Some reflections on the future of the water quality of the Corumbataí River basin, São Paulo State, Brazil

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Abstract The waters of Corumbataí River in the middle and eastern part of São Paulo State, Brazil, are extensively used for human consumption; their water quality has been modified mainly due to increasing pressure caused by population growth, accompanied by a more accentuated industrial development for the whole São Paulo State in the early 1970s. The Corumbataí River basin has, over time, received significant emissions of municipal waste products and discharges of wastewater, sludge, sewage, sanitary and industrial effluents, but the first effluent treatment plant at Rio Claro city was only inaugurated at the end of the 1990s. Data on river water quality from two widely spaced locations in the Corumbataí River basin are reported in this paper; they indicate the need for continuous initiatives and efforts by decision makers in order to improve and preserve the water quality in the basin for the 21st century.

Key words Corumbataí River basin; water quality; physical and chemical parameters; surface water; rainwater

INTRODUCTION

The Corumbataí River basin extends over an area of about 1581 km^2 in the middle and eastern part of São Paulo State, Brazil. It is a sub-basin of the giant Paraná sedimentary basin that extends over an area of 1 700 000 km^2 (1 000 000 km^2 in Brazil). The Corumbataí River is the main drainage in the basin, flowing from the cuestas zone to the confluence with the Piracicaba River (Fig. 1). Rio Claro city is the largest (480 km^2) and most populated (170 000 inhabitants) municipality in the basin. Monthly measurements of the flow rate during the last 26 years have been undertaken at Santa Terezinha (a district belonging to the Piracicaba municipality), close to the confluence with the Piracicaba River (DAEE, 2002). The discharge frequency distribution (Conceição & Bonotto, 2002) indicates that 37.4% of the observed values are between 10 and 20 m^3 s^{-1}. The average monthly flow is 26.4 m^3 s^{-1}, the maximum recorded value is 168.4 m^3 s^{-1} (February 1995) and the minimum recorded value is 6.0 m^3 s^{-1} (September 1994) (Conceição, 2000).

The climate of the region is tropical, characterized by a wet summer (October to March) and dry a winter (April to September) (Inácio & Santos, 1988). The area often has 55–65 days of rain per year, with more than 80% of the precipitation falling

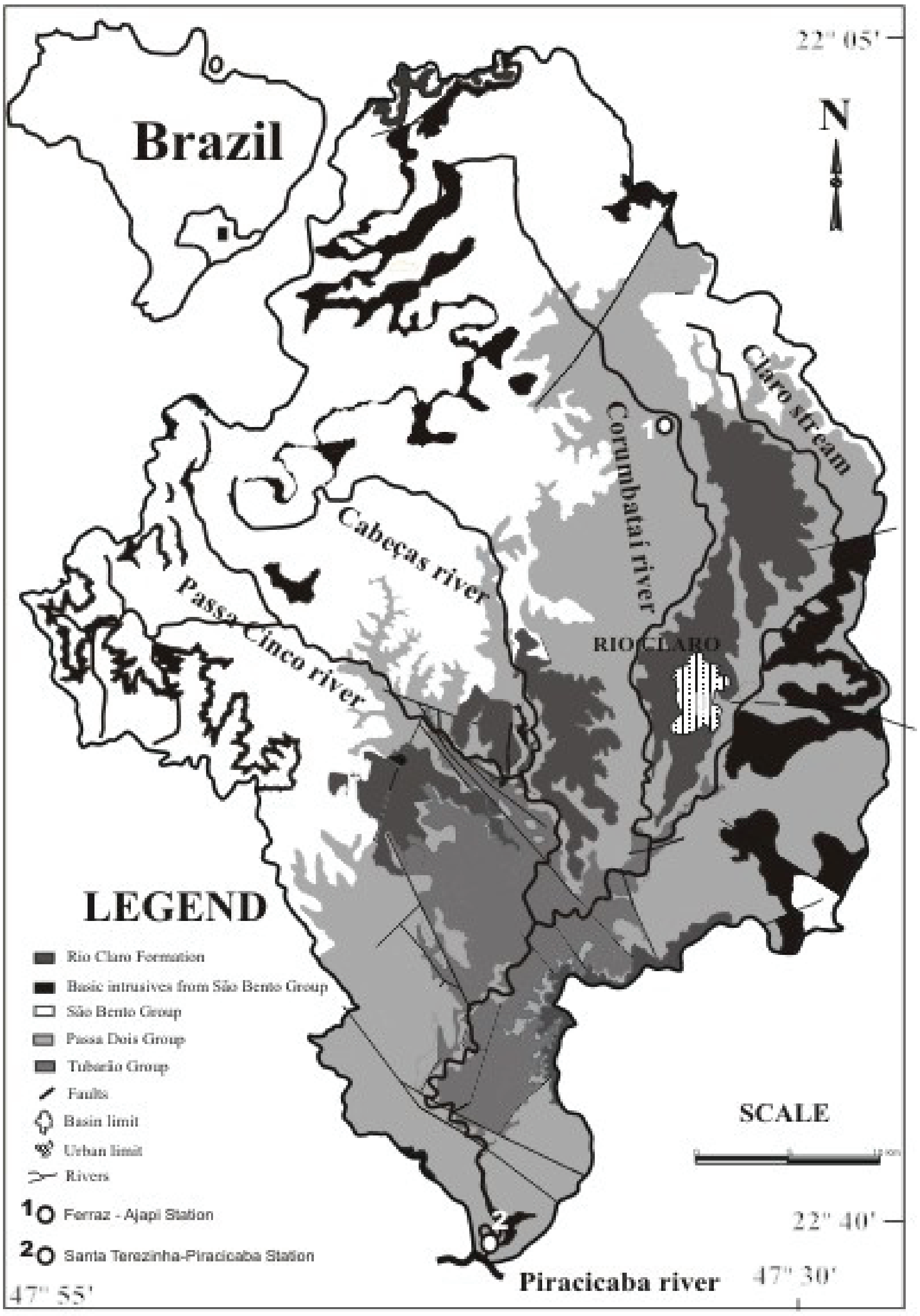

Fig. 1 Sketch map of the study area and location of the sampling sites. Modified from Lima (2000).

between October and March (Bonotto & Mancini, 1992). The mean annual rainfall is 1572 mm, and the discharge of the Corumbataí River is closely linked to rainfall (Conceição, 2000).

In order to evaluate the present state of water quality in relation to human impacts and possible future trends, water samples were collected and analysed for the following parameters: pH, conductivity, dissolved oxygen, hardness, dry residue, sodium, calcium, potassium, magnesium, sulfate, nitrate, chloride, bicarbonate and phosphate.

EXPERIMENTAL METHODS

Surface water and rainwater samples were collected between January 1998 and January 1999 for chemical analyses. The surface water samples were collected at two widely spaced locations in the Corumbataí River basin, i.e. upstream from Rio Claro city in the Ferraz-Ajapi district (upper reach) and downstream from Rio Claro city, at the confluence of the Corumbataí River with the Piracicaba River (in the Santa Terezinha district, Piracicaba city) (lower reach) (Fig. 1). These sites were chosen with the aim of verifying the changes in the concentrations of constituents due to the presence of Rio Claro city, since it has been often considered responsible for causing modifications to the surface water quality.

The rainwater samples were collected at the meteorological station situated at CEAPLA (Center for Environmental Analysis and Planning) in the campus of UNESP (University of the State of São Paulo), Rio Claro city, and in the Palmeiras district, located about 4 km from the Rio Claro city centre.

The water samples were stored in polyethylene flasks (volume ~2 L), with the pH and dissolved oxygen (DO) readings being conducted in the field. The pH measurements were performed with a digital portable meter coupled to a combination glass electrode; buffer solutions equilibrated with the sample temperature were utilized to calibrate the equipment before the analyses. The DO and conductivity values were measured by potentiometry using specific probes.

The sampling flasks were transported to the laboratory where aliquots were divided for evaluating the dry residue, anions and cations. The suspended solids were separated by filtering each sample through a 47-mm diameter Millipore membrane of 0.45-μm porosity. The dry residue (DR) content was evaluated by evaporating the filtrate to dryness in a weighed flask that was dried to constant weight at 180°C, with the increase in flask weight representing the DR (APHA, 1989).

The chloride content was measured by potentiometry using an ion selective electrode. Nitrate, phosphate and sulfate were determined by spectrophotometry (Hach, 1992). The total alkalinity was determined by titration using a titrator with sulfuric acid standard solution to an end point evidenced by the colour change of a standard indicator solution (APHA, 1989). The values obtained corresponded to the bicarbonate concentrations since neither carbonate nor hydroxide were characterized.

The analyses of dissolved sodium and potassium were undertaken using an atomic absorption spectrophotometer, whereas standard procedures were utilized for characterizing dissolved calcium and magnesium by inductively coupled plasma atomic emission spectrometry (ICP-AES).

Calcium hardness (as $CaCO_3$) and magnesium hardness (as $MgCO_3$) of the water samples were determined by the colorimetric method (wavelength 522 nm) after chelating calcium with EGTA and calcium and magnesium with EDTA (Hach, 1992). The Ca and Mg contents evaluated by this technique allowed calculation of total hardness (TH), according to the equation (Todd, 1959):

$$\text{TH (mg L}^{-1}\text{)} = 2.5\ \text{Ca (as } CaCO_3\text{)} + 4.1\ \text{Mg (as } CaCO_3\text{)} \quad (1)$$

RESULTS AND DISCUSSION

All chemical data for surface waters and rainwater are given in Tables 1–3 and plotted in Figs 2 and 3. The average pH value was 6.8 upstream and downstream from Rio Claro city, despite the distance between the monitoring stations. The average dissolved oxygen concentration was slightly higher upstream than downstream from Rio Claro city, indicating better conditions of the water quality in the Corumbataí River above Rio Claro city. This is more clearly evidenced by the conductivity data, as the average value downstream from the city was about four times higher than that upstream. The conductivity in rainwater is lower than that of surface waters, as expected. The variability of the dry residue data agrees with that of the conductivity, i.e. the average value is higher downstream from Rio Claro city than upstream.

Table 1 Results of chemical analyses of surface waters from the Corumbataí River at the Ajapi-Ferraz monitoring station, upstream from Rio Claro city, São Paulo State, Brazil.

Parameter	Unit	Date of sampling						Average
		08/13/98	09/23/98	10/21/98	11/18/98	12/23/98	01/20/99	
pH	-	7.0	6.7	7.0	6.5	6.7	6.7	6.8
Conductivity	μS/cm	48.7	38.1	41.3	39.3	55.3	69.9	48.8
Dis. oxygen	mg/L	7.3	7.4	7.3	7.5	7.7	7.3	7.4
Dry residue	mg/L	67.0	35.0	65.0	61.0	199.0	125.0	92.0
Sodium	mg/L	1.5	2.0	2.1	2.1	3.0	2.9	2.3
Potassium	mg/L	1.5	1.3	1.2	1.1	1.7	1.5	1.4
Magnesium	mg/L	0.9	1.7	1.7	1.6	2.0	2.3	1.7
Calcium	mg/L	4.3	9.2	9.8	9.0	9.1	8.3	8.3
Sulfate	mg/L	1.0	12.0	1.0	1.0	7.0	30.0	9.0
Nitrate	mg/L	5.3	5.3	2.2	6.2	5.3	7.5	5.3
Chloride	mg/L	1.1	1.4	1.3	1.4	1.7	1.4	1.4
Bicarbonate	mg/L	8.0	8.0	10.0	9.0	13.0	16.0	11.0
Phosphate	mg/L	0.04	0.9	0.3	0.2	0.6	0.6	0.4
Hardness	mg/L	14.2	30.2	31.5	29.0	31.2	30.3	27.7

Table 2 Results of chemical analyses of surface waters from Corumbataí River at Santa Terezinha monitoring station, downstream from Rio Claro city, São Paulo State, Brazil.

Parameter	Unit	Date of sampling						Average
		08/13/98	09/23/98	10/21/98	11/18/98	12/23/98	01/20/99	
pH	-	6.7	6.8	7.3	6.5	6.8	6.9	6.8
Conductivity	μS/cm	284.4	170.7	208.0	206.0	179.8	182.8	205.3
Dis. oxygen	mg/L	6.7	6.9	7.3	6.5	7.3	6.8	6.9
Dry residue	mg/L	191.0	127.0	154.0	195.0	217.0	172.0	176.0
Sodium	mg/L	0.5	7.6	8.4	10.7	6.9	6.2	6.7
Potassium	mg/L	8.7	4.2	3.5	4.6	2.9	2.2	4.4
Magnesium	mg/L	4.8	5.5	6.7	4.7	6.6	6.8	5.8
Calcium	mg/L	18.5	18.6	17.7	16.4	16.8	12.1	16.7
Sulfate	mg/L	17.0	48.0	44.0	21.0	32.0	37.0	33.0
Nitrate	mg/L	9.2	10.6	8.4	13.6	13.2	9.2	10.7
Chloride	mg/L	1.1	4.4	4.1	6.2	4.5	3.8	4.0
Bicarbonate	mg/L	40.0	30.0	30.0	30.0	25.0	26.0	30.0
Phosphate	mg/L	0.2	1.0	0.6	0.1	0.9	2.7	0.9
Hardness	mg/L	66.1	69.1	71.8	60.3	69.2	58.1	65.8

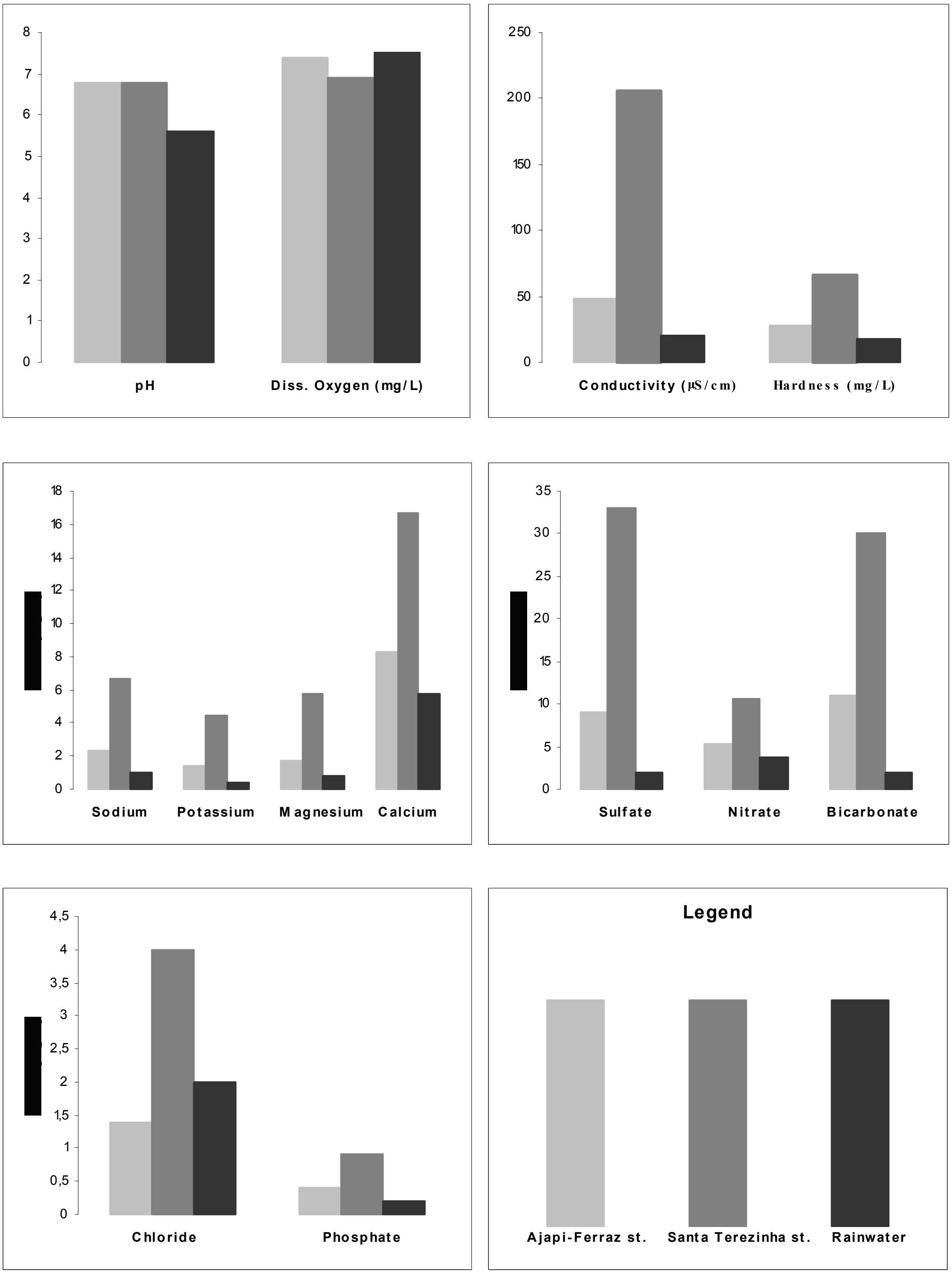

Fig. 2 Average values for analyses of surface water and rainwater samples collected in the Corumbataí River basin between January 1998 and January 1999.

Data for the analysed cations and anions in rainwater plotted on a standard Piper (1944) diagram, demonstrate that they are Ca-dominated in terms of dissolved cations and Cl-NO_3-dominated in terms of dissolved anions. The surface waters upstream from Rio Claro city (Ajapi-Ferraz station) tend to be mixed in terms of dissolved cations,

Table 3 Results of chemical analyses of rainwater samples collected between January 1998 and January 1999 at Rio Claro city, São Paulo State, Brazil.

Parameter	Unit	Range	Average	Parameter	Unit	Range	Average
pH	-	4.1–6.6	5.6	Sulfate	mg/L	<2.0–8.0	2.0
Conductivity	μS/cm	5.8–60.7	20.3	Nitrate	mg/L	1.3–8.4	3.8
Dis. oxygen	mg/L	6.8–8.0	7.5	Chloride	mg/L	1.1–3.4	2.0
Sodium	mg/L	0.06–3.1	1.0	Bicarbonate	mg/L	1.0–8.0	2.0
Potassium	mg/L	0.03–1.6	0.4	Phosphate	mg/L	0.01–1.0	0.2
Magnesium	mg/L	0.08–1.8	0.8	Hardness	mg/L	7.0–38.0	18.0
Calcium	mg/L	2.7–12.3	5.8				

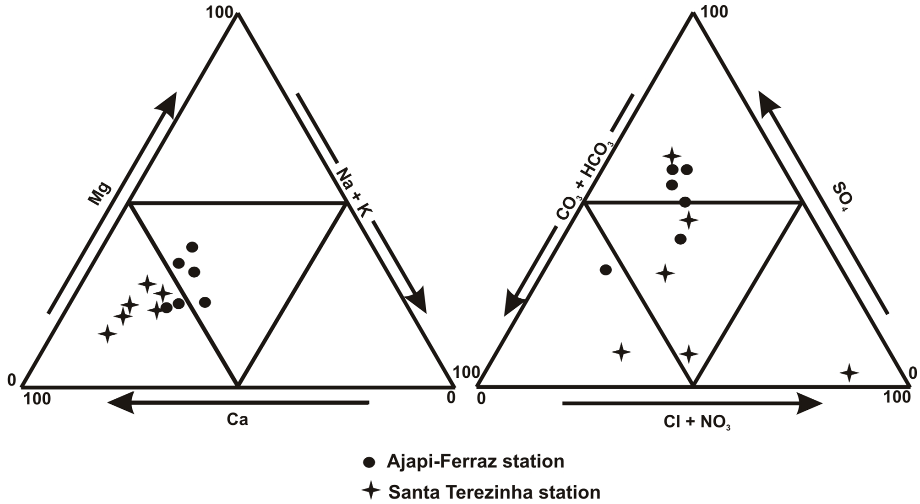

Fig. 3 Data for surface waters from Corumbataí River basin plotted on a partial Piper (1944) diagram.

and are dominated by HCO_3 or SO_4, or are mixed in terms of dissolved anions (Fig. 3). However, the surface waters downstream from Rio Claro city (Santa Terezinha station) are Ca-dominated in terms of dissolved cations and are mixed, or HCO_3-dominated or Cl-NO_3 and SO_4-dominated in terms of dissolved anions (Fig. 3).

The average dissolved cations/anions and hardness are also always higher in the monitoring station located downstream from Rio Claro city (Fig. 2). The average dissolved cations and anions in rainwater are lower than those in the Corumbataí River, as expected, except for chloride in the waters upstream from Rio Claro city. Bonotto & Lima (2006) verified the occurrence of increasing concentrations of organic matter (and LOI-loss on ignition) in sediments in the Corumbataí River, which were attributed to anthropogenic activities in the drainage basin. This is confirmed by the population growth observed for Rio Claro city (Fig. 4), which was accompanied by increased industrial development that occurred across the whole of São Paulo State in the early 1970s, and has risen to about 16% in its interior (Garcia, 2000). The transport and plastic industries have developed greatly during this period in the Corumbataí River basin (Garcia, 2000).

The population presently supplied by the waters of the Corumbataí River is about 502 000 inhabitants, and is expected to grow to 666 000 by 2020 (Moretti, 2001). As a

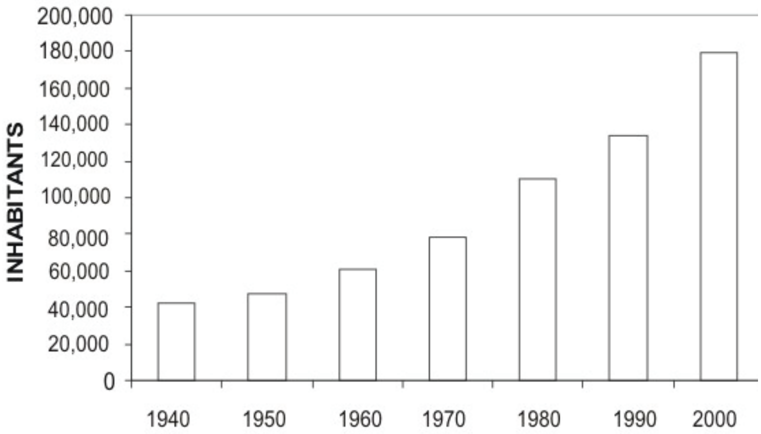

Fig. 4 Population growth at Rio Claro city in the Corumbataí River basin. Data from Sampaio (1987) and Garcia (2000).

Table 4 Pollution load (kg BOD day^{-1}) during year 2000 in the Corumbataí River basin, São Paulo State, Brazil. Data from Belondi (2003).

City	Pollution load		
	Residential	Industrial	Total
Analândia	143	12.1	155.1
Corumbataí	93	30.0	123.0
Charqueada	633	-	633
Ipeúna	185	31.3	216.3
Rio Claro	8 820	27 198	36 018
Santa Terezinha*	1 804	149 580	151 384
Santa Gertrudes	838	-	838
Total	12 516	176 844	189 400

* Piracicaba city

consequence, the urban demand for water in the basin, which presently is 1.9 m^3 s^{-1}, is expected to rise to about 2.6 m^3 s^{-1} by the year 2020 (Moretti, 2001). The actual demand for water in the basin is 54% for urban purposes, 26% for agricultural activities and 20% for industrial use, but there is a strong trend of increasing consumption in all sectors (Moretti, 2001). The major problem related to the urban use of the water, which has caused deterioration of water quality in the Corumbataí River, is the direct discharge of domestic waste water without any treatment. Table 4 indicates the levels of pollution load based on BOD data during year 2000 for the municipalities in the Corumbataí River basin; it indicates the important contribution of Rio Claro city to the discharge of effluents, which is only lower than that released by the sugar cane industry in producing sugar and alcohol in the Santa Terezinha district (Piracicaba municipality).

Thus, all the chemical data reported in this investigation clearly indicate poorer conditions of the water quality in Corumbataí River after reaching Rio Claro city. This is related to the fact that the drainage in the Corumbataí River basin has received, over time, significant emissions of municipal waste products and discharges of wastewater, sludge, sewage, sanitary and industrial effluents, while the first effluent treatment plant for Rio Claro city was only inaugurated at the end of the 1990s.

The Rio Claro city urban area significantly and detrimentally affects the quality of the hydrological resources, and the results of this study certainly show the need for continuous efforts and appropriate management strategies in order to reduce the discharge of pollutants, because the waters of Corumbataí River are very important for present and future generations. The situation is a difficult to resolve mainly due to economic rather than technical restrictions (Moretti, 2001). It has been predicted that an adequate improvement in the water quality in the whole basin would require financial resources of about US$ 35 millions up to year 2020 (Moretti, 2001), which is a very high amount for the local municipalities to invest. However, such demand is often remembered during periodic regional meetings involving representatives from several segments of society interested in the adequate management of the basin, and constituting a positive initiative to reach the expected scenario in the near future.

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