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ALTERATION EVALUATION IN MICROBASIN DRAINAGE SYSTEMS AS A SUPPORT TO THE GEOENVIRONMENTAL ZONING OF HYDROGRAPHIC BASINS

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ABSTRACT: This project has the objective of evaluating the importance of alterations in the drainage system of a hydrographic basin during 23 years and classifying its drainage microbasins considering the alteration degree. The methodology involved aerial photograph interpretation, analysis of drainage system morphometrical variables and multivariate statistics, by using cluster analysis technique and discriminant analysis. The results make it possible to affirm that there were important alterations in the composition of the drainage system, and the morphological variables which most contributed to the discrimination of the microbasins on the analyzed dates were the density drainage and the hydrographic density. Based on these variables, the microbasins were classified according to the alteration degree.

RÉSUMÉ: Ce travail traite des altérations observées dans um réseau de drainage d'un bassin hydrographique pendant une période de vingt trois ans. Il a pour but d'évaluer la signification de ces altérations et aissi de classer ses micro basins par rapport au degré d'altération. La méthodologie utilisée comprend l'interprétation de photos aériennes, l'analyse des variables morphométriques du réseau de drainage et la statistique à variables multiples, à partir de techniques d'analyse de groupement et de l'analyse par discrimination. Les résultats obtenus ont permis de constater des altérations significatives dans la composition du réseau de drainage. De plus, em considérant toujours la période analysée, les variables morphométriques qui ont apporté le plus contribution dans le classement des micro bassins ont été la densité de drainage et la densité hydrographique.

INTRODUCTION

The hydrographic basin drainage system acts as a record of the alterations occurred inside it and reflects the alterations conditioned by natural processes or anthropic activities, either by alterations in water quality or by the drainage system configuration itself.

Time alterations in the drainage system composition, either by alterations in its structure, form or even by the loss or growth of new channels, act as a geoindicator of the basin environmental conditions, since they reflect the occurrence of anthropic or current natural processes, establishing new dynamics for the surface water runoff.

This project intends to evaluate the importance of the alterations in microbasins of a hydrographic basin, based on the morphometric variables of its drainage system and classify the microbasins according to their alteration degrees afterwards. The analysis of the alterations refer to a period of 23 years and were carried out by using aerial photographs dated 1972 and 1995.

The ranking of the channels in the drainage systems was done according to a classification proposed by Strahler (1957) with modifications, since this author uses only the channels of permanent course. In this research, the channels which were considered as drainage channels were all those that could be identified in the aerial photographs and which could let the water flow linearly, including those of intermittent course,

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since these channels constitute an important variable for the water flow on the basin and are the most susceptive to alterations.

To determine the morphometric variables, the drainage systems were digitized, georeferred and turned into topology. Multivariate statistical procedures were used in order to evaluate the importance of the alterations which occurred in the microbasins and to classify them according to the alteration degree. The discriminant analysis statistical process was used for the significance test, and the cluster analysis was used for the classification of the microbasins in alteration degrees.

The area selected to apply the methodology was the basin of the Capivari River, with an area of 1,560 km² and located in the east central region of the State of São Paulo-Brazil. It is a region where the third largest industrial pole of the country exists and which presents a diversity of ways of occupation and use of the land. The basin was divided in 64 microbasins of 4th, 5th and 6th ramification orders, which are identified by the letter "B" followed by a specific number, such as, B-1, B-2...B-64.

MORPHOMETRIC ANALYSIS OF THE HYDROGRAPHIC BASINS - A BRIEF HISTORY

The first descriptive interpretations referring to drainage systems date back to the beginning of the 19th century. Playfair (1802, apud Horton, 1945), based on visual observations, reported the relationships of the main course of a river and its tributaries, forming a cluster of channels and communicating valleys, determining, thus, "the common junction law".

Horton (1945), based on Playfair's law, for the first time uses a quantitative analysis in drainage system, establishes a channel classification system in a hydrographic system and determines new fundamental laws relating the number and the length of channels.

Strahler (1957) uses a channel classification system with some modifications with regard to the system defined by Horton. According to Strahler's system, the channels without tributaries are considered first order; from the confluence of two first order channels come the second order channels, and so on, being the hydrographic basin order the value of the highest channel order.

Besides the variables *bifurcation ratio* (Rb) and *ratio of the average length* (Rlm) defined by Horton (1945), others had already been defined and used before, such as *drainage density (*Dd*),* which expresses the ratio between the total length of rivers of several orders and the area of the drainage basin, and *hydrographic density* (Dh), also called *stream frequency* (Fs), which relates the total number of streams, which corresponds to the number of first order channels by Strahler classification (1957), to the basin area.

While studying the drainage system evolution, Schumm (1956) defines the variables *maintenance coefficient* (Cm) and *relief ratio* (Rr). The maintenance coefficient represents the minimum area necessary in a basin to keep a one meter outflow channel running. In this conception, as the dissection of the relief goes on, the area available for channel carving grows smaller, determining an inverse correlation between the maintenance coefficient values and the drainage density and hydrographic density.

The application of multivariate statistics on an environmental evaluation involving morphological variables was made by Wood-Smith & Buffington (1996) in evaluating the impact of using the land in the condition of the drainage channels in the Southwest of Alaska-USA. The authors used discriminant analysis to test the classification previously adopted for degraded and non-degraded rivers and also to determine the variables which most contributed to the discrimination among the rivers.

In this research, since it is a comparative study involving internal alterations which occurred in a system (hydrographic microbasins) during a certain period of time, the analyzed morphological variables were separated in two groups: variables related to the morphology and variables related to the drainage system composition.

The variables related to the morphology were considered unaltered for the same microbasin within the analyzed period of time and, therefore, were not directly applied in the analysis of the alterations which occurred in the period. The variables which belong to this group are: Area (A) and perimeter (P), longest length (L), middle width (dm), circularity ratio (Ic), maximum altimetric amplitude (Hm) and relief ratio (Rr).

The variables related to the drainage system composition include linear, aerial and hipsometrical variables and consist of those subject to alterations within the analyzed period. Due to this fact, they constitute potential parameters to picture the occurred alterations. Belong to this group: total number of rivers (N1), number of channels per order (Ni), bifurcation ratio (Rb), drainage system total length (Lt), total length of channel per order (Li), ratio of the average length (Rlm), drainage density (Dd), hydrographic density (Dh), maintenance coefficient (Cm), surface course extension (Eps) and topographic texture (Tt).

INFORMATION SURVEYING AND PROCESSING

Due to the large area covered by the basin of the Capivari river and to the large amount of information necessary to do the research, a work procedure was used that enabled a fast and accurate generation and handling of data that could interface other data sources. The main procedures involved were: photointerpretation, data digitization and processing.

To identify the drainage systems of the 64 microbasins which constitute the basin of the Capivari river, approximately four hundred stereoscopic pairs of aerial photographs were used et a scale of 1:25,000, dated 1972 and 1995. A Carl Zeiss mirror stereoscope was used and a table stereoscope with magnifying lenses, to observe the details.

The data digitization and processing were done by using the software Autocad Map 3.0®. It is an application program linked to the platform of the program Autocad® which allows the handling and interaction of many data files at the same time and have some tools commonly used in GIS (Geographic Information Systems) to obtain numerical data and terrain topology.

After the image preparation process, the digitization was carried out. In this process, it is important that the system digitization of each microbasin be made separately and the channels of each order must be digitized in distinct layers, as well as the tracing of the basin border. This procedure has the objective of making it easy to create topologies to obtain numerical data.

The topology creation covers the final step of the process and they are the ones which provide not only the attainment of numerical data but also the association of information. Seeking to obtain the necessary data for the analysis of the drainage systems, polygon topologies were used to obtain the area (A) and the perimeter (P) and network topologies were used to obtain the total number of channels (Nt), the system total length (Lt), the number of channels per ramification order (Ni), the total length per ramification order (Li) and the average length per ramification order (Lmi). The other morphometric variables were obtained based on these primary variables.

MULTIVARIATE STATISTICAL ANALYSIS

The multivariate statistics involves statistical methods which have the objective of detecting relations in a set of data and variables by analyzing them together and not focusing a variable at each time, as it occurs with univariate statistics. A prerequisite for this kind of analysis, according to Manly (1986), is that the variables themselves be considered of equal importance at first. For this work discriminant analysis was used to determine the importance of alterations in the microbasins considering the drainage systems in 1972 and in 1995 and cluster analysis, with the objective of grouping the microbasins according to the alteration degree in their drainage systems.

RESULTS AND DISCUSSIONS

To use the data which refer to the drainage composition in the multivariate statistical analysis of the alterations occurred in such microbasins, it was important to have a previous evaluation of the variables, considering the existing relationship among them, its applicability to the statistical methods and also their individual importance as a geoindicator of the environmental alterations which occurred in the system. The initial goal was to reduce the number of variables for the statistical analysis.

In this context, a correlation analysis was carried out considering the alteration rate of each variable from 1972 to 1995, i.e., the loss percentage (negative) or gain percentage (positive) in the drainage systems of 1995 in relation to the drainage systems of 1972. The correlation matrix obtained (Figure 1) indicates a correlation of 100% between the variables Dd, Lt, Cm, Eps and Tt and the variables Dh, Nt, and N1, confirming the interdependence existing among them. In this way, it would only be necessary if a variable of each of the two groups are available to represent the alterations occurred in all the others.

	Nt	Lt	Dd	Dh	Cm	Eps	Tt	N1	L1	Lm1	Rb1-2	RLm2-1	N2	L2	Lm2
Nt	1.0	.8	.8	1.0	-.9	-.9	.8	1.0	.5	-.8	-.4	-.0	.9	.6	-.6
Lt	.8	1.0	1.0	.8	-1.0	-1.0	1.0	.8	.7	-.5	-.3	-.0	.7	.6	-.4
Dd	.8	1.0	1.0	.8	-1.0	-1.0	1.0	.8	.7	-.5	-.3	-.0	.7	.6	-.4
Dh	1.0	.8	.8	1.0	-.9	-.9	.8	1.0	.6	-.8	-.2	.1	.8	.6	-.5
Cm	-.9	-1.0	-1.0	-.9	1.0	1.0	-1.0	-.9	-.7	.6	.3	.1	-.8	-.6	.5
Eps	-.9	-1.0	-1.0	-.9	1.0	1.0	-1.0	-.9	-.7	.6	.3	.1	-.8	-.6	.5
Tt	.8	1.0	1.0	.8	-1.0	-1.0	1.0	.8	.6	-.5	-.3	-.0	.7	.6	-.4
N1	1.0	.8	.8	1.0	-.9	-.9	.8	1.0	.6	-.8	-.2	.1	.8	.6	-.5
L1	.5	.7	.7	.6	-.7	-.7	.6	.6	1.0	-.0	.2	-.3	.3	.2	-.2
Lm1	-.8	-.5	-.5	-.8	.6	.6	-.5	-.8	-.0	1.0	.4	-.2	-.7	-.5	.6
Rb1-2	-.4	-.3	-.3	-.2	.3	.3	-.3	-.2	.2	.4	1.0	.3	-.7	-.4	.5
RLm2-1	-.0	-.0	-.0	.1	.1	.1	-.0	.1	-.3	-.2	.3	1.0	-.2	.5	.7
N2	.9	.7	.7	.8	-.8	-.8	.7	.8	.3	-.7	-.7	-.2	1.0	.7	-.7
L2	.6	.6	.6	.6	-.6	-.6	.6	.6	.2	-.5	-.4	.5	.7	1.0	.0
Lm2	-.6	-.4	-.4	-.5	.5	.5	-.4	-.5	-.2	.6	.5	.7	-.7	.0	1.0

Figure 1. Correlation matrix considering the alteration rate of the microbasin variables of the Capivari river basin from 1972 to 1995.

Based on the results of the correlation matrix and also due to its great acceptance and utilization in hydrographic basin geoenvironmental analysis, the variables *drainage density* (Dd) and *hydrographic density* (Dh) were selected to represent each of the groups. These variables are self-independent and show data normally distributed.

The *drainage density* (Dd) expresses the ratio between the total length of the channels and the microbasin area and illustrates the availability of channels for the linear waterflow. The *hydrographic density* (Dh) relates the total number of rivers and the microbasin area. The variances in Dh, as mentioned by Christofoletti (1974), reflect in alterations of the hydrological behavior of a hydrographic basin in its most fundamental aspect, i. e. , to lose or gain new water streams, and this is confirmed by the correlation of 100% with N1. In short, significative variances in Dd and in Dh indicate how much a basin changed for losing or gaining new water streams.

By using these variables, the multivariate statistical process of the discriminant analysis was done for the 64 microbasins in 1972 and 1995, with the objective of submitting the data to the significance test, i. e., evaluate whether the alterations were meaningful or not. For this, the following hypothesis were initially considered:

- Null hypothesis (Ho) - there was no alteration in the microbasins of the Capivari river basin from 1972 to 1995.
- Alternative hypothesis (H1) - there were alterations in the microbasins of the Capivari river basin from 1972 to 1995.

The results obtained with the assistance of the program Statistica® (Table 01) indicate a value F equal to 3.90 for degrees of freedom 2 (numerator) and 127 (denominator). The standardized distribution value of F for these degrees of freedom is 3.00, for a significance level $\alpha = 0.05$. Since F (calculated) is bigger than F (standardized), there is a sound basis to reject Ho, that is, it may be affirmed that there were significative statistical alterations in the microbasins in the considered period of time. This fact may be proved by the low value obtained for p-level=0.023.

Table 01: Discriminant analysis results obtained by using the program Statistica® for the 64 microbasins of the Capivari river basin in 1972 and 1995.

Significance test $\alpha = 0.05$	**Percent correct**	**Squared Mahalanobis' distances (d^2)**	**Wilks' λ for the variables**
F(2,127)= 3.90 (calculated)	G72 (basins 1972) = 50.8%	$D^2 = 0.245$	Dd = 0.968
F(2,127) = 3.00 (standardized)	G95 (basins 1995) = 64.6%		Dh = 0.986
p-level = 0.023	Total = 57.7%	**Wilks λ for the model**	
		Wilks $\lambda = 0.942$	

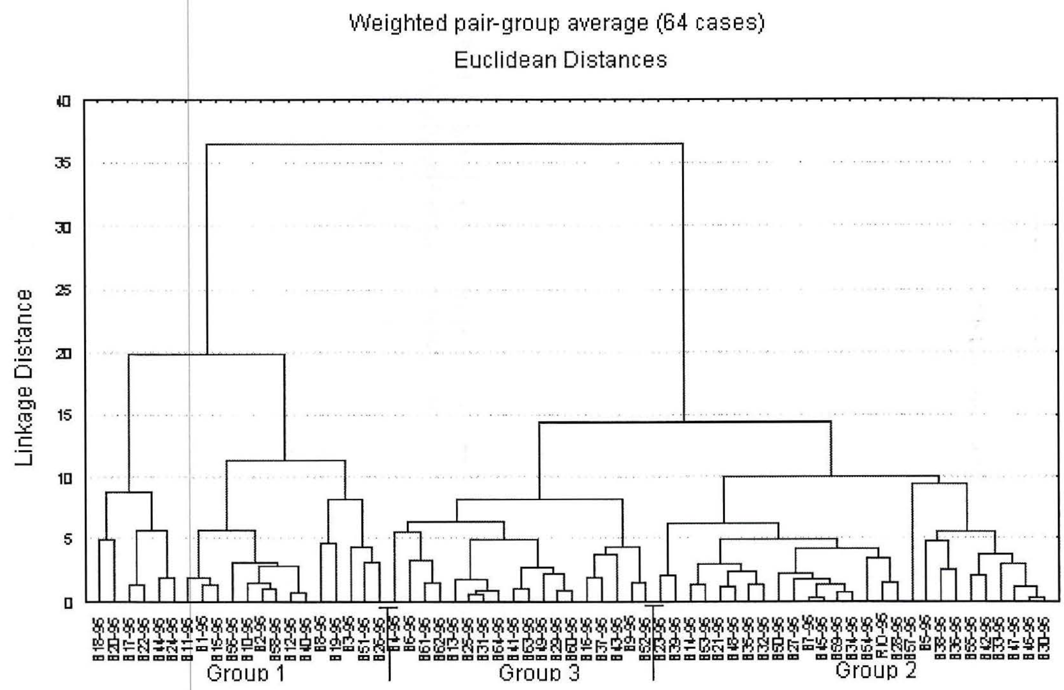

Figure 2. Hierarchical tree obtained for the 75 microbasins of the Capivari river basin considering the alteration rate of the variables Dr and Dh from 1972 to 1995.

Considering the higher influence of Dh and Dd in discriminating the basins and their importance as alteration indicators in the number and length of channels, a cluster analysis was made considering the alteration rates (percentage) of these variables from 1972 to 1995, with the objective of grouping the basins according each alteration degree in the linear runoff of surface water.

An hierarchical tree methods and weighted pair-group method were used, considering distance coefficient and Euclidean distance measurement as similarity criterion. It can be observed in the obtained hierarchical tree (Figure 02) three case groups, defined, previously as Group 1, Group 2 and Group 3. (Table 02).

Table 02: Microbasins classification per alteration degree based on the groups obtained with the cluster analysis.

Group	**Microbasin List**
Group 1	B26, B24, B40, B44, B56, B58, B51, B22, B20, B18, B19, B17, B15, B12, B10, B8, B11, B3, B2, B1
Group 2	B28, B30, B32, B34, B36, B38, B42, B46, B48, B50, B54, B59, B57, B55, B53, B47, B45, B39, B35, B33, B27, B23, B21, B24, B7, B5, rio
Group 3	B52, B60, B62, B64, B63, B61, B49, B43, B41, B37, B31, B29, B16, B25, B13, B9, B6, B4

In order to analyze and determine a terminology to the groups defined by the cluster analysis, a discriminant analysis was repeated, now considering the cases classified per groups. The main results are shown in Table 03. It can be observed a highly significative discrimination for group 1, where $F(2,37) = 5.07$ and the p-level=0.011, and, therefore, it was classified as of *high degree alteration.*

For the other groups, the significance test does not prove the alterations among the groups, however, it can be observed by D^2 and the percent correct that group 2 is better discriminated than groups 3. Therefore, Group 2 was defined as of *middle degree alteration* and Group 3 as of *low degree alteration.* Figure 03 shows the map with the arrangement of the microbasins classified.

Table 03. Discriminant analysis results obtained in the program Statistica® for the 3 groups defined by the cluster analysis.

	Group 1	**Group 2**	**Group 3**
significance test *α = 0,05*	F(2,37)= 5.07 (calculated) F(2,37) = 3.25 (standardized) p-level = 0,011	F(2,51)= 1.52 (calculated) F(2,51) = 3.20 (standardized) p-level = 0.227	F(2,34)= 0.30(calculated) F(2,34) = 3.30 (standardized) p-level = 0.743
Porcent correct	G72 (B 1972) = 50.0% G95 (B 1995) = 75.0% Total = 62.5%	G72 (B 1972) = 55.5% G95 (B 1995) = 66.6% Total = 61.1%	G72 (B1972) = 50.0% G95 (B1995) = 66.6% Total = 58.3%
squared Mahalanobis Distances (d^2)	$D^2 = 1.096$	$D^2 = 0.239$	$D^2 = 0.073$
Wilks Lambda	Wilks λ = 0,682	Wilks λ = 0,936	Wilks λ = 0,983

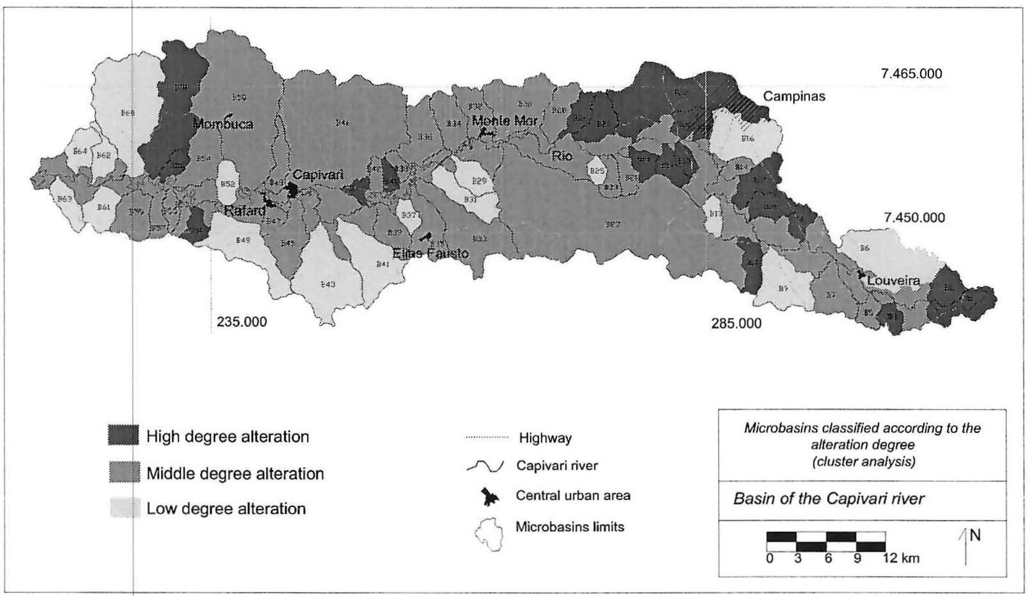

Figure 3. Microbasins Classification of the Capivari river basin according to the alteration degree

CONCLUSIONS

Since the morphometric analysis was made only based on the time alterations in each of the microbasins and didn't involve analysis between microbasins, it was necessary to separate the variables which didn't suffer significative alterations in the considered period of time (morphological variables) from those subject to significative alterations (drainage system composition variables). Only the variables referring to the drainage system composition were used in the statistical analysis of the alterations.

The maximum correlation presented by variables Dd, Lt, Cm, Eps and Tt, and by the variables Dh, Nt and N1, when the time alteration rates were used, was expected, considering the existing interdependence between them. In this way, only one variable from each of these two groups would be enough to represent the time alterations in the microbasins as so. The variables Dd and Dh were chosen to be used in the multivariate statistical analysis of the alterations occurred in the microbasins because they constitute widely known and accepted as meaningful parameters in geoenvironmental analysis of hydrographic basins. The discriminant statistical analysis let us affirm that there were significative alterations in the microbasin drainage system composition of the Capivari river basin from 1972 to 1995. The variables which more contributed for the discrimination among the microbasins were Dh and Dd.

The microbasins were classified according to the alteration degree in the drainage system composition, based on the alteration rates of the variables Dh and Dd. For this purpose, it was used cluster analysis and the microbasins could be grouped in three groups (classes): High alteration degree, middle alteration degree and low alteration degree. The designation given to each of the groups, later called classes, could be confirmed with the re-execution of the discriminant analysis, but considering each group separately this time.

The microbasins classified as having high alteration degree are located on the east sector, where the urban growth is sharper (Figure 03). The microbasins of this group are mainly fourth order ramification and small, what can be contributing to more expressive values of alteration rates. On the other hand, some larger and of higher ranking microbasins, classified as having middle alteration degree, may have underestimated values when compared with those obtained for smaller basins, since for the latter, small differences in the number of first order channels or in the total length of channels may represent great variations in the variables Dd and Dh.

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