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ORIGINAL ARTICLE

Water quality, pollutant loads, and multivariate analysis of the effects of sewage discharges into urban streams of Southeast Brazil

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Abstract Water demand, pollution, and climate change threaten water security in industrialized and urbanized regions worldwide, especially in developing countries. Investments in massive infrastructure have often not met the water needs of the population, requiring water resource managers to adopt new approaches, such as decentralized and regionalized management at the micro-basin scale. However, little is known about the impact of anthropogenic activities on the water quality and vulnerability of streams that cross urban areas and feed into the main rivers and reservoirs supplying cities and industrial regions. The main goals of this research were to evaluate the water quality, pollutant loads, and effect of untreated sewage discharges in streams of the Piracicaba river basin, in the municipality of Americana, Southeast Brazil. The water quality parameters evaluated were as follows: pH, dissolved oxygen, electrical conductivity, biochemical oxygen demand, inorganic phosphorus, total phosphorus, total nitrogen, real colour, turbidity, total dissolved solids, metals (Ba, Cr, Cu, Ni, Pb, Cd, and Zn), total coliforms, and *Escherichia coli*. Descriptive statistics and multivariate analyses were performed. The results revealed chemical and biological degradation of the water resources, and vulnerability of the urban streams due to the release of untreated sewage into these waterways. The findings indicate the need for an immediate implementation of policies to monitor and control discharges of industrial effluents into the sewage collection systems, as well as discharges of sewage into rainwater drainage systems, together with the maintenance of green spaces.

Keywords Metals · *Escherichia coli* · PCA · Micro-basin

1 Introduction

The global trend towards increasing urbanization has altered the geographical distribution of the population. In 2007, for the first time in history, a majority of people lived in cities. This trend has continued, with the United Nations estimating that in 2014, 54% of the global population was concentrated in urban areas (UN 2014).

In developing countries such as Brazil, this phenomenon has been especially intense, supported by economic and industrial growth. According to Brazilian demographic census reports, in 1970 the population was 96 million inhabitants, with 56% (54 million people) living in urban areas (IBGE 2016). In 2014, the estimated Brazilian urban population reached around 172 million, equivalent to an urbanization rate of 85% (UN 2014). This growth occurred in a disorderly fashion, with consequences including urban sprawl, pollution, environmental degradation, and scarcity of natural resources (Medeiros et al. 2013).

One of the most evident consequences of this urban growth model is the threat to water security and water safety in some regions of Brazil, despite the fact that approximately 12% of the total global amount of available

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fresh water is found in the country (ANA 2012). Here, the vulnerability of water resources in industrialized and densely populated regions has been worsened by the extraction of water for consumption, together with land use change, poor sanitation infrastructure, and possible climate change.

São Paulo State is economically the most important region of Brazil and is home to approximately 44 million people according to official statistics (IBGE 2016). This region has experienced scarcity of water resources, notably in the east, where industrialization and urbanization are greatest. One strategy adopted to face this problem was the installation of large-scale reservoir infrastructure in the 1960s, including the Cantareira system in the Piracicaba river basin (PRB), which is one of the world's largest systems of interconnected reservoirs (Coutinho et al. 2015). This system produces around 36 m^3 s^{-1} of water, of which 31 m^3 s^{-1} is diverted to supply the needs of the São Paulo metropolitan area (SPMA), while another 5 m^3 s^{-1} is used to meet water requirements in the PRB (Manca et al. 2014). The distribution of water has generated regional conflicts, because the PRB has faced a water shortage caused by the expansion of urban areas, as well as other problems associated with the lack of sanitation infrastructure, discharge of industrial effluents, and weather conditions.

The population of the PRB is around 4.6 million, and despite investments in sanitation over the last decade, approximately 60% of domestic sewage is discharged into the rivers and streams without any prior treatment (COBRAPE 2011). This affects the quality of life of the population and the resilience of aquatic ecosystems of the PRB (Machado et al. 2018; Botelho et al. 2013; Meche et al. 2010; Jardim et al. 2008; Salomão et al. 2008; Fostier et al. 2005; Krusche et al. 2002; Ometo et al. 2000).

In the period 2013–2014, a severe dry season led to an unprecedented water crisis and exposed the weakness of the Cantareira reservoir system in the face of potential climate change. This example shows that the construction of massive storage and water treatment infrastructure, which dominated water management in the twentieth century, has not met the basic human needs for freshwater in São Paulo State, where the water availability limit was reached following the damming of the main rivers in the 1950s in order to meet the electricity demand. Furthermore, the installation of massive infrastructure has significant political, economic, social, and environmental costs making it a questionable option (Gleick 2003). Hence, new approaches for water resources management need to emerge that consider ecological, economic, and social constraints.

Some studies have proposed the use of small-scale decentralized facilities as an alternative to complement the installed large-scale infrastructure (Gleick 2003; Brooks and Holtz 2009). This approach includes water management at the spatial scale of micro-basins, which incorporate the springs and water bodies that feed the main rivers. This scale requires political cohesion among different municipalities, the decentralization of water resources management, and the inclusion of communities in the debates, involving all stakeholders (Gleick 2003; Poustie and Deletic 2014). However, rural and urban streams have been overlooked by scientists and water resources managers, especially in developing countries, so little is known about the effects of anthropogenic disturbance of the landscape on the pollutant load generated from tributaries and discharged into the main rivers and reservoirs that supply cities, industries, and irrigated crops.

Given the context of the water resources in urban and industrialized areas of Brazil and other developing countries, these streams are highly vulnerable because they receive effluent discharges from small industries and domestic sewage (Machado et al. 2018; Galfi et al. 2016; Beghelli et al. 2015; Poustie and Deletic 2014; Jabeen et al. 2014; Sandoval et al. 2014; Alves et al. 2013; Medeiros et al. 2013; Zeilhofer et al. 2010; Medeiros et al. 2009; Moreira and Fazza 2008; Jamwal et al. 2008; Daniel et al. 2002; Martinelli et al. 1999), which are not monitored or controlled by the environmental agencies. Therefore, studies at this spatial scale can assist in strategic planning and the management of natural resources at municipal and local scales, as well as encourage public policies focusing on water security and the improvement of water quality in urban and rural streams.

One of the main tributaries in the PRB is the Quilombo river, an important source of water for the industries in the region, which discharges its pollutant loads into the Piracicaba river (Botelho et al. 2013). The Quilombo watershed extends to 390 km^2 (Daniel et al. 2002) and includes the municipalities of Americana, Nova Odessa, Sumaré, Hortolândia and parts of the municipalities of Paulínia and Campinas, where approximately 1.9 million people live. The Quilombo river mouth is located in the city of Americana, with a population of 224,551 inhabitants, of which 99.5% live in the urban area. This municipality is an important hub for textile and clothes production, with 1850 industries related to this industrial sector, and a GDP of around US$ 3.43 billion (IBGE 2016).

In the city of Americana, the Recanto stream, a tributary of the Quilombo, received the discharges of domestic sewage from Nova Odessa, without any treatment, until the year 2012. Nova Odessa has 51,242 inhabitants, with an urbanization rate of 98.4%, and the regional economy is based on the services sector (59%) together with textile, metallurgical, and foundry industries (41%), generating a GDP of US$ 1.36 billion (IBGE 2016). In this city, in 2012 sewage collection reached 95%, although only 7% was treated (CETESB 2013).

Medeiros et al. (2009, 2013) performed preliminary evaluations of water quality, and the environmental impact of Nova Odessa sewage discharges on the water and sediments of the Recanto stream in the city of Americana. Evidence was found for the contamination of water by sewage together with high concentrations of metals, downstream of domestic sewage discharges. Therefore, our hypothesis is that urban streams in the Americana region are continuously vulnerable due to sewage pollution and land use patterns, threatening the water quality of the Quilombo river, one of the main water bodies of the Piracicaba river basin.

The main goals of the present research were to evaluate the water quality and the loads of transported pollutants in urban streams in Southeast Brazil, considering the effects of domestic sewage discharges and possible clandestine inputs. Statistical approaches using principal component analysis and Tukey's multi-comparison test were carried out to evaluate several water quality parameters, including limnological variables and metals concentrations, and to assist in the formulation of guidelines for the management of the water resources.

2 Materials and methods

2.1 Location and characterization of the hydrographic micro-basins

Monitoring was performed in 2012 at the mouths of three streams in the municipality of Americana: the Recanto (sites P1 and P2), Santa Angélica (site P3), and Pylles (site P4) streams (Fig. 1).

In the case of the Recanto stream, evaluation was made of the effect of inputs of domestic sewage from Nova Odessa city. For this reason, two points were monitored, one at the mouth (P1), 250 m downstream from the domestic sewage discharge, and another (P2) 10 m upstream from the discharge (Table 1). Land use in the micro-basins consisted of residences, small factories, and grassland.

According to the Köppen classification, the climate of the Americana region is tropical with a dry season (Aw). For all months of the year, the monthly average temperature exceeds 18 °C, and in at least one month of the year the average total rainfall is less than 60 mm. The average total annual rainfall is 1292 mm, with the wettest and driest months being January (average of 239 mm), and July (average of 27 mm), respectively (CEPAGRI 2016).

The micro-basin of the Recanto stream includes two reservoirs that supply the city of Nova Odessa, which highlights the importance of this area in the context of the hydric resources in the region (Medeiros et al. 2009).

2.2 Stream flow and rainfall

Flow rates were measured with an FP 111 flow metre, which had a measurement range of 0.1–6.1 m s^{-1} and accuracy of 0.03 m s^{-1}. Rainfall data were provided by the Americana city council, which operated a pluviometer installed in the central region of the municipality, within the coverage area of the micro-basins studied.

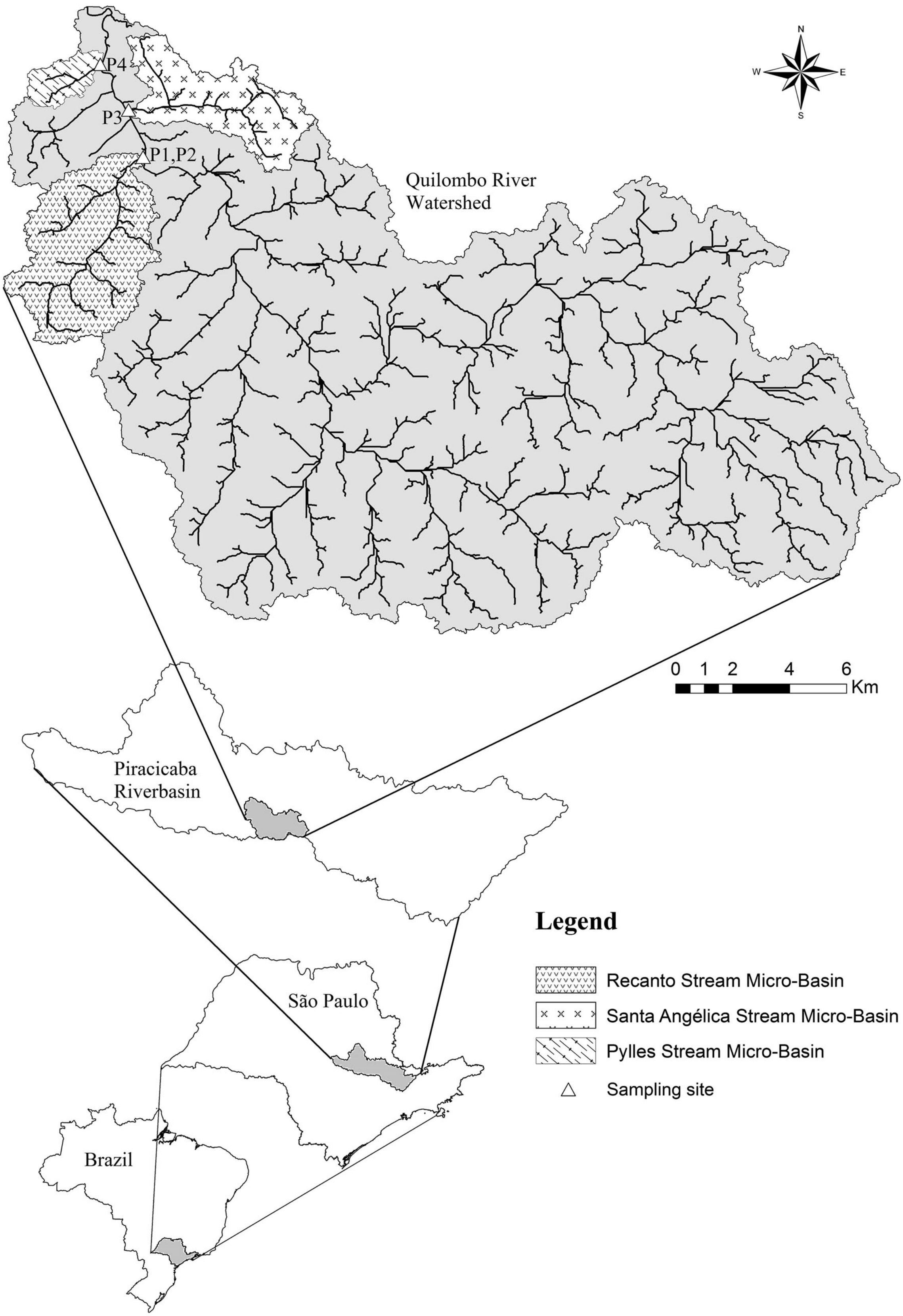
2.3 Physical and chemical water quality parameters

Water samples used to evaluate limnological parameters were collected at a depth of up to 0.20 m, in the central area of the transverse section of the streams, on a monthly basis from August 2011 to November 2012. Measurements of pH and dissolved oxygen (DO) were conducted in the field, using a pH metre (model TEC-3MP, TECNAL) and an oximeter (model AT-150, ALFAKIT), respectively.

Analyses were also made of electrical conductivity (EC) (model TEC-4MP conductivimeter, TECNAL), biochemical oxygen demand (BOD) using the respirometer method (BOD Track II, HACH), inorganic phosphorus (Pinorg), and total nitrogen (Ntotal) using visible spectrophotometer and specific reagents (model DR 2700, HACH), real colour (Colour) (model DR 890 colorimeter, HACH), turbidity (model TB 1000 turbidity metre, TECNOPON), and total dissolved solids (TDS), following the methodologies established by APHA (2012).

Determination of the metals barium (Ba), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), cadmium (Cd), and zinc (Zn) aimed to evaluate the effect of untreated domestic sewage discharges into the Recanto stream. To achieve this, water samples were collected on five days (30 August 2011, 11 November 2011, 22 August 2011, 19 September 2011, and 25 June 2013). The analyses were performed by inductively coupled plasma optical emission spectrometry (ICP-OES), using an Agilent model 720 instrument equipped with a "sea-spray" type nebulizer. The experimental conditions used for these analyses were: radio-frequency power of 1.10 kW, plasma argon flow of 15.0 L min^{-1}, and nebulizer pressure of 200 kPa. Calibration standard solutions were prepared from a multi-element stock solution (100.0 mg L^{-1}). Detection limits, calculated based on the standard deviations of the readings of ten analytical blanks, were as follows: 0.8 µg L^{-1} (Ba), 3.4 µg L^{-1} (Cr), 3.2 µg L^{-1} (Cu), 1.4 µg L^{-1} (Ni), 1.4 µg L^{-1} (Pb), 1.1 µg L^{-1} (Cd), 2.5 µg L^{-1} (Zn), and 2.0 µg L^{-1} (Mn) (Medeiros et al. 2013).

The results for the surface waters were then compared to the limits provided in the World Health Organization guidelines for drinking water (WHO 2011), following the approach adopted elsewhere (Jabeen et al. 2014; Gumbo et al. 2016). The results were also compared with those


P4
P3
P1,P2
Quilombo River Watershed
N
W
E
S
0 1 2 4 6
Km
Piracicaba Riverbasin
São Paulo
Brazil
Legend
Recanto Stream Micro-Basin
Santa Angélica Stream Micro-Basin
Pylles Stream Micro-Basin
Sampling site

◀**Fig. 1** Piracicaba river basin in São Paulo State, Southeast Brazil, showing the Quilombo river watershed and the micro-basins of the streams monitored: Recanto stream, downstream from the domestic sewage discharge (*P1*); Recanto stream upstream from the same place (*P2*); Santa Angélica stream (*P3*); and Pylles stream (*P4*)

obtained in previous studies of streams in the Piracicaba river basin (Machado et al. 2018; Medeiros et al. 2013; Silva et al. 2012; Medeiros et al. 2009; Filoso et al. 2003; Daniel et al. 2002; Krusche et al. 2002; Martinelli et al. 1999; Ometo et al. 2000).

2.4 Water microbial analyses

Microbial analyses of the water samples consisted of counts of total coliforms (TColif) and *Escherichia coli* (*E.coli*), using Defined Substrate Technology (DST). The chromogenic substrate used was COLILERT 18 (IDEXX Laboratories Inc., Westbrook, Maine, USA), which has been recommended and used for analyses of the quality of natural water (Fremaux et al. 2009; Buckalew et al. 2006; Niemela et al. 2003).

2.5 Pollutant loads

The following parameters were selected to estimate the pollutant loads received by the Quilombo river from its streams in the municipality of Americana: total dissolved solids, total nitrogen, BOD, metals (Ba, Cr, Cu, Ni, Zn, and Mn), and *E. coli*.

The pollutant loads were calculated using the following expression:

$$PL = 0.0864 \times C \times Q \quad (1)$$

where PL is the pollutant load (kg day^{-1} or MPN day^{-1}), C is the pollutant concentration (mg L^{-1} or MPN L^{-1}), and Q is the stream flow (L s^{-1}).

2.6 Statistical analysis

Descriptive statistics and Spearman correlations of the limnological and metals water quality parameters were performed to evaluate trends, data variability, and the relationships among the variables (Kikuchi et al. 2017; Hartmann et al. 2016; Bilgin 2015).

Principal component analysis (PCA) was used to understand the contribution of each water quality parameter to the observed variability (Gumbo et al. 2016; Walker et al. 2015; Jabeen et al. 2014; Legendre and Legendre 2012; Dalal et al. 2010; Ouyang et al. 2006).

The Kaiser–Meyer–Olkin (KMO) test was employed to evaluate the suitability of the samples for the PCA (Kaiser 1974). In this test, the redundancy of the variables is checked by means of partial correlation analysis. It is not appropriate to apply factor analysis when the correlations among the variables are near zero or very weak, because it is not possible to summarize the information. The KMO value ranges from 0 to 1, with values above 0.6 indicating that the variables and samples evaluated are suitable for factor analysis (Gumbo et al. 2016; Gholizadeh et al. 2016; Mao et al. 2013).

Due to the differences in the dimensional sizes of the studied variables, it was necessary to standardize the data before performing the PCA. This was achieved by means of the z-scores standardization function, as shown in the following equation (Liu et al. 2003):

$$Z_{ij} = \frac{\left(X_{ij} - Xm_j\right)}{S_i} \quad (2)$$

where Z_{ij} is the jth value of the standardized variable Z_i, X_{ij} is the jth observation of the ith variable, Xm_j is the mean for the jth variable, and S_i is the standard deviation for the ith variable.

The components considered were those that had eigenvalues higher than unity and explained at least 5% of the data variation (Gomes et al. 2014). In the selected principal components, the variables with higher loadings were retained (Mukhopadhyaya et al. 2014; Andrews et al. 2002). These variables were submitted to one-way ANOVA (not assuming equal variances) and the Tukey's honestly significant difference (HSD) multiple comparisons test ($\alpha = 5\%$), in order to identify differences in water quality among the sampling sites. The normal distribution of the data was confirmed using the Kolmogorov–

Table 1 Locations of the monitoring stations in São Paulo State, Southeast Brazil, and micro-basin information for each stream: Recanto stream, downstream from the domestic sewage discharge (P1); Recanto stream upstream from the same place (P2); Santa Angélica stream (P3); and Pylles stream (P4)

Stream	Latitude	Longitude	Total area (km^2)	Urbanized area (%)
Recanto (P1)	22°45′42″S	47°19′01″W	23.9	21
Recanto (P2)	22°45′47″S	47°19′10″W	23.6	21
Santa Angélica (P3)	22°44′46″S	47°19′18″W	14.6	47
Pylles (P4)	22°43′59″S	47°19′55″W	3.3	81

Smirnov test (at the 95% confidence level). All the statistical analyses were performed using the R software environment (R Core Team 2016) and Assistat® v. 7.7 software (Silva and Azevedo 2016).

3 Results and discussion

3.1 Flow and water quality of urban streams

The flow rates of the Recanto, Santa Angelica, and Pylles streams varied from 0.10 to 0.48 $m^3\ s^{-1}$, from 0.03 to 0.81 $m^3\ s^{-1}$, and from 0.03 to 0.17 $m^3\ s^{-1}$, respectively. These values were proportional to the temporal distribution of rainfall observed in this region, which amounted to 1759 mm from August 2011 to November 2012. The greatest flows in the Recanto and Santa Angélica streams were 0.47 and 0.81 $m^3\ s^{-1}$, respectively, on 2 May 2012, influenced by the rainfall, with accumulated precipitation for the three preceding days totalling 57.8 mm. The greatest flow in the Pylles stream was 0.11 $m^3\ s^{-1}$ on 4 June 2012, when 13.0 mm of rainfall was recorded. Table 2 shows the results obtained for the water quality indicators measured in the tributaries of the Quilombo river in the municipality of Americana.

The pH values ranged from 7.0 to 8.5, within the range from 6.5 to 8.5 recommended in the World Health Organization guidelines (2011). This range was also observed by Medeiros et al. (2009) in the Recanto stream, upstream of sewage discharges from Nova Odessa, and by Silva et al. (2012), Martinelli et al. (1999), and Machado et al. (2018) in streams of the PRB.

The WHO (2011) guidelines for drinking water do not provide any reference values for electrical conductivity, turbidity, real colour, dissolved oxygen, inorganic phosphorus, total phosphorus, total nitrogen, biochemical oxygen demand, total dissolved solids, total coliforms, and *E. coli*.

In the present study, 1500 $\mu S\ cm^{-1}$ was considered the threshold electrical conductivity (EC) for potable drinking water, as reported by Jabeen et al. (2014). The observed values were below this limit, with the Recanto stream showing the highest mean value of 329.7 $\mu S\ cm^{-1}$, which was 231 and 62% higher than the means for the Pylles and Santa Angélica streams, respectively. Other studies of tributaries of the Piracicaba river crossing urbanized areas have reported mean electrical conductivities similar to or higher than those obtained here, with values of 597.5 $\mu S\ cm^{-1}$ (Daniel et al. 2002), 271.8 $\mu S\ cm^{-1}$ (Ometo et al. 2000), and 306.0 $\mu S\ cm^{-1}$ (Silva et al. 2012).

Turbidity values less than 0.2 NTU are expected for well-managed municipal water supplies (WHO 2011). It can be seen from the results shown in Table 2 that this value was exceeded for all the samples. The Recanto stream presented the greatest turbidity range (14.4–217.0 NTU), which was superior to that measured by Medeiros et al. (2009) (17.5–80.0 NTU) near the P2 site. The mean turbidity of the Recanto stream was 27.9 and 56.7% higher, respectively, compared to the mean values obtained for the Santa Angélica and Pylles streams.

The Recanto stream showed the highest mean real colour (268.1 mg Pt L^{-1}), which was 181 and 61% higher than the values obtained for the Santa Angélica and Pylles streams, respectively. This could be attributed to the discharge of textile industrial effluents into the municipal sewage collection system, as indicated by the blue colour of fresh sewage released into the Recanto stream.

Among the streams evaluated, the lowest mean dissolved oxygen concentration was observed in the Recanto stream, reaching 2.6 mg L^{-1}, which was higher than the concentration of 0.85 mg L^{-1} measured by Medeiros et al. (2009). The mean DO values obtained for the Santa Angélica and Pylles streams were 167 and 118% higher than for the Recanto stream. It is possible that the low level of dissolved oxygen in the Recanto stream could have been due to point source organic material pollution caused by the inefficient sewage treatment system, resulting in oxygen consumption by aerobic organisms during degradation processes. This phenomenon has been observed previously in streams of the Piracicaba river basin (Daniel et al. 2002; Ometo et al. 2000).

The mean inorganic phosphorus (Pinorg) concentration obtained for the Recanto stream was 2176 and 876% higher, compared to the values obtained for the Santa Angélica and Pylles streams, respectively.

The mean concentration of total nitrogen in the Recanto stream was 236 and 33% higher than for the Santa Angélica and Pylles streams, respectively. Based on the land use in the micro-basins monitored, where there was no significant agricultural activity, it could be inferred that Pinorg and Ntotal were mainly influenced by point source pollution from the discharge of domestic sewage, particularly in the case of the Recanto stream. In other streams of the Piracicaba river basin, located in regions of intensive sugar cane cultivation, the levels of nitrogen are associated with the use of chemical fertilizers, as reported by Krusche et al. (2002) and Filoso et al. (2003).

Following the same trend as the other chemical parameters, the highest mean BOD was found for the Recanto stream (96.8 mg L^{-1}), which was 340 and 205% higher than the values observed for the Santa Angélica and Pylles streams, respectively. There is a shortage of BOD monitoring studies at the micro-basin scale in the PRB region, hindering comparison with the values obtained in the present research. However, in the mouth of the Quilombo river (downstream of the streams studied), BOD

Table 2 Means, standard deviations, and ranges of water quality indicators for the Recanto stream, downstream of the domestic sewage discharges (P1), the Santa Angélica stream (P3), and the Pylles stream (P4), in São Paulo State, Southeast Brazil

Indicator	Unit	P1	P3	P4
pH	–	7.7 ± 0.4	7.5 ± 0.3	7.6 ± 0.4
		7.2–8.5	7.1–7.9	7.0–8.0
EC	$\mu S\ cm^{-1}$	329.7 ± 84.5	99.2 ± 31.8	204.2 ± 60.9
		207.4–414.2	54.6–137.7	128.8–290.5
Turbidity	NTU	58.3 ± 78.4	39.3 ± 78.9	37.2 ± 69.7
		14.4–217.0	3.3–200.0	3.4–179.0
Colour	$mg\ Pt\ L^{-1}$	268.1 ± 154.2	95.3 ± 56.2	102.9 ± 40.8
		81.0–462.0	24.0–180.0	55.0–160.0
DO	$mg\ O_2\ L^{-1}$	2.60 ± 1.62	6.93 ± 1.32	5.66 ± 2.05
		0.80–5.50	4.70–8.40	2.30–8.40
Pinorg	$mg\ L^{-1}$	4.78 ± 2.68	0.21 ± 0.19	0.49 ± 0.23
		1.20–8.50	0.08–0.57	0.18–0.86
Ntotal	$mg\ L^{-1}$	11.57 ± 6.77	3.47 ± 0.58	8.68 ± 1.55
		3.10–20.70	2.90–4.40	6.90–11.30
BOD	$mg\ O_2\ L^{-1}$	113.5 ± 70.6	22.0 ± 6.7	31.7 ± 7.4
		34.0–182.0	15.0–32.0	20.0–43.0
TDS	$mg\ L^{-1}$	673.6 ± 289.7	453.0 ± 444.9	688.4 ± 680.4
		382.0–1082.0	33.0–1090.0	180.0–1820.0
TColif	MPN per 100 mL	$9.12 \times 10^7 \pm 1.23 \times 10^8$	$2.11 \times 10^6 \pm 1.23 \times 10^6$	$3.45 \times 10^7 \pm 5.33 \times 10^7$
		1.2×10^5–2.40×10^8	4.10×10^5–4.50×10^6	1.70×10^6–1.20×10^8
E. Coli	MPN per 100 mL	$5.20 \times 10^6 \pm 8.98 \times 10^6$	$1.72 \times 10^5 \pm 2.14 \times 10^5$	$1.37 \times 10^6 \pm 2.13 \times 10^6$
		1.30×10^4–2.60×10^7	4.10×10^3–6.20×10^5	1.20×10^4–6.30×10^6

EC electrical conductivity, *Colour* real colour, *DO* dissolved oxygen, *Pinorg* inorganic phosphorus, *Ntotal* total nitrogen, *BOD* biochemical oxygen demand, *TDS* total dissolved solids, *TColif* total coliforms count, *E.coli Escherichia coli* count

varied from 6.0 to 67.0 mg L^{-1} in 2012, with a mean of 33.0 mg L^{-1} (CETESB 2013), which was about one-third of the mean value found for the Recanto stream, indicating its polluting potential.

In contrast to the trends observed for the other water quality indicators, the TDS values obtained for the Recanto and Pylles streams were very similar, with a difference of only 2%, and were 49 and 52% higher, respectively, compared to the value for the Santa Angélica stream. This parameter is related to micro-basin land use, and it is likely that the higher urbanization rate for the region of the Pylles stream favoured run-off.

Microbial analyses of all the water samples confirmed the presence of pollution and the risk to water safety due to high levels of total coliforms and *E.coli*. The Recanto stream showed the highest mean values for total coliforms and *E.coli*, followed by the Pylles and Santa Angelica streams, corroborating the findings of Medeiros et al. (2009) and Queiroz and Berro (2011) concerning the microbial contamination of water in the urban streams of Americana city. Despite the fact that there are no substantial agricultural activities in these micro-basins, these findings are of concern, because there are still families living on the banks of the streams and in forest fragments in the urbanized area, growing vegetable and breeding domestic animals such as horses, cows, and chickens for subsistence. This population is therefore at risk of flooding and primary contact with polluted water.

3.1.1 Correlation structure and multivariate analysis

The common sampling dates in 2012 (June 4, August 22, September 19, and November 21) were considered in the correlation and principal component analyses of the 20 limnological and metals variables for the urban streams of Americana city. Application of the KMO test resulted in a coefficient of 0.71, demonstrating that the sample size of the water quality dataset was adequate for PCA, since there was sufficient redundancy in the data to perform the factor analysis. Similar values, using similar sample sizes, were obtained in other water quality studies in watersheds (Gumbo et al. 2016; Mao et al. 2013).

Table 3 provides the correlation matrix, while Table 4 shows the significances of the correlations. These results supported our hypothesis that urban streams in the Americana region are continuously vulnerable due to sewage pollution, highlighting the strong and significant negative correlations of dissolved oxygen with EC ($r = -0.73$), Pinorg ($r = -0.83$), Ntotal ($r = -0.86$), and BOD ($r = -0.90$), as well as the moderate correlations of *E.coli* with Pinorg ($r = 0.63$), Ntotal ($r = 0.69$), BOD ($r = 0.66$), EC ($r = 0.57$), and DO ($r = -0.57$).

The TDS parameter only showed a strong and significant correlation with real colour ($r = 0.80$), suggesting that its variability was probably associated with surface run-off and, consequently, with soil use and land occupation. The results (Table 3) also showed strong correlations between the metals and the limnological variables associated with the discharge of domestic sewage, from which it could be inferred that industrial effluents were being released into the sewage collection system. Correlation coefficients exceeding 0.70 ($p < 0.01$) were obtained for the following pairs of variables: Cr-Pinorg, Cr-BOD, Cu-Pinorg, Ni-Pinorg, Pb-EC, Pb-DO, Pb-Ntotal, Zn-EC, Zn-Pinorg, Zn-Ntotal, Zn-*E.coli*, and Mn-*E.coli*.

Application of PCA to the water quality variables generated five principal components with eigenvalues greater than 1.0, which explained around 90% of the total variance of the water dataset (Fig. 2).

The first component, accounting for 46.9% of the total variance, was associated with Ntotal, Pinorg, Zn, EC, DO, Cr, Pb, TColif, and Cu. This component could be interpreted as representing the influence of point sources of pollution, such as discharges of municipal sewage and industrial effluents. The second component, accounting for 15.8% of the total variance, was associated with Ni and *E.coli*, indicative of the influence of discharges of industrial effluent into the sewage collection system, as well as Fe and TDS, reflecting the effect of non-point sources such as run-off, since the subtropical soils of the Americana region contain high concentrations of this metal (Medeiros et al. 2009). The third component (PC3, accounting for 10.8% of the total variance) presented a high loading for turbidity, showing the influence of organic matter present in the hydric resources of the region, as well as Cd, associated with industrial activities in Americana. PC4 (8.9% of the total variance) and PC5 (7.3% of the total variance) showed high loadings for Mn and Ba, respectively, probably due to discharges of effluents from specific industrial sources.

The principal component analysis also revealed differences among the water quality datasets for the three basins evaluated, notably in the case of the Recanto stream, for which greater dispersion of the water quality values was observed (Fig. 3). In Fig. 3, it can be seen that the variables that showed the smallest angles, relative to the PC1 axis (Cu, TColif, Zn, EC, Pinorg, Pb, Ntotal, and DO), had the greatest influence in segregation of the three basins. The variables that showed angles of around 45°, relative to the PC1 axis (Fe, Ni, *E.coli*, pH, and Colour), were responsible for greater dispersion of the results for the Recanto stream water samples (Legrenge and Legrenge 2012).

3.2 Pollutant loads transported by urban streams

The results of the multivariate analyses were used to identify the main pollutant loads released into the Quilombo river from the urban streams of Americana city, close to its mouth at the Piracicaba river (Table 5). The Recanto stream presented the highest loads of pollutants (with the exception of TDS and Ba), reflecting the effect of sewage discharges from Nova Odessa city. The influence of the flow resulted in the Santa Angélica stream showing the second largest load of metals, nutrients, sediments, and bacteria released into the Quilombo river, followed by Pylles stream.

The highest loads of *E.coli* were observed after rainy days, associated with higher flows, probably related to non-point source pollution from clandestine connections of sewage pipes to rainwater drainage systems, as occurs in many Brazilian cities (Tucci 2007), leading to increased transport of water contaminants. Other researchers have reported increases of *E.coli* concentrations in small tributaries after rainfall events (Riou et al. 2007; Galfi et al. 2016), demonstrating the importance of studying the phenomena of pollutant transport from micro-basins, within the context of water resources. The mean *E.coli* load in the Recanto stream was 586 and 237% higher than in the Santa Angélica and Pylles streams, respectively.

In the case of the Ntotal load, the mean value for the Recanto stream was 14 and 136% higher, compared to the Santa Angélica and Pylles streams, respectively, representing the smallest difference among the pollutant loads analysed.

Except for barium, all the metal pollutant loads were higher for the Recanto stream. Comparing the mean daily metals loads for the Recanto stream with those for the Santa Angélica and Pylles streams, respectively, the values were higher by 701 and 5522% (Cr), 824% and 1068% (Cu), 2167% and 7273% (Ni), 3202% and 4099% (Zn), 220 and 209% (Mn), and 190 and 1,030% (Pb). The Ba load in the Santa Angélica stream was 28 and 145% higher than in the Recanto and Pylles streams, respectively.

The highest load of total dissolved solids was observed for the Santa Angélica stream (16.21 t day^{-1}), which was 25 and 418% higher than for the Recanto and Pylles streams, respectively. Taking the micro-basin areas into consideration the mean specific TDS loads were 0.54 t $(day\ km^2)^{-1}$, 1.11 t $(day\ km^2)^{-1}$, and 0.95 t $(day\ km^2)^{-1}$ for the Recanto, Santa Angélica, and Pylles streams,

Table 3 Spearman coefficients for the correlations among water quality indicators of the urban streams of Americana, in São Paulo State, Southeast Brazil

Spearman correlation	pH	EC	Turb	Colour	DO	Pinorg	Ntotal	BOD	TDS	TColif	*E.coli*	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
pH	1																			
EC	0.21	1																		
Turb	−0.28	0.41	1																	
Colour	0.47	**0.58**	0.47	1																
DO	−0.48	***−0.73***	−0.22	***−0.69***	1															
Pinorg	0.34	***0.86***	0.48	**0.66**	***−0.83***	1														
Ntotal	0.42	***0.85***	0.08	0.51	***−0.86***	***0.82***	1													
BOD	0.32	**0.66**	0.27	0.55	***−0.90***	***0.78***	***0.81***	1												
TDS	**0.60**	0.14	0.04	***0.80***	−0.55	***0.27***	0.27	0.34	1											
TColif	0.23	0.32	−0.06	−0.07	−0.33	0.48	0.55	0.30	−0,16	1										
E.coli	0.27	**0.57**	0.17	0.31	**−0.57**	**0.63**	***0.69***	**0.66**	0.13	0.36	1									
Ba	−0.03	0.40	−0.33	−0.36	0.03	0.10	0.30	−0.01	−0.52	0.17	0.19	1								
Cd	0.15	0.32	0.41	0.03	−0.19	0.38	0.19	0.19	−0.11	0.20	0.51	0.27	1							
Cr	0.18	**0.68**	0.22	0.20	**−0.61**	***0.71***	**0.64**	***0.74***	−0.15	0.41	0.54	0.33	0.24	1						
Cu	0.35	**0.65**	0.31	0.32	**−0.58**	***0.79***	**0.62**	**0.66**	0.03	0.53	**0.65**	0.27	0.54	***0.85***	1					
Ni	0.19	**0.60**	0.25	0.05	−0.45	**0.70**	0.54	0.51	−0.26	**0.59**	**0.62**	0.41	**0.60**	***0.86***	***0.92***	1				
Pb	0.40	***0.72***	−0.09	0.28	***−0.76***	**0.59**	***0.75***	**0.67**	0.12	0.25	0.38	0.47	0.13	***0.75***	0.53	0.55	1			
Zn	0.42	***0.75***	0.27	0.43	**−0.68**	***0.75***	***0.74***	**0.65**	0.22	0.51	***0.71***	0.31	**0.62**	**0.67**	***0.88***	***0.78***	**0.58**	1		
Fe	0.13	0.31	0.19	−0.04	−0.40	0.53	0.38	0.52	−0.29	0.55	0.44	0.03	0.23	***0.81***	**0.66**	***0.78***	0.46	0.39	1	
Mn	0.39	0.28	0.17	0.22	−0.43	0.54	0.50	0.55	0.17	0.54	***0.80***	−0.01	**0.62**	0.34	**0.67**	0.56	0.07	**0.68**	0.38	1

Values in bold type indicate significance at the 0.05 level (2-tailed)

Values in bold italic type indicate significance at the 0.01 level (2-tailed)

Table 4 Significance values for the Spearman correlations among water quality indicators of the urban streams of Americana, in São Paulo State, Southeast Brazil

Spearman significance	pH	EC	Turb	Colour	DO	Pinorg	Ntotal	BOD	TDS	TColif	*E.coli*	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
pH	–																			
EC	0.51	–																		
Turb	0.37	0.18	–																	
Colour	0.12	**0.05**	0.12	–																
DO	0.12	***0.01***	0.48	***0.01***	–															
Pinorg	0.27	***0.01***	0.11	**0.02**	***0.01***	–														
Ntotal	0.18	***0.01***	0.80	0.09	***0.01***	***0.01***	–													
BOD	0.31	**0.02**	0.40	0.07	***0.01***	***0.01***	***0.01***	–												
TDS	**0.04**	0.66	0.90	***0.01***	0.06	0.40	0.39	0.29	–											
TColif	0.46	0.31	0.85	0.84	0.30	0.11	0.06	0.35	0.63	–										
E.coli	0.40	**0.05**	0.60	0.33	**0.05**	**0.03**	***0.01***	**0.02**	0.68	0.25	–									
Ba	0.94	0.20	0.30	0.25	0.91	0.76	0.34	0.98	0.08	0.61	0.56	–								
Cd	0.65	0.31	0.18	0.92	0.54	0.22	0.56	0.56	0.74	0.52	0.09	0.40	–							
Cr	0.57	**0.02**	0.49	0.53	**0.04**	***0.01***	**0.03**	***0.01***	0.64	0.19	0.07	0.30	0.46	–						
Cu	0.26	**0.02**	0.33	0.31	**0.05**	***0.01***	**0.03**	**0.02**	0.93	0.07	**0.02**	0.40	0.07	***0.01***	–					
Ni	0.56	**0.04**	0.43	0.88	0.14	***0.01***	0.07	0.09	0.41	**0.04**	**0.03**	0.18	**0.04**	***0.01***	***0.01***	–				
Pb	0.19	***0.01***	0.78	0.37	***0.01***	**0.04**	***0.01***	**0.02**	0.70	0.43	0.23	0.12	0.68	***0.01***	0.08	0.06	–			
Zn	0.17	***0.01***	0.39	0.17	**0.02**	***0.01***	***0.01***	**0.02**	0.48	0.09	***0.01***	0.33	**0.03**	**0.02**	***0.01***	***0.01***	**0.05**	–		
Fe	0.68	0.32	0.56	0.90	0.20	0.08	0.22	0.08	0.37	0.06	0.15	0.93	0.46	***0.01***	**0.02**	***0.01***	0.13	0.21	–	
Mn	0.21	0.38	0.60	0.48	0.17	0.07	0.10	0.07	0.59	0.07	***0.01***	0.97	**0.03**	0.28	**0.02**	0.06	0.82	**0.02**	0.23	–

Values in bold type indicate significance at the 0.05 level (2-tailed)

Values in bold italic type indicate significance at the 0.01 level (2-tailed)

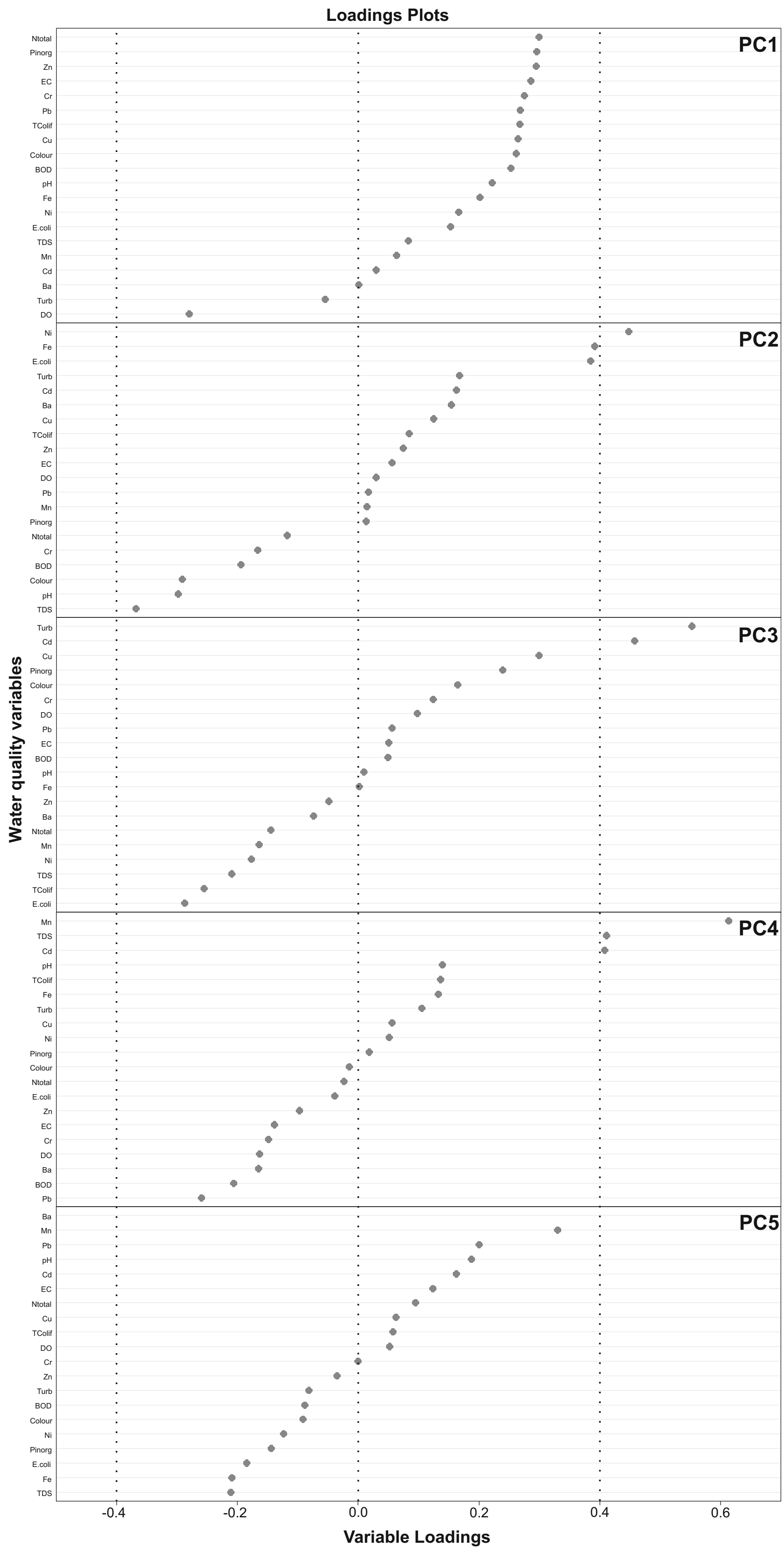


Fig. 2 Principal components and loadings for water quality indicators of the urban streams of Americana, in São Paulo State, Southeast Brazil

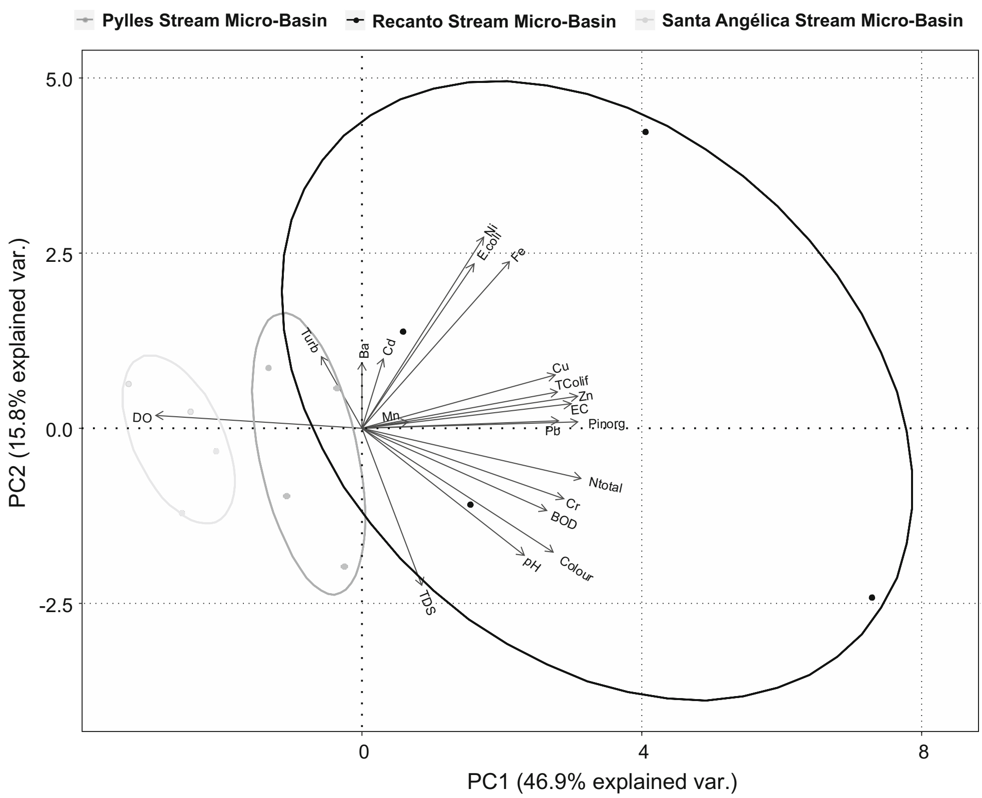


Fig. 3 Principal component analysis correlation biplot for raw water quality indicator data of the urban streams of Americana, in São Paulo State, Southeast Brazil

respectively. This considerably reduced the relative difference observed between the Santa Angélica and Pylles streams, from 418 to 17%. These results indicated the importance of ecosystem services provided by grasslands and urban green spaces in contributing to better water quality (Martinico et al. 2014), because the Recanto micro-basin has a lower degree of urbanization (21%), compared to the Santa Angélica (47%) and Pylles (81%) areas, leading to a lower specific TDS load. Other studies have also described the influence of urbanization and industrialization on the degradation of water resources in catchments of developed and developing countries including Brazil (Medeiros et al. 2013; Daniel et al. 2002; Silva et al. 2013), Colombia (Sandoval et al. 2014), the USA (O'Neill et al. 2013; Gholizadeh et al. 2016), South Africa (Gumbo et al. 2016), Portugal (Gomes et al. 2014), India (Jabeen et al. 2014; Jamwal et al. 2008), Australia (Hatt et al. 2004), Turkey (Bilgin 2015), Sweden (Galfi et al. 2016; Berndtsson and Bengtsson 2006) and Finland (Metsäranta et al. 2005).

3.3 Effect of urban sewage on water resources

The effect of point source pollution due to the discharge of sewage from the city of Nova Odessa into the Recanto stream, in the city of Americana, was evaluated using the measurements of potentially toxic metals, which were selected based on the results of the multivariate analyses (Table 6).

The presence of heavy metals in water resources can be attributed to natural sources, such as parent rocks and processes of soil formation in the micro-basin; contamination due to human activities, and other anthropogenic factors (Yi et al. 2011). In order to evaluate the impact of water pollution due to sewage discharges, measurements of metal concentrations in the Santa Angélica and Pylles streams were used to obtain a regional reference.

The water from the mouth of the Recanto stream (site P1) showed the highest concentrations of Zn, Ni, Cu, Cr, and Pb with average concentrations that were 1311, 718, 424, 372, and 170% higher, respectively, compared to site P2 (upstream). These increases suggested a significant release of industrial effluents into the Nova Odessa sewage system, during the period of the present study, especially from metallurgical and foundry industries.

Chromium is used in the metallurgical and pigment production sectors (Barnhart 1997), while zinc, copper, lead, and nickel are present in effluents derived from metallurgical and foundry activities, as well as in domestic sewage (Gomes et al. 2014; Yi et al. 2011; Singh et al. 2005; McGrath 1995; Baker and Senft 1995; Kiekens 1995).

Table 5 Means, standard deviations, and ranges of pollutant loads in the Recanto stream, downstream from the domestic sewage discharge (P1), the Santa Angélica stream (P3), and the Pylles stream (P4), in São Paulo State, Southeast Brazil

Pollutant	Unit	P1	P3	P4
E.coli	MPN day^{-1}	$5.49 \times 10^{16} \pm 9.29 \times 10^{16}$	$8.01 \times 10^{15} \pm 1.09 \times 10^{16}$	$1.63 \times 10^{16} \pm 3.39 \times 10^{16}$
		1.46×10^{14}–2.70×10^{17}	9.56×10^{13}–3.00×10^{16}	4.77×10^{13}–9.25×10^{16}
Pinorg	kg day^{-1}	64.25 ± 28.78	8.21 ± 9.76	3.53 ± 2.73
		32.83–102.82	1.24–27.58	0.65–8.37
Ntotal	kg day^{-1}	142.24 ± 250.39	125.32 ± 72.60	60.22 ± 39.16
		63.16–249.78	44.32–210.47	27.22–135.13
Ba	kg day^{-1}	5.55 ± 4.93	7.12 ± 7.79	2.91 ± 2.07
		2.22–13.03	0.98–19.21	0.07–4.92
Cr	kg day^{-1}	4.93 ± 4.24	0.61 ± 0.80	0.09 ± 0.08
		0.62–11.87	0.05–2.51	0.01–0.27
Cu	kg day^{-1}	4.63 ± 3.80	0.50 ± 0.58	0.27 ± 0.29
		0.23–10.10	0.12–1.65	0.03–0.74
Ni	kg day^{-1}	5.96 ± 9.26	0.26 ± 0.40	0.08 ± 0.08
		0.09–20.57	0.02–1.09	0.01–0.17
Zn	kg day^{-1}	81.05 ± 90.73	2.45 ± 1.91	1.93 ± 1.62
		1.75–223.95	0.09–5.11	0.38–4.29
Pb	kg day^{-1}	1.16 ± 1.11	0.40 ± 0.52	0.10 ± 0.08
		0.22–4.13	0.03–1.61	0.01–0.26
Mn	kg day^{-1}	39.90 ± 37.68	12.46 ± 5.75	12.91 ± 7.44
		7.84–107.83	6.74–21.00	1.89–24.88
TDS	t day^{-1}	12.71 ± 12.75	16.21 ± 20.71	3.13 ± 1.34
		3.96–34.64	1.60–51.79	1.72–5.35

E.coli Escherichia coli count, *Pinorg* inorganic phosphorus, *Ntotal* total nitrogen, *Ba* barium, *Cr* chromium, *Cu* copper, *Ni* nickel, *Zn* zinc, *Pb* lead, *Mn* manganese, *TDS* total dissolved solids

In all streams, the mean concentration of Ba, Cu, and Cd was below the limits established by WHO (2011) for drinking water. In the Recanto stream, downstream of the sewage discharge (P1), the mean concentrations of Cr, Ni, and Pb exceeded the established values for drinking water by 570, 166, and 496%, respectively.

Upstream of the sewage discharge (site P2), only the mean values for Cr and Pb exceeded the WHO (2011) reference limits, by 42 and 121%, respectively. The Santa Angélica stream showed the lowest concentrations of the metals evaluated in this study, indicative of better conditions in terms of water quality, with mean concentrations of all the metals below the limits established by WHO (2011). In the case of the Pylles stream, the Pb concentration exceeded the reference value by 80%. Preliminary, research by Medeiros et al. (2013) indicated an influence of sewage discharges from Nova Odessa on the concentration of metals, especially Cr, in the water and sediments of the Recanto stream.

No reference values have been established by WHO (2011) for Zn and Mn in drinking water. However, concentrations above around 4000 μg L^{-1} for Zn and 100 μg L^{-1} for Mn impart undesirable tastes to drinking water (WHO 2011). The mean Zn concentrations were below this value at all the sites, while all the mean Mn concentrations exceeded the limit value, notably in the case of the Pylles stream.

Leite (2002) measured the concentrations of metals (Cd, Cr, Cu, Fe, Mn, and Zn) in the water and sediments of the Salto Grande reservoir, located in Americana city, demonstrating that the system was polluted and degraded by inputs from agricultural and industrial activities in the PRB. Moreira and Fazza (2008) evaluated metal pollution in urban streams of Limeira, a city near Americana, obtaining mean concentrations of 1,085 μg L^{-1} (Cr), 194 μg L^{-1} (Cu), 207 μg L^{-1} (Ni), 876 μg L^{-1} (Pb), and 1010 μg L^{-1} (Zn), which were higher than found in the present investigation.

These experimental results demonstrated the polluting potential of urban streams flowing into rivers and reservoirs that supply water to industrial parks and the population in the Americana region, including the Quilombo river and other waterways.

Table 6 Means, standard deviations, and ranges of metal concentrations in the Recanto stream, downstream (P1) and upstream (P2) of sewage discharges from Nova Odessa city, the Santa Angélica (P3), and the Pylles stream (P4)

Metal	Unit	P1	P2	P3	P4
Ba	$\mu g\ L^{-1}$	284.2 ± 85.7	203.1 ± 128.2	171.5 ± 132.6	501.4 ± 401.8
		201.4–490.4	36.5–384.4	46.4–370.5	25.3–948.4
Cr	$\mu g\ L^{-1}$	334.9 ± 356.8	71.0 ± 49.3	17.7 ± 17.0	18.4 ± 13.5
		65.5–981.2	34.9–170.1	<3.4–48.5	<3.4–35.6
Cu	$\mu g\ L^{-1}$	236.2 ± 127.5	45.1 ± 36.9	12.9 ± 9.9	46.1 ± 17.1
		20.1–397.9	9.1–103.7	<3.2–31.8	4.4–45.6
Ni	$\mu g\ L^{-1}$	171.2 ± 207.0	22.8 ± 19.2	5.6 ± 7.4	14.0 ± 14.5
		8.2–496.1	2.6–54.4	<1.4–21.1	1.4–32.1
Pb	$\mu g\ L^{-1}$	59.6 ± 28.9	22.1 ± 11.6	10.8 ± 13.3	18.0 ± 17.1
		20.0–99.5	10.8–48.5	<1.4–39.4	2.0–44.1
Zn	$\mu g\ L^{-1}$	3340.8 ± 3051.1	236.7 ± 106.5	83.5 ± 56.7	343.3 ± 169.9
		155.4–6900.0	73.2–383.2	<2.5–170.7	93.7–580.3
Mn	$\mu g\ L^{-1}$	1944.9 ± 970.3	1466.2 ± 605.4	380.3 ± 47.1	3074.6 ± 2377.2
		697.9–3172.3	375.0–2400.0	319.4–438.1	315.9–5500.0

Ba barium, *Cr* chromium, *Cu* copper, *Ni* nickel, *Pb* lead, *Zn* zinc, *Mn* manganese

3.3.1 ANOVA and Turkey test

Analysis of variance (ANOVA) was performed for the limnological variables (Table 7) and the metals (Table 8), considering those variables that showed the smallest angles relative to the PC1 axis in the reduced component space (Fig. 3).

Table 7 provides a comparison of the water quality at the outlets (mouths) of the three hydrographic basins evaluated, enabling differentiation among them. The Recanto stream (P1) presented significant differences ($p < 0.01$) for DO, EC, and Pinorg, demonstrating greater degradation of water quality due to sewage discharges. On the other hand, the Santa Angélica stream (P3) showed the best water quality indicator values, especially for EC and Pinorg, for which the values were significantly different ($p < 0.01$), compared to the Recanto and Pylles streams.

The results obtained for the potentially toxic metals revealed significantly higher values ($p < 0.01$) downstream of sewage discharges into the Recanto stream, especially for Pb and Cu. In addition, there were no significant differences between the results for P2 (upstream of the point source of pollution) and the other streams. This suggested that industrial effluents were discharged into the sewage collection system of the municipality of Nova Odessa, contributing to the vulnerability of this important regional stream.

3.4 Guidelines for the management of hydric resources

The results obtained in this work enabled the identification of two driving forces responsible for the pollution of water bodies in the hydrographic micro-basins of the municipality of Americana (Table 9).

The first is related to diffuse pollution caused by urban expansion and the reduction of green areas in the micro-basins, together with the clandestine connection of sewage outlets to the rainwater drainage systems. The impacts caused by the reduction of green areas include sediment discharges and associated high Fe levels at the mouth of the Quilombo river. The *E.coli* load associated with clandestine discharges of sewage into the rainwater drainage system reached 2.29×10^{17} MPN day^{-1} in the rainy season, representing an increase of 165%, relative to the annual mean.

The management guidelines associated with this driving force are within the scope of the municipality of Americana and include the monitoring and control of water quality in

Table 7 Results of ANOVA and Tukey's test for the limnological variables that presented PCA eigenvalues higher than unity for the micro-basins studied

Indicator	Unit	P1	P3	P4
DO**	mg O_2 L^{-1}	2.60b	6.91a	5.93a
EC**	$\mu S\ cm^{-1}$	329.70a	99.20c	204.20b
Ecoli#	–	5.89a	4.87a	5.64a
Ntotal*	mg L^{-1}	11.57a	3.47b	8.68ab
Pinorg#**	–	2.63a	1.21c	1.65b
TDS	mg L^{-1}	673.60a	453.00a	688.40a
TColif#	–	7.56a	6.84a	7.31a
Turbidity#	–	1.55a	1.02a	1.09a

**Significant at 1% probability ($p < 0.01$); *Significant at 5% probability ($p < 0.05$); #Data normalized (Shapiro–Wilk test, $\alpha = 5\%$) by log transformation of the original data. Letter show significant difference among streams

Table 8 Results of ANOVA and Tukey's test for identification of differences in metal concentrations among the micro-basins studied

Metal	Unit	P1	P2	P3	P4
Cr#**	–	2.23a	1.82ab	0.92b	1.01b
Fe#*	–	4.51a	4.49ab	4.17ab	4.03b
Mn#	–	3.20a	3.07a	2.57a	3.27a
Ni#	–	1.82a	1.10a	0.42a	0.79a
Pb**	$\mu g\ L^{-1}$	59.59a	22.05b	10.75b	17.98b
Ba#**	–	2.44a	2.20b	2.07b	2.56a
Cu#**	–	2.25a	1.52b	0.98c	1.41b

**Significant at 1% probability ($p < 0.01$); *Significant at 5% probability ($p < 0.05$); #Data normalized (Shapiro–Wilk test, $\alpha = 5\%$) by log transformation of the original data. Letter show significant difference among streams

the rainwater drainage network, with the identification of the locations of illegal sewage discharges, in order to reduce the diffuse pollutant load discharged at the mouth of the Quilombo river.

The second driving force is associated with point source pollution due to the discharge of untreated sewage from the city of Nova Odessa into the Recanto stream in Americana. The main impacts include elevated load of nutrients, as well as potentially toxic metals derived from the discharge of industrial effluents into the Nova Odessa sewage collection system, necessitating the formulation of guidelines for the management of water resources within the scope of this municipality.

Considering the nutrient and organic loads discharged at the mouth of the Quilombo river, derived from the Americana urban streams, the Recanto stream alone accounted for 59% (BOD), 84% (Pinorg), and 43% (Ntotal) of the total loads of these pollutants. This indicated the need for a recommendation concerning the treatment of Nova Odessa sewage.

The same trend was observed for the loads of metals, since 90% (Cr), 69% (Pb), and 85% (Cu) of the loads discharged at the mouth of the Quilombo river originated from the Recanto stream. This demonstrated the need to monitor and control the quality of sewage from Nova Odessa, identifying the sources of industrial effluents clandestinely released by local industries.

4 Conclusions

The findings of this research revealed the vulnerability and degradation of water resources in urban micro-basins in Southeast Brazil, threatening the Quilombo river, which is one of the main water supply sources in the Piracicaba river basin. The discharges of untreated sewage directly into streams, combined with the release of sewage into rainwater collection systems, and the reduction of green areas, increase the risks to streams that cross urban areas and are not monitored and controlled by the Brazilian environmental agencies.

The most important pollution source identified was sewage discharge from the municipality of Nova Odessa, which significantly influenced various water quality parameters, especially dissolved oxygen, electrical conductivity, inorganic phosphorus, lead, and copper. These emissions pose serious risks to public health, due to the presence of microbial contamination, as well as potentially toxic metals, in a water body used for animal husbandry and the irrigation of small subsistence vegetable plots.

Multivariate analysis employing a large number of physical, chemical, and biological water parameters was used to

Table 9 Driving forces for the degradation of hydric resources, environmental impacts, and pollutant loads discharged at the mouth of the Quilombo river, and guidelines for the management of urban hydrographic micro-basins in Southeast Brazil

Driving forces	Environmental impacts in the micro-basins	Quality indicators of affected water	Mean pollutant load	Management guidelines
Urbanization of Americana	Clandestine connection of sewage outlets to the urban drainage system	*Escherichia coli*	8.64×10^{16} MPN day^{-1} (along 2012)	Monitoring and control of water quality in the drainage network; Identification of clandestine discharges of domestic sewage
	Surface impermeabilization	Fe, TDS	32.1 t day^{-1} (Fe) 1.4 t day^{-1} (TDS)	Increase green spaces in the micro-basins to reduce loss of sediments
Nova Odessa sewage system	Discharge of untreated Nova Odessa sewage into the Recanto Stream	BOD, Ntotal, Pinorg, EC, DO, TColif,	2.54 t day^{-1} (BOD) 327.8 kg day^{-1} (Ntotal) 76.3 kg day^{-1} (Pinorg)	Treatment of sewage from Nova Odessa
	Discharge of industrial effluents into the Nova Odessa city sewage system	Cr, Pb, Cu	5.45 kg day^{-1} (Cr) 1.25 kg day^{-1} (Pb) 4.82 kg day^{-1} (Cu)	Monitoring and control of sewage quality; Identification of clandestine discharges of industrial effluents

identify the main factors that contributed to the degradation of hydric resources in urban micro-basins in Southeast Brazil. This enabled the proposal of guidelines for the management of these resources, involving monitoring and control of water quality in the rainwater drainage system of the city of Americana and the sewage collection network of Nova Odessa, in order to identify clandestine discharges o domestic and industrial effluents into these collection systems. Such measures would reduce the loads of pollutants released into the main rivers of the Piracicaba river basin, which is one of the most economically important regions of Brazil and is facing serious problems of water scarcity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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