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PROPOSAL OF A WATER QUALITY INDEX FOR THE BAIXO JACUÍ REGION, RS, BRAZIL

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ABSTRACT

This work aims to determine the degree of contamination of surface waters that are affected by coal processing and steel industry activities located in the Baixo Jacuí region of Rio Grande do Sul State. The sampling period was from May /94 to November/95. The following variables were analyzed in the water samples: temperature, pH, turbidity, conductivity, total dissolved solids, dissolved oxygen and metals (Pb, Cr, Cd, Fe, Ni, Co, Mn, Zn and Cu). Using Factor Analysis, the information was reduced, in order to improve visualization and interpretation of spatial and temporal variations on water resources. As a result, a Water Quality Index (WQI) was created. By the observation of the WQI behavior along the water courses and during the studied period, it was possible to verify the existence of local contamination in those streams subjected to a direct influence of coal activities (Conde, Capão da Roça and Ratos streams). In rivers such as Jacuí and Taquari, alterations in the water quality (from local anthropogenic sources) were not observed. Hydrological data from Conde stream basin allowed us to verify that the water quality index is sensitive to flow variations in the more contaminated water courses.

RESUMO

O presente trabalho tem como objetivo determinar o grau de contaminação das águas superficiais afetadas pelas atividades de processamento de carvão e siderurgia, localizadas na região do Baixo Jacuí, estado do Rio Grande do Sul. O período de amostragem foi de Maio/94 a Novembro/95. Os parâmetros pH, turbidez, condutividade, sólidos totais dissolvidos, oxigênio dissolvido e metais (Pb, Cr, Cd, Fe, Ni, Co, Mn, Zn and Cu) foram determinados nas amostras de águas. Análise Fatorial foi aplicada de forma a reduzir as informações e facilitar a visualização e interpretação das variações espaciais e temporais das águas superficiais. Como resultado, um Índice de Qualidade de Água (IQA) foi elaborado. A partir do comportamento do IQA ao longo dos cursos d´água, no período de tempo estudado, foi possível verificar a existência de contaminação nos arroios (Conde, Capão da Roça e Ratos), que apresentam influencia mais direta das atividades de carvão. Nos rios Jacuí e Taquari, não foram observadas alterações da qualidade da água (das fontes locais antropogênicas). Dados hidrológicos da bacia do arroio do Conde permitiram verificar que o Índice de Qualidade da Água é sensível à variação do fluxo nos cursos d' água mais contaminadas.

INTRODUCTION

The largest Brazilian coal reserves are located in the State of Rio Grande do Sul, which accounts for 60 % (near 3 million tons/year) of the country total production. Coal activities are primarily concentrated in the Jacuí river basin, and the Baixo Jacuí region has 19 % of the total state coal reserves.

The Jacuí River receives direct and indirect affluents and effluents from coal processing and steel industry areas. The Conde and Ratos streams are located in the right hand margin of the Jacuí River, which is characterized by the presence of coal mines. Conde stream, particularly, suffers a direct and significant influence from coal contamination, receiving effluents from several inadequate disposal sites of coal waste and from the preparation plant of the Mining Company of the Rio Grande do Sul – CRM. Up to now little is known about the contamination extent originated from local anthropogenic sources. The purpose of the current work is to contribute to the understanding of the influence of coal activities in the water contamination of this region, determining physical, and chemical parameters. A Water Quality Index (WQI) was elaborated, in order to reduce information and enable the visualization and interpretation of spatial and temporal alterations of the water bodies. Different WQI methods and variables had been reported in several works (Haase & Possoli, 1993; Haase *et al.*, 1989; Costa *et al.*, 1984; Stodjda & Dojlido, 1983).

The factor analysis technique was applied in order to evaluate the relevance degree of different variables in the water courses contamination in the Baixo Jacuí region, which was caused by coal processing and steel industries activities. The data obtained from the characterization of surface waters was used to evaluate the pollution degree of the region.

MATERIALS AND METHODS

The water courses selected for this study consisted of four streams: Conde, Capão da Roça, Taquara and Ratos, and two rivers: Jacuí and Taquari. The selection was based on the existing influence of coal processing and steel industry activities in these water bodies. The location of all sampling sites, and the major pollution sources are illustrated in Figure 1.

Water samples were taken monthly, from May/94 to November/95, preserved with suprapure HNO_3, pH<2, and stored at 4°C until chemical analysis were done.

The following variables were studied in the water courses: temperature, pH, turbidity, conductivity, total dissolved solids (TDS), dissolved oxygen (DO) and total metals (Pb, Cr, Cd, Fe, Ni, Cu, Co, Mn and Zn). The methodology used for the determination of such parameters followed the procedures recommended by the Standard Methods (APHA, 1992) and the analysis were made in triplicates. Other parameters were determined, but they weren't taken into consideration due to insufficient data and/or the fact that a significant data fraction was below the detection limit of the analytical methods.

Determinations of metallic elements in water were performed by ICP-AES-Sequential-38 S, utilizing ultrasound nebulizer to detect low concentrations. The instrument was calibrated with standard and reference solution.

Flow was measured at some points in Conde stream basin (points 2, 3, 4 and 5) with micro hydrometric current meters. The flow was not determined for the other points because the available devices did not permit the measurement in large-volume water courses.

The Water Quality Index (WQI) was determined by the Factor Analysis technique, by Principal Components Method, using the computer software STATISTICA FOR WINDOWS 4.3^{T}.

Factor Analysis is a generic name given to a class of Multivariate statistical methods, whose primary purpose is to define the underlying structure in a data matrix. This method can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions (factors). The objective is to find a way of condensing the information contained in a number of original variables into a smaller set of variables (factors) with a minimum loss of information.

Factor Analysis consists of three basic steps (Hair *et al.*, 1998): the preparation of the correlation matrix to meet the specified objectives of grouping variables; the extraction of factors, and the possible data rotation to a final solution, in the search for simple and easily interpretable factors. Unrotated factor solutions extract factors in their order of importance.

In order to compare the monthly obtained WQI results for each point, a standard WQI was estimated to the Baixo Jacuí region.

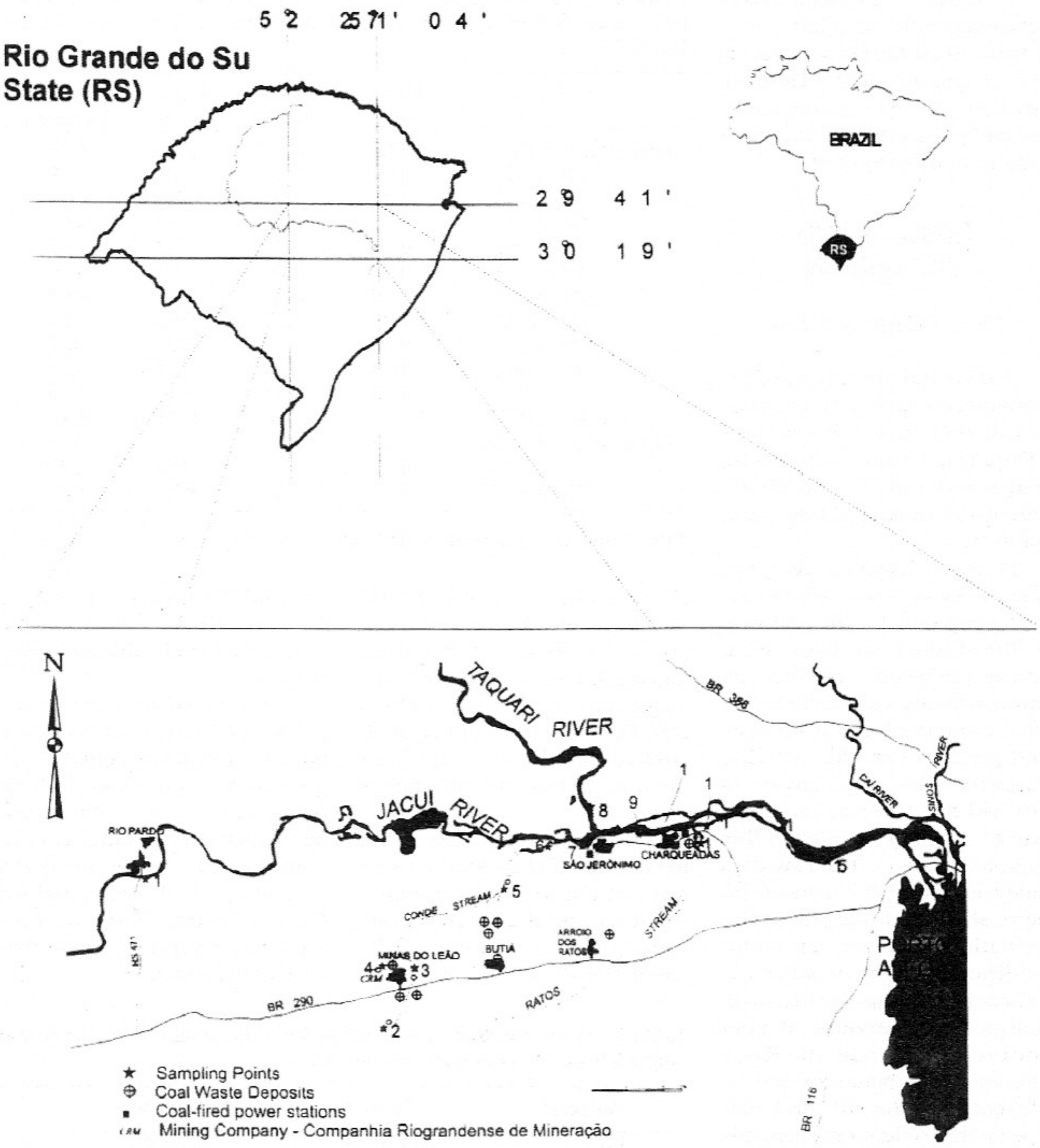

Figure 1 – Surface water sampling sites in the Baixo Jacuí region, Rio Grande do Sul State, Brazil.

In order to establish WQI reference value, this index was estimated for the point 1 (Jacuí-river) and point 2 (Taquara stream), which represent background points in relation to the contamination by coal.

RESULTS AND DISCUSSION

Water Quality Index

A descriptive analysis of the variable, mean value and standard deviation, for the streams (Taquara, Conde, Capão da Roça and Ratos) and rivers (Jacuí and Taquari), is shown in Table 1.

Table 1 – Mean and standard deviation for the studied variables in rivers (Jacuí and Taquari) and streams (Conde, Capão da Roça, Taquara and Ratos)

Variables	Rivers Mean	Standard Deviation	Streams Mean	Standard Deviation
Temperature (°C)	20.9	4.51	20.3	4.80
Pb (µg/L)	11.2	7.30	26.8	73.9
Cr (µg/L)	6.08	4.05	17.3	47.1
Cd (µg/L)	0.63	0.58	2.10	6.02
Fe (mg/L)	2.92	1.64	7.32	16.7
Ni (µg/L)	8.16	8.06	24.0	37.0
Cu (µg/L)	7.05	8.35	15.5	43.0
Co (µg/L)	1.83	1.23	9.63	15.1
M (µg/L)	58.1	30.7	352	459
Zn (µg/L)	42.8	55.8	107	222
pH	6.80	0.41	6.40	0.76
Turbidity (UNT)	35.5	31.2	1343	7799
Conductivity (µs/cm)	28.5	25.4	221	266
TD (mg/L)	15.01	11.7	110	132
DO (mg/L)	8.41	1.08	8.07	1.30

TDS: Total dissolved solids; DO: Dissolved oxygen.

It was observed that the highest mean values were found in the streams, for the majority of the studied variables, what can be attributed to the fact that these streams are located near to the contamination sources and present a smaller dilution capacity. This explanation is also valid for pH and DO mean values, slightly smaller in this region (Table 1). The raw data analysis, although not presented here, show that, despite pyrite oxidation influence on water acidification, there were no pH values alterations in sites with a significant amount of coal (point 4 – Capão da Roça stream). This behavior can be attributed to the still undeveloped pyrite oxidation, since this reaction proceeds slowly in time (Daniels, 1996). Nevertheless, in Conde stream (point 3), an acidic pH value was observed, probably induced by pyrite oxidation from old disposal sites.

The Factor Analysis technique was applied to the 15 studied variables. The variables used to calculate the WQI were selected from the correlation matrix. The selection criteria was based on the variables capacity to present correlation among themselves, with significance ranging between 0.1% to 5%. The WQI was applied to all studied variables, except temperature, pH and dissolved oxygen.

The correlation between the pH and the metals was not significant, due to the fact that only the total metal concentrations were considered in this study, since the dissolved elements showed extremely low values (< LD). Those values can be attributed to pH values between 6.4 and 6.8.

A new set of synthetical variables (common factors) was obtained using the Principal Components method. Only the first component was considered, based on the most important and common part of the analyzed variables, which accounted for 68% of the total variance. Factor 1 was interpreted as the Water Quality Index.

Table 2 – Water common factors in the Baixo Jacuí region for the period ranging from May /94 to November/95

Variables	Factor 1	Factor 2
Pb	0.779528	0.402963
Cr	0.895741	0.414406
Cd	0.851365	0.392988
Fe	0.938514	0.161942
Ni	0.845237	-0.105891
Cu	0.816265	0.293120
Co	0.940881	-0.079418
Mn	0.848660	-0.473132
Zn	0.707374	-0.106316
Turbidity	0.631723	0.250612
Conductivity	0.780176	-0.596640
TDS	0.785533	-0.589433
Total variance	0.677252	0.134966

All variables had high factor loading in the Factor 1, except for turbidity, which presented a low loading coefficient < 0.63. The other variables presented positive loading > 0,7 and were characterised by variables with greater influence from coal contamination (Table 2).

The highest WQI score value, the worst the water quality. WQI tends to enhance from the origin to the mouth of a water course and presents a distribution with mean value equal to zero and variance equal to the unity.

The highest score value was registered at point 4. It was classified as an extreme value (outlier) as it was at 8.6 standard deviations away from the mean value. This extreme value points out to a local critical situation. The WQI data obtained in this work was classified according to these considerations.

Figure 2 shows the WQI results obtained from the Conde stream basin. There were obvious signs of the coal processing activities influence during May/94 to November/95. Point 2, located upstream from contaminating sources, presented a mean WQI value of -0.37 (Fig.2). Point 3 showed an increase in the WQI value to 0.62, which can be attributed to the existence of three coal waste deposits nearby (Teixeira *et al.*, 1999). The most contaminated point was located in Capão da Roça stream (point 4), a Conde stream affluent. This water course presented mean and maximum WQI values of 2.66 and 8.6, respectively, due to significant amounts of coal tailings from washing process discharged by the Companhia Riograndense de Mineração (CRM). Point 5, located at Conde stream, in the mouth of Martins stream (downstream to point 3), presented a better water quality index (mean WQI equal to 0.04), in spite of the contribution of coal waste deposits. The greater distance from this sampling point to the contamination sources can explain this value. Between points 5 and 6 (at the mouth of Conde stream), an improvement in water quality was observed (mean WQI value equal to -0.21), due to the absence of new anthropogenic sources. Point 11, located at the mouth of Ratos stream, did not show any significant quality alteration, despite the disposal area of coal waste located upstream, and the WQI value remained equal to the one found at points 2 and 6 (-0.33).

There was no trace of any hypothetical trend for WQI increase, in Jacuí river, from upstream to downstream, since a short part of the river was studied. It was located, precisely, in the region suffering from processing coal influence (Fig. 3). The WQI mean presented a constant pattern along the river, with small variation ranging from -0.29 to -0.24. This suggests that the local anthropogenic sources do not play a significant role in water quality, as a result of its large flow and consequent dilution capacity. Results obtained in Jacuí river were in agreement with data from DMAE (1981), reporting the non-variability of waters along Jacuí river. The pollutants discharged into the water are probably suffering an accumulation process in the Jacuí basin sediments. This fact was verified through the metallic elements determinations.

We can confirm, from the standard WQI (0.13) estimation, that the sites submitted to coal contamination are represented by cases where quality indices are greater than 0.13. The standard WQI, allowed us to state that the areas contaminated by coal are concentrated around points 3 and 4, and that all the other areas are not considerably affected by coal-processing activities.

Relation between water quality index and flow

Flow measurements were obtained, as mentioned before, for some determined sites of the studied area. Characteristic flow values for these sites are illustrated in Table 3.

The possibility of flow values greater than those measured in this study was verified through the permanence curve. This is an important observation, since it can indicate the possibility of the existence of more critical periods than those measured. Two critical situations were verified and can be explained by precipitation effect on coal waste deposits.

The intense precipitation permeates in the waste deposits and drains off to the rivers, transporting solid residues. During this period, the precipitations produce a constant load, due to the association of the water rain and the solid residues. This situation leads to critical conditions during more intense precipitation periods, since the effluents from waste deposits, probably contaminated, carried out to the water courses. Thus, there is a significant load in the river, even with its higher dilution capacity. This condition is even more critical in small rivers located closer to the waste deposits.

During the dryness period, the less intense precipitation on the coal waste deposits can lead to critical condition, since pollutant loads can reach the rivers associated with a low dilution capacity.

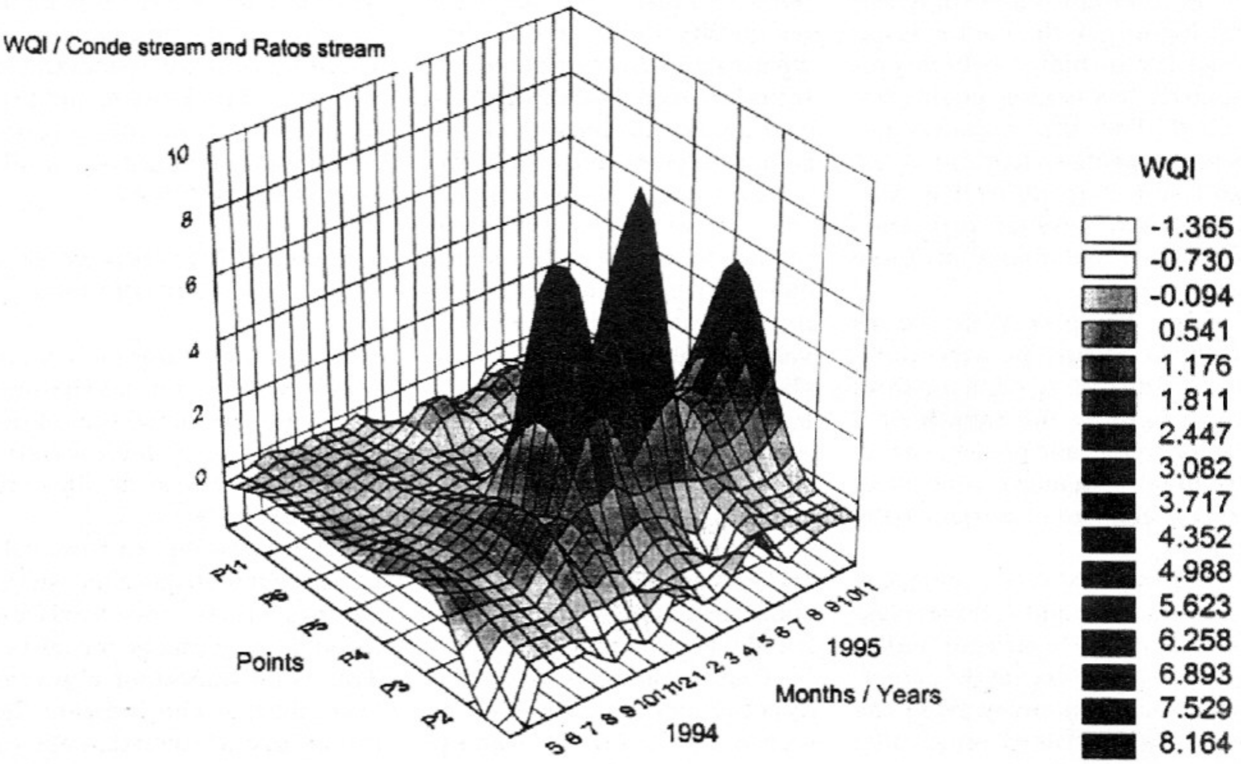

Figure 2 – Conde (points 2, 3, 4, 5 and 6) and Ratos streams (point 11), Water quality index calculated for the period of May/94 to November/95.

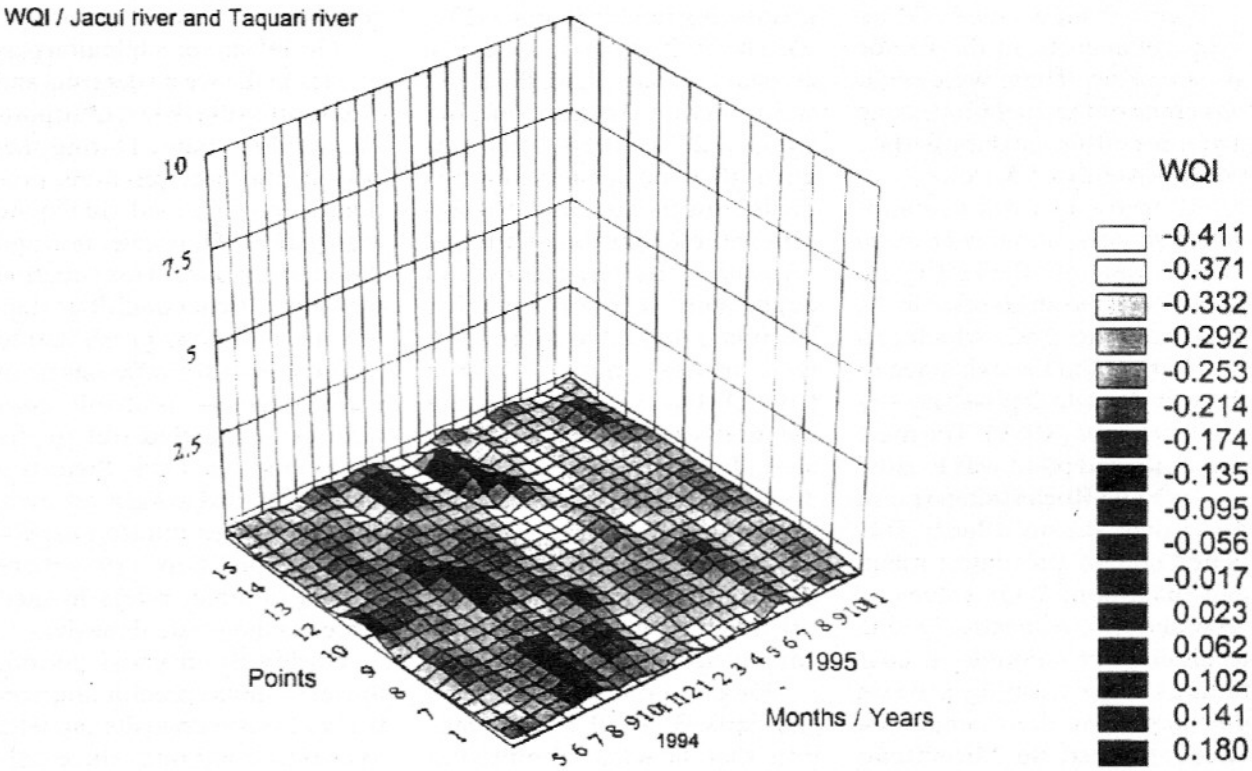

Figure 3 – Water quality index in the Jacuí (points 1, 7, 9, 10, 12, 13, 14 and 15) and Taquari rivers (point 8) calculated for the period of May/94 to November/95.

Table 3 – Characteristic flow values in the observed site.

Site	Mean flow L/s	Minimum flow for 7 days and 10 years L/s *	Flow with 95% permanence L/s
2	279	5.60	7.76
3	525	10.5	14.6
4	225	4.52	6.26
5	2850	57.2	79.2
6	5427	109	151

* From: Tucci (1996)

Table 4 shows permanence curve values of measured flow and percentual fraction. It is observed for high flow values that probabilities are < 1.0, since the permanence curve has been adjusted just for two low-flow regional values. A similar probability was verified in the same month for most cases, considering different sites. As predicted, the most significant probabilities have occurred in low-precipitation months. February/95 can be considered the most critical month of the sampling period, since points 2 and 3 values represent around 68 % of the permanence curve. November/95 showed a more significant permanence curve probability for points 4 and 5, around 71.0 % and 74.3 %, respectively. These results are in disagreement with those previously obtained for points 2 and 3, since in those sites, it was not possible to measure the flow during the period of low precipitation (January/95, February/95 and March/95).

Figures 4 and 5 present the relationship between quantity (flow) and quality (WQI). At point 2 (Fig.4), the WQI variation shows that, even with an alteration in quantity (flow), quality remains preserved ($r = 0.105$; $p = 0.678$). This is attributed to pollution sources absence in this point. Figure 5 shows the scatteplot (with regression line) of WQI and flow for points 3, 4 and 5, revealing a reduction in the quality index during high-flow periods ($r = -0.317$; $p = 0.053$). It was observed that, at point 4, the flow is higher than in the other points and they are extreme values.

Table 4 – Measured flow and permanence curve percentual

Month/year	Flow L/s Site 2	P C P % Site 2	Flow L/s Site 3	P C P % Site 3	Flow L/s Site 4	P C P % Site 4	Flow L/s Site 5	P C P % Site 5
May/94	–	–	192	39.2	140	22.8	1.812	32.3
June/94	333	7.6	395	21.6	204	13.4	–	–
July/94	1.162	<1	1.216	<1	727	< –	–	–
August/94	526	<1	761	5.6	173	17.5	–	–
September/94	401	3	646	9.6	217	12.0	2.442	25.3
October/94	60	50	129	48.9	–	–	623	57.4
November/94	167	24.6	414	20.5	143	22.2	–	–
December/94	81	42.5	98	55.6	30	60.9	572	59.4
January/95	131	30.6	75	62.1	–	–	–	–
February/95	29	67.8	59	67.9	–	–	–	–
March/95	91	40.0	146	45.8	–	–	–	–
April/95	79	43.1	86	58.7	–	–	962	47.2
May/95	97	38.0	100	55.1	–	–	573	59.4
June/95	56	51.6	78	61.1	–	–	271	77.0
July/95	683	<1	4.080	<1	–	–	–	–
August/95	418	2	534	14.3	198	–	–	–
September/95	590	<1	1.454	<1	–	–	–	–
October/95	332	7.7	439	19.0	142	22.4	–	–
November/95	92	39.3	102	54.6	20	71.0	304	74.3

P C P %: Percentual fraction of permanence curve %

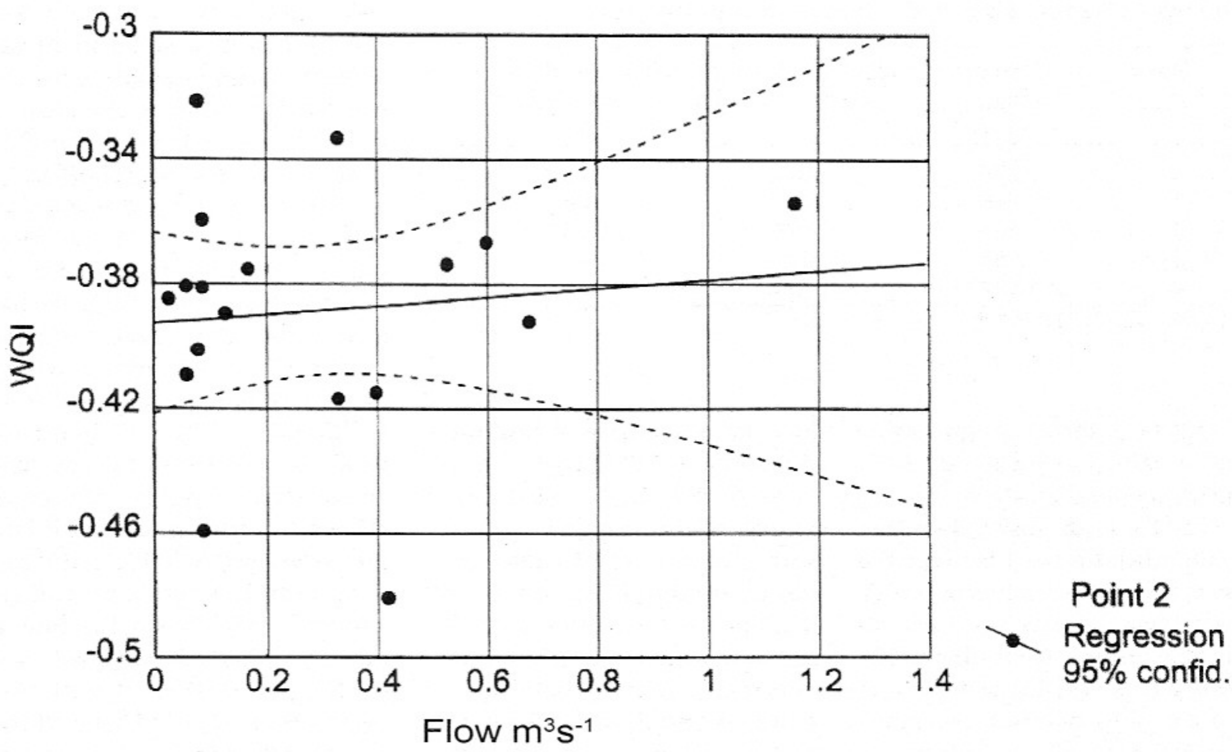

Figure 4 – Relation between water quality index and flow at sampling point 2

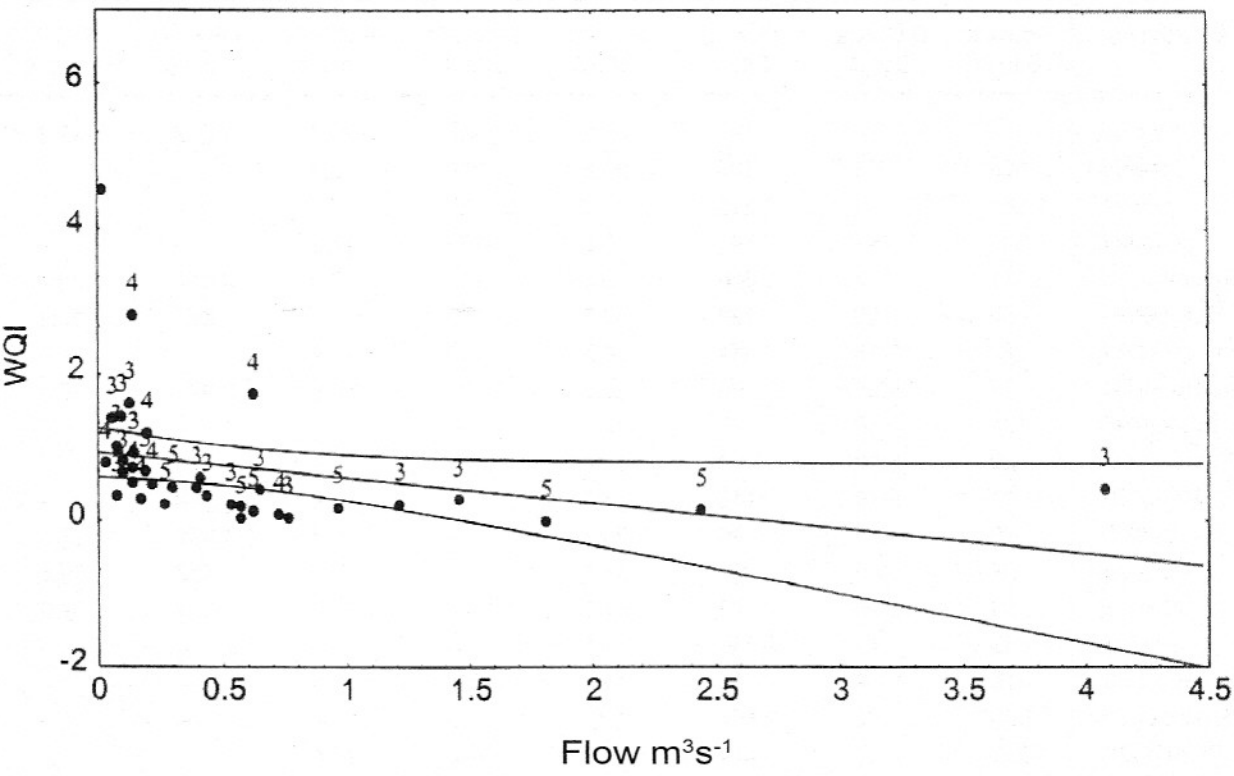

Figure 5 – Relation between water quality index and flow at sampling point 3, 4 and 5.

CONCLUSION

The use of the Factor Analysis technique, in order to determine the Water Quality Index (WQI), allowed the interpretation of spatial and time trends in the studied water bodies.

The behavior of WQI values are related to distinct hydrological conditions and to the distance of sources contamination. The influence of anthropogenic sources was verified only in Conde and Capão da Roça streams (points 3 and 4). The water quality of Jacuí river was not significantly altered.

The WQI was calculated based on the chemical composition of the water, which describes punctual-in-time situations, thus it did not provide evidences of structural and functional alterations in the ecosystem as a whole.

Critical condition in coal waste deposits was observed during periods of intense precipitation and dryness, especially in small water courses near waste deposits.

Hydrological results from the Conde stream basin showed that the WQI was sensitive to variations in the flow water bodies' for the most contaminated sites.

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