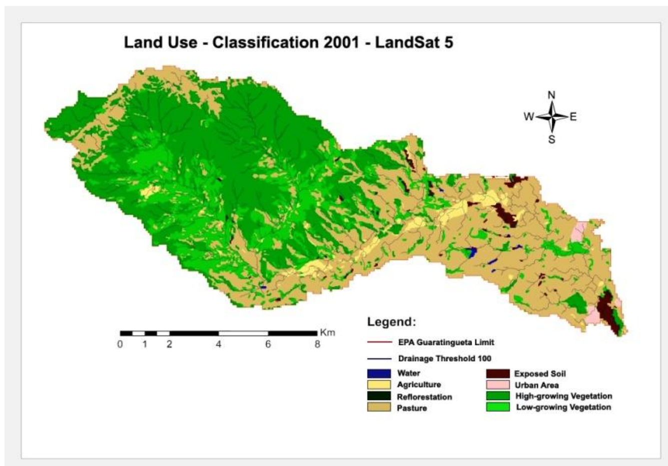
Figure 4.2. Buffer with the APPS of drainage and springs.

Observing figure 4.2, from 13008.24 km^2 of the total APA, 2293.47 Km^2 were occupied by APPS of drainage and springs, which represents 17.63% of the total area.

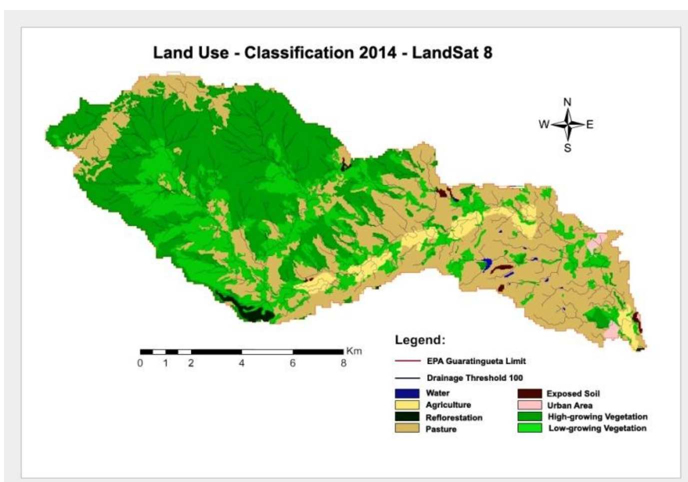
The images with the classes that have been defined in item 3.2, step 3 were cut using the limit of APA that was generated in step 1. As a result of this cutting, it was possible to generate the table 4.1, with the classes and their quantifications. It was possible to perform the step 4 and to run the cross-tabulation function with the classified image and the APP, gathering the table 4.2. The classified images can be viewed in Figure 4.3 (a), (b) and (c).



(a)



(b)



(c)

Figure 4.3. Results of the semiautomatic classification of the selected dates for this work.

Visually comparing the images classified at the three years analyzed, it can be observed that the areas classified as agriculture and bare soil occupy the same geographic space in the years analyzed, therefore it is possible to use these two classes together at the time of quantitative analysis (Tables 4.1 and 4.2); another detail that should be noted is the presence of the reforestation class only in the year 2014; this fact was confirmed by the use of RapidEye image, at the same year, where reforestation is present. The areas of low-growing vegetation also showed variations in the analyzed years; this is due mainly to climatic variation each year, leaving the low growing vegetation more or less vigorous sized on each date analyzed. For the other classes there was nothing that stood out in the process of visual analysis of classifications.

Table 4.1. Area, in hectares, of each mapped class.

Classes of the EPA		1989		2001		2014	
NA	Water	33.66	0.26%	16.56	0.13%	18.54	0.14%
ANT	Agriculture	462.15	3.55%	331.11	2.55%	477.45	3.67%
ANT	Reforestation	0.00	0.00%	0.00	0.00%	77.76	0.60%
ANT	Pasture	5424.03	41.70%	5407.02	41.57%	5091.03	39.14%
ANT	Exposed Soil	92.43	0.71%	205.92	1.58%	52.83	0.41%
ANT	Urban Area	76.68	0.59%	79.11	0.61%	71.82	0.55%
Sub Total ANT		**6055.29**	**46.55%**	**6023.16**	**46.30%**	**5770.89**	**44.36%**
NANT	High-growing Vegetation	4879.89	37.51%	4635.09	35.63%	4528.17	34.81%
NANT	Low-growing Vegetation	2039.40	15.68%	2333.43	17.94%	2690.64	20.68%
Sub Total NANT		**6919.29**	**53.19%**	**6968.52**	**53.57%**	**7218.81**	**55.49%**
Total		**13008.24**	**100%**	**13008.24**	**100%**	**13008.24**	**100%**

Quantitative analysis shows that the classified area presents disturbed, with 46.55% (1989), 46.30% (2001) and 44.36% (2014) of anthropized area, and the area has not disturbed 53.19 % (1989), 53.57% (2001) and 55.49% (2014).

Analyzing the numerical results from Table 4.1 we note that there are a lot of anthropized areas. When those areas are confronted with their geographic location, it is possible to realize that they are located in the vicinity of the stream Guaratinguetá. This fact may indicate that the water collected at the capitation point has been very exposed to the pollution effects by pesticides and carrying of chemical fertilizers.

To better analyze the use and occupation of land surrounding of the springs, in phase 4 was conducted an intersection of the three planes of information (3 dates) from the image classification with the buffer of APP. The results are shown in Table 4.2, comparative for the years analyzed.

Table 4.2. Comparison between the area of each class mapped in APP of drainage and springs.

Classes of the APP		1989		2001		2014	
NA	Water	8.91	0.39%	5.13	0.22%	3.60	0.16%
ANT	Agriculture	67.77	2.95%	59.40	2.59%	73.62	3.21%
ANT	Reforestation	0.00	0.00%	0.00	0.00%	4.41	0.19%
ANT	Pasture	784.89	34.22%	780.12	34.01%	755.91	32.96%
ANT	Exposed Soil	5.49	0.24%	26.91	1.17%	6.39	0.28%
ANT	Urban Area	3.96	0.17%	4.68	0.20%	5.58	0.24%
Sub Total ANT		**862.11**	**37.59%**	**871.11**	**37.98%**	**845.91**	**36.88%**
NANT	High-growing Vegetation	930.69	40.58%	895.50	39.05%	875.97	38.19%
NANT	Low-growing Vegetation	491.76	21.44%	521.73	22.75%	567.99	24.77%
Sub Total NANT		**1422.45**	**62.02%**	**1417.23**	**61.79%**	**1443.96**	**62.96%**
Total		**2293.47**	**100%**	**2293.47**	**100%**	**2293.47**	**100%**

As previously placed 13008.24 km^2 of the APA, 2293.47 Km^2 were occupied by APPS. This area was divided into the use and occupation of land classes, representing 17.63% of the total area. Table 4.2 also shows this result objectively.

Quantitative analysis of APP in Table 4.2 shows that the area classified as anthropized, with 37.59% (1989), area 37.98% (2001) and 36.88% (2014), keeps constant. The same applies to the non anthropized areas, with 62.02% (1989), 61.79% (2001) and 62.96% (2014).

When comparing the area of high growing vegetation in the APP it is seen that there were decreases. It is also possible to observe a strong incidence of pasture 34.22% (1989), 34.01% (2001) and 32.96% (2014). In addition if we consider that the vegetation of low growing is very susceptible to human disturbance, such as pasture, this type of vegetation should be monitored more closely, on this account it contributes with large percentages in the APPS, 21.44% (1989), 22 75% (2001) and 24.77% (2014).

These results indicate that the dynamics of the landscape surrounding the river and the vicinity of the water capitation point increase the possibility of water pollution that supplies the city. Improper land use inside the APPs commits the Guaratinguetá sub-basin APA, mainly in relation to agricultural practices, especially rice cultivation, which is known historically, occurs near the water capitation point during the study period.

The study showed that in 1989 the total area classified as APP, 37.59% were anthropized, rising to 37.98% in 2001 and 36.98% in 2014. Although there was a small decrease in this area in 2014, the fact indicates a high percentage of human anthropization in areas that should be preserved natural vegetation. For some years it was possible to do data association of water quality, measured directly at the point of capture, by specialized agencies.

With the report of the National Water Agency [12] was able to associate data measured of water quality at the capitation point, in 2001, which found that the intensive use of fertilizers drained in the Guaratinguetá river by rice paddies was seriously hurting water supply of the City. In 2008, the Department of Water and Sewage [13] concludes after measures for water quality at the capitation point that the water resources of the river were still affected by agricultural activities by rice paddies that drain pesticides on site.

The study indicates that using the numerical results together with the positional observation of classes inside the APA, and more specifically into the APPs, there is need for revitalization of APPs inside the Guaratinguetá APA, in order to meet the law, protect watersheds and also avoid large investments in water treatment arriving for public consumption.

5. CONCLUSIONS

The results show the ability of TerraHidro system automatically defines a watershed, limiting the area of environmental protection from a given point on the drainage.

The results also show that the minimum range imposed by Brazilian law for protection of forest in the area surrounding the Guaratinguetá rivier is not being respected into the Guaratinguetá APA, suggesting increased enforcement for preservation of water sources and in terms of pollutants, leading to the government lower investment to maintain the level of sewage treatment in the city and the water quality adequately to serve the population of the Guaratinguetá city.

The study indicates that the forest area devastated was replaced, mostly, by areas called here as anthropized. In this particular case they are near to the capitation point, and related to crops that may be making pesticide use. Thus, a closer inspection may encourage the restoration of riparian vegetation, preserving the necessary environmental range.

It was possible to evidence with the multi-temporal evaluation of satellite images and the historical evaluation that included a 25-year period, that the condition of land use and occupation around the water capitation point remains the same throughout the period. This fact is strongly indicative, even not having water quality data for all years of satellite images, which currently, the situation of water quality in the Guaratinguetá River remains the same for the evaluated years provided by reports.

It is understood that to improve the environment surrounding the river, especially respecting the range of environmental protection, its water quality will be improved even downstream of the capitation point; so it is expected a decrease of investment in water treatment available to the population. According to ICMBio the same procedure should be applied to other APA of São Paulo State and should facilitate the enforcement action ICMBio.

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