THE USE OF REMOTE SENSING IN DETERMINATION OF THE IMPERMEABLE SOIL GROWTH IN THE BELEM RIVER BASIN AREA

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ABSTRACT

In tropical countries especially, urban hydrographic basins hit by convective rains are characterised by the rapid increase in the flowoff of rainwater, consequently resulting in floods. The main cause of these floods is urbanisation itself. In developing countries, where planning of the settlement of the basins is virtually non-existent, population growth, in addition to the rural exodus, leads to the uncontrolled proliferation of building construction and the paving of roads. For this reason, the process of making urban soil impermeable is the main contributing factor for the occurrence of floods. In the study of hydrology, the mathematical models for the simulation of flood rates and flood areas, use the waterproofing of the soil as one of the parameters for the simulation of drainage flowoff, based on the rainfall for a determinate period of recurrence. This paper presents the results obtained by the quantification and mapping of the spatial distribution of the impermeable areas of the Belem River Basin, one of the main hydrographic basins in Curitiba (in the state of Parana), at two different points in time. For this purpose, digital classification techniques of remote sensed images were used at two different stages, in 1988 and 1996. The flood areas in the Belem River Basin were represented in IPPUC's (Urban Research and Planning Institute of Curitiba) official map of the flood of 21 February 1999.

1 INTRODUCTION

The uneven heating of the earth's surface results in the appearance of layers of air at different densities, which generates a thermal stratification of the atmosphere at an unstable equilibrium. The disruption of this equilibrium for whatever reason, such as wind, overheating or even a drop in atmospheric pressure, leads to a rapid and violent ascension of less dense air, capable of reaching high altitudes with rapid condensation of the clouds hygroscopic particles and thus causing the so-called 'tropical/summer rains'. In the study of Hydrology, these rains are called thermal convective, typical of tropical regions and characterised by the presence of 'cumulus nimbus', clouds of a dark lead grey colour. These rains are very intense, have short duration and are, sometimes, followed by hail. They are concentrated in medium to small areas of hydrographic basins, the drainage channels of which cannot cope with outflow and therefore overflow, especially in those which have been made highly impermeable by the urbanisation process. In Curitiba, the process of formation and precipitation of these rains finds favourable conditions in the months from November to March.

The summer (convective) rain which occurred on 21 February 1999 showed some variation in its intensity - the rain station Estação Pluviográfica Curitiba Prado Velho, at PUCPR (the Catholic University of Parana), registered a record of 96.8 mm in one and a half hours of rainfall. The maximum water level of the Belem River, which flows through the Catholic University Campus, rose above its normal level at this time of year, from 0.70m to a critical level of 6.20m. Such a level is equivalent to a hydrological risk (Period of Recurrence) of 100 years, which was simulated in the study 'Hydraulic Model of the Simulation of Flood Rates in the Belem River Basin', concluded by Fendrich in 1996. This flood caused the population innumerable problems and enormous losses at the beginning of last year.

The Belem River is one of the tributaries from the right bank of the Iguaçu River, and it is found entirely within the Curitiba Municipal Region as the main river bed follows a North-South direction, as shown in Figure 1. It crosses highly populated areas, from suburbs on the outskirts of the city, in the North and South regions, to the central areas of the City of Curitiba, the Capital of the State of Parana (Brazil).

The waterproofing of the urban soil is the main contributing factor in the occurrence of floods. In the case of the Urban Basin of the Belem River, the waterproofing of the soil was one of the main factors that contributed to the flood that occurred on the 21 February. Thus, one of the objectives of this paper is to demonstrate how the use of remote sensing can contribute to the quantification and mapping of the impermeable areas in urban basins. In order to do so, a study of different time periods was carried out aiming to demonstrate the evolution of the state impermeability of the Belem River Basin over a period of 8 years. Furthermore, information obtained in the field was added to the study 'Hydraulic Model of the Simulation of Flood Rates in the Belem River Basin', for the charting of the areas flooded in February 1999.

2 MATERIAL

The cartographic base used was the digital mapping of the city of Curitiba on a scale of 1:2,000, supplied by IPPUC.
Spot (French) and Landsat (American) satellite images were used. These images had the following characteristics: Spot Images - panchromatic band, 10m spatial resolution, dated 16 December 1988 and 13 May 1996;TM5 Landsat Images - 3 band (visible), 4 and 5 bands (infrared), 30m of spatial resolution, dated 27 March 1988 and 18 April 1996.
For the charting of the flooded area in the 21 February floods, the map charted in the 'Application of the Hydraulic Model to the Belem River Basin in Curitiba: Forecast of Flood Rates and Assessment of Flood-Prone Areas' was digitized.
The work was carried out on Microcomputers with the following configuration: Pentium 3, 500 MHz, 128 Mb RAM, 4.3 Gb HD and peripheral devices. The software packages used were: Microstation (Bentley) and Image Analyst (Intergraph).

3 METHODOLOGY

3.1 Geometric Correction of Images

The use of the geometric correction technique is applied when it is necessary to adjust an image to a cartographic or thematic base. In these cases the technique has fundamental importance, providing the basis for an integrated analysis of the data from different sources. For this reason, the geometric correction was the first step taken in the digital processing of images. For this purpose, the ground control points were obtained from the digital cartographic base (mapped by IPPUC) on a scale of 1:2,000. The Spot images were thus corrected and integrated to the digital mapping. The Landsat images were then corrected through the image vs image process, so that they could be perfectly registered (with the same resolution) and superimposed on the Spot images, allowing the integration of both.

3.2 Fusion of Images

This technique is employed in order to obtain an image with the spectral characteristics of Landsat (3,4 and 5 band) and the spatial characteristic of Spot (10m resolution). The result of this fusion is a color image with a higher level of detail than the original images. For this integration to be carried out, a technique called IHS transformation was used. This data integration technique has been used by several authors such as CARPER, LILLESAND and KIEFER (1990), HARRIS and MURRAY (1990), PINTO (1991), ROCHA (1993), FERREIRA (1995), ROCHA et al. (1995) and RIBEIRO (1997), mentioned by SCHMIDLIN (1998). The images generated by this process may be seen in Figures 2 and 3.

3.3 Digital Classification

One of the main objective of remote sensing is to be able to distinguish and identify the different composition of the surface materials. This distinction and identification is made possible because surface materials have specific behavior in terms of the electromagnetic spectrum, and this behavior can be used to identify them.
The automatic classification of multi-spectral satellite images aims to associate each and every pixel of that image to a 'label' describing a real object (vegetation, soil, etc.). In this manner, the numeric values associated to each pixel, defined according to the reflectiveness of the materials which make up that pixel, are identified in terms of a type of surface that is depicted (water, type of vegetation, soil, rock, etc.), and are then called *themes*.
When this kind of operation is carried for all the pixels in a pre-determined area, the result is a thematic map showing the geographic distribution of a *theme*, such as the classes of land use. One can then say that the classified satellite image is a kind of thematic digital map.
The biggest problem encountered in the classification is that it represents a rather vast simplification in relation to the enormous complexity that exists in a satellite image. What happens is that the pre-defined classes are normally incomplete in relation to reality, or they are an extremely variable mix of a series of real surfaces. One can even reach

extreme conclusions such as defining classes that don't exist or that cannot be differentiated based on the available multi-spectral data. Hence the need to verify the results of the classification in relation to known data. Any information about surface objects that have to be classified is, therefore, of great assistance to the classification process.

Another aspect of the classification is that the majority of the techniques available are simply based on the grouping of spectral intensity values, represented by digital numbers present in the images. It is known that the information contained in a satellite image is based as much on the intensity (shade of gray or color) of each individual pixel as on the spatial arrangement of the pixels (texture and form). The standard classification techniques, therefore, supply us only with the spectral characteristics, setting aside the textural characteristics. In that sense, the classification presents satisfactory results in terms of indicating the types of surface coverage, characterized simply by variations in intensity.

3.3.1 Supervised digital classification - Maximum Likelihood Method

There are essentially two approaches to the classification of multi-spectral satellite images. The first approach, called supervised classification, in which the user identifies some of the pixels belonging to the desired classes and leaves the task of locating the remaining pixels belonging to those classes to the computer program, based on some predetermined statistical rule.

The second approach is called unsupervised classification. In this approach the algorithm decides, also based on statistical rules, which classes should be separated and which pixels belong to each class. In the current study the supervised classification approach was employed.

An area of an image that the user identifies as being representative of one of the classes is called a *training area.* A *training area* is normally defined by the user who traces its boundaries directly on the image. Several *training areas* may be defined for a single class in order to assure that the pixels that belong to it are really representative of the class.

All the pixels within a *training area* for a specific class make up the so-called training set for that class. To each class in an image is attributed its own training set. The digital numbers (or shades of gray) of the pixels in the training set, in each of the spectral bands, are then compared to the digital numbers of each pixel of the image as a whole, in order to decide to which class they belong.

There are a variety of methods through which the unknown pixels can be compared to the pixels in the training set.

The method used in the current study takes into consideration the estimated distance of the averages, uses statistical parameters and is called the *maximum likelihood* method.

3.4 Spectral characteristic of urban areas

When dealing with urban areas, the satellite images have certain characteristics, with the predominance of a high intensity of the values of pixels in the image, mainly in band 3 (visible) and band 5 (medium infrared), which results in colors varying mainly from light pink to purple in the color composition used - 5R4G3B. For the classification of the impermeable areas inside the Urban Hydrographic Basin of the Belem River, the following classes were selected: secondary forest (vegetation in public parks), fields (lawns), dirty field, exposed soil (*loan areas*). These were later grouped into a single class and considered permeable areas, the impermeable areas were the remaining areas. The result of the classification is shown in figures 4 and 5.

4 RESULTS

The results of the digital classification process, in the 1988 and 1996 images, were cross-related to the permeability coefficient map of the Hydrographic Basin of the Belem River (k1, k2 and k3) and to the district boundaries, thus generating the values presented in Tables 1 and 2 that follow. An increase, of around 555.78 hectares in a period of 8 years, in the impermeable area was noted.

4.1 Flooded area in the February 1999 floods

The mapping of the flooded area in the floods of 21 February 1999 was carried out by digitizing the information gathered from two sources: speedy field investigations juxtaposed with COMEC's *planimetric* base of 1:10,000, and with the map generated by Fendrich's (1996) 'Hydraulic Model of Flood *Rate* Simulation in the Belem River Basin'.

The result of the mapping is shown in Figure 6. The flooded area was approximately 592 ha (5,920,000 m²).

Table 1. Area In Hectares Obtained Through Digital Classification - 1988 Image

Nº	District	ha								
		Permeable Area				Inpermeable Area				Total
		K1	K2	K3	Total	K1	K2	K3	Total	
50	Abranches	165			165	94.16			94.16	259.16
9	Água Verde		80.95	3.6	84.55		372.16	6.54	378.7	463.25
14	Ahú	29.65	29.42	1.88	60.95	49.8	70.55	4.28	124.63	185.58
4	Alto da Glória		19.75		19.75		68.11		68.11	87.86
5	Alto da Rua XV		11.8	6.81	18.61		88.62	40.2	128.82	147.43
35	Bacacheri		1.56		1.56		3.33		3.33	4.89
52	Barreirinha	44.1	11.39		55.49	40.72	13.72		54.44	109.93
10	Batel		27.57		27.57		141.86		141.86	169.43
11	Bigorrilho		12.99		12.99		76		76	88.99
34	Boa Vista		1.19		1.19		4.98		4.98	6.17
13	Bom Retiro	51.15	15.66	1.98	68.79	91.29	24.88	2.64	118.81	187.6
56	Boqueirão		145.13	151.87	297		335.61	579.2	914.81	1211.81
16	Cabral		70.46		70.46		130.19		130.19	200.65
51	Cachoeira	55.2			55.2	29.64			29.64	84.84
1	Centro		18.18	8.21	26.39		202.14	99.27	301.41	327.8
3	Centro Cívico		12.27	13.87	26.14		33.74	31.93	65.67	91.81
6	Cristo Rei		34.34	2.84	37.18		95.88	11.72	107.6	144.78
39	Fanny		17.09	9.88	26.97		132.79	41.49	174.28	201.25
23	Guabirotuba		42.88	24.73	67.61		144.12	49.32	193.44	261.05
26	Guaira		28.72	17.14	45.86		131.06	53.43	184.49	230.35
38	Hauer		19.94	25.75	45.69		66.82	292.17	358.99	404.68
17	Hugo Lange		30.31	8.9	39.21		39.6	28.69	68.29	107.5
7	JD. Botânico		57.42	31.97	89.39		127.22	61.09	188.31	277.7
22	J. das Américas		62.67	16.12	78.79		216.85	18.66	235.51	314.3
15	Juvevê		19.93		19.93		103.5		103.5	123.43
40	Lindóia		5.73	8.96	14.69		35.32	66.42	101.74	116.43
12	Mercês	11.76	48.08		59.84	13.58	114.01		127.59	187.43
41	Novo Mundo		33.35	1.85	35.2		222.51	3.6	226.11	261.31
25	Parolin		12.9	13.16	26.06		110.54	89.1	199.64	225.7
32	Pilarzinho	131.18			131.18	83.74			83.74	214.92
27	Portão		18.13		18.13		96.4		96.4	114.53
24	Prado Velho		14.43	24.41	38.84		46.32	158.75	205.07	243.91
8	Rebouças		8.44	9.91	18.35		140.6	138.61	279.21	297.56
2	São Francisco	3.71	18		21.71	7.69	105.28		112.97	134.68
33	São Lourenço	112.37	21.43		133.8	78.24	13.07		91.31	225.11
49	Taboão	1.88			1.88	0.87			0.87	2.75
37	Uberaba		115.47	156.05	271.52		207.35	188.53	395.88	667.4
31	Vista Alegre	70.83			70.83	62.4			62.4	133.23
57	Xaxim		73.45		73.45		193.95		193.95	267.4
*	TOTAL	**676.83**	**1141.03**	**539.89**	**2357.75**	**552.13**	**3909.08**	**1965.64**	**6426.85**	**8784.6**

Table 2. Area in hectares obtained through digital classification - 1996 Image

Nº	District	ha								
		Permeable areas				Inpermeable areas				Total
		K1	K2	K3	Total	K1	K2	K3	Total	
50	Abranches	141.52			141.52	117.63			117.63	259.15
9	Água Verde		75.61	2.72	78.33		377.45	7.47	384.92	463.25
14	Ahú	22.58	26.03	1.93	50.54	57.03	73.7	4.31	135.04	185.58
4	Alto da Glória		17.43		17.43		70.43		70.43	87.86
5	Alto da Rua XV		14.41	5.77	20.18		89.94	41.31	131.25	151.43
35	Bacacheri		1.51		1.51		3.38		3.38	4.89
52	Barreirinha	32.64	7.62		40.26	52.21	17.45		69.66	109.92
10	Batel		25.73		25.73		143.7		143.7	169.43
11	Bigorrilho		11.85		11.85		77.14		77.14	88.99
34	Boa Vista		1.1		1.1		5.07		5.07	6.17
13	Bom Retiro	46.63	14.55	2.76	63.94	95.3	26.64	1.72	123.66	187.6
56	Boqueirão		112.74	85.57	198.31		366.35	647.16	1013.51	1211.82
16	Cabral		71.1		71.1		129.55		129.55	200.65
51	Cachoeira	38.4			38.4	46.44			46.44	84.84
1	Centro		16.07	6.35	22.42		204.35	101.03	305.38	327.8
3	Centro Cívico		12.12	11.81	23.93		34	33.87	67.87	91.8
6	Cristo Rei		28.16	1.95	30.11		102.31	12.36	114.67	144.78
39	Fanny		10.25	2.05	12.3		139.69	49.25	188.94	201.24
23	Guabirotuba		32.49	14.73	47.22		154.26	59.57	213.83	261.05
26	Guaira		10.78	2.98	13.76		149.06	67.53	216.59	230.35
38	Hauer		18.54	20.82	39.36		68.46	296.86	365.32	404.68
17	Hugo Lange		27.85	7.98	35.83		42.09	29.58	71.67	107.5
7	JD. Botânico		46.66	25.69	72.35		138	67.34	205.34	277.69
22	J. das Américas		46.46	8.29	54.75		233.18	26.37	259.55	314.3
15	Juvevê		18.23		18.23		105.2		105.2	123.43
40	Lindóia		2.55	4.93	7.48		38.54	70.41	108.95	116.43
12	Mercês	9.34	40.66		50	16.2	121.22		137.42	187.42
41	Novo Mundo		20.43	0.22	20.65		235.46	4.54	240	260.65
25	Parolin		8.83	5.24	14.07		114.95	96.68	211.63	225.7
32	Pilarzinho	115.18			115.18	99.74			99.74	214.92
27	Portão		16.13		16.13		98.4		98.4	114.53
24	Prado Velho		12.56	22.29	34.85		47.69	160.97	208.66	243.51
8	Rebouças		7.7	8.21	15.91		141.04	140.75	281.79	297.7
2	São Francisco	2.73	17.13		19.86	8.54	106.27		114.81	134.67
33	São Lourenço	98.61	18.17		116.78	91.87	16.4		108.27	225.05
49	Taboão	1.6			1.6	1.15			1.15	2.75
37	Uberaba		74.54	84.59	159.13		248.56	259.7	508.26	667.39
31	Vista Alegre	62.2			62.2	71.09			71.09	133.29
57	Xaxim		37.67		37.67		226.72		226.72	264.39
*	TOTAL	**571.43**	**903.66**	**326.88**	**1801.97**	**657.2**	**4146.65**	**2178.78**	**6982.63**	**8784.6**

5 RECOMMENDATIONS

- It is recommended that the mapping and quantification work on impermeable areas be extended to other Hydrographic Basins within the whole of the Curitiba Metropolitan Region. The remote sensing techniques presented in this study are of low cost and swift implementation, which makes their application possible in other highly urbanized cities in Brazil.
- The use of other classification methods, based on different mathematical models, must be tested and evaluated among themselves, with the aim of choosing the most precise method to be applied in urban areas.
- With regard to floods in Urban Macrodrainag*e*, in cities with high rates of soil impermeability, we emphasize:
  - Continued studies using mathematical models for the hydraulic simulation of flood rates in other urban rivers in Curitiba, in the Metropolitan Region of Curitba, in the rest of the state of Parana, and even in other Brazilian states. The rivers for which there is fluviometic data available, can be researched so that one can obtain a deeper physical knowledge of the response of hydrographic basins to intense rains occurring on terrain with ever increasing rates of soil impermeability, due to a high degree of soil usage and occupation.
  - That the topographic rates of floods, as well as the flood areas of the Urban Hydrographic Basin of the Belem River, be used as an instrument for the Urban Planning of Curitiba. These could be used by the City Council of the Municipal District, in issues that refer to floods in the Urban *Macrodrainage* system, especially those registered on 21 February 1999, equivalent to hydrodynamic simulation for the period of recurrence (100 years).
- It is further recommended that efforts and resources be directed at the development of hydrological studies related to the trinomial (Storage x Utilization x Infiltration) of rainwater, for the reduction of the levels of water in the maximum outflow, minimizing the extension of the flood prone areas for the community that occupies the flood areas of the hydrographic basins.
- For the mapping of the areas inundated by floods, it is recommended that digital terrain models (DTM) be used along with field data and data simulated by hydraulic models.

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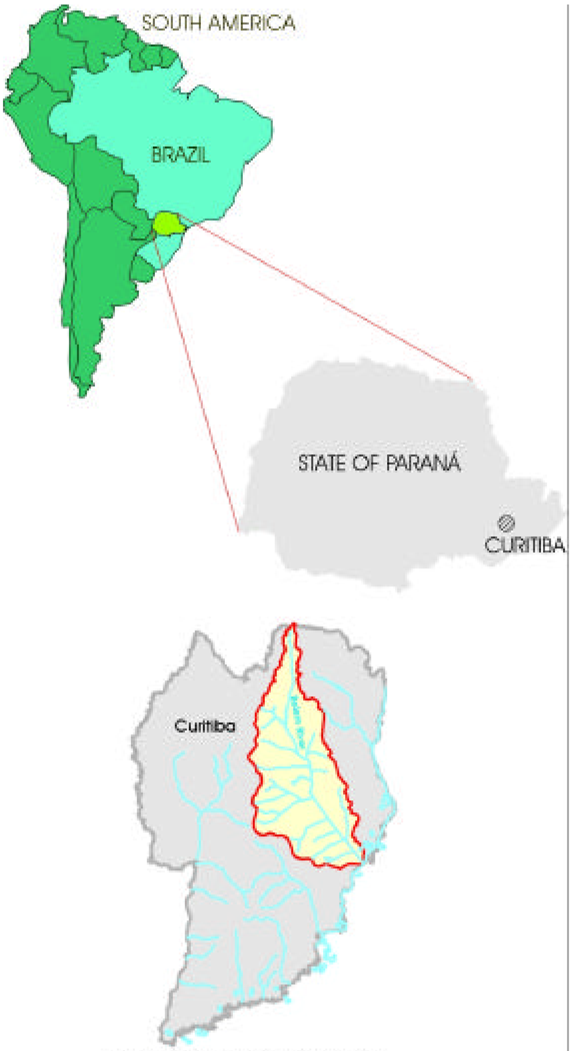

Figure 1. Localization of the Belem River Basin in the District of Curitiba, Capital of the State of Parana.

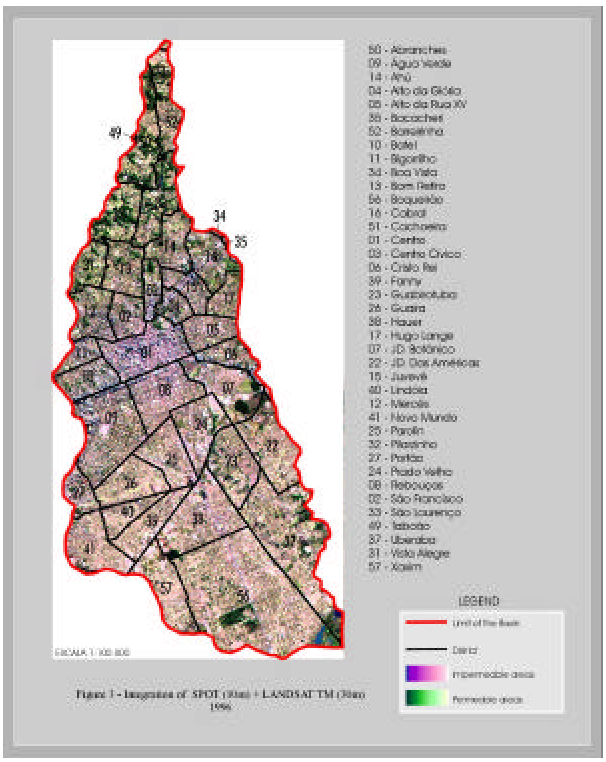

Figure 1 - Integration of SPOT (10m) + LANDSAT TM (30m) 1996

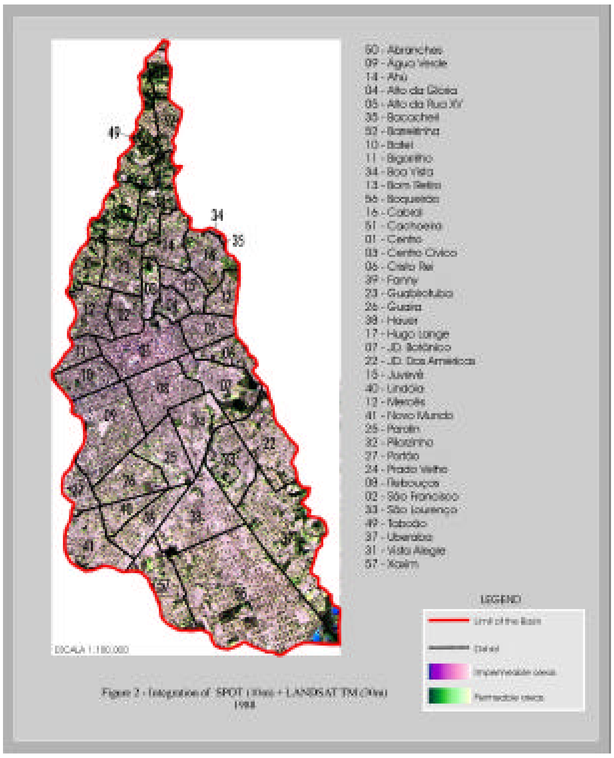

Figure 2 - Integration of SPOT (10m) + LANDSAT TM (30m) 1988

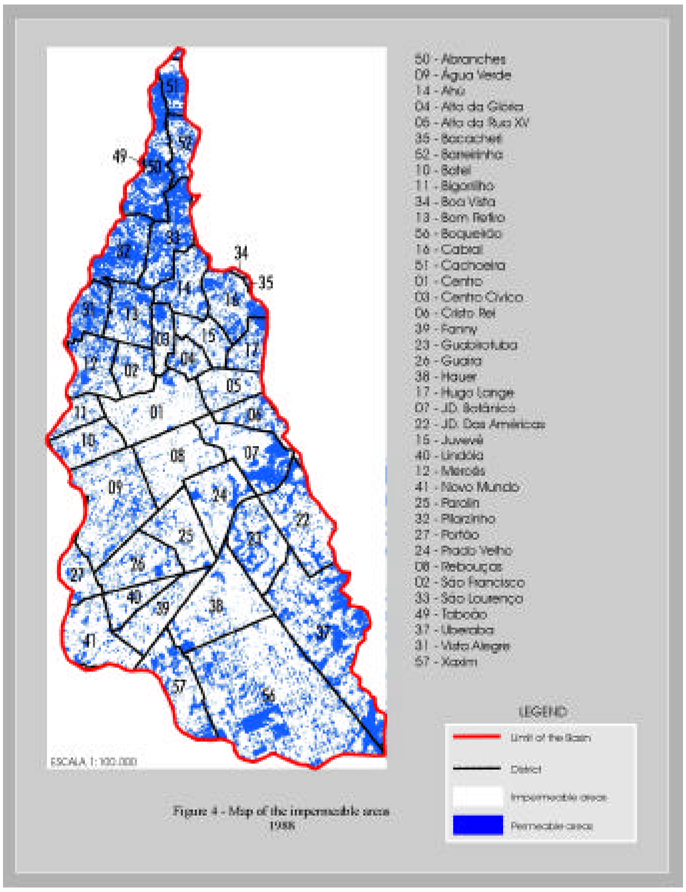

Figure 4 - Map of the impermeable areas 1988

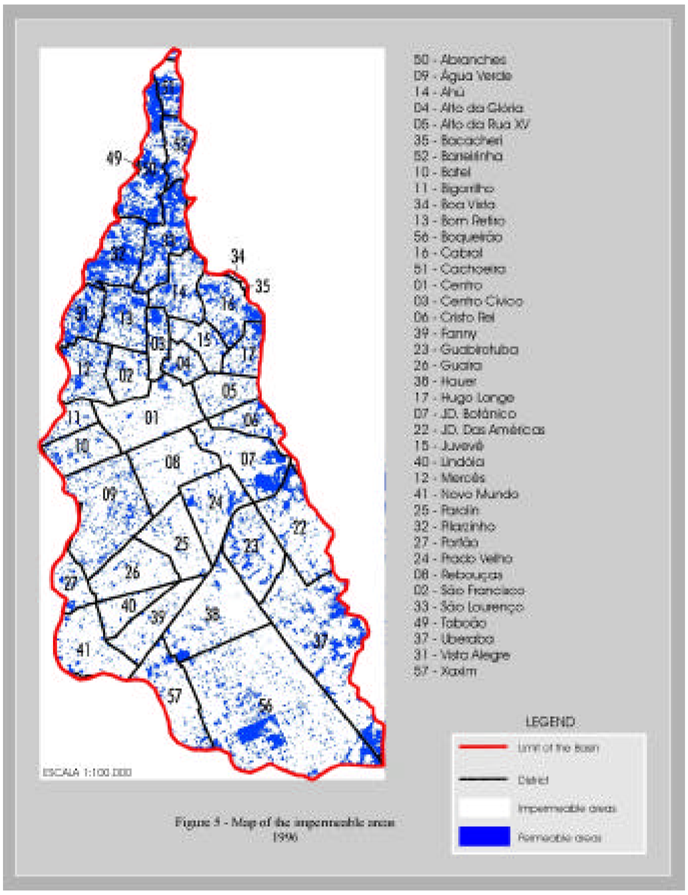

Figure 5 - Map of the impermeable areas 1996

Figure 6. Flooded area in the flood of 21 February 1999.
(Fendrich, 1996; IPPUC, 1998; COMEC, 1998; ENGEFOTO/INTEC, 1999)