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EFFICIENCY OF THE CURVE NUMBER METHOD OF RAINWATER RETENTION

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ABSTRACT

The present study presents the results of research whose main objective was to use hydrological data on flow to verify the efficiency of the parameter curve number (CN) of rainwater retention in river basins on a regional scale, through multivariate statistical analysis, to contribute to the administration and management of water resources. The CN is part of the method of estimating flow used by the Soil Conservation Service (SCS). This rainfall-runoff model is used to estimate flow in small river basins, based on soil data and the evolution of land use and occupation. The method was applied to 14 hydrographic sub-basins - PR, whose confluences coincide with the gauging stations, to set up the sampling points for the multivariate statistical analysis of canonical correlation. The result of the canonical correlation, represented by the canonical R was equal to 0.90 with canonical R^2 equal to 0.81, chi-square (χ^2) of 15.8577 and DF (degrees of freedom) equal to 7, which is very significant and expresses a high correlation between the method and flow rates. These results confirm the hypothesis that the CN can be validated by the flow.

Keywords: Canonical correlation; River basins; Model validation.

RESUMO/ RESUMEN

EFICIÊNCIA DO MÉTODO "CURVE NUMBER" DE RETENÇÃO DE ÁGUAS PLUVIAIS

Resultados de um estudo cujo objetivo geral foi verificar a eficiência, com dados hidrológicos de vazão, o parâmetro "curve number" (CN) de retenção de águas pluviais em bacias hidrográficas, na escala regional, através da análise estatística multivariada visando contribuir para a gestão e manejo dos recursos hídricos. O CN faz parte do método de estimativa de vazões do Soil Conservation Service (SCS), um modelo chuva-vazão que é utilizado para estimar vazões em pequenas bacias com base em dados pedológicas e de evolução de uso e ocupação do solo. O método foi aplicado em 14 sub-bacias hidrográficas – PR, cujo exutório coincidisse com as estações de coleta de vazão, visando compor os pontos amostrais para a análise estatística multivariada de correlação canônica. O resultado da correlação canônica, representada pelo R canônico foi igual a 0.90 com R^2 canônico igual a 0.81, qui-quadrado (χ^2) de 15.8577 e GL (graus de liberdade) igual a 7, o que é muito significativo e expressa alta correlação entre o método e as vazões. Estes resultados confirmam a hipótese de que o CN pode ser validado pela vazão.

Palavras-chave: Correlação canônica; Bacias hidrográficas; Validação de modelo.

EFICIENCIA DEL MÉTODO "CURVE NUMBER" DE RETENCIÓN DE AGUA DE LLUVIA

Los resultados de un estudio cuyo objetivo general fue verificar la eficiência, utilizando los datos de flujo hidrológicos, el parámetro "curve number" (CN) de retención de agua de lluvia en las cuencas hidrográficas, a escala regional, mediante un análisis estadístico multivariante, para contribuir a la gestión y manejo de los recursos hídricos. La CN es parte de la estimación de flujo del Soil Conservation Service (SCS), un modelo de precipitación-flujo que se utiliza para estimar los caudales en cuencas pequeñas con base en datos del suelo y evolución del uso y la ocupación. El método se aplicó a 14 sub-cuencas – PR, exutório que coincidió con la colección fluyen estaciones, Para componer los puntos de muestreo para el análisis multivariante de correlación canónica. El resultado de la correlación canónica representado por R canónica fue igual a 0,90 con R2 canónica igual a 0,81, chi-cuadrado ($\chi2$) de 15.8577 y GL (grados de libertad) igual a 7, que es muy significativo y expresó alta correlación entre las tasas de método y de flujo. Estos resultados confirman la hipótesis de que la CN puede ser validada por el flujo.

Palabras clave: Correlación canónica; Cuencas hidrográficas; Validación del modelo.

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INTRODUCTION

Information on land use is important to establish basin management policies as it reflects the evolution of the occupation of its surface and conservation activities. This data includes key elements of the infiltration capacity and water retention of the runoff in a basin, such as the type of use and ground cover. This research aimed to evaluate the efficiency and feasibility of using the CN parameter (curve-number) of the rainfall-runoff model developed by the Soil Conservation Service (SCS), an agency of the Department of Agriculture of the United States of America (USDA). This parameter is often used to estimate flows in small basins based on data that can be derived from remote sensing and Geographic Information Systems. Furthermore, the temporal evolution of the rainwater retention potential of river basins through the study of use and ground cover, derived from satellite images for the management of water resources was also observed.

A simple and widely used method in hydrological models of river basins worldwide, the CN method has been used by researchers such as Hawkins, 1993; Jacobs; Srinivasan, 2005; Tedela et al., 2008; Santos et al, 2007; Banasik; Woodward 2010; Dog et al., 2011; and Araujo Neto et al. 2012. The SCS method is based on the concept that the superficial laminar flow produced in a given event is a function of the total height of the precipitated sheet and the losses that occur primarily due to infiltration, plant interception and retention in depressions in the terrain (TYAGI et al., 2008).

However, when working with methods that assign numerical weights to generate matrices resulting from the interrelationship of important variables such as slope, soil types and land use, the veracity of these results is questionable.

Under this assumption, the motivation for the development of this research is based on the intention to examine flow variables for the analysis and management of physical elements in the landscape and its processes, which is extremely necessary to reach significant results. There is also a concern to ascertain whether methods that are based on assigning numerical weights to arrive at generalizations about the areas studied are consistent with reality.

This research takes into account the physical variables of soil, geomorphology and the evolution of use and occupation that were confronted with data on flow and rainfall in order to discover the extent to which CN can be considered an efficient method for hydrological surveying.

STUDY AREA

The study area of this research, the Ivaí river basin (Figure 1), was selected as it presents flow and rainfall data that match the proposed objectives, as well as regional maps on a 1: 250,000 scale, in order to check if the method being analyzed is compatible with this scale, with the images in the raster format and the hydrological data.

The Ivaí basin, fully contained in the State of Paraná, in the regions comprising the second and third plateaus, it is located between the UTM coordinates 224,214.2 m and 7,465,630.6 m; 525,920.2 m and 7,170,625.7 m; it has a total area of 35,845 km2. However, it was necessary to reduce the study area from the total area of the basin (Figure 1), given that the last flow collection station, right on the mouth of the Ivaí River, showed no consistent data and so had to be discarded, which reduced the study area to 34,419 km2.

The Ivaí River arises from the confluence of the Dos Patos and São João rivers, in the southern portion of the State of Paraná, specifically in the Serra da Boa Esperança region on the border of the municipalities of Prudentópolis and Ivaí (BALDO, 2006).

The geological data is composed of sediment corresponding to the Passa Dois group, consisting of the Irati, Serra Alta, Terezina and Rio do Rasto formations; the São Bento Group that covers the Piramboia and Botucatu formations; the Serra Geral Formation, which covers much of the vast

Botucatu desert; the sandstone Caiuá Formation of the Bauru group; and in some places, partially covered by unconsolidated sediments (BALDO, 2006).

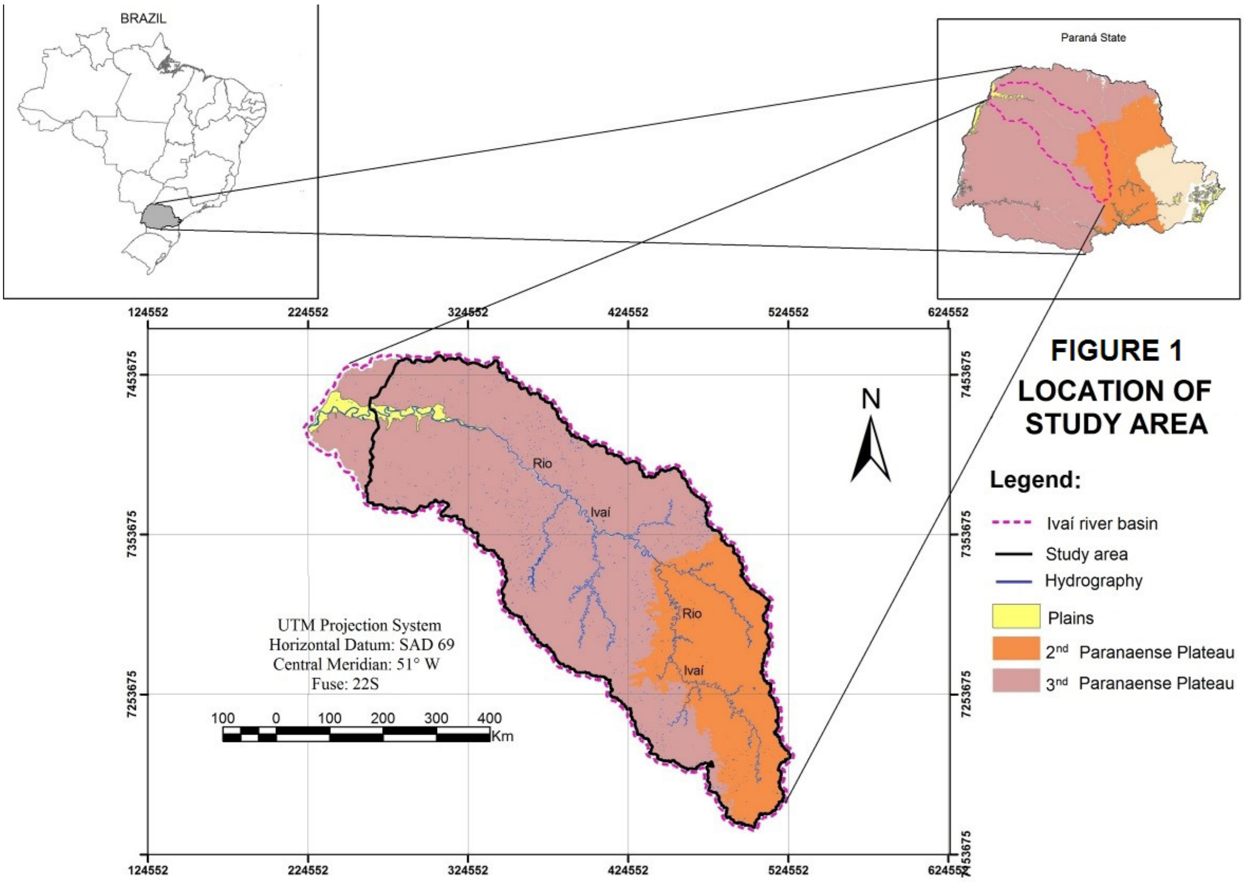


Figure 1 – Location of the study area: Ivaí River Basin – PR

According to Maack (1981), the orographic system of the Ivaí basin clearly shows the correlation between existing forms and the geological formation. Altitudes in the basin range from below 300 to over 1300 meters from the mouth to the source. The Ivaí River begins in the Second Plateau and cuts through the whole of the Third Plateau in a northwest direction.

As this basin has a large territory it also has a very wide range of soils. Among the most commonly found are: Cambisols, Oxisols, Ultisols, Nitosols and Neosols, according to the classification of the Brazilian Agricultural Research Corporation EMBRAPA (2008), updated from the data obtained from EMBRAPA (1984).

According to the Agronomical Institute of Paraná (IAPAR, 1994) the climate of the study area falls into in two main types; the first is tropical and covers the lower reaches and the middle of the basin and the second is subtropical and comprises the upper reaches of the basin. In the lower Ivaí, the highest average total temperatures, above 22 ° C, occur in October, January and December, while the lowest, around 9 ° C, occur in August, July and April (Caramori, 1989) and are associated with the predominant type of soil cover, favoring the development of forest vegetation (Seasonal Semi-deciduous Forest and Mixed Ombrophile Forest).

MATERIAL AND METHODS

To fulfil the proposed objectives a database was created with information derived from Landsat images and data about the soil derived from soil maps on a scale of 1: 250,000, EMBRAPA (1984).

The temporal variation of the cover was used to check the evolution of the urban density and the degree of its impact on the hydrology and this variation was estimated using Landsat images.

Using Landsat 5 satellite images and ensuring the same seasonality, the survey had a multi-temporal period of twenty-five years (1986 and 2011). A supervised classification of the multispectral images was carried out using the ENVI version 4.5 software developed by ENVI® (1997).

The classifier used was the Minimum Distance, which compared to the other alternatives (Parallelogram, MAXVER, Mahalanobis, among others), presented the smallest confusion matrix. In this method the class models are characterized by spectral symmetry, where the minimum distance method assigns each unknown pixel to a class with the closest average. The categories of use adapted from the Technical Manual of Soil Use (IBGE, 2013) for this research were Water Bodies, Natural Forests and/or Forestry, Pasture, Agriculture and Urban Areas.

THE CURVE NUMBER METHOD OF THE SOIL CONSERVATION SERVICE (SCS)

The Soil Conservation Service (SCS) of the United States Department of Agriculture has proposed a simplified method for estimating runoff in small rural basins. This estimate is based on data that are relatively easily obtained, such as land use and cover, rainfall and soil type. The method became popular in hydrological studies because of its easy application. Subsequently, ways of estimating the input parameters from satellite pictures have been proposed, such as the study by Ragan and Jackson (1980), which introduced an adaptation and simplification of its parameters. The method is to estimate the effective rainfall (Equation 1), the portion of the volume precipitated that forms the surface runoff, and with this superficial runoff.

The effective rainfall is given by:

$$Q = ((P - 0.3s) 2) / (P \quad 0.7s) \qquad \text{(Equation 1)}$$

Where,

Q = flow time of the laminate in mm

P = precipitation in mm

S = maximum charging capacity of the basin after a 5-day precipitation history, in mm

The maximum recharge capacity is associated with the physical characteristics of the basin, in terms of soil and vegetation cover (Equation 2).

$$S = (24500 / CN) - 254 \qquad \text{(Equation 2)}$$

For this calculation, the CN parameter, Curve Number, should be determined. This is a standard value that describes the combination of soil type, prior moisture and the use and cover in the basin.

As a basin does not have uniform characteristics in terms of soil and vegetation cover, the representative value of the basin can be obtained by weighting each value present in the basin area by the proportion of the area associated with the value:

$$CN = \frac{\sum_{i=1}^{n} cn_i a_i}{A} \qquad \text{(Equation 3)}$$

Where

CN = curve number;

A = area of the basin;

cn = curve number of a part of the basin;

a = area associated with a number of curves in the basin.

In this study, to derive the value of the CN parameter the associations between the classes of coverage and occupation obtained from the orbital images and the hydrological group of the soil were analyzed. For this hydrological classification, the soil information used was provided by EMBRAPA (1984).

The original table of the SCS method is wide and has a large number of combinations. In the study by Ragan and Jackson (1980), this amount of possibilities was restricted due to the ability to map the cover using satellite images. Based on this simplification, and considering the classes present in the study area, a simplified table was proposed, according to Table 1:

Table 1 - SCS simplified curve number CN

Land Use	Hydrological soil group			
	A	B	C	D
Agriculture	62	71	78	81
Water bodies	100	100	100	100
Pasture	25	59	75	83
Natural forests and/or Forestry	36	60	70	76
Urban areas	77	85	90	92

The duration curve is an important source pointing to potential water regulation, and it was produced by placing the daily flow rates observed during the period considered in descending order. With the range of variation of flow, the class intervals were defined and the intervals were placed in descending order and the number of events in each interval was checked against the absolute frequency. The relative frequency (absolute frequency/data number) was calculated for each interval and accumulated following the previous order. Charts were plotted with the lower limit of each range (ordinate) and the corresponding cumulative relative frequency (abscissa). The standard deviations were also calculated from the mean and coefficient of variation (ratio of standard deviation and mean).

The same procedure was applied to produce the annual maximum flow and minimum of 7 days, 15 days, 30 days, 60 days and 90 days.

CANONICAL CORRELATION ANALYSIS (CCA)

The purpose of the canonical correlation is to simultaneously relate multiple independent and dependent variables. The canonical correlation measures the strength of the association between the two sets of variables. The strength of the relationship between pairs of variables is reflected mainly by first function canonical coefficients (R canonical). When squared (R2 canonical), these coefficients represent the amount of variance in a linear compound of the canonical function assigned to another compound of the same function. The aim of the canonical correlation analysis is primarily to verify the association between two groups of variables, thus being able to relate certain hydrological data with variables that show the physical state of the river basin. It is the technique that yielded the best results, since the cluster analysis and factor analysis did not have positive results.

To carry out the multivariate statistical analysis, we used the free Statistical BioEstat 5.3 software (AYRES et al., 2007), developed by the Department of Statistics at the Federal University of Pará in Brazil.

In this research, to meet the proposed objectives - to discover and evaluate which physical determinants best explain the hydrological behavior in the sub-basins in order to validate the CN methods - the flow data were compared (X = Q (TP); STD; CV; Q (max), Q (min7); Q (min15); Q (min30); Q (min60); Q (min90)) with physiographic variables (Y = average CN (1986 and 2011)), of 14 sub-basins.

RESULTS AND DISCUSSION

The result of the subdivision of the Ivai river basin into fourteen (14) sub-basins equivalent to 14 sampling points, as statistical data can be seen in Table 2.

The percentages of the areas are given in relation to sub-basin 14 whose confluence coincides with the last collection points of flow of the study area. In addition to 1 to 5, the sub-basins that do not receive contributions from hydrographic areas from sub-basins upstream are 7, 10 and 13.

Table 2 – Ivaí river basin area per compartment

Compartmentalization	Area (km²)	Percentage (%)
Sub 1	1054.1	3
Sub 2	1089.6	3
Sub 3	3566.5	10
Sub 4	8545.2	25
Sub 5	2611.9	8
Sub 6	12703.8	37
Sub 7	3277.1	10
Sub 8	19436.1	56
Sub 9	1553.3	5
Sub 10	854.2	2
Sub 11	22498.5	65
Sub 12	28403.1	83
Sub 13	802.5	2
Sub 14	34419.3	100

Figure 2 shows the permanence curve of the average monthly flow rates of the total area of this research (Sub-basin 14), i.e., the retention capacity of surface water and duration of flow. It is also related to the frequency of occurrence of different magnitudes of flow. These results are the average values in the time interval of 27 years, including the monthly data for the years 1985 to 2012, both for the duration curve, maximum, minimum, standard deviation and coefficient of variation. Since the average is a value that represents various others, often it is not sufficient to evaluate a set of data. More steps are important, to show the difference (dispersion) that exists between the mean and the values of the set. Therefore this research is noteworthy for using the standard deviation and coefficient of variation in addition to mean values.

The duration curve of the flow shows significant curvature (Figure 2). The shape of the curve has significance and reflects the rate of flow conditions in the basin and in the river channel. According to Destefani (2005), the greater the curvature the greater the variability of the flow caused by fast flow rates and low flow basis. Figure 2 shows this situation precisely for the Ivaí river basin, as in approximately 10% of the total flow time the flow goes from 2,500 to 500 m^3/s, a variation of 2,000 m^3/s.

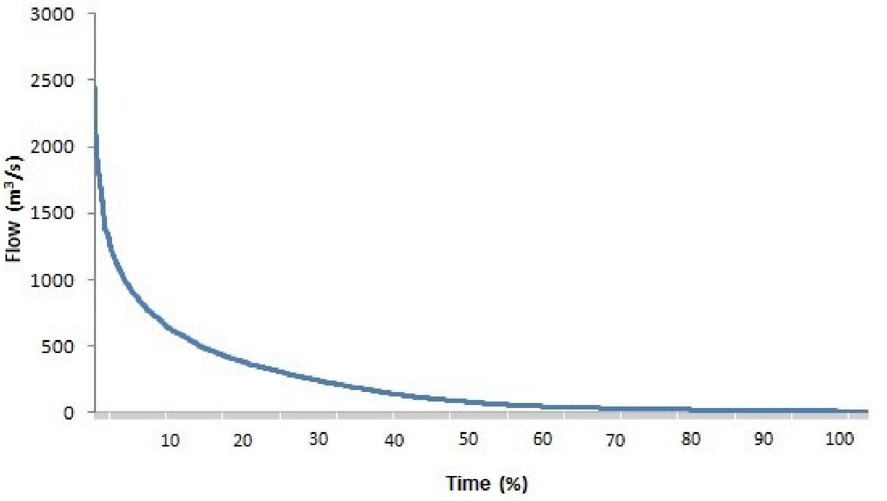


Figure 2 – Permanence curve.

This condition has been noted for the Ivaí River, which has an extremely oscillatory river flow with little contribution from the water table. This is observed during the very low flows during dry periods. These differences are shown by the results of the flow of the historical average: annual maximum and minimum for the same period, 1985-2012, shown in Figure 3.

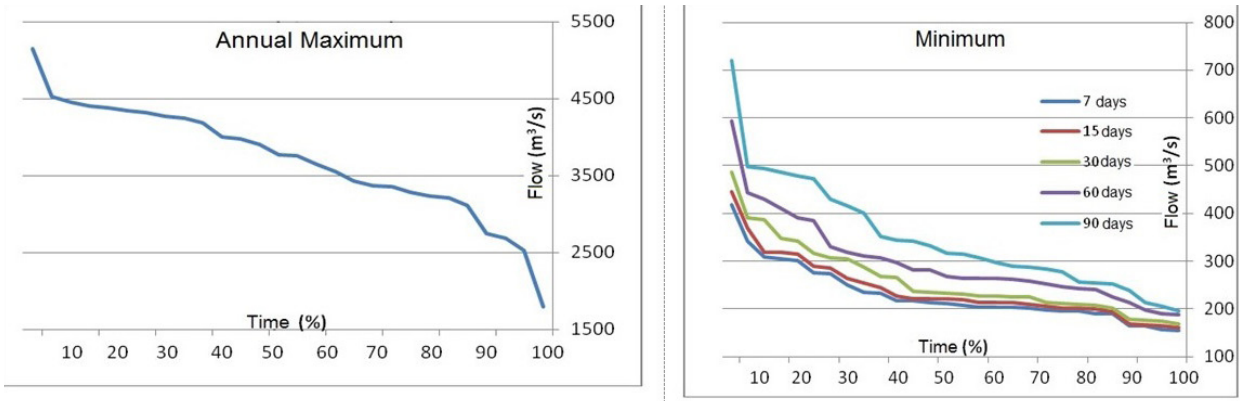


Figure 3 – Average Daily Flows: Annual Maximum and Minimum of the Ivaí River Basin – PR. (1985-2012)

According to Destefani (2005), among the knowledge of the hydrological regime of river systems, high magnitude and intensity flows are receiving increased attention because it is during the period when rivers reach the high water phase that the most rapid and significant environmental changes have been found, from the geomorphological aspect (sculpturing and modification of the bed forms, margins and even the plain), depending mainly on the ecological situation (connectivity between the channel and the plain) and the human context (loss of crops, destruction of homes and businesses, with material and often human losses). These aspects show that floods are hydrological events that can cause environmental and economic instability. The large magnitude flows have high water, discharge and volume levels that could cause flooding. They are portrayed by flood and flooding events that differ mainly in their magnitude and effect, as the floods exceed the flow capacity of the channel causing overflows and spreading water in low-lying areas adjacent to the channel.

It can be hard to determine what magnitude of flow can be considered full, especially if it does not spread as flooding. There is no method or technique that provides a standardized threshold to determine the discharge point from which full capacity begins. Thus, each researcher has the freedom to define a wave or flood peak according to their research objectives. In general, monthly or yearly highs correspond to peak maximum discharge occurring during the months or years respectively, regardless whether it spreads as flooding or not (Destefani, 2005).

As can be seen in Figure 3, the variation of the annual maximum occurs between 1,800 and 5,144 m^3/ S, characteristic of the most natural regulation, presented by the shape of the curvature. For the minimums, which represent the periods of drought, the duration curve has less inclination for the 7-day dry period and is more inclined in the 90-day dry period, with lower extreme values. They varied 155-719 m^3/s.

The total area of the basin comprises 34,419 km^2. This area was classified on two dates: 1986 and 2011, to verify the changes that can be observed in this period. The result of the classification is shown in Figures 4a and 4b.

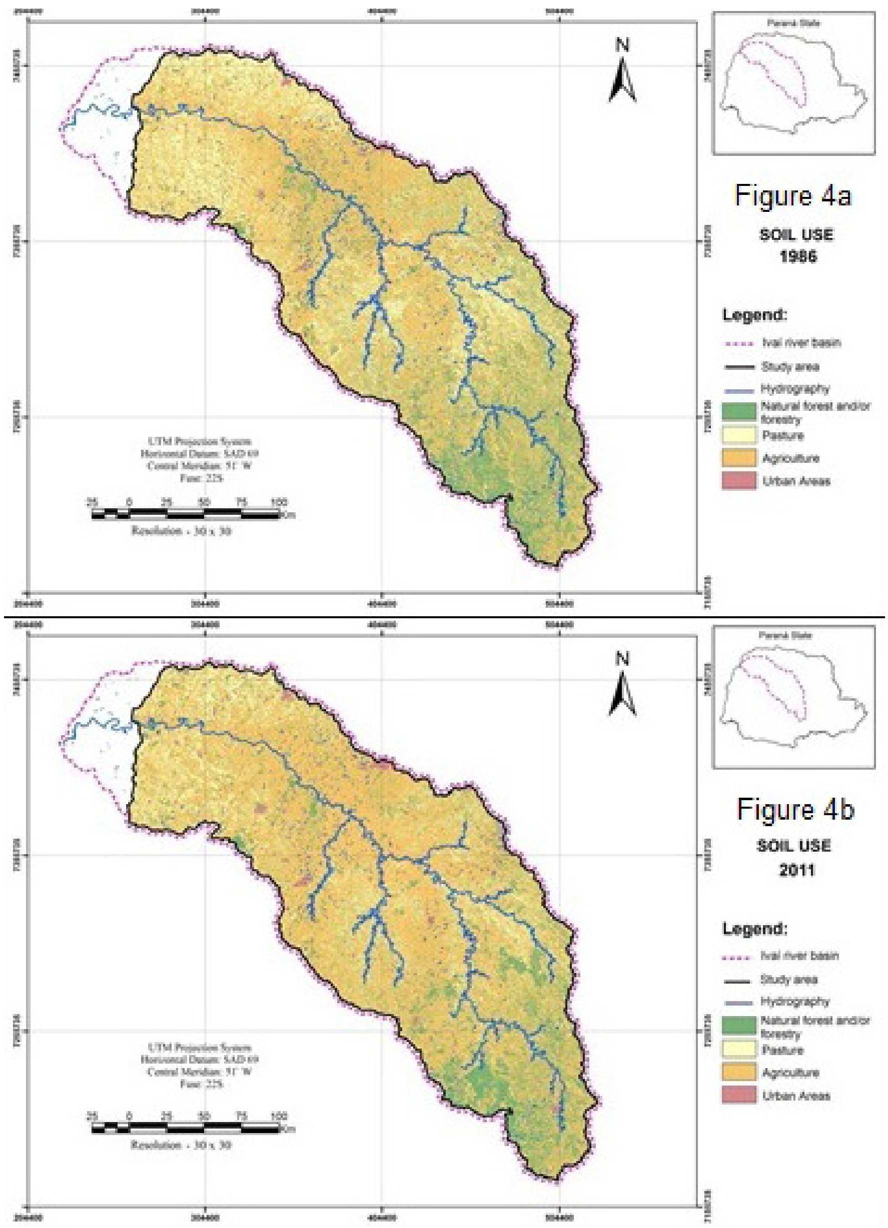


Figure 4 – Use and occupation: (a) - 1986 and (b) - 2011.

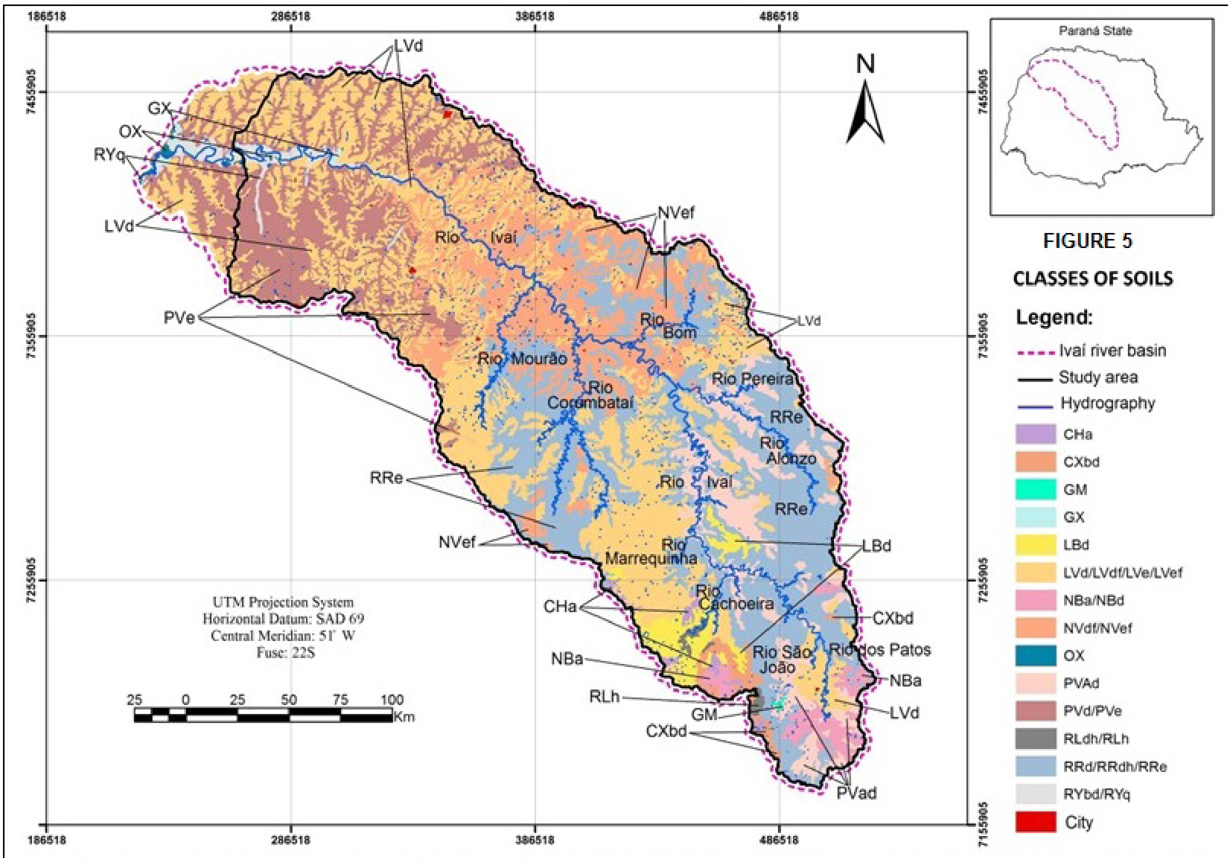
The percentage of the area associated with each type of cover was calculated based on these thematic maps and is shown in Table 3.

Table 3 – Evolution of the use and occupation of land in the Ivaí river basin, PR

Land Use	1986 (%)	2011 (%)	Variation
Water bodies	0.5	0.5	0.0
Natural forests and / or Forestry	17.5	16.3.	-1.2
Pasture	20.4	12.4	-7.9
Agriculture	61.1	69.7	8.6
Urban areas	0.5	1.1	0.5

It was found that the most significant occupations in the Ivaí river basin are agriculture and pasture concentrated throughout the area, especially in the central part toward the mouth of the main river and next the areas of natural forests, which are concentrated in the top, near the head water.

The soil type was derived from soil maps on a scale of 1: 250,000, EMBRAPA (1984). The pedological distribution of the study area is shown in Figure 5.



Key: Cambisols: CH, CXbd; **Gleysols:** GM, GX; **Latosols**: LBd, LVd, LVdf, LVe, LVef; **Nitosols**: NBa, NBD, NVdf, NVef; **Histosol**: OX; **Argisols**: PVAd, PVd, PVe; **Neosols**: RLdh, RLH, RRD, RRdh, RRE, RYbd, RYq.

Figure 5 – Soil Map.

According to Figure 5 and Figure 6, 33.56% of the area studied is formed by Latosols (LBD LVd LVdf, LVe, LVef); 19:30% of Argisols (PVAd, PVd, PVe); 28.21% by Neosols (RLdh, RLH, RRD, RRdh, RRE, RYbd, RYq); 17:20% by Nitosols (NBa, NBD, NVdf, NVef); 1.61% by Cambisols (CH, CXbd); and Gleysols (GM, GX) and Neosols (RLdh, RLH, RRD, RRdh, RRE, RYbd, RYq) which together account for less than 1%.

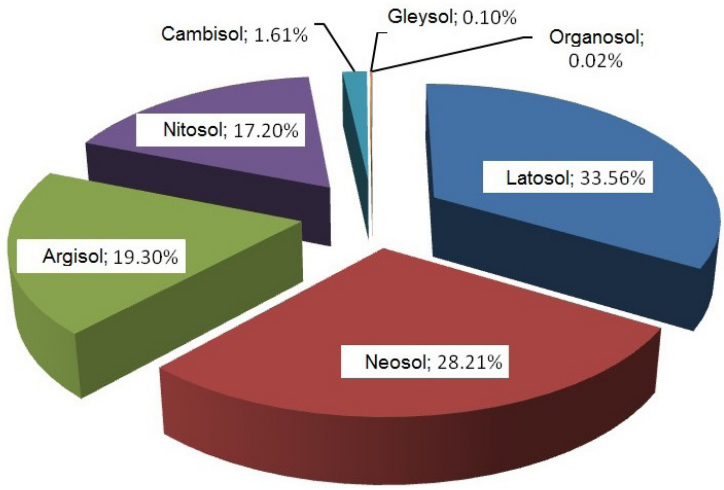


Figure 6 – Percentage of soil classes – Ivaí river basin, PR.

These data allowed the spatial distribution of the hydrological soil classification to be determined, as shown in Figure 7.

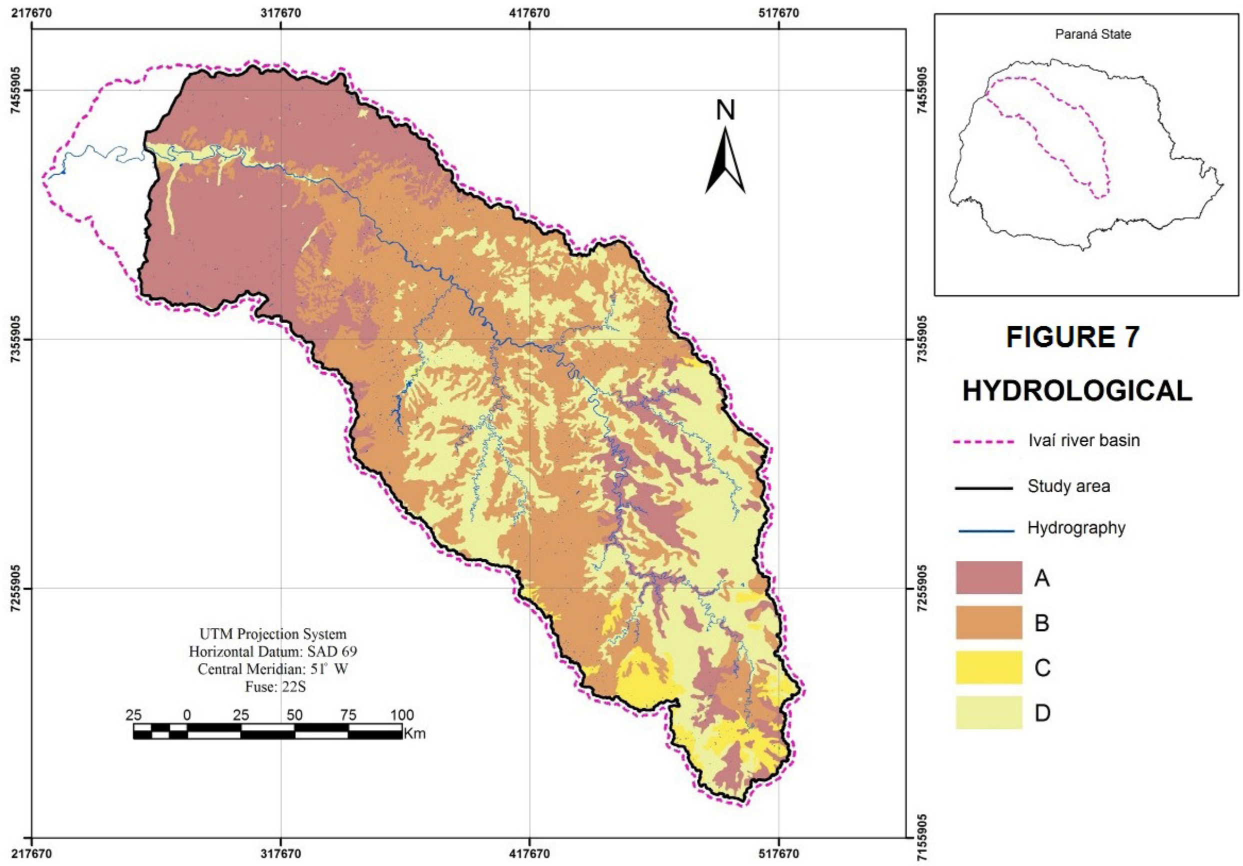


Figure 7 – Hydrological soil classification.

The hydrological group A accounted for 28% of the study area and 34% of Latosols (Oxisols) and 66% of Pozolic soil (Ultisol) with the characteristics of deep and well drained sandy soils; hydrological group B made up 40% of the study area and is composed of 60% of Latosols (Oxisols), 39% of Nitosols and 1% Argisols Pozolic soil (Ultisol) with characteristics of sandy soils with little clay, providing better infiltration runoff; hydrological group C comprised 3% of the study area and contained 48% of Cambisols, 49% of Nitosols and 4% Neosols it had more loamy soil characteristics than the group B, with low permeability; hydrological group D comprised 28% of the study area and consisted of more than 99% Neosols and less than half a percent of Gleysols and Organosols, which present characteristics of very impermeable soils with heavy clay.

Using the factors shown in Table 1, it was possible to determine the values of the curve number (CN) for each pixel of the image and thus obtain the spatial distribution of the parameter in the basin on the two dates in question. The result is shown in Figure 8. Dark shades are associated with low values of the parameter, whereas light shades correspond to high values of the CN.

Comparing the figures of the two dates shows that in the northern part of the basin low CN values were replaced by higher values, reflecting the expansion of agriculture (Figure 8).

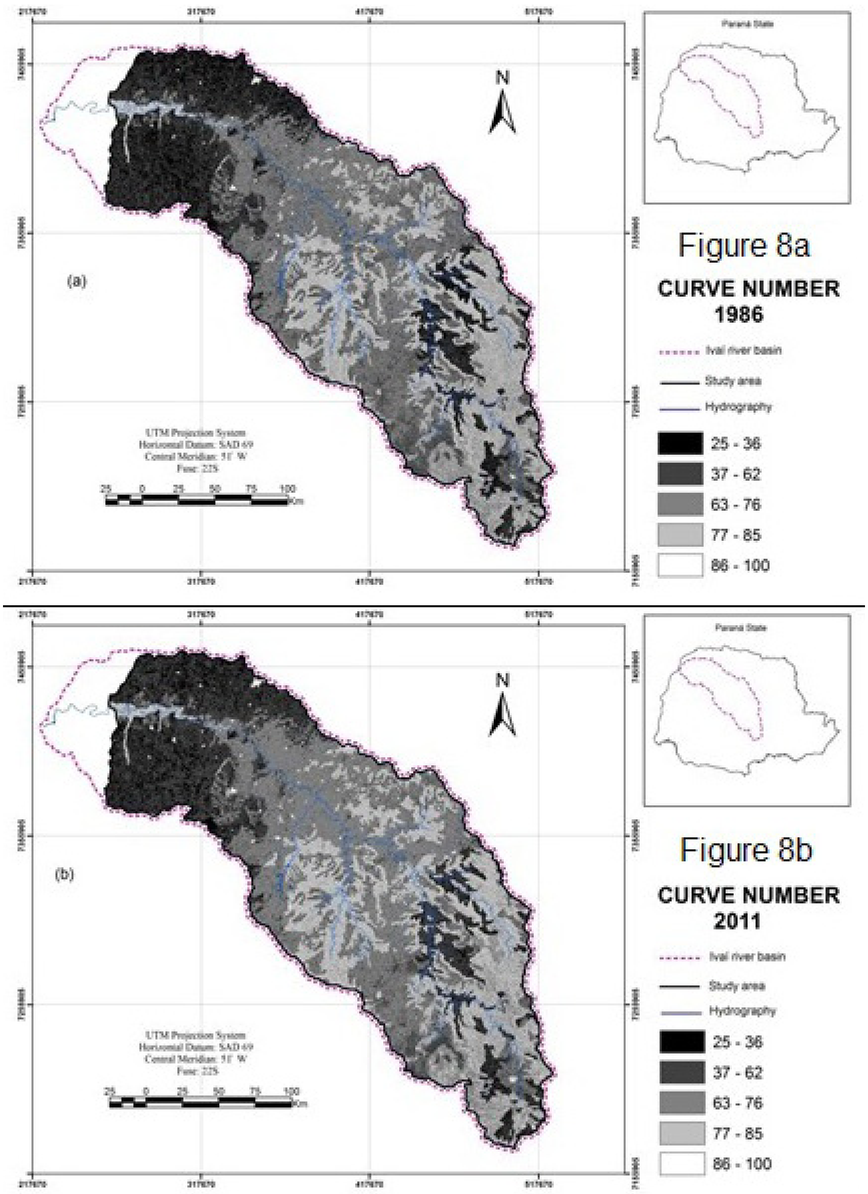


Figure 8 – Maximum soil retention Map: (a) - 1986 and (b) - 2011.

Next, the evolution of the CN was analyzed by comparing the thematic maps shown in Figure 9 pixel to pixel.

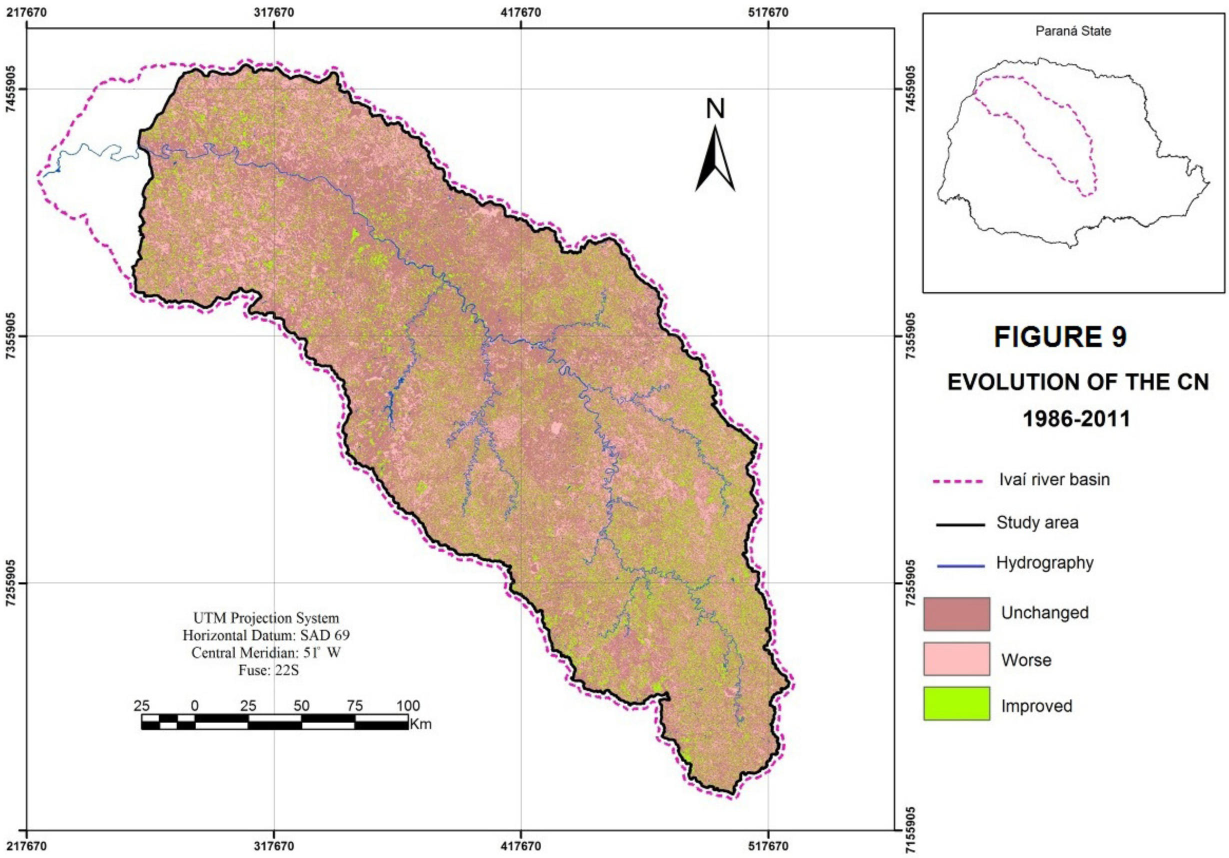


Figure 9 – CN confrontation map.

This analysis shows that a large part of the basin remains unchanged, that is, around 63% of the Ivaí basin area continues with the same CN value. It was also observed that 22% of the pixels reflected the increase in the impermeability and 15% indicated a decrease (Figure 10).

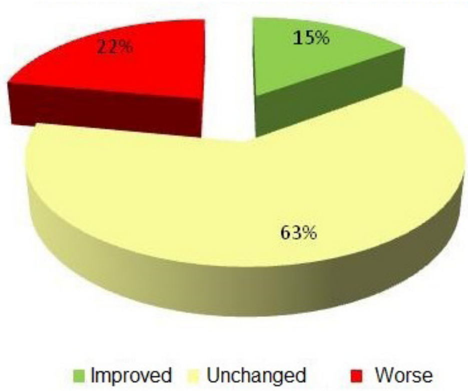


Figure 10 – Permeability change from 1986 to 2011.

It was observed that the main cause of the increase in impermeability was that urbanization and agricultural use also increased 0.5% and 8.6% respectively in areas of fragile soils and high concentrations of clay, which favors runoff over infiltration. Although the use of pasture decreased by 7.9%, the space was mostly filled by urban areas, resulting in an increased flow curve, or the worsening of the CN values.

CN AVERAGE FOR SUB-BASIN

The results of the synthesis of the parameters of the potential maximum rainwater retention of the CN are expressed numerically in Table 4.

Table 4 – Potential degradation by sub-basin - Ivaí river basin

Sub-basin	year 1986	year 2011	CN Average (%)
	CN (0-100%)	CN (0-100%)	
1	67	68	68
2	68	68	68
3	70	71	70
4	69	70	69
5	71	73	72
6	69	71	70
7	75	76	75
8	71	72	72
9	69	71	70
10	69	70	69
11	71	72	72
12	69	71	70
13	53	56	54
14	66	68	67

As can be seen from Table 4 and Figure 11, sub-basin 2 was the only one that did not show variations in the results of the CN in the years analyzed (1986 and 2011).

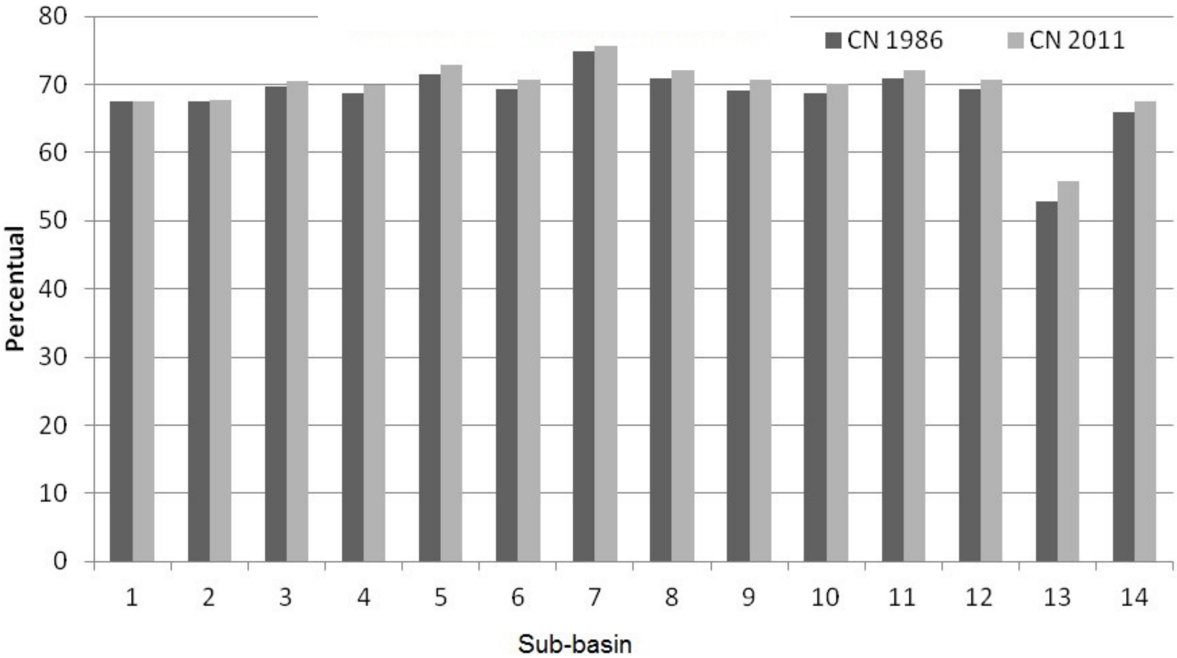


Figure 11 – Comparative data of the CN by sub-basin (1986 and 2011).

The sub-basin that had the lowest percentage of soil impermeability was 13 (emphasis mainly on the year 1986) and the sub-basins of the highest percentages of CN's or flow potential were 7, 5, 8 and 11. In general, the basin of the Ivaí River, represented by sub-basin 14, has the potential flow of medium to high, with a percentage of 68 in 2011; this percentage declined in relation to 1986. These data were used to validate the method, discussed below.

CANONICAL CORRELATION ANALYSIS (CCA)

Table 5 shows the data that makes up the first canonical set of variables which, when related by a multivariate statistical method, confirms the potential of the survey method of the maximum retention in hydrographic basins (second group of variables - CN). Thus, the group of dependent variables are 09: average flow - Q (TP); maximum flow rate - Q (max), the minimum flow rates (7, 15, 30, 60 and 90 days), the standard deviation (STD) and the coefficient of variation (CV), for the average period 1985-2012.

Table 5 – Key hydrological parameters by sub-basin – Ivaí River PR

Sub-basin	Q (TP)	SD	CV	Q (max)	Q (min7)	Q (min15)	Q (min30)	Q (min60)	Q (min90)
1	27.7.	26.88	0.92	291.7	3.6	4.1	5.0	6.7	9.3
2	26.6	24.89	0.86	286.5	3.7	4.2	5.1	6.6	9.3
3	23.1.	21.70	0.26	332.0	2.9	3.3	4.1	5.5	9.1
4	24.4	20.39	0.10	245.3	3.9	4.6	5.4	6.8	9.0
5	20.9	18.83	0.35	335.8	2.4	2.7	3.3	4.5	6.7
6	22.5	18.62	0.07	244.9	3.9	4.4	5.1	6.4	8.5
7	23.4	22.46	0.29	447.4	1.8	2.1	2.7	3.9	6.4
8	23.4	19.93	0.04	272.0	3.7	4.1	4.8	6.3	8.4
9	22.0	9.70	0.28	149.1	8.7	9.8	10.9	12.3	13.3
10	23.1.	10.06	0.51	89.0	8.2	9.6	11.2	13.2	14.6
11	22.6	16.82	0.03	206.8	5.1	5.5	6.2	7.6	9.6
12	20.2	14.13	0.02	152.6	5.6	6.0	6.6	7.8	9.5
13	17.4.	5.41.	0.39	76.3	10.8.	11.3.	11.8	12.7	13.3
14	19.6	12.53	0.02	107.5	6.7	7.0	7.6	8.7	10.1.

Key: Q = Flow; TP = Dwell Time; SD = Standard Deviation; CV = Coefficient of Variation; Q (max) = Maximum Annual Flow rates (mean values); Q (min) = minimum flow rates (average values).

The results of the canonical correlation applied to the CN can be seen in Table 6 below.

Table 6 – Canonical correlation: CN related to flow – Ivaí river basin.

	R canonical	R^2 canonical	Chi-square	GL	p-value
CN	0.90	0.81	15.8577	7	0.03

For the CN the result of canonical correlation, represented by R canon was equal to 0.90 with high canonical R squared of 0.81, chi-square (χ^2) of 15,857 and GL (Degrees of Freedom) equal to 7, which is very significant and expressed a high correlation between the method and flow rates, especially as regards the coefficient of variation at $p < 0.05$, which relates the standard deviation to the average. In addition, the minimum flow of 30, 60 and 90 days were also explained by the CN with $p < 0.05$. These results confirm the hypothesis that the CN can be validated by the flow, because according to the results, they are not independent and are highly related (AYRES et al., 2007; BOGO et al., 2010).

FINAL CONSIDERATIONS

In conclusion, it is clear that CN methodology is a good tool to identify fragile areas and constraints when considering the evolution of land use and occupation by multi-temporal analysis. The main objective of the analysis of canonical correlation applied to the frequency matrix obtained through the database allows the association of the various types of flow, with the CN method, thus being able to verify the efficacy of the method. The results of the analysis performed showed that:

1. The canonical correlations were high considering the level of significance of 5%;
2. The canonical correlation analysis allowed us to observe that the groups considered are not

independent, that is, the groups considered are strongly correlated;

3. These results demonstrate that the CN method reflects the reality of the physical elements of the landscape and its processes and that assigning numerical weights to arrive at generalizations about the areas studied are consistent with reality.

The method permits the consideration of important variables for the analysis and management of physical elements of the landscape and its processes when working with sets of data, which is essential to obtain full and effective results.

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