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Inadequate riparian zone use directly decreases water quality of a low-order urban stream in southern Brazil

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ABSTRACT

Considering the current importance watercourses quality conservation, it is important to establish relationships between parameters that enable evaluation of the origins of changes in water quality, allowing actions to mitigate them. However, it is important to improve the association of different variables and to take sufficient samples. This study associates usual techniques and parameters to analyse the water quality of an urban river from Paraná State, Brazil. For this, we used biological indicators (aquatic macroinvertebrates), physical-chemical (temperature, turbidity, true colour, pH, DO and $BOD_{5,20}$) indicators and microbiological (faecal and total coliforms) indicators. These indicators were related to land use and occupation classes obtained from high resolution QuickBird 2 images. For this association, the surroundings (450 meters buffer) of three distinct points of the river were considered: I. Near the spring; II. In the downtown city; and III. In a residential neighbourhood. Different values of physical, chemical and microbiological variables were detected along the river, showing evident relationships between them and with the use and occupation of the urban and peri-urban space in the characterization of surface waters. The association design was able to detect the landscape effect on water quality in a coherent way and that these connections were mainly related to suppression of the riparian forest present in the surroundings, further demonstrating the importance of this vegetation for the maintenance of watercourse quality.

Keywords: aquatic macroinvertebrates, physical-chemical parameters, water resources.

O uso e ocupação inadequados da zona ciliar diminuem a qualidade da água de um rio urbano de pequena ordem no sul do Brasil

RESUMO

Visto a importância da conservação da qualidade dos cursos hídricos atualmente, torna-se indispensável estabelecer relações entre variáveis que permitam avaliar as origens de alterações na qualidade das águas, permitindo a realização de ações que possam minimizá-las. Contudo, é importante buscar melhorias na associação das diferentes variáveis, com esforço amostral adequado. O presente associa técnicas e parâmetros comumente utilizados e de fácil acesso para analisar a qualidade da água de um rio urbano no estado do Paraná. Para isso, foram utilizados indicadores biológicos (macroinvertebrados aquáticos), físico-químicos (temperatura, turbidez, cor verdadeira, pH, OD e $DBO_{5,20}$) e microbiológicos (coliformes fecais e totais). Esses indicadores foram relacionados com os tipos de uso e ocupação da terra obtidos a partir de imagens QuickBird2. Para essa associação foram considerados o entorno (450 metros de *buffer*) de três pontos distintos do rio: I. Próximo a nascente; II. No centro da cidade e III. Em um bairro residencial. Diferentes valores de variáveis físicas, químicas, microbiológicas e da comunidade de macroinvertebrados foram detectados ao longo do rio, demonstrando relações evidentes entre si e com o uso e ocupação do espaço urbano e peri-urbano na caracterização de águas superficiais. Concluímos que a associação utilizada conseguiu detectar o efeito da paisagem na qualidade da água de forma coerente e que estas relações estão principalmente atreladas a supressão da mata ciliar presente no entorno, demonstrando a importância desta vegetação para a manutenção da qualidade dos cursos hídricos.

Palavras-chave: macroinvertebrados aquáticos, parâmetros físico-químicos, recursos hídricos.

1. INTRODUCTION

Throughout history, watercourses have played an important role in supporting society, but the expansion of human settlements and urban areas has intensified the deterioration of water quality, as watercourses have become targets of indiscriminate disposal of effluents and alterations (Larson *et al.*, 2019). In Brazil, Permanent Preservation Areas consist of marginal strips of legally protected watercourses, which may or may not present native vegetation. Moreover, their environmental function is to safeguard water resources, landscape, geology, soil and local biodiversity, besides offering sustenance and well-being to human populations (Brasil *et al.*, 2009). Thus, if water quality is the result of a series of natural phenomena occurring in a watershed, it can reasonably be considered that the way man changes these natural systems, uses and occupies the land, has a direct impact on water quality (WHO, 2004; Silveira *et al.* 2016).

Water quality is usually evaluated from the perspective of physical and chemical variables. However, these evaluations can be limited and lead to instantaneous diagnosis of the studied section. On the other hand, bioindicators, represented in watercourses mainly by aquatic macroinvertebrates, are organisms chosen for their sensitivity or tolerance to environmental changes. Given the dynamics of their respective life cycles, they represent scenarios in a broader spatial and temporal ways, including changes in land-use

The municipality of Irati, located in the south-central region of Paraná state, Brazil, is strategically important from the standpoint of environmental conservation, since the area includes the watershed of the three main river basins of Paraná State: the Iguaçu, Ivaí and Tibagi River Basins (Maack, 2017; Mazza *et al.*, 2005). The municipality has undergone diversification and expansion of economic activities over time, accelerating the anthropization and heterogenization of the landscape and generating pressures on water courses, especially on the Antas River, which has a large part of its course located within the urban area (Orreda, 2004).

The Antas River is a low-order river and an important tributary of the Imbituvão River, from where the waters are collected for region supply, being part of Tibagi River Basin. However, the Antas River currently presents serious problems related to water quality and suppression of riparian forest, particularly showing irregular occupation of the banks and discharge of effluents (Andrade and Felchak, 2009; Haberland *et al.*, 2012). The main objective of this study was to evaluate and associate physico-chemical and biological variables taking into account the influence of the land use and occupation. This work was designed to obtain information with little space-time effort, associating water quality indexes and land use, mainly related to urbanization. Furthermore, we stress the pioneering of this study for the central west region of Paraná state, contributing to the preservation of the Antas River.

2. METHODS AND MATERIAL

2.1. Characterization and location of study areas

The present study was developed in Irati, Paraná, whose climate according to Köppen-Geiger climate classification is Cfb. The average temperature of 17.5°C, 1476 mm is the average annual rainfall. July is the driest month, with an average of 4 mm rainfall and October the rainiest with a mean of 175 mm (IAPAR, 2018). The city is located in the phyto ecological region of Mixed Ombrophilous Forest and the sections of the present study are concentrated specifically in the Alluvial Ombrophilous Forest typology, although the vegetation is in process of regeneration or non-existent.

Three points in the urban perimeter of Irati were selected for sampling: Point 1: (25°30'1.50" S / 50°37'43.39" W) stretch with riverbed characterized by sandy-rocky bottom, 3 m wide, presenting remnants of native vegetation, as well as areas of forestry and recovery. Point 2: (25°28'13.76" S / 50°39'28.91" W) sandy / muddy watercourse segment, 5 m wide average, a region marked by absence of riparian vegetation and irregular occupation of the margin. Point 3: (25°27'43.00" S / 50°39'20.86" W) stretch with 4 m wide, on average, characterized by sandy bottom and predominantly with slab and partial presence of riparian forest. Based on the theory that rivers follow the principle of a continuum system (Larsen *et al.*, 2019), collection points selection followed the choice criterion according to landscape composition change.

2.2. Land Use

A QuickBird 2 high resolution spatial image was used, the image had the atmosphere corrected by dark-object subtraction algorithm, which minimizes shadow effects and possible detection errors in the sensor (Chavez Jr., 1988). In sequence, the radiance values of the image were converted to reflectance and the radiometric resolution was converted to 8 bits. The image was still orthorectified by the digital elevation model (DEM) and the multispectral - RGB (2.4 m) and panchromatic (0.61 m) bands, was merged to obtain the monochromatic spatial resolution. After the image pre-processing, it was clipped by buffers of 450 m radius, with the centre in the coordinates of the collection points. This radius size was determined to avoid overlapping between the sampled points (specifically Points 2 and 3, see Figure 1B) preventing spatial autocorrelation between the sampled water quality parameters (Frieden *et al.*, 2014). Another important criterion for determining the radius is the landscape scale that influences macroinvertebrates community, since 500-meters distant environmental changes can jeopardize the aquatic community (Yirigui *et al.*, 2019).

In sequence, classes of land use were defined: I. Arboreal vegetation, represented by the Mixed Ombrophylous Forest or Araucaria Forest; II. Agriculture and field, represented by the cultivation of commercial species fields / herbaceous-shrub vegetation; III. Forests represented by field areas with occurrence of isolated trees; IV. Urban perimeter area represented by areas with low density of built-up area; and V. Urban Area represented by built up (developed) and / or paved areas (with high density of built up area). The interpretation work was performed by cognitive interpretation and manual vectoring, followed by association to the predefined classes. The validation of the classification was done by field verification. We assumed that by not using automatic or semi-automatic classification methods, accuracy measurements are redundant. After the interpretative work, the calculation of areas by class and their respective occupancy rates obtained; all this process was performed in SPRING 5.4.3 (Camara *et al.*, 1996) a free and open source software developed by the National Institute for Space Research (Brazil).

2.3. Water quality variables, macroinvertebrates collection and identification

Monitoring of water quality for both physicochemical and microbiological variables and for macroinvertebrates was carried out through eight monthly collections from April to November 2013 at the three points studied. The water samples were submitted to the following physicochemical analyzes: temperature, turbidity, pH, dissolved oxygen (DO), chemical oxygen demand ($BOD_{5,20}$); and microbiological tests: FC - Faecal coliforms (*Escherichia coli*) and TC – Total coliforms. The macroinvertebrates were sampled using "D" net with 300µm mesh. Collected material was taken to laboratory for screening and individuals were identified at taxonomic level of family (subclass for Annelida) for application of the biological indexes.

2.4. Data analysis

The physical-chemical and microbiological variables were analyzed using the water quality index (WQI_{CETESB}), which consists of nine variables, including six of the seven variables sampled, for which we resized the weights of each variable: Temperature (W_i = 0.14); Turbidity (W_i = 0.12); pH (W_i = 0.16); DO (W_i = 0.23); $BOD_{5,20}$ (W_i = 0.14) and FC (W_i = 0.21). These variables were also compared between the points by analysis of variance (one-way ANOVA), where the points were the factor (with 3 levels), and the dependent variables were water quality parameters. The four collections were replicates. The assumptions of Gaussian distribution and homogeneity of variance were checked using Shapiro-Wilks and Bartlett tests, respectively. When the data did not match the premises, they were transformed by means of square root.

The results for macroinvertebrates were estimated by calculating 5 indexes: I. Relative percentage of Chironomidae (% Chironomidae); II. Relative percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT); III. BMWP'- Biological Monitoring Working Party, modified by IAP (2003); IV. ASPT - Average Score Per Taxon; and V. RAPHD - Rapid Assessment Protocol for Habitat Diversity (Callisto *et al.*, 2002). To compare if there were differences in macroinvertebrate community as a function of the individual's abundance, a Permutational Multivariate Analysis of Variance (PERMANOVA) test (Anderson, 2008) was applied, with 999 permutations of residues in the complete model, and Bray-Curtis distance (Legendre and Legendre, 1988). In order to compare this difference between the communities and association of possible patterns with physical chemical variables, we applied a CCA test (Canonical Correspondence Analysis), which was adjusted by the stepwise method, which incorporated only physical-chemical variables that presented a significance greater than 5% to the model (Ter Braak, 1986). Finally, Pearson correlations were calculated between the indexes presented above with the percentages obtained in the land-use and occupation classification, using the "vegan" package (Oksanen *et al.*, 2017) of the R-project 3.3.3.

3. RESULTS AND DISCUSSION

Image classification revealed a contrast between the percentages of the classes for each point. Point 1 presented 0.22 km² (34.4%) of forest and 0.18 km² (28.1%) of peri-urban area, respectively; Point 2 presented 0.56 km² (87.50%) of urban area; and Point 3, 0.28 km² (43.8%) of periurban area and 0.24 km² (37.5%) of woods, respectively (Figure 1C).

The mean values of physicochemical and microbiological variables are presented in Table 1. Among the variables of water quality that presented significant variation, are FC and TC (Figure 2). Statistical differences were found between the area of river spring (Point 1 (*a*)) and the urban and peri-urban region (Points 2 and 3 (*b*)), making clear the negative influence of this area on the quality of river waters.

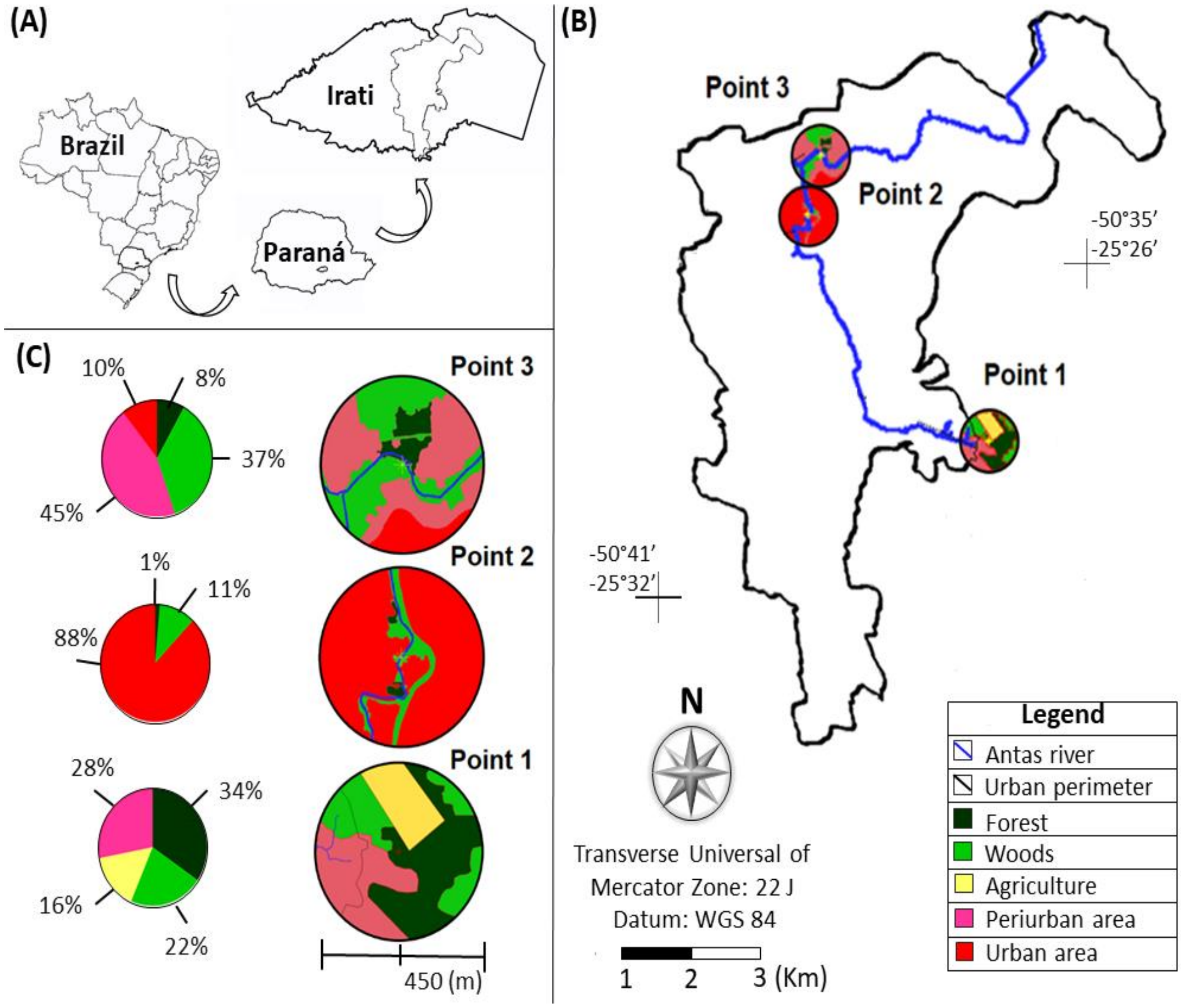

Figure 1. (A) geographical location of Irati and its urban perimeter in Paraná state, Brazil (B) Location map of Antas River and its route within Irati urban perimeter, showing the collection points with 450 m classified buffers. (C) On the right are the buffers and their classes, according to the legend in Figure 1B, and on the left a pie chart with the percentages of area for each buffer.

Table 1. Mean and standard deviation of physicochemical and microbiological variables of the eight collections.

	Point 1		**Point 2**		**Point 3**		**MAV**
Temp. (ºC)	16.6	± 4.0	17.0	± 4.0	17.4	± 4.2	-
Turbidity (NTU)	27.7	± 15.2	41.9*	± 38.5	37.5	± 34.8	40
pH	6.9	± 1.4	7.2	± 0.2	7.2	± 0.3	6 - 9
TrueColour (uH)	90.5	± 48.8	95.6	± 59.2	92.6	± 69.3	-
DO (mgL^{-1})	8.3	± 0.5	8.0	± 0.6	8.3	± 0.7	< 6
$BOD_{5,20}$ (mgL^{-1})	1.2	± 0.4	4.48*	± 2.8	2.5	± 1.2	3
TC ** (CFU)	9650*	± 6676	44775*	± 24180	43825*	± 25954	200
FC ** (CFU)	700*	± 967	12162*	± 9894	13762*	± 8596	0

Legend: MAV - Maximum Allowed Value, by CONAMA Resolution No. 357/2005 (CONAMA, 2005) for Class I waters; * Values above those allowed; ** Significant difference between points for 5% probability.

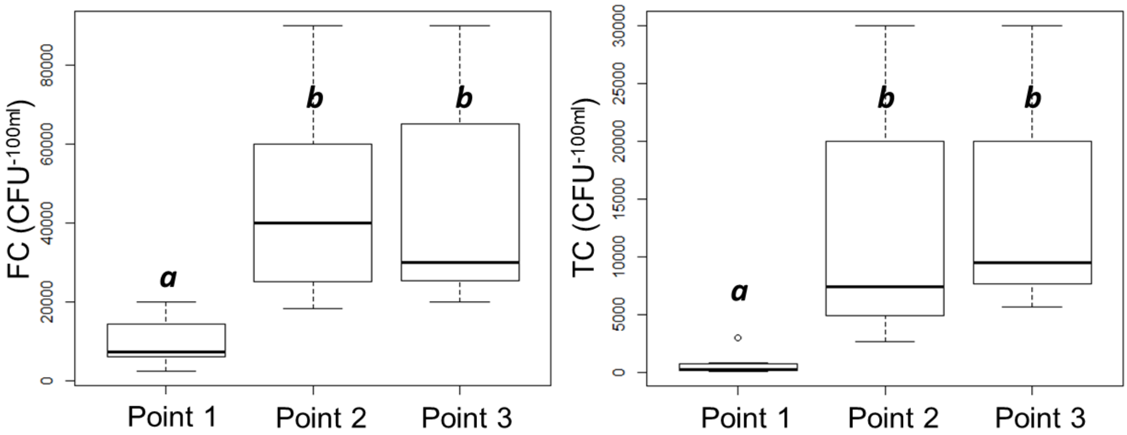

Figure 2. Boxplots of microbiological variables of water quality from three points of the Antas River (Irati, Paraná). The means followed by the same letter (*b*) do not differ statistically by the Tukey test at 5% significance.

In Brazil, studies commonly reveal high presence of *E. coli* in freshwaters, mainly in sites with agriculture and urbanization predominance (Mello *et al.*, 2018). Handam *et al.* (2018), for example, found values 170.6 and 192.3 times greater than allowed by the legislation for FC and TC, respectively, in Rio de Janeiro. *E. coli* is a variable that represents a real faecal contamination of water, and Figure 2 reflects the condition of urbanization that occurs in Points 2 and 3. Considering the large occupation area around Point 2 (88% of urban area), it is possible to relate the occurrence of these pathogenic organisms with discharge of sanitary effluents, corroborating the studies of Haberland *et al.* (2012), who verified high values of *E. coli* in points with the highest human occupation in the Antas River. In spite of this, it is important to emphasize that even though this difference exists, the values of TC and FC in the three points presented values higher than those allowed by Brazilian legislation (Table 1); therefore, areas with a higher percentage of agricultural area do not represent certainty of values according legislation, as also found by Pessoa *et al.* (2018).

None of the other variables evaluated here presented statistically different values between the points. However, for Point 2, only $BOD_{5,20}$ and Turbidity exceeded the permitted values determined by the current government legislation and regulations (5 mg/L and 40 NTU, respectively) (Table 1), unlike Andrade and Felchak (2009) and Haberland *et al.* (2012), who verified values higher than allowed by legislation in all points sampled in the same river studied here. This result confirms field-work observations, that indicated the possibility of contribution of domestic effluents upstream of collection sites and corroborates the results of Pessoa *et al.* (2018), which found higher $BOD_{5,20}$ values at points with higher indexes of human occupation.

Regarding the macroinvertebrate community, PERMANOVA showed significant difference between sampling points ($F_{2,23} = 2.26$, $p = 0.026$) and the correspondence analysis can represent this difference through the formation of groups referring to each collection and the largest association of tolerant taxa with $BOD_{5,20}$ and TC, indicative of pollution (Figure 3).

The CCA adds information that the water quality variables significantly influence the macroinvertebrate community. Specifically, BOD and TC are responsible for the differences in water quality and, consequently, in the distinctions of macroinvertebrate assemblages between the points studied.

The first axis of CCA (CCA 1 = 0.79) is highly correlated with BOD and all macroinvertebrate samples from Point 1, since the arrow corresponding to BOD is opposite for this group, it can be concluded that the BOD values are smaller in Point 1 and larger in some samples from Points 2 and 3. TC is negatively correlated with samples from Point 1 and positively correlated with samples from Points 2 and 3.

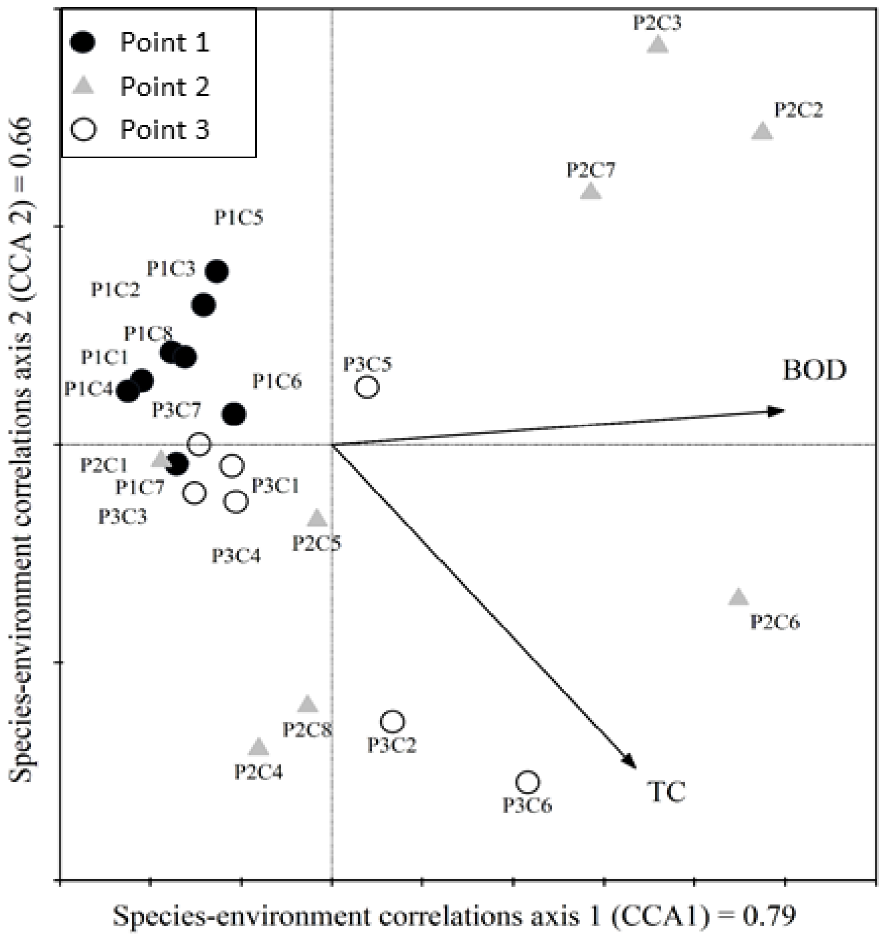

Figure 3. CCA associating the community of macroinvertebrates (represented by P1, P2 and P3 and collections, C1 to C8), with physical chemical and microbiological variables ($BOD_{5,20}$ and TC, $p < 0.05$).

It is also observed that Point 1 was grouped with greater cohesion and presented smaller variation in its values, since Points 2 and 3 were stored in a larger group (with high variation), the same pattern found for microbiological variables when submitted to ANOVA (Figure 3). This differentiation between the points demonstrates direct response of these organisms to environmental quality of the water body (Strohschoen *et al.*, 2009; Silva *et al.*, 2015; Chagas, *et al.*, 2017).

In relation to the quality biotic indexes (Table 2), % Chironomidae, % EPT and BMWP' and ASPT indexes, it is observed that better values were found in Point 3 followed by Point 1, and the worst values were associated to Point 2. The RAPHD and WQI_{CETESB} indicated higher scores for Point 1, followed by Point 3 and lastly Point 2. However, WQI_{CETESB} establishes the same category for the three points (Table 2). The configuration of these indexes values are probably due to urban occupation in its surroundings, since Point 1 is near a river spring, Point 2 is located in the urban center of the city and Point 3 is also in an urban setting, but presenting lower population density and riparian forest, as observed in Figure 1C.

The RAPHD showed significant correlation with land use, areas of forest and arboreal vegetation (rPearson = (+) 0.99, p = 0.046). The difference of the RAPHD, as well as the WQI_{CETESB} in relation to the other indexes should be emphasized, since they take into account the structural- and physicochemical variables of the environment, respectively, factors that can explain this association between vegetation and the index (Callisto *et al.*, 2002). In this way, $BOD_{5,20}$ was also correlated with RAPHD (rPearson = (-) 0.99, p = 0.05), relating domestic sewage contamination with urbanization densities (Venancio *et al.*, 2010).

Table 2. Biotic and environmental quality indexes calculated for three stretches of the Antas River (Irati, Paraná, Brazil).

	Point 1	Point 2	Point 3
%Chironomidae	70. 81	62.22	48.99
%EPT	8.93	3.33	31.86
BMWP'	74[A]	58[B]	97[A]
ASPT	4.35[D]	3.86[E]	5.10[C]
RAPHD	91[F]	28[G]	71[H]
WQI_{CETESB}	66[G]	54[G]	56[G]

Legend: A - Doubtful; B - Polluted; C - Questionable quality; D - Moderate pollution; E - Severe pollution; F - Natural; G - Impacted; H - Altered; I – Good.

The WQI_{CETESB} was not significant, however, when correlated directly with the variables that compose it; we found a significant relation of agricultural culture with pH and TC (rPearson = (+) 0.99; $p < 0.01$). This association demonstrates coherence, considering the loss of soil nutrients and organisms (Silveira *et al.*, 2016), as observed in Point 1, the only site presenting such a category, with values of 15% (Figure 1C). All the other variables showed trends to the expected (that riparian's forest reduction decrease the water quality), but did not show significance for this level of probability.

In general, urban rivers have a lower density (or even absence) of sensitive organisms when compared to preserved areas; but in rural waterways there is an increase in the density of these organisms, reinforcing their low tolerance for anthropic changes (Ometto *et al.*, 2004; Hepp *et al.*, 2010). The change in land use causes homogenization of the functional structure of the aquatic insect community (Castro *et al.*, 2018). However, the data of Point 3 resemble features of natural areas; this point was placed in an area where the river already passed through the downtown city, riparian forest are present again and a resilient process can be found.

This demonstrates that restoration of riparian forest can be a determining factor in water quality. Riparian zones over 15m width are more suitable for maintenance of macroinvertebrate community composition and trophic structure, but even a reduced riparian-zone width can maintain minimal conditions to support these communities (Moraes *et al.*, 2014). Moreover, despite the higher importance of forest conservation at watershed scale, restoration of riparian zone is a basic feature to improve the water quality (Mello *et al.*, 2018). Considering this forest as a linking element that acts like an environmental filter between terrestrial and aquatic ecosystems, it is necessary to re-evaluate the current practices of land use and occupation in their environment (Gregory *et al.*, 1991; Roy *et al.*, 2003; Larson *et al.*, 2019).

4. CONCLUSION

The Antas River and its tributaries, from their springs to their mouths, presents several types of land use, such as agricultural, industrial and even domestic sewage treatment, activities that have high environmental impacts. The present work pointed out that inadequate land use and occupancy reflects negatively impacts water quality of the ecosystem. This work also showed the effectiveness of the use of orbital images and geoprocessing techniques using joint physical-chemical and biological parameters for monitoring watercourses. These processes could complement the current water quality monitoring and facilitate collaborative efforts to confirm presumable pollution sources, being punctual or diffused.

We can conclude that water quality variables and landscape use association was effective, so a spatial landscape vision can improve the surface characterization for riparian land planning and use. More studies like the one presented here, studying other rivers and/or basins in urban regions, or the contrast with preserved areas, thus verifying the effect of riparian forest in the recovery of water quality, will contribute to a better understanding of the effects of urbanization in water courses. In addition, this type of study can be applied to evaluate the effects of restoration/mitigation actions on rivers and/or habitats, giving support to conservation of these urban ecosystems.

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