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Abstract

Purpose – This study presents a comparative analysis of water quality data in an urban micro watershed to study the magnitude of impacts on the water quality parameters over the last decade. The purpose of this paper is to evaluate the degree of deterioration using the water quality index.
Design/methodology/approach – Rapid urban growth without proper land use and occupation planning results in the overload of urban water resources. Therefore, a literature review was conducted on the research subject published in the dissertation databases of the Engineering Faculty of Ilha Solteira, which resulted in the selection of two dissertations on water quality in the Ipê Stream, Ilha Solteira – SP, Brazil. The results will be evaluated according to the Brazilian laws and regulations in force.
Findings – This study shows that pollution and degradation in the stream intensified during the study period, with the most impacted areas within the urban perimeter.
Practical implications – The increasing impacts underscore the need for efficient measures such as implementation of retention reservoirs, elimination of clandestine sewage connections and restoration of riparian forests.
Originality/value – This study highlights the need to monitor the water quality of streams in order to establish preventive and mitigating measures to avert the growing environmental impacts and to ensure quality water for future generations.

Keywords Brazil, Literature review, Water quality, Micro watershed

Paper type Case study

1. Introduction

Rapid urban growth and disorderly and unplanned land use and occupation in recent decades have resulted in problems that affect the environment and accelerate natural processes such as erosion, which cause silting and overload of water resources located in the urban and peri-urban areas of cities. The rainwater collected by the cities' drainage system reaches the water bodies contaminated with solid waste, chemicals and domestic sewage, compromising the overall water quality.

Many articles have been published that prove the importance of water quality studies, considering the anthropogenic pollution of surface waters (Pesce and Wunderlin, 2000; Tong and Chen, 2002; Debels *et al.*, 2005; Rosemond *et al.*, 2009; Sharma and Kansal, 2011; Espejo *et al.*, 2012).

The environmental problems faced by the society point to the inadequate use of natural resources, indicating that economic and social development must be compatible with the conservation and protection of the environment (Mota, 2003).

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Although Brazil is privileged in terms of water resources, urban areas are facing water shortage, which underscores the importance of sustainable management and preservation, especially for urban streams with increased flow peaks, which cause deterioration in water quality.

Thus, this survey studied how these impacts have emerged in the micro watershed of the Ipê Stream, taking into account the influence of land use and occupation, as well as precipitation.

2. Study area

The municipality of Ilha Solteira is located in the Northwest region of São Paulo, 20°38′44″ South latitude, 51°06′35″ West longitude, 659 km² land area, with a population of 25,144 inhabitants, with the largest proportion residing in the urban area (Prefeitura Municipal de Ilha Solteira, 2013).

Figure 1 shows the location of the municipality of Ilha Solteira.

3. Methodology

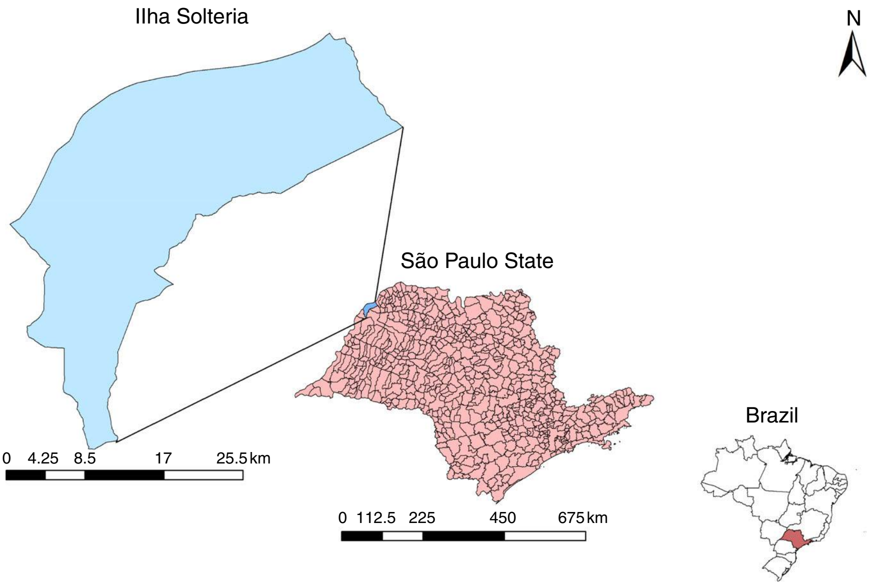
A literature review of water quality studies was conducted in the study area published in the dissertation databases of the Engineering Faculty of Ilha Solteira.

Of the 27 results found, three dissertations addressing water quality on the micro watershed of the Ipê Stream were identified. However, due to data availability, two were used in the study.

The methods and equipment used in the studies identified were based on Standard Methods for Examination of Water and Wastewater (American Public Health Association, 1995) and the Hach spectrophotometer method.

Ten quality parameters, analyzed monthly from March to August in 2002 and 2011, were used in the discussion of this paper. As the Ipê Stream was not classified according to the CONAMA Resolution 357/05, it was considered as a Class 2.

Figure 2 shows the hydrography of the watershed with the monitored points.



Source: Prepared by the authors

Figure 1. Location map of the municipality of Ilha Solteira

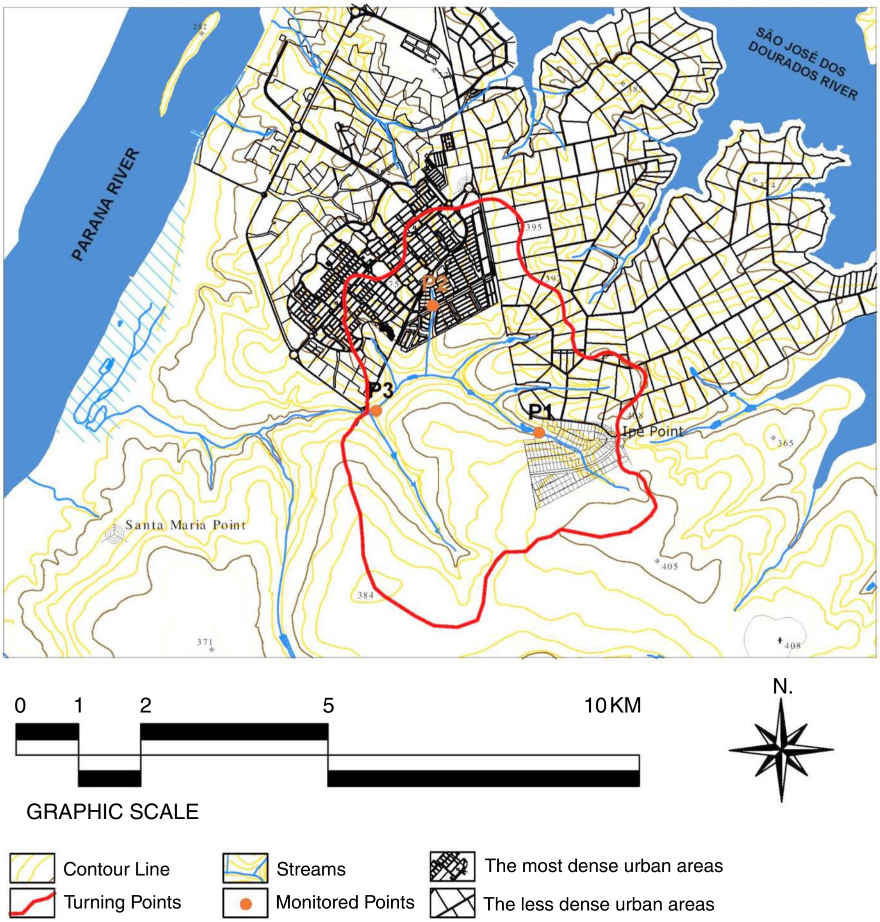


Figure 2.
Map of the micro watershed of the Ipê Stream with monitoring points

Source: Prepared by the authors

The water quality index (WQI) developed by the National Sanitation Foundation of the USA, an important tool for qualitative monitoring of the watershed, was also used in the discussion since the considered parameters reflect the contamination due to the discharge of domestic effluents.

4. Results and discussion

4.1 Sampling points

The data were collected from two dissertations published in 2003 and 2011 and the analyses used in this work were performed between March and August, 2002 and 2011. The sampling points used by the authors have the same geographical coordinates and Table I shows the details.

4.2 Sources of diffuse pollution

In his work, Poleto (2003, p. 55) addresses the pollution sources near the sample collection points, considering that these sources can generate changes in the physical, chemical and biological water parameters. In this respect, he observed that in the section before point P1, there is sporadic effluent discharge from a frog farm; the section at point P2 is the largest recipient of diffuse source pollution due to its proximity to the city – which has clandestine sewage connections, a connection of the municipality's vehicle patio discharging detergents and probable flows from one of the sewage stations. As for point P3, Poleto (2003) observed a ditch in the section before the collection site, which is a garbage dump in a riverside property. Ortega (2011) did not carry out the same analysis, but underscored the intensification of problems caused by negligent land use in 2011 (water erosion, wind erosion, ravines).

4.3 Pluviometric and flow indicators

As for precipitation, Poleto (2003) and Ortega (2011) considered the sampling day and the three days before. Table II shows the sampling collection dates of Poleto (2003) and Ortega (2011), with the values of the monthly and daily rainfall.

In 2002, there was rainfall close to the sample collection in May and July, and in June, there was no precipitation. In 2011, there was less rainfall in the sampling period and rainfall in the day of collection was recorded in March.

The flow at points P1 and P2 showed similar behavior in 2002 and 2011, and the values did not change much. The largest flow was recorded in P3 and the smallest was recorded in P2. Figure 3 show the flow in 2002 and 2011.

4.4 Land use and occupation

As for land use and occupation in the contributing area, Figure 4 shows the distribution of the total area for different uses in 2002. Poleto (2003) noted that most of the land is used for pasture and also highlighted (Poleto, 2003) the reduction of riparian areas in the study period.

Points	Elevation (*m*)	Latitude (*S*)	Longitude (*W*)	Location
P1	351	20° 27′ 09″	51° 18′ 59″	Section of the Córrego do Ipê Stream (after the Ipe neighborhood)
P2	343	20° 25′ 46.5″	51° 20′ 06.8″	Stretch of the Córrego "Sem Nome" (Jardim Aeroporto)
P3	308	20° 26′ 55.9″	51° 20′ 41.8″	Mouth of the watershed Córrego do Ipê Stream

Source: Ortega (2011)

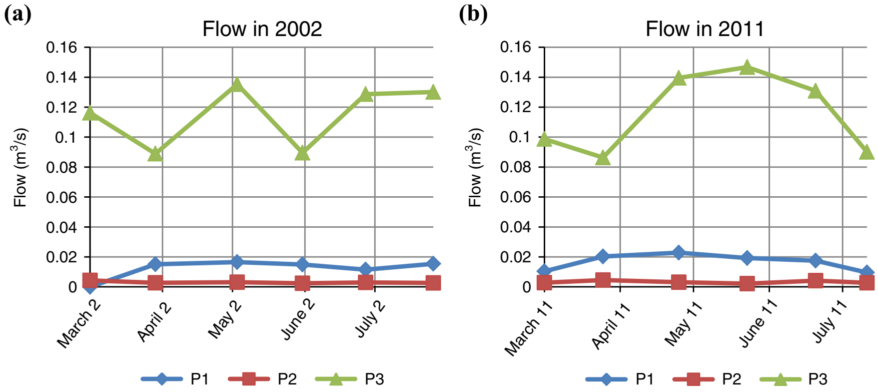
Table I. Sample points, geographical coordinates and elevation

Date	Author	Total rainfall (mm)	D0 (mm)	D1 (mm)	D2 (mm)	D3 (mm)
March 27, 2002	Poleto (2003)	107.2	0.0	0.0	0.0	43.2
April 24, 2002		0.8	0.0	0.0	0.0	0.0
May 22, 2002		52.6	0.3	10.4	2.80	12.50
June, 19, 2002		0.0	0.0	0.0	0.0	0.0
July 23, 2002		44.2	0.5	19.30	16.00	0.0
August 21, 2002		34.3	0.0	0.0	0.0	0.0
March 28, 2011	Ortega (2011)	126.1	2.3	0.0	0.0	0.0
April 21, 2011		221.0	0.0	0.0	0.0	0.0
May 22, 2011		258.1	0.0	0.0	0.0	0.0
June 19, 2011		180.2	0.0	0.0	0.0	0.0
July 17, 2011		268.1	0.0	0.0	0.0	0.0
August 7, 2011		55.7	0.0	0.0	0.0	0.0

Notes: D0, sampling day; D1, first day before sampling; D2, second day before sampling; D3, third day before sampling

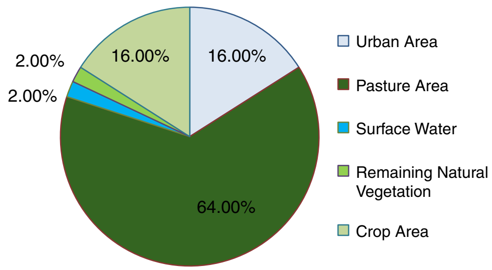
Source: Values from the database of the Hydraulic and Irrigation Area, available at: www.agr.feis.unesp.br/irrigacao.php (accessed April 30, 2016)

Table II. Rainfall on the sampling dates



Source: Ortega (2011)

Figure 3.
Flow in sampling points



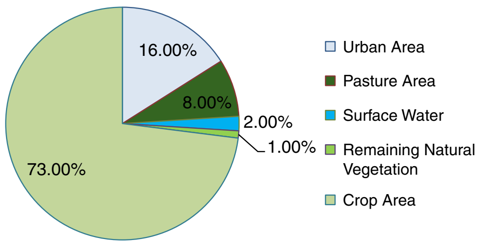
Source: Ortega (2011)

Figure 4.
Land use and occupation in 2002

Ortega points out the substantial change from pasture areas to sugarcane plantations in 2011, caused by anthropogenic activity and changes in the Brazilian economic sector over the last decade, as shown in Figure 5.

Figure 6 shows a comparison between the satellite images of the watershed corresponding to August 6, 2002 and August 7, 2011, obtained from the Landsat image database program, NASA. The observation indicates significant change in land use and cover during the 9-year period: there are more green areas that correspond to the crop areas.

Figure 7 shows the mapping of the Canasat Project – which monitors the sugarcane cultivation through Landsat satellite images, CBERS and Resources at-I, available at INPE/DGI free of cost – for 2003 and 2011.



Source: Ortega (2011)

Figure 5.
Land use and occupation in 2011

(a) (b)

Notes: (a) 2002; (b) 2011
Source: Satellite image from the database of the Landsat program, obtained by LandsatLook Viewer

Figure 6. Comparative image of land use cover

(a) (b)

Notes: (a) 2003; (b) 2011
Source: Modified image of the Canasat-Area Project site

Figure 7. Image of sugarcane cultivation

The image shows that in 2003, there was no sugarcane cultivation (represented by green areas) in the city of Ilha Solteira, differing from 2011, which shows the expansion of this crop.

4.5 Comparative analysis of quality parameters

The ten quality parameters analyzed are turbidity, temperature, total solids, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, total phosphorus and thermotolerant coliforms.

According to Poleto (2003, p. 116), the turbidity levels are related to the suspended material in the water bodies. Figure 8 shows the turbidity values obtained by Poleto (2003) and Ortega (2011).

From March to August 2011, the overall turbidity increased compared to 2002 (overall average increase of 11.66 NTU); in July, only point P2 showed a reduction from 174.68 to 33.5 NTU, resulting from daily and cumulative rainfall in 2002, which did not occur in 2011 (no precipitation). This confirms the direct relationship between this parameter and the rain season as during precipitation, the pollutants are carried by surface runoff to the water body, especially in eroded environments without riparian vegetation, which increases turbidity. CONAMA resolution 357/05 sets a limit of 100 NTU for a Class 2 river, which, in 2002, was extrapolated by a single point.

In 2011, one of the highest turbidity values was at point P3 in July. Since there was no precipitation in the days before the sampling period, Ortega (2011) attributes this result to a possible increase in dilution and/or depuration capacity of the stream at that point.

The total solids represent the solid residues from erosion, which are carried to water bodies by surface runoff, causing silting of the riverbed and damage to aquatic life. Figure 9 shows the results obtained by Poleto (2003) and Ortega (2011).

The data analysis in Figure 9 shows the significant change in solid concentration at the sampling points in 2002 and 2011. In 2002, concentrations ranged from 101 to 365 mg/l, with an average of 201.17 mg/l at point P1, from 108 to 749 mg/l, with an average of 237.17 mg/l at point P2, and from 161 to 498 mg/l at point P3, with an average of 400.17 mg/l. It can be seen that the average in point P3 is much higher than at the other points, which Ortega (2011) attributes to the fact that point P3 is downstream in the watershed under study, which is the mouth. Moreover, in 2011, there was a 45.46 percent increase in total solids.

At point P3, in July 2002, there was a decrease of 337 mg/l compared to June, a behavior similar to what occurred in May 2011 at that point (decrease of 433 mg/l compared to April). On analyzing rainfall on these dates, it is clear that there was accumulated rainfall, which may have diluted the solids in the water. However, in May 2002, even with the accumulated precipitation, there was a high value of solids. These concentration changes are mainly from rainfall, which can either dilute pollutants or carry materials and sediments.

The pH analysis showed no major changes in 2002 and 2011, with overall averages of 6.64 and 6.67, respectively. CONAMA Resolution 357/05, which sets a pH range from

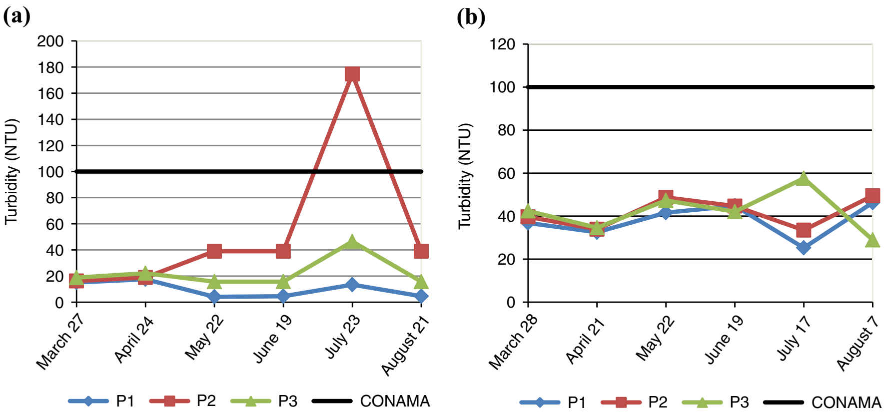
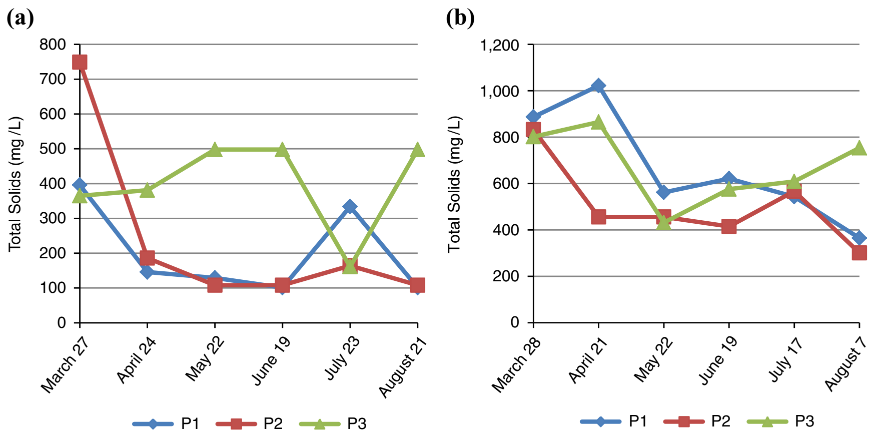


Figure 8. Turbidity

Notes: (a) 2002; (b) 2011
Source: Ortega (2011)



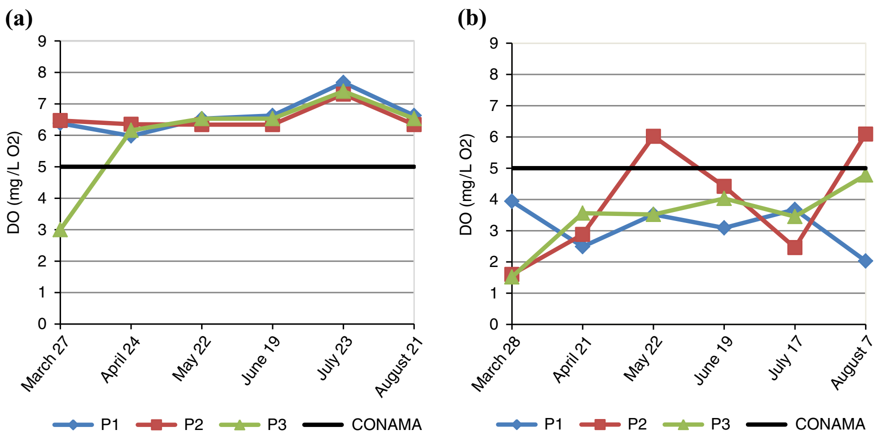
Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

Figure 9.
Total solids

6.00 to 9.00 for a Class 2 river, was not met in April, June, July and August 2002 at point P1; however, in 2011, there were no non-standard results. The water temperature also did not show considerable changes in those years.

Figure 10 shows the results for DO, evidencing the DO variation in the dry and wet seasons.

In the Ipê Stream, Poleto (2003) observed seasonal variations in DO content, with lower values in the dry season and higher values in the wet season, which can be explained by the increased natural turbulence of water and higher dilution of pollution loads during precipitation. With the exception of P3 in March, all points remained above the limit of 5.0 mg/l O_2 set by CONAMA 357/05 for a Class 2 river. The introduction of organic matter in a water body results in the increased consumption of DO by the decomposing micro-organisms (VonSperling, 1996). This assertion can be verified in 2011, where Ortega (2011) obtained lower DO levels than those obtained by Poleto (2003), and with higher variations over the sampling period. This can be attributed to the pollution increase in the stream from



Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

Figure 10.
DO

2002 to 2011 and also to the fact that in 2011, the samples were collected in a period of low rainfall. Only point P2, in May and August 2011, showed values within the CONAMA standard since the others always had values below the limit of 5.0 mg/l O_2mg/l.

Figure 11 shows the BOD results.

All sampling points had samples in which the BOD concentration was above 5.0 mg/L O_2, set by CONAMA. In 2002 and in 2011, there was an irregular BOD variation with precipitation: in some cases, it decreases due to the dissolution of organic matter and in others it reaches its maximum value. Poleto (2003) attributes these variations to the pump overflowing the discharge of the sewage stations and also to the clandestine discharge of organic matter, especially at point P2. In 2011, there was an increase in BOD averages at the three points, more evident at point P2.

Figure 12 shows the COD results. The Federal law and the State of São Paulo do not include COD, but it is crucial in the characterization of sanitary sewage and effluents

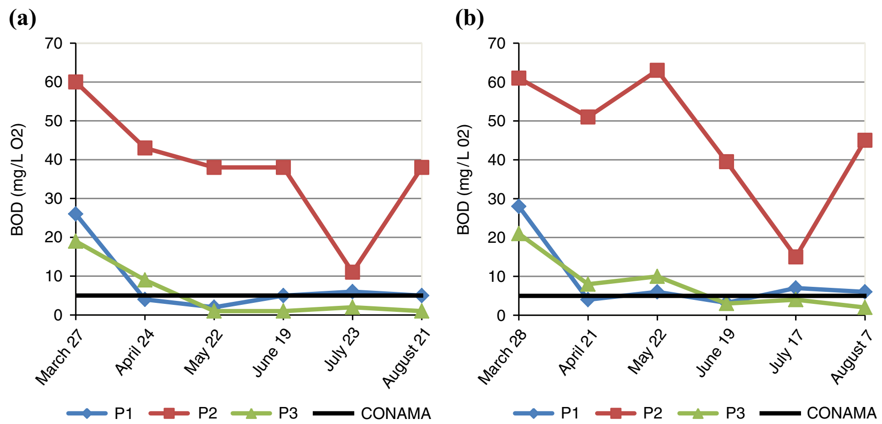


Figure 11. BOD

Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

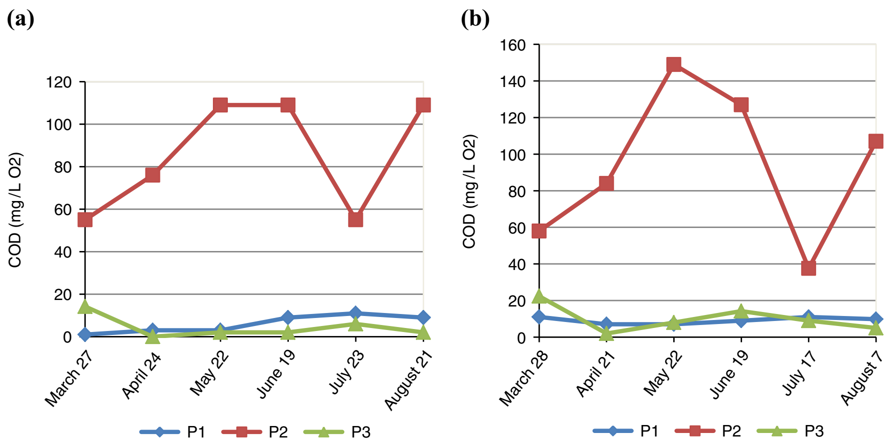


Figure 12. COD

Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

since high values of this parameter indicate contamination by discharge, often originating from industries.

The data analysis in Figure 12 shows the high variation in the COD concentration at point P2, and the highest values for the other points, both in 2002 and in 2011. This may be related to the pollutant load released at that point, resulting from clandestine sewage and closer proximity to the urban area – factors that have worsened in nine years, as well as its lowest flow. The overall COD average in 2002 was 31.95 mg/l O_2 and in 2011, it was 37.66 mg/l O_2, which corresponds to an increase of 5.71 mg/l O_2.

Nitrogen and phosphorus are essential minerals for biological processes; therefore, it is important to know their concentrations in order to characterize the effluents for treatment. Figure 13 shows the results obtained by Poleto (2003) and Ortega (2011) for total nitrogen.

Irregular nitrogen variation was observed for 2002 and 2011. This type of occurrence is due to the discharge of detergents directly into point P2 and the transport of soil fertilizers and manures without proper conservation, during the wet seasons, at points P1 and P3 (Poleto, 2003, p. 87), which shows that in 2011, these pollution sources were in effect. Point P2 showed the highest concentrations of nitrogen, showing that it was the most impacted point.

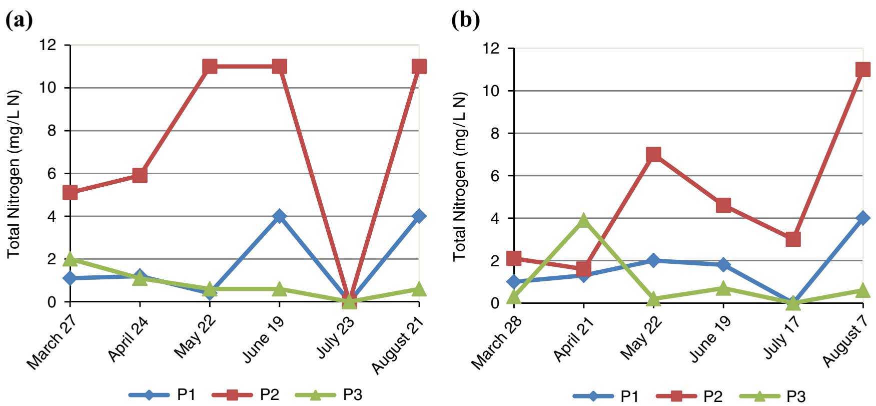
Figure 14 shows the results obtained by Poleto (2003) and Ortega (2011) for total phosphorus.

The data analysis in Figure 14 shows that in 2002 and in 2011, 100 percent of the samples were above the maximum value allowed by CONAMA 357/05 for Class 2 water. The most significant variations in phosphorus concentration occurred at point P2, possibly due to clandestine sewage and car wash water.

In 2011, there was an overall average of reduced phosphorus from 1.69 mg/lp obtained in 2002 to 0.59 mg/lp, which corresponds to 65.1 percent.

The variation levels of nitrogen, phosphorus and total solids could be associated with the change in land use and occupation of perennial crops and sugarcane pastures.
Figure 15 shows the data obtained in the studies of Poleto (2003) and Ortega (2011) for the concentration of thermotolerant coliforms in the Ipê Stream.

The data analysis in Figure 15 shows that in 2002, most samples at point P1 and 100 percent of the samples at point P2 were above the maximum value allowed by CONAMA 357/05 for Class 2 water (1.0E+03 CFU/100 ml). Only point P3 showed values within that standard. High concentrations of pathogenic bacteria in the water increase the risk of waterborne diseases, which are public health problems.



Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

Figure 13.
Total nitrogen

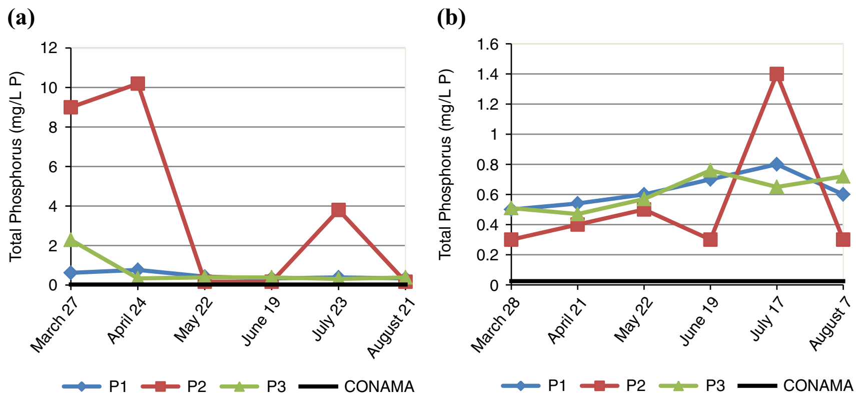


Figure 14.
Total phosphorus

Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

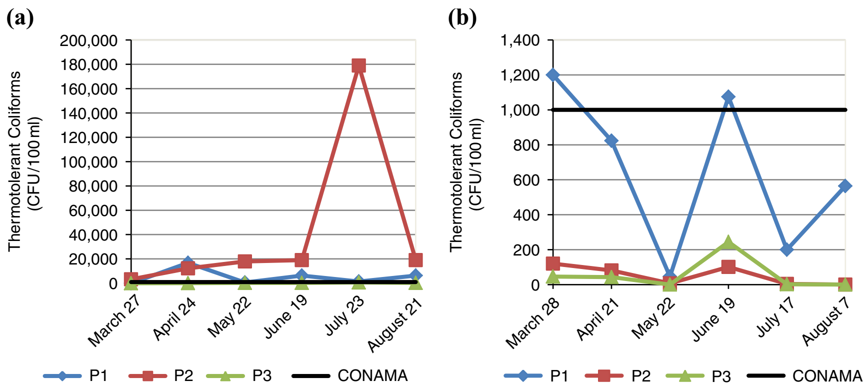


Figure 15.
Thermotolerant coliforms

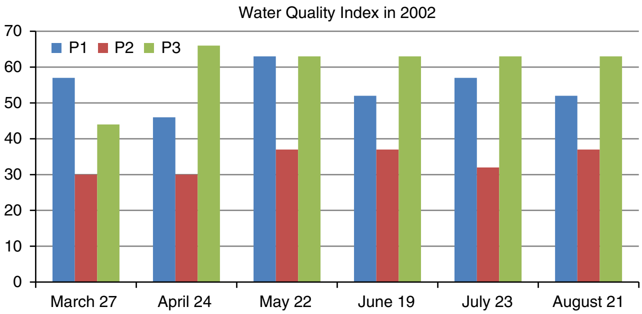
Notes: (a) 2002; (b) 2011
Source: Ortega (2011)

In 2011, Ortega obtained different results: only in March and June, at point P1, the values exceeded the CONAMA limit. He reported that the overall average in 2002 was 1.57E+04 CFU/100 ml, whereas in 2011, the average was 253 CFU/100 ml, concluding that the thermotolerant coliforms levels in 2002 were much higher compared to 2011 (Ortega, 2011, p. 121). A reason that may explain these results is the change in land use and occupation, which markedly reduced the access of animals to the stream. Soil degradation increased over the years, which emphasizes the need to preserve the area, in order not to jeopardize the water quality even more.

4.6 WQI

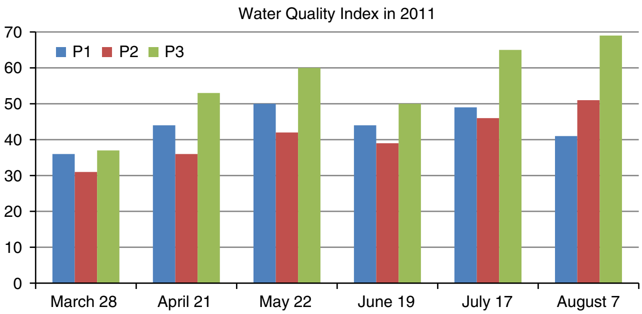
The WQI results obtained by Poleto (2003) and Ortega (2011) are shown in Figures 16 and 17, respectively.

The data analysis in Figures 16 and 17 indicates that point P2 was the most impacted since 2002 and this is due to anthropogenic activity from its proximity to the urban area. In 2011, however, there was a small improvement in the quality indicators of this point, contrary to what occurred at points P1 and P3, which showed an overall decrease in the quality index values. The improvement in point P2 may be related to the lowest



Source: Ortega (2011)

Figure 16. Water quality index at points P1, P2 and P3 in 2002



Source: Ortega (2011)

Figure 17. Water quality index at points P1, P2 and P3 in 2011

rainfall in the study area in 2011, which reduced the rainwater contaminated by urban pollution, collected by the cities' drainage system and released into the water body.

In terms of the classification according to CONAMA, point P1 showed averages of 54.5 and 44 on the WQI scale in 2002 and 2011, respectively, decreasing from good to regular quality. Point P2 had averages of 33.8 and 40.8 on the WQI scale, going from poor in 2002 to regular quality in 2011. However, point P3 had averages of 60.3 and 55.7 on the WQI scale in 2002 and 2011, respectively, remaining within the good quality level despite the decrease.

5. Conclusions

One of the limitations of the use of quality indices is the overall classification of the water, through the relationship of various parameters, but without highlighting the parameters that exceed the threshold values (Espejo *et al.*, 2012). However, the WQI used was efficient to evaluate the water quality at the points studied. The lowest mean of WQI was observed at the point P2, where the discharge of domestic effluents was evidenced.

In 2002, the Ipê Stream showed high levels of coliforms, nutrients and organic matter, the levels of which, according to Poleto (2003), are similar to typical low concentration sewage. In 2011, there was an increase in the levels of turbidity, total solids, BOD, COD and a reduction in the DO concentration, which indicates the increased impacts, in particular, at point P2. The total phosphorus and coliforms rates were lower in 2011 due to changes in land use and land cover. Although point P2 showed improved WQI values, it should be noted that it still had lower values than the other points in most of the parameters analyzed. It is necessary to improve the sewage system, eliminating clandestine sewage connections, to reduce fecal contamination at this point.

Given this situation, it is clear that pollution and degradation have intensified, hence the need to combine a policy of efficient water resources, environmental planning and education. The increasing impacts underscore the need for efficient measures such as implementation of retention reservoirs and restoration of riparian forests, highly degraded in the case of Ipê Stream, as well as encouraging the population to report violations of the Forest Code and not discard waste in the stream margins in order to protect and thereby prevent permanent impairment of the water resources of the micro watershed.

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