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Streams pollution in a luxury tourism municipality in the Serra da Mantiqueira (Southeast Brazil)

Poluição em riachos em um município de turismo de luxo na Serra da Mantiqueira (Sudeste do Brasil)

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Abstract: Aim: Our aim was to analyze the limnological characteristics of streams located in a luxury tourism municipality in the Serra da Mantiqueira (Southeast Brazil). **Methods:** We analyzed water physical and chemical variables of six sampling sites located in three streams of the Sapucaí-Guaçú River Basin along the urban area of the municipality of Campos do Jordão and one sampling site in the Rio da Prata stream, as a reference location not impacted by urban pollution (São Paulo, Brazil). We measured some physical and chemical variables of the water and analyzed the concentration of nutrients (forms of N and P) in the streams close to the basin's sources (Sites 1, 2 and 3), within and downstream of the urban area (sites 4 and 5), downstream of the municipality's Wastewater Treatment Plant (WWTP) (Site 6) and the reference location (Site 7). To find out whether there were differences in limnological variables among the sampling sites we used the Analysis of Variance (ANOVA). To order the sampling sites according to the variation in their limnological characteristics we applied a Principal Component Analysis (PCA). **Results:** Our results showed that sites 1, 2 and 3, although close to the sources, presented limnological changes in relation to the reference location (Site 7) due to urban occupations in their surroundings. The sampling sites 4 and 6 are the most polluted due to urbanization and the discharge of effluents from the WWTP, respectively. The stretch between these two locations (Site 5) proved to be less polluted due to the autodepuration process. **Conclusions:** We concluded that the streams in the Sapucaí-Guaçú River Basin are polluted, although at different levels. The urban area of Campos do Jordão causes pollution of the streams in its surroundings due to surface runoff and the discharge of untreated sewage due to the lack of access to sewage services for a large part of the population. The absence of tertiary treatment at the WWTP leads to pollution of the stream after the release of its effluent.

Keywords: organic pollution; Wastewater Treatment Plant (WWTP); treated effluents; urbanization; Campos do Jordão.

Resumo: Objetivo: Nosso objetivo foi analisar as características limnológicas de riachos localizados em um município de turismo de luxo na Serra da Mantiqueira (Sudeste do Brasil). **Métodos:** Nós analisamos variáveis físicas e químicas da água de seis pontos de coleta localizados em três riachos da bacia do rio Sapucaí-Guaçú ao longo da área urbana do município de Campos do Jordão e um ponto de coleta no Rio da Prata, como referência de local não impactado por poluição urbana (São Paulo, Brasil). Nós medimos algumas variáveis físicas e químicas da água e analisamos a concentração de nutrientes (formas de N e P) nos riachos próximos às nascentes da bacia (Pontos 1, 2 e 3), dentro e após a área urbana (Pontos 4 e 5), após a Estação de Tratamento de Esgoto (ETE) do município (Ponto 6) e no local de referência (Ponto 7). Para averiguar se houveram diferenças nas variáveis limnológicas entre os pontos de coleta utilizamos a Análise de Variância (ANOVA). Para ordenar os pontos de coleta de acordo com a variação de suas características limnológicas nós aplicamos uma Análise de Componentes Principais (PCA). **Resultados:** Nossos resultados mostraram que os pontos 1, 2 e 3, embora próximos às nascentes, apresentaram alterações limnológicas em relação ao local de referência (Ponto 7) por causa das ocupações urbanas em seu entorno. Os pontos 4 e 6 são os mais poluídos devido à urbanização e ao lançamento de efluentes da ETE, respectivamente. O trecho entre estes dois locais (5) mostrou-se menos poluído devido ao processo de autodepuração. **Conclusões:** Nós concluímos que os riachos da bacia do rio Sapucaí-Guaçú estão poluídos, embora em diferentes níveis. A área urbana de Campos do Jordão causa a poluição dos riachos em seu entorno devido ao escoamento superficial e ao lançamento de esgotos não tratados pela falta de acesso a serviços de esgotamento sanitário de grande parte da população. A ausência de tratamento terciário na ETE leva à poluição do riacho após o lançamento de seu efluente.

Palavras-chave: poluição orgânica; Estação de Tratamento de Esgoto (ETE); efluentes tratados; urbanização; Campos do Jordão.

1. Introduction

Several organic compounds are emitted by sewage from urban, industrial, and agricultural areas (Singh et al., 2020; Ribeiro & Leite, 2021). Among these sources of pollution, the discharge of untreated or partially treated domestic sewage stands out, which results in chemical pollution (Schwarzenbach et al., 2010). Domestic sewage, for example, contains a large amount of nutrients, especially different forms of nitrogen and phosphorus. Even after primary and secondary treatment, sewage released into aquatic ecosystems causes eutrophication (Figueroa-Nieves et al., 2014; Preisner et al., 2021). This pollution promotes the deterioration of water resources, which has direct and indirect effects on various sectors of the economy, tourism, environment, and human health (Quadra et al., 2019).

In Brazil, only 56% of the population is served by a sewage system; and just over half of all produced sewage (52.2%) is treated (SNIS, 2023). However, these data are quite varied when different Brazilian regions, states and municipalities are analyzed. For example, in the northern region only 33% of the population has adequate sewage disposal, while in the southern region this percentage is 65% (ANA, 2017). Among municipalities this difference is also large. According to data from the Agência Nacional de Águas (National Water Agency) for the year 2013 (the most recent available data set), in the state of São Paulo, the municipality of Piracicaba had 100% of its sewage collected and treated, São Carlos had 91% of treated sewage, while Campos do Jordão had only 30.33% of treated sewage. Another point to be highlighted is that urban sewage treatment in Brazil is carried out partially with only the removal of coarse and suspended solids and organic matter. In developed countries in the northern hemisphere, sewage treatment is carried out in three stages (preliminary, secondary, and tertiary treatment), while in Brazil tertiary treatment is not carried out. Furthermore, irregular sewage discharges into aquatic environments act as non-point sources of pollution, making them difficult to detect and control, especially in urbanized areas (De Souza et al., 2009). The limnological characterization of water bodies is an important diagnostic, descriptive and qualitative approach to verify water quality, environmental changes, and possible anthropogenic impacts on aquatic ecosystems. Additionally, this characterization is important to support decision-making and environmental recovery measures (Marotta et al. 2008).

The Serra da Mantiqueira is a mountain range that stretches across three southeaster Brazilian states (São Paulo, Minas Gerais and Rio de Janeiro) and has great biodiversity and a high level of endemism (Gonzaga & Menini-Neto, 2017). In a list of 100 irreplaceable natural heritage sites on the planet, created in 2013, the Serra da Mantiqueira occupies 44th place in the ranking of threatened species with extinction (Le Saout et al., 2013). This mountain range is an important watershed for river basins in the southeast region of Brazil, such as the Rio Grande basin, the Tietê River and the Paraíba do Sul River (CETESB, 2023). The Serra da Mantiqueira is an important hub for tourism and gastronomy and has several municipalities classified as tourist resorts. Campos do Jordão is one of these tourist resorts, which receives visits from approximately 4 million tourists per year. Most of these visitors stay in the city throughout the winter season (June to August) (Fedrizzi et al., 2017). More than half of the tourists have a monthly income of more than 10 minimum wages (Hirata, 2013), which reflects the luxury tourism in the region.

The region of Campos do Jordão is located near several conservation units and environmental protection areas (EPA), such as the Campos do Jordão State Park (CJSP), the Serra da Mantiqueira EPA, the Campos do Jordão State EPA and the Campos do Jordão Municipal EPA, which were created in the 1980s. Even though the city is surrounded by protected areas, several water bodies cross the urban area of the municipality received raw domestic sewage until 2014. From this year onwards, the wastewater treatment plant (WWTP) was implemented in the city (CETESB, 2023). According to the Instituto Água e Saneamento (Water and Sanitation Institute) (IAS, 2023), the population of Campos do Jordão served by sewage collection and treatment is 28,428 inhabitants for a total population of 46,974 people (IBGE, 2023). Thus, approximately 46% of the municipality's population does not have treated sewage.

Our aim was to analyze the limnological characteristics (physical and chemical variables of water) of the streams in the Sapucaí-Guaçú River basin along the urban area of the municipality of Campos do Jordão. We sampled streams close to the sources of the river basin, within and downstream of the urban area, and downstream of the WWTP. We used a sampling site in the Rio da Prata stream, located in a conservation area in the municipality of Santo Antônio do Pinhal, as a reference for a location not impacted by urban pollution. We expected to find higher nutrient concentrations, reduced dissolved oxygen and higher turbidity in the streams under effect of urbanization, including the effluent of the WWTP, indicating streams pollution.

2. Materials and Methods

2.1. Study area

Campos do Jordão is a municipality located in the eastern region of São Paulo state, with a population of 46,974 inhabitants (IBGE, 2023). The city is located 1,639 meters above sea level and, therefore, it is the city located at the highest altitude in Brazil (IBGE, 2011). Its climate is temperate maritime (Cfb) according to the Köppen-Geiger classification, i.e., there is less rain in winter, but rainfall is abundant and well distributed throughout the year (Beck et al., 2018). The average maximum temperature during summer is 24 °C and the average minimum temperature is 13 °C. During the winter, the average maximum is 18 °C and the average minimum is 5 °C. Santo Antônio do Pinhal is a neighboring municipality to Campos do Jordão and has similar relief and climate characteristics (SEADE, 2019). Both cities are in the Serra da Mantiqueira, in the Atlantic Forest biome, with the economy focused on the tourism sectors (Almeida, 2006). Tourism is the main economic activity in Campos do Jordão and during the July school holidays and public holidays there is an increase of up to 400,000 inhabitants.

The Campos do Jordão WWTP is operated by the Companhia de Saneamento Básico do Estado de São Paulo (SABESP) and has the capacity to treat around 213 litters of sewage per second. According to SABESP (2017), this WWTP was the first one in Latin America to have a closed environment processing system, with treatment of gases arising from its processes. Furthermore, it is considered the most modern WWTP in Brazil as it is the first with ultrafiltration technology using membrane bioreactors (MBR) (São Paulo, 2014).

The main rivers in the region are the Sapucaí-Guaçu stream and its tributaries in Campos do Jordão, and the Rio da Prata stream in Santo Antônio do Pinhal, being sub-basins of the Serra da Mantiqueira hydrographic basin. We chose seven sampling sites, six of them in the Sapucaí-Guaçu River basin and one sampling site in the Rio da Prata basin. In Campos do Jordão we established one sampling site in the Piracuama stream (1), one sampling site in the Serraria stream (2), one sampling site in the Capivari stream (3), three sampling sites in the Sapucaí-Guaçu stream (4, 5 and 6). Sites 1, 2 and 3 are located close to the sources of the river basin but are moderately surrounded by urban areas. Site 4 is located close to the lower limit of the urban area and site 5, approximately 5 km downstream of site 4, in a rural area. Site 6 is located right after the discharge of effluents from the municipality's WWTP. In Santo Antônio do Pinhal we chose one sampling site in the Rio da Prata stream (Site 7). This site is located upstream the urban area of the municipality, and we chose it as a reference location, as it has a minimum of anthropic interference (Figure 1).

2.2. Data collection

We carried out the field sampling on March 13th (2019), between 12:00 and 3:00 pm. At each sampling site we measured the limnological variables in triplicates (5 m distance): temperature, pH, dissolved oxygen, turbidity, and electrical conductivity in the water with a multiparameter probe (Horiba U-50). We also collected surface water samples in polyethylene bottles for later chemical analysis in the laboratory. At the Laboratório de Ecologia Aquática (Aquatic Ecology Laboratory) (UNESP Rio Claro) we determined the concentration of total inorganic nitrogen (TIN) (nitrite, nitrate and ammonia nitrogen) (Koroleff, 1976, Mackereth et al., 1978), total nitrogen (TN) (Mackereth et al., 1978), total phosphorus (TP), dissolved phosphorus (DP) and orthophosphate (Golterman et al., 1978), alkalinity (Boyd, 1981), and suspended solids (Mudroch & MacKnight, 1994) in the water samples. We used 0.45 µm fiberglass filters to dissolved nutrients measurements (TIN, DP and orthophosphate).

2.3. Data analysis

We tested for significant differences ($p<0.05$) in the limnological variables among the different locals (sampling sites). Previously, we evaluated and confirmed that the conditions of data normality and homoscedasticity had been met. Then, we applied the Analysis of Variance (ANOVA) and the Tukey's test a *posteriori*. These analyses and their respective graphs were applied using the GraphPad Prism 5.0 software (GraphPad Software, 2007). We applied a Principal Components Analysis (PCA) to water variables (explanatory variables) and sampling sites to ordinate the streams (sampling sites) according to the variation of their water characteristics, and to analyze the correlation among the sampling sites and their relations with the abiotic variables using the vegan package (Oksanen et al., 2022) in the R environment (4.2.2) (R Development Core Team, 2019).

3. Results

The water variables were, in general, quite different among sampling sites, except for temperature, with values always close to 20 °C. Site 7 (reference local) presented the lowest

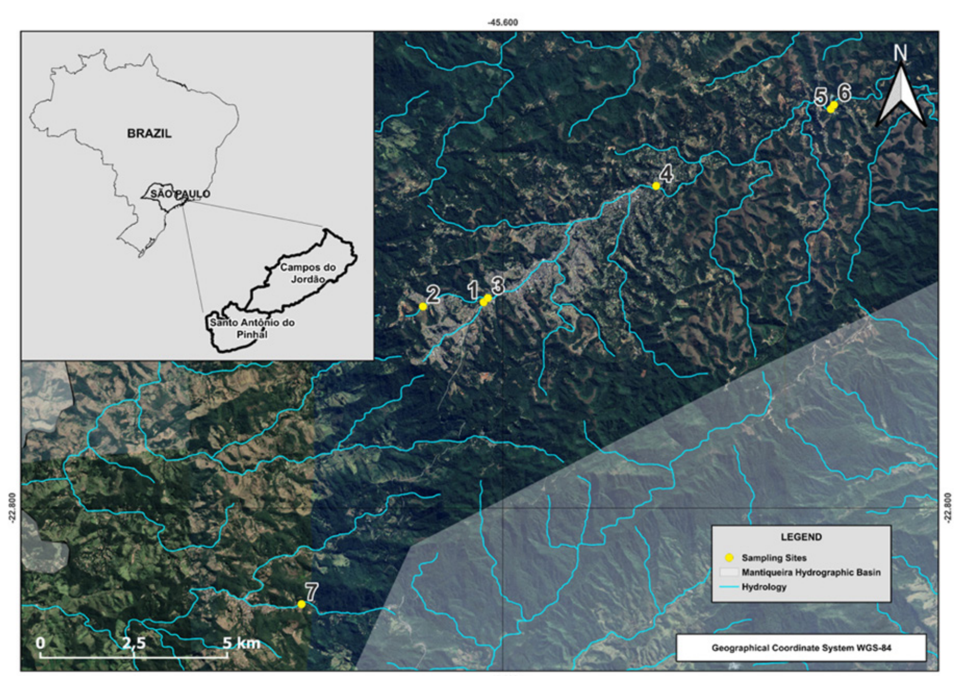

Figure 1. Maps of Brazil, São Paulo State and the municipalities of Campos do Jordão and Santo Antônio do Pinhal, highlighting the sampling sites in the Serra da Mantiqueira hydrographic basin: (1) Piracuama stream, (2) Serrania stream and (3) Capivari River, close to the sources of the Sapucaí-Guaçu River basin; (4) and (5) Sapucaí-Guaçú stream within and downstream of the urban area of Campos do Jordão, respectively; (6) Sapucaí-Guaçú stream downstream of the WWTP; (7) Rio da Prata stream, reference site in the Rio da Prata basin in Santo Antônio do Pinhal.

values of the different forms of nitrogen and phosphorus, turbidity and electrical conductivity and the highest value of dissolved oxygen (Figure 2). We highlight the highest values especially of the different forms of phosphorus were found in sites 4 and 6. In site 4 the values of TP (139.7 µg L^{-1}), DP (122.5 µg L^{-1}) and orthophosphate (58.1 µg L^{-1}) were only lower than site 6 with values of TP (191.5 µg L^{-1}), DP (132.8 µg L^{-1}) and orthophosphate (106.0 µg L^{-1}). However, the concentrations of these nutrients were higher than in other locations (Figure 2).

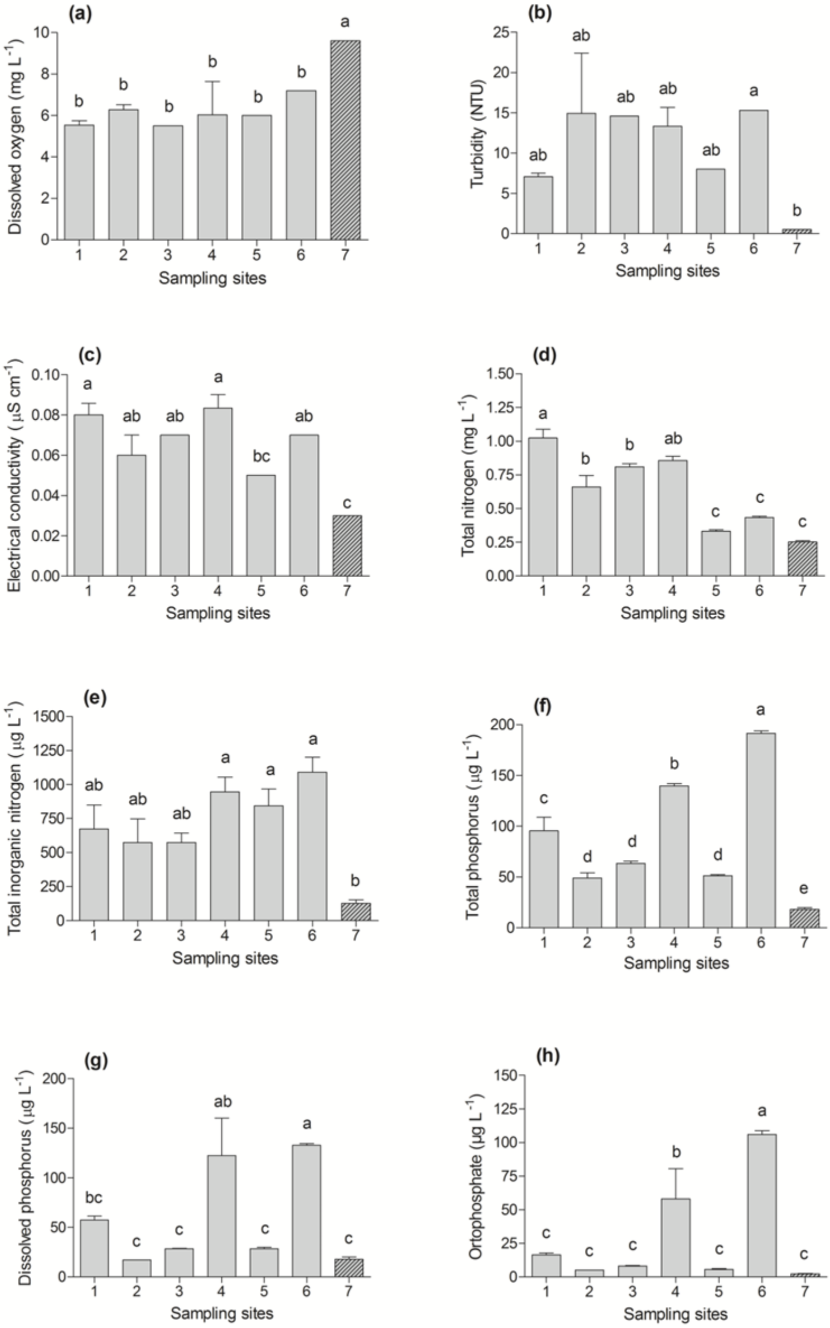

Figure 2. Means (bars) and standard deviation (vertical lines) of dissolved oxygen (a), turbidity (b), electrical conductivity (c), total nitrogen (d), total inorganic nitrogen (e), total phosphorus (f), dissolved phosphorus (g) and orthophosphate (h) at different sampling sites. The hachured bar in each graph represents the reference location. Different letters indicate significant differences ($p<0.05$). ANOVA one-way – F statistic: (a) $F=15.98$, $p<0.01$; $dF=6$; (b) $F=3.52$, $p<0.05$, $dF=6$; (c) $F=13.56$, $p<0.01$; $dF=6$; (d) $F=44.12$, $p<0.01$; $dF=6$; (e) $F=6.56$, $p<0.01$; $dF=6$; (f) $F=342.0$, $p<0.01$; $dF=6$; (g) $F=11.94$, $p<0.01$; $dF=6$; (h) $F=20.80$, $p<0.01$; $dF=6$.

The PCA showed that the sampling sites were ordered according to a pollution gradient. The most important variables in ordering the sampling sites in PC1 were, respectively, TP, TIN, turbidity, and orthophosphate (Figure 3; Table 1). The sampling sites located in the upper and lower quadrants on the right side of the graph are the most polluted and those located in the upper and lower quadrants on the left are lower polluted or without pollution. It is also possible to observe that the replicas of some sites have very similar characteristics (e.g. sites 6 and 3) and other replicates have little similar characteristics (e.g. points 1 and 2).

Table 1. The factor coordinates of the variables based on correlations to axes 1 and 2 (PC1 and PC2) of the Principal Components Analysis (PCA). The most representative variables for each axis are highlighted in bold.

Variables	PC1	PC2
Temperature (T)	0.38	0.50
pH	-0.40	**0.78**
Electrical conductivity (Cond)	-0.65	0.07
Turbidity (Turb)	**0.86**	0.01
Dissolved oxygen (DO)	-0.69	-0.45
Total nitrogen (TN)	0.69	0.64
Total inorganic nitrogen (TIN)	**0.89**	-0.14
Orthophosphate (PO4)	**0.84**	-0.36
Dissolved phosphorus (DP)	**0.80**	-0.37
Total phosphorus (TP)	**0.92**	-0.25
Alkalinity (Alk)	0.46	0.68
Suspended solids (SS)	0.12	0.36

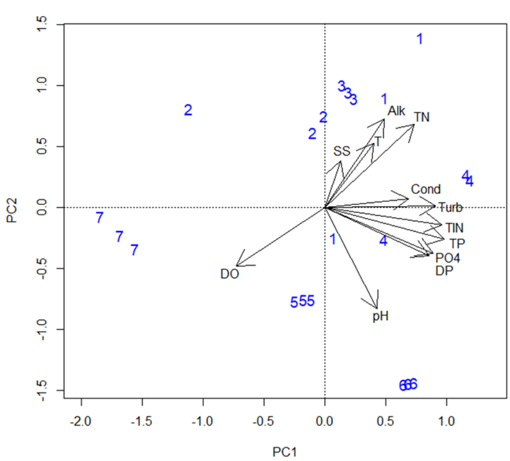

Figure 3. Biplot of the Principal Components Analysis (PCA) showing the ordination of the sampling sites and replicates (1-7), and the explanatory variables (limnological variables) related to axes 1 and 2. Proportion explained by both axes: PC1 = 46.72% and PC2 = 20.13%. Limnological variables codes: electrical conductivity (Cond), turbidity (Turb), dissolved oxygen (DO), total nitrogen (TN), total inorganic nitrogen (TIN), orthophosphate (PO4), dissolved phosphorus (DP), alkalinity (Alk) and suspended solids (SS).

4. Discussion

The results obtained showed that, except for site 7, all other sites suffered some anthropogenic impact, for example, expansion of the urban area, release of domestic effluents and aquaculture. Sites 1, 2 and 3 are located close to the sources of the streams, however, the surroundings of these sites have urban occupations. At these sites, TN and TP values were significantly higher than site 7 and reflect the impacts of land use and occupation. Site 1, although located close to the stream source, has an artificial lake populated with carp in its proximity. Aquaculture effluents contain water with high concentrations of nitrogen and phosphorus due to unconsumed feed and fish excreta (Camargo & Amorim, 2020). Site 2 was the one with characteristics closest to the reference site (7), as it is the one with the least human occupation around it. However, it had significantly higher TN and TP concentrations than site 7. In fact, streams surrounded by agricultural areas, even with low population density, present changes in limnological characteristics, such as higher concentrations of nutrients, due to diffuse pollution, as noted by Harrison et al. (2019) in a southwest Irish catchment. Site 3 located downstream of the previous sites has an extensive urban area upstream and the entry of sewage and surface runoff water is possibly the cause of the high concentrations of nitrogen and phosphorus. Site 4 located at the lower end of the urban area was one of the most polluted sites and had high concentrations of nutrients, especially phosphorus.

In Brazil, other rivers in municipalities with accelerated and disorderly urban occupation have high levels of pollution from domestic effluents, due to lack of sewage collection, treatment, or inefficient sewage treatment (Santos et al., 2018). Evaluating the water quality of the Cancela-Tamandaí River in the municipality of Santa Maria (Rio Grande do Sul, Brazil), Santos et al. (2018) also observed evidence of pollution from the discharge of untreated sewage. The urban population of Santa Maria is 95% of its total population, with 37% of inhabitants without sanitation. Campos do Jordão has 99.38% of its population living in urban areas, and only 46% of its inhabitants have a sewage system (IAS, 2023). According to SABESP (2017), all collected sewage is treated at the Campos do Jordão WWTP. In this context, we highlight that, despite the existence of the WWTP, around 46% of its resident population remains without sewage treatment, leading to greater pollution in the urban section of the Sapucaí-Guaçú River basin. In a study in the Piabanha River (Rio de Janeiro, Brazil), Costa et al. (2020) observed that there was an improvement in water quality in the last decade due to the treatment system expansion in the municipality of Petrópolis. However, these authors also indicated that the discharge of untreated sewage remains the main source of urban pollution and increase in phosphorus in this river.

If we consider axis 1 of the PCA and the nutrient concentrations, we can observe that site 5 was less polluted than site 4. This improvement in limnological characteristics is probably due to the autodepuration process. The distance, in a straight line, between the two points is approximately 5.5 km and we observe a much smaller urban occupation of the surrounding area, in addition to a greater presence of riparian forest. The autodepuration process was also observed in the Camanducaia River (Piracicaba River basin, SP) after the urban perimeter (Alberto & Ribeiro-Filho, 2012). In a sampling carried out in 2008, these authors found a decrease of approximately three times in the concentration of orthophosphate at the site located approximately 10 km from the urban area of the municipality of Amparo (SP). This municipality discharged untreated domestic sewage from 65 thousand inhabitants into the Camanducaia River, being the main source of pollution (Alberto & Ribeiro-Filho, 2012). We found an approximately 10-fold reduction in the orthophosphate concentration in the Sapucaí-Guaçu River, between points 4 and 5, that is, after the urban area of Campos do Jordão, which may indicate the occurrence of autodepuration. These results also showed that site 6, located after the release of effluents from the WWTP, again presented water in worse conditions. We highlight the TP and orthophosphate values in site 6, which were the highest values of all the sampled locations. Primary and secondary treatments, even in modern treatment systems and with ultrafiltration technology using membrane bioreactors (MBR), can remove up to 90% of organic matter from sewage, but the removal of nutrients and specifically phosphorus is greatly reduced (Cornelli et al., 2014). When analyzing the WWTP discharge with secondary treatment in Brazil, Finkler et al. (2023) observed that treated sewage impacted water chemistry and nutrient loads in rivers. Among the limnological variables analyzed, electrical conductivity and phosphorus were those that showed the greatest differences between the sites upstream and downstream of the WWTP. For example, in the Monjolinho River (São Carlos, SP) the electrical conductivity was approximately 2 times higher, and the phosphorus concentration increased by 10 times after the effluent was released (Finkler et al., 2023). We also observed significant differences in these variables between sites 5 and 6 in the Sapucaí-Guaçu River, that is, upstream and downstream of the WWTP. We found that the average values of electrical conductivity, TP and orthophosphate increased by 1.4, 3.7 and 18 times, respectively, after the release of "treated" sewage. In a study on the effects of sewage effluent on water quality in a Caribbean tropical river in Puerto Rico, Figueroa-Nieves et al. (2014) observed that about 90% of the downstream of daily flux of orthophosphate comes from WWTP effluent, highlighting the increase in phosphorus load in rivers by treated effluents. Despite these results regarding phosphorus, we did not observe a significant increase in TIN concentration in the Sapucaí-Guaçú River after the WWTP. This may be due to treatment with MBR, such as the one carried out in Campos do Jordão, which can control nitrogen concentrations but is not capable of removing different forms of phosphorus (Cornelli et al., 2014).

The operation of WWTPs is essential to improve water quality and environmental health in populated areas, but the removal of nutrients requires their infrastructure for an efficient advanced treatment (Carey & Migliaccio, 2009). When treated ineffectively, effluents from WWTPs can lead to more nutrient pollution on aquatic environments than nonpoint sources of sewage (Popova et al., 2006), as WWTPs tend to overwhelm receiving waters, altering their limnological characteristics and nutrient processes (Carey & Migliaccio, 2009), as observed in the streams in the Serra da Mantiqueira sampled in our study.

Although Brazilian legislation (CONAMA Resolution Nº. 357/2005) establishes norms and guidelines for the discharge of effluents into bodies of water "[…] not causing the conditions and water quality standards established for the respective classes to be exceeded […]" (Brasil, 2005), environmental agencies normally do not evaluate and monitor nutrient loads and concentrations in aquatic environments. However, in developed countries in the northern hemisphere, such as those in the European Community, the laws are more specific and stricter and there is a requirement for tertiary treatment of sewage to remove nutrients (Soares, 2020). In Brazil, economic investments in sewage treatment are scarce (Finkler et al., 2023). Furthermore, the impacts of treated effluents on tropical rivers, coupled with the large increase in urbanization in these regions, are still poorly studied when compared to rivers in temperate regions (Figueroa-Nieves et al., 2014; Finkler et al., 2023). Therefore, we highlight the importance of studies using this limnological approach to evaluate urban sewage pollution and the impacts of treated effluents on aquatic ecosystems.

We conclude that the streams in the Sapucaí-Guaçú River basin presented different levels of pollution from urban sewage. The stretches of the Sapucaí-Guaçu River downstream of the urban area of the municipality of Campos de Jordão and the WWTP are the most polluted sites, presenting high concentrations of phosphorus. The limnological characteristics of streams close to their sources also reflect the impacts of land use and occupation. In this way, we indicate that the urban area of Campos do Jordão causes pollution of the streams in its surroundings due to surface runoff and the discharge of untreated sewage due to the lack of access to sewage services for a large part of the population. The absence of tertiary treatment at the WWTP leads to pollution of the stream after the release of its effluent. Therefore, we highlight the importance of expanding sewage services and investing in tertiary treatment technologies to maintain water quality and minimize the degradation of aquatic ecosystems, especially in municipalities whose main economic activity is the luxury tourism.

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References

Agência Nacional de Águas – ANA, 2017. Atlas Esgotos: despoluição de bacias hidrográficas. Brasília: ANA.

Alberto, A., & Ribeiro Filho, B.G., 2012. Influência do despejo de esgoto doméstico nas características limnológicas do rio Camanducaia, bacia hidrográfica do rio Piracicaba, Estado de São Paulo. Acta Sci. Biol. Sci. 34(2), 173-179. http://doi.org/10.4025/actascibiolsci.v34i2.6708.

Almeida, J.G. 2006. A (in) sustentabilidade do turismo no entorno de Campos de Jordão-SP [Tese de Doutorado em Ciências da Comunicação]. São Paulo: Escola de Comunicações e Arte, Universidade de São Paulo.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., & Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci. Data 5(1), 180214. PMid:30375988. http://doi.org/10.1038/sdata.2018.214.

Boyd, C.E., 1981. Water quality in warmwater fish culture. Auburn: Craftmaster Printers.

Brasil. Ministério do Meio Ambiente, 2005. Resolução CONAMA n. 357, de 17 de março de 2005. Diário Oficial da União [da] República Federativa do Brasil, Poder Executivo, Brasília, DF. Retrieved in 2023, October 10, from https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Resolucao/2005/res_conama_357_2005_classificacao_corpos_agua_rtfcda_altrd_res_393_2007_397_2008_410_2009_430_2011.pdf

Camargo, A.F.M., & Amorim, R.V., 2020. Fish farming in cages: a practice to be restricted in Brazil. Acta Limnol. Bras. 32, e101. http://doi.org/10.1590/s2179-975x5519.

Carey, R.O., & Migliaccio, K.W., 2009. Contribution of wastewater treatment plant effluents to nutrient dynamics in aquatic systems: a review. Environ. Manage. 44(2), 205-217. PMid:19458999. http://doi.org/10.1007/s00267-009-9309-5.

Companhia Ambiental do Estado de São Paulo – CETESB, 2023. Relatório de qualidade das águas interiores no estado de São Paulo: 2022 [online]. São Paulo: CETESB. Retrieved in 2024, March 26, from https://cetesb.sp.gov.br/aguas-interiores/wp-content/uploads/sites/12/2023/09/Relatorio-de-Qualidade-das-Aguas-Interiores-no-Estado-de-Sao-Paulo-2022.pdf

Companhia de Saneamento Básico do Estado de São Paulo - SABESP, 2017. Campos do Jordão possui uma estação de tratamento de esgotos com a arquitetura em estilo europeu [online]. São Paulo: SABESP. Retrieved in 2023, October 10, from https://site.sabesp.com.br/site/imprensa/noticias-detalhe.aspx?secaoId=65&id=7527

Cornelli, R., Amaral, F.G., Danilevicz, A.M.F., & Guimarães, L.B.M., 2014. Métodos de tratamento de esgotos domésticos: uma revisão sistemática. Rev. Estud. Ambientais 16, 20-36.

Costa, D.A., Soares de Azevedo, J.P., Dos Santos, M.A., & dos Santos Facchetti Vinhaes Assumpção, R., 2020. Water quality assessment based on multivariate statistics and water quality index of a strategic river in the Brazilian Atlantic Forest. Sci. Rep. 10(1), 22038. PMid:33328517. http://doi.org/10.1038/s41598-020-78563-0.

De Souza, J.D., Sluter, C., & Braga, M.C.B., 2009. Modelo espaço-temporal em SIG para análise de qualidade da água em uma Bacia Hidrográfica. Bol. Ciênc. Geod. 15, 224-244.

Fedrizzi, V.L.P., de Castro Mendes, B., & Schliemann, M., 2017. Tourism of events in Campos do Jordão: CJCVB strategies to attract events. Rev. Turismo Contemporaneo 5, 55-70. http://doi.org/10.21680/2357-8211.2017v5n0ID12561.

Figueroa-Nieves, D., McDowell, W.H., Potter, J.D., Martínez, G., & Ortiz-Zayas, J.R., 2014. Effects of sewage effluents on water quality in tropical streams. J. Environ. Qual. 43(6), 2053-2063. PMid:25602222. http://doi.org/10.2134/jeq2014.03.0139.

Finkler, N.R., Gücker, B., & Cunha, D.G.F., 2023. Nutrient uptake in tropical rivers receiving wastewater treatment plant discharge: high mass removal but low nutrient uptake efficiencies. Ecol. Indic. 154, 110865. http://doi.org/10.1016/j.ecolind.2023.110865.

Golterman, H.L., Climo, R.S., & Ohnstad, M.A.M., 1978. Methods for physical and chemical analysis of freshwaters. Oxford: IBP.

Gonzaga, D.R., & Menini-Neto, L., 2017. Estado de conservação da Serra da Mantiqueira: ameaças, lacunas, avanços e perspectivas do conhecimento da flora. In: Barbosa, B.C., Resende, L.O., Prezoto, F., & Gonçalvez, E.L., eds. Tópicos em sustentabilidade e conservação. Juiz de Fora: Edição dos autores, 77-86.

GraphPad Software, 2007. Prism (data analysis software system), version 5.0 for Windows [online]. San Diego, California: GraphPad Software. Retrieved in 2023, October 10, from http://www.graphpad.com

Harrison, S., McAree, C., Mulville, W., & Sullivan, T., 2019. The problem of agricultural 'diffuse' pollution: getting to the point. Sci. Total Environ. 677, 700-717. PMid:31071672. http://doi.org/10.1016/j.scitotenv.2019.04.169.

Hirata, S.R. 2013. Gestão da visitação em unidades de conservação: o caso do Parque Estadual de Campos do Jordão, SP [Dissertação de Mestrado em Gestão Ambiental]. Piracicaba: Universidade de São Paulo. http://doi.org/10.11606/D.91.2013.tde-21082013-101623.

Instituto Água e Saneamento – IAS, 2023. Municípios e Saneamento: Campos do Jordão (SP) [online]. Retrieved in 2023, October 10, from https://www.aguaesaneamento.org.br/municipios-e-saneamento/sp/campos-do-jordao#

Instituto Brasileiro de Geografia e Estatística – IBGE, 2011. Agência IBGE Notícias: IBGE disponibiliza coordenadas e altitudes para 21.304 localidades brasileiras [online]. Retrieved in 2023, October 10, from https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/14126-asi-ibge-disponibiliza-coordenadas-e-altitudes-para-21304-localidades-brasileiras

Instituto Brasileiro de Geografia e Estatística – IBGE, 2023. Cidades e Estados: Campos do Jordão [online]. Retrieved in 2023, October 10, from https://www.ibge.gov.br/cidades-e-estados/sp/campos-do-jordao.html

Koroleff, F. 1976. Determination of nutrients. In: Grasshof, K., ed. Methods of seawater analysis. Wenheim: Wiley VCH, 117-181.

Le Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T.M., Bertzky, B., Butchart, S.H.M., Stuart, S.N., Badman, T., & Rodrigues, A.S.L., 2013. Protected areas and effective biodiversity conservation. Science 342(6160), 803-805. PMid:24233709. http://doi.org/10.1126/science.1239268.

Mackereth, F.J., Heron, H.J., & Talling, J.F., 1978. Water analysis: some revised methods for limnologists. London: Freshwater Biological Association.

Marotta, H., Santos, R.O., & Enrich-Prast, A., 2008. Monitoramento limnológico: um instrumento para a conservação dos recursos hídricos no planejamento e na gestão urbano-ambientais. Ambiente Soc. 11(1), 67-79. http://doi.org/10.1590/S1414-753X2008000100006.

Mudroch, A., & MacKnight, S.D., 1994. Handbook of techniques for aquatic sediments sampling. Boca Raton: CRC Press. http://doi.org/10.1201/9781466571761.

Oksanen, J., Simpson, G.L., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H.B.A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M.O., Lahti, L., McGlinn, D., Ouellette, M.-H., Cunha, E.R., Smith, T., Stier, A., Ter Braak, C.J.F. & Weedon, J. , 2022. vegan: Community Ecology Package. R package version 2.6-4 [online]. Retrieved in 2023, October 10, from https://CRAN.R-project.org/package=vegan

Popova, Y.A., Keyworth, V.G., Haggard, B.E., Storm, D.E., Lynch, R.A., & Payton, M.E., 2006. Stream nutrient limitation and sediment interactions in the Eucha-Spavinaw Basin. J. Soil Water Conserv. 61, 105-115.

Preisner, M., Neverova-Dziopak, E., & Kowalewski, Z., 2021. Mitigation of eutrophication caused by wastewater discharge: a simulation-based approach. Ambio 50(2), 413-424. PMid:32451969. http://doi.org/10.1007/s13280-020-01346-4.

Quadra, G.R., Teixeira, J.R.P.V.A., Barros, N., Roland, F., & Amado, A.M., 2019. Water pollution: one of the main Limnology challenges in the Anthropocene. Acta Limnol. Bras. 31, e203. http://doi.org/10.1590/s2179-975x5118.

R Development Core Team, 2019. R: A language and environment for statistical computing. Version 3.6.1 [online]. Vienna: R Foundation for Statistical

Computing. Retrieved in 2023, October 10, from http://www.R-project.org

Ribeiro, B.A., & Leite, A.F., 2021. Comportamento espaço-temporal do oxigênio dissolvido e dos coliformes termotolerantes na região do médio/baixo curso do rio Paraíba do Sul, Norte Fluminense, Rio de Janeiro, Brasil. In: Silva, M.W., Ramos, T.T., Ribeiro, D.A. Pesquisas socioespaciais e ambientais. II Seminário de Pesquisa do Programa de Pós-Graduação em Geografia da UFF/Campos. Niterói: UFF, 185-201. http://doi.org/10.4322/978-65-86819-10-6.a01.

Santos, S.A.D., Gastaldini, M.D.C.C., Pivetta, G.G., & Schmidt Filho, O., 2018. Qualidade da água na bacia hidrográfica urbana Cancela Tamandaí, Santa Maria/RS. Soc. Nat. 30(2), 23-44. http://doi.org/10.14393/SN-v30n2-2018-2.

São Paulo. Governo do Estado, 2014. Campos do Jordão ganha Sistema de Esgotamento Sanitário com tecnologia de ponta [online]. São Paulo: SP Notícias. Retrieved in 2023, October 10, from https://www.saopaulo.sp.gov.br/ultimas-noticias/campos-do-jordao-ganha-sistema-de-esgotamento-sanitario-com-tecnologia-de-ponta/

Schwarzenbach, R.P., Egli, T., Hofstetter, T.B., Von Gunten, U., & Wehrli, B., 2010. Global water pollution and human health. Annu. Rev. Environ. Resour. 35(1), 109-136. http://doi.org/10.1146/annurev-environ-100809-125342.

Singh, J., Yadav, P., Pal, A.K., & Mishra, V., 2020. Water pollutants: origin and status. In: Pooja, D., Kumar, P., Singh, P. & Patil, S., eds. Sensors in water pollutants monitoring: role of material. advanced functional materials and sensors. Singapore: Springer, 5-20. http://doi.org/10.1007/978-981-15-0671-0_2.

Sistema Estadual de Análise de Dados – SEADE, 2019. SEADE Municípios [online]. Retrieved in 2023, October 10, from https://municipios.seade.gov.br/

Sistema Nacional de Informações sobre Saneamento – SNIS, 2023. Diagnóstico Temático: Serviços de Água e Esgoto – Visão geral – Ano de referência 2022 [online]. Retrieved in 2024, April 2, from https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis/produtos-do-snis/diagnosticos/DIAGNOSTICO_TEMATICO_VISAO_GERAL_AE_SNIS_2023.pdf

Soares, A., 2020. Wastewater treatment in 2050: challenges ahead and future vision in a European context. Environ. Sci. Ecotechnol. 2, 100030. PMid:36160927. http://doi.org/10.1016/j.ese.2020.100030.

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