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WATER QUALITY OF A STREAM SUBJECT TO THE RELEASE OF INDUSTRIAL EFFLUENT IN AN ENVIRONMENTAL PROTECTED AREA

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ABSTRACT: This study evaluated the water quality of the Peri-Poçu Stream, Upper Paraná River basin, which is subjected to the effects of daily discharge of industrial effluent. Water samples were collected in August, September, November and December, 2013, at three sites (discharge of the effluent, upstream and downstream). At these sites, we determined temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD) and flow (Q). The pollutant load was estimated at each site to assess the role of the effluent as a polluter. From the ordination generated by the Principal Components Analysis we observed a clear spatial distinction, with the sites of discharge and downstream distinguished from the upstream site by the highest EC, BOD and pH, and by the lowest values of DO and Q. The mean values of the pollutant load were significantly different between sites, with the highest value found at the site of effluent discharge. The results highlight the need for efforts to better manage of water resources in the Mato Grosso do Sul State, especially those located in protected areas as is the case of the Peri-Poçu Stream in order to reduce costs to combat water pollution and conserve natural resources.

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KEY WORDS: Water Resources; Physic-Chemical Parameters, Environmental Impacts; Monitoring.

QUALIDADE DA ÁGUA DE UM CÓRREGO SUJEITO A DESCARGA DE EFLUENTE INDUSTRIAL EM UMA ÁREA DE PROTEÇÃO AMBIENTAL

RESUMO: Este estudo avaliou a qualidade da água do córrego Peri-Poçu, bacia do alto rio Paraná, o qual está sujeito aos efeitos do despejo diário de efluente industrial. Amostras de água foram obtidas em agosto, setembro, novembro e dezembro/2012, em três pontos (descarga do efluente, montante e jusante). Foram determinados para os diferentes pontos: temperatura, pH, condutividade elétrica oxigênio dissolvido, demanda bioquímica de oxigênio e vazão. Para avaliar a contribuição do efluente como agente poluidor foi estimada a carga poluidora em cada ponto. A partir da ordenação gerada pela Análise de Componentes Principais observou-se nítida distinção espacial, com os pontos de descarga e jusante separarando-se do ponto montante pelos maiores valores de condutividade elétrica, demanda bioquímica de oxigênio e pH e pelos menores valores de oxigênio dissolvido e vazão. Os valores médios da carga poluidora diferiram significativamente entre os pontos, com o maior valor registrado no ponto de descarga do efluente. Os resultados evidenciam a necessidade de esforços para melhor gerenciamento dos recursos hídricos no estado do Mato Grosso do Sul, especialmente daqueles situados em unidades de conservação como é o caso do córrego Peri-Poçu, a fim de diminuir os custos de combate à poluição das águas e conservar os recursos naturais existentes.

PALAVRAS-CHAVE: Recursos Hídricos; Parâmetros Físico-Químicos; Impactos Ambientais; Monitoramento.

INTRODUCTION

There is currently great concern about the impact of human activities on aquatic environments (JARAMILLO-VILLA; CARAMASCHI, 2008). Rivers and streams are freshwater ecosystems more susceptible to the effects of human activities, especially in respect of the diffuse load of urban and agricultural pollution and the discharge of industrial and domestic effluents. Specifically in relation to effluents, it is emphasized that the inappropriate treatment or even no treatment can severely undermine the availability in quantity and quality of water resources (PERES; COELHO; FERREIRA, 2009; CUNHA; CALIJURI, 2010). This situation becomes clear when the pollutant load exceeds the carrying capacity of the water body.

This way, researches that provide information on the water quality of water bodies are essential to support the development of effective management and monitoring (CALIJURI; BUBEL, 2006). The monitoring of water quality stands out as one of the main tools to support policies for planning and management of water resources, since it works as a sensor that enables the monitoring of the use of water bodies, demonstrating its effects on qualitative characteristics of the water (GUEDES et al., 2012).

In Brazil, water quality standards for water bodies were established by the CONAMA[1], Resolution 357, from March 18, 2005 (BRASIL, 2005), which classifies water bodies into classes according to their uses and establishes distinct quality standards for each class. Thus, this resolution constitutes an important instrument of the National Water Resources Policy (Law 9433) (BRASIL, 1997), since the monitoring of aquatic ecosystems should preferably promote the comparison between the observed environmental condition and the desirable situation by means of physic-chemical water parameters established for the class in which the aquatic environment was classified (CUNHA; CALIJURI, 2010). In State of Mato Grosso do Sul, location of the present study, the CECA/MS, Resolution 36, from June 27, 2012 (MATO GROSSO DO SUL, 2012), based on CONAMA Resolution 357/05, deals with the classification of water bodies and environmental guidelines for such classification, and establishes the conditions and standards for effluent discharge.

In a national context, several studies concerning the assessment and monitoring of water quality using physic-chemical parameters have been conducted mainly in the southern and southeastern (CARVALHO; SCHLITTER; TORNISIELO, 2000; GERTEL; TAUK-TORNISIELO; MALAGUTTI, 2003; DONADIO; GALBIATTI; PAULA, 2005; ALVES et al., 2008; SILVA et al., 2009; LUCAS; FOLEGATII; DUARTE, 2010; MANARA; CLEMENTE, 2011; SCHNEIDER et al., 2011; ALVES et al., 2012; BORGES; BARROS-JR, 2012; ORTEGA; CARVALHO, 2013). Although, the Mato

[1] Conselho Nacional do Meio Ambiente

Grosso do Sul State stands out by the large number of water bodies and that many of them are more subject to the effects of the discharge of effluents (industrial, agro industrial and domestic), studies with this approach are scarce in the state (PEDROZA; CARVALHO; MONTEIRO, 2009; PINTO; OLIVEIRA; PEREIRA, 2010; SOUZA et al., 2012). Specifically for the southern region of this state, studies with this approach are inexistent.

In this context, given the increasing need for diagnosing the environmental status of water systems and providing subsidies for their monitoring, this study aimed at evaluating the water quality of the Peri-Poçu Stream, in the southern Mato Grosso do Sul State, which is under the effects of daily discharge of industrial effluent. The importance of this study lies on the fact that this stream is within two sustainable use protected areas: the Environmental Protection Area of the Islands and *Várzeas*[2] of the Paraná River and the Environmental Protection Area of the Iguatemi River and, therefore, may evidence the misuse of resources within areas that are legally mandated to protect the biological diversity, regulate the process of occupation and ensure the sustainable use of natural resources.

2 MATERIAL AND METHODS

2.1 STUDY AREA

The Peri-Poçu Stream is a right bank tributary of the Vito-I-Cuê Stream, Upper Paraná River basin, Mato Grosso do Sul State, and is located near the border of the states of Mato Grosso do Sul and Paraná, and of the Republic of Paraguay (Figure 1).

[2] Plain subject to periodic overflow of water courses (GUIRAO; CISOTTO; BARBOSA, 2012).

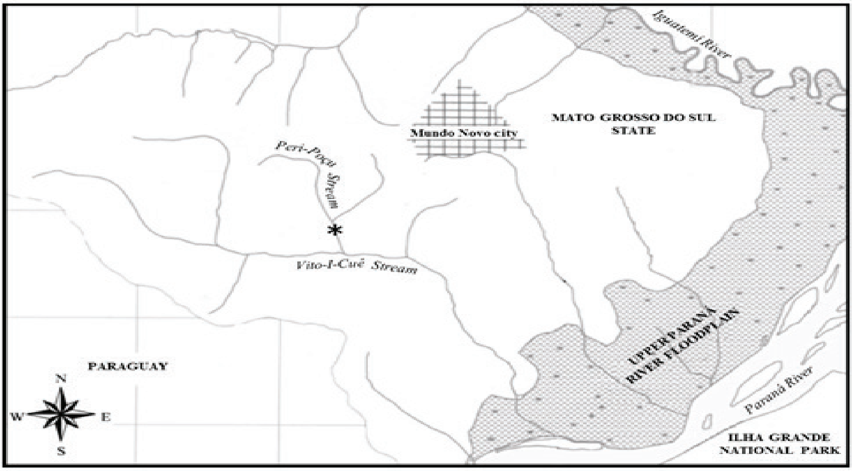

Figure 1. Location of Peri-Poçú Stream, upper Paraná River basin
* = samplig site.

This stream has about 5 km length and exhibits along its course different types of impacts as collapsing margins by cattle trampling, deviation from its course, replacement of riparian vegetation by pastures, construction of fish farming ponds, dams, pipe of the BR 163 highway, and discharge of industrial effluent.

2.2 DATA COLLECTION

In order to evaluate the effects of the latter impact on the water body, three sampling sites were selected, defined as upstream, discharge point and downstream, as described in Table 1.

Table 1. Environmental characteristics of the sampling sites of the Peri-Poçu Stream

(continued)

Site	Characteristics
Upstream 23°57'57.14"S 54°19'30.57"W	Located near the pipe of the BR 163 highway and 100 meters above the point of discharge of industrial effluents. Marginal vegetation is basically composed of guinea grass and a few scattered trees, mainly *Cecropia* (embauba). Around 2.0 m wide and 0.7 m deep.
Discharge 23°58'0.58"S 54°19'27.12"W	Located at the discharge point of the effluent into the stream. Marginal vegetation is similar to the previous site. About 1.3 m wide and 0.6 m depth.

(conclusion)

Downstream 23°58'12.18"S 54°19'25.81"W	Located in the final stretch of the stream, around 1.0 km far from the discharge point. Marginal vegetation is composed of a wide strip of riparian vegetation on both banks and the surroundings are occupied by intense agricultural activity. Approximately 2.0 m wide and 0.5 m deep.

The values of temperature, pH and electric conductivity - EC of the water were registered in the field, at an average depth of 20 cm. The temperature (°C) of water was determined using a mercury bulb thermometer. Measurements of pH and EC (μS /cm) were taken with the aid of a multiparameter probe (Hanna - SED/12500 V).

For the determination of dissolved oxygen - DO (mg/L) and biochemical oxygen demand - BOD (mg/L) water samples were placed in amber bottles and sent to the laboratory of the State University of Mato Grosso do Sul for analysis. The determination of BOD was performed by the incubation method without dilution (20°C, 5 days). Concentrations of DO and BOD were determined by the Winkler method, modified by Golterman; Clymo; Ohmstad (1978).

The average flow (Q) of each site was calculated using the formula: Q = A x V, where Q = flow (m^3/s), A = area (m^2), V = average velocity (m/s). Measures of depth (m) and width (m) at six equally spaced points at approximately 1.0 m each were taken, using the average arithmetic, to calculate the area. Water velocity was obtained through displacement time of a floating object along a distance set monthly at each site. This procedure was performed every sampled month.

2.3 DATA ANALYSIS

Descriptive statistics (minimum and maximum values, average and standard deviation) was used for an exploratory analysis of the physic-chemical variables in a spatial approach.

The interactive effect of physic-chemical parameters (temperature, pH, EC, DO, BOD and Q) in the water body was assessed by Principal Component Analysis (PCA) using PC-ORD 5.0 (MCCUNE; MEFFORD, 2006). For selecting the axes it was used the Broken-stick criterion (JACKSON, 1993), in which the axis with calculated eigenvalue higher than the Broken-stick eigenvalue is retained for interpretation.

Aiming to identify which physic-chemical variables contributed most to the structuring of the axes, Pearson correlations were performed between the scores of the PCA axes and the original data matrix (GREIG-SMITH, 1983). The physic-chemical variables with significant correlation ($p < 0.05$) proved importance in structuring the axes.

In order to evaluate the contribution of the industrial effluent as a polluter, the pollutant load (PL) was estimated for each sampling site (upstream, discharge and downstream), obtained by the formula: $PL = BOD * V$. The values of the pollutant load were transformed into kilograms/day. Based on this information it was possible to infer about the self-depuration process of the stream.

One-way analyses of variance were run to check for significant differences in the scores of PCA axes and in values of the pollutant load between the different sampling sites (upstream, discharge and downstream). Differences between the means of the pollutant load were evaluated using the a posteriori Tukey test. All statistical tests were performed using the software Statistica 7.0 (STASOFT, 2005).

3 RESULTS

Water temperature ranged between 16.0 and 26.0°C, with little variation between the sampling sites (Figure 2A). The concentration of DO ranged from 4.7 to 7.9 mg/L, the highest average value (7.3 mg/L) was found in the site upstream of the discharge (Figure 2B). On the other hand, the BOD varied from 0.61 to 5.86 mg/L and showed an inverse trend with higher mean values recorded at the point of discharge (5.5 mg/L) and downstream (5.7 mg/L) (Figure 2C).

The pH ranged from 6.4 to 7.5, with higher average values at the point of discharge of the effluent (7.2) and downstream (7.1) (Figure 2D). The EC had the highest variation, from 12.0 to 315.0 μS/cm, the point of discharge (242.3 μS/cm) showed the highest average value (Figure 2E). The Q varied between 0.2 and 0.5 m^3/s, with the highest average value verified in the site upstream (0.5 m^3/s) (Figure 2F).

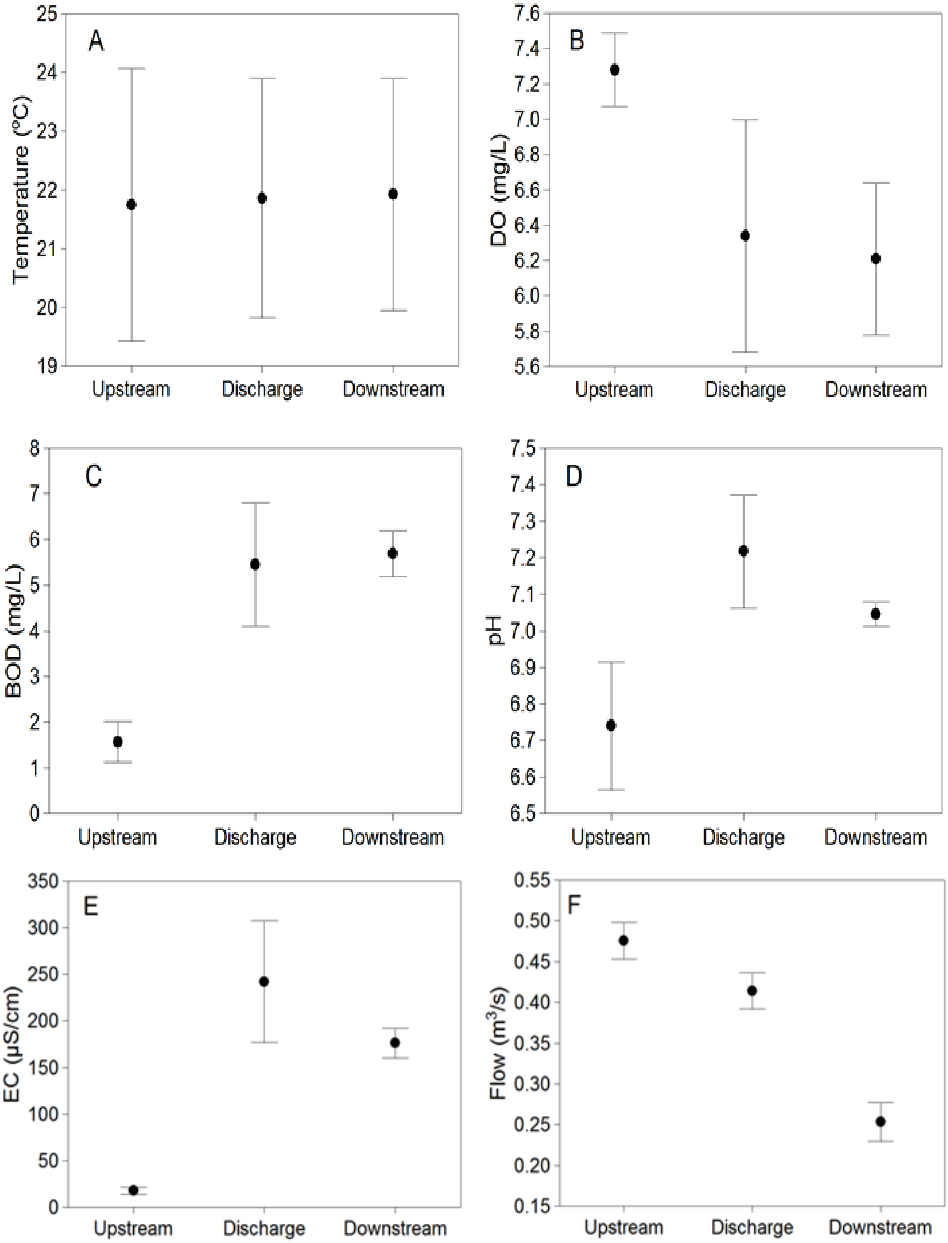

Figure 2A, 2B, 2C, 2D, 2D, 2F. Mean values of physico-chemical variables in the three sampling sites of the Peri-Poçu Stream during the study period. Means are represented by circles and standard error by vertical bars. DO = dissolved oxygen; BOD = biochemical oxygen demand; EC = Electrical conductivity

Considering the PCA results, only the axis 1 was retained for interpretation, which explains 54.3% of data variability. This axis represented a gradient of DO, Q, BOD, EC and pH. The DO and Q were positively correlated with the axis 1 ($r = 0.63$ and $r = 0.59$, respectively), and BOD ($r = -0.88$), EC ($r = -0.93$) and pH ($r = -0.93$) negatively.

The ordination generated by the PCA indicated a clear spatial separation in relation to physical and chemical parameters, which was confirmed by analysis of variance ($F = 9.40$, $p = 0.006$). Therefore, point of discharge and the site downstream were distinguished from the site upstream for higher values of EC, BOD and pH, and for lower values of DO and Q (Figure 3).

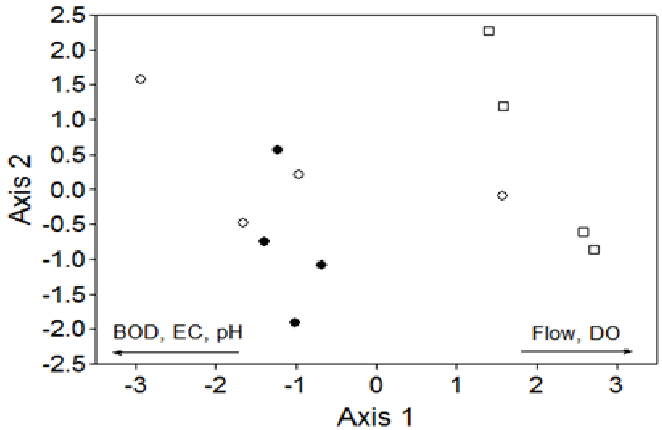

Figure 3. Scatter plot of scores of the first two PCA axes. BOD = biochemical oxygen demand, EC = electrical conductivity and DO = dissolved oxygen, squares = upstream, filled circles = discharge, and empty circles = downstream.

Regarding the pollutant load in the stream, the mean values were different between sampling sites ($F = 6.77$, $p = 0.02$) with the highest average value recorded at the point of discharge of the effluent (189.5 kg/day) (Figure 4). The Tukey test revealed that the point of discharge was significantly different ($p = 0.013$) from the site upstream.

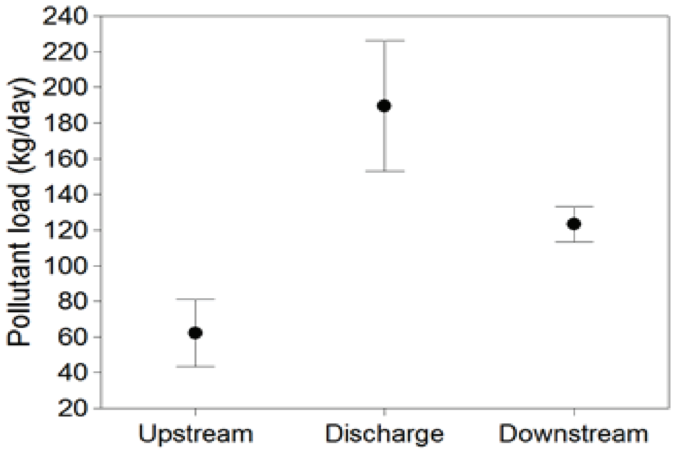

Figure 4. Mean values of pollutant load (kg/day) in the three sampling sites. Means are represented by circles and standard error by vertical bars.

4 DISCUSSION

The results pointed out that the Peri-Poçu Stream present spatial distinction relative to the interactive effect of physic-chemical parameters. The separation of the discharge and downstream sites from the upstream site by the higher values of EC, BOD and pH indicate that the effluent possibly is contributing a large input of organic matter into the stream, an indication of pollution.

The EC of the water reflects the concentration of dissolved solids (PERES; COELHO; FERREIRA, 2009), and as more solids are added the greater the conductivity due to the increase of ions (PHILIPI JR; ROMERO;BRUNA, 2004; LIBÂNIO, 2008). Furthermore, the increased ionic concentration can evidence variations in the decomposition of organic matter discharged (GUERESCHI; FONSECA-GESSNER, 2000; PEREIRA-SILVA et al., 2011). Importantly, although this parameter does not discriminate the ions present in the water, it is an important indicator of possible pollution sources (ZUIN; IORIATTI; MATHEUS, 2008).

Although the CONAMA Resolution 357/05 does not establish maximum allowable levels of EC in freshwater environments, according to CETESB (2011), levels above 100 μs/cm indicate impacted environments. Therefore, the finding of high EC in the discharge point and downstream, with average values of 215.3 μs/cm (maximum of 353 μs/cm) and 176.3 μs/cm (maximum of 220 μs/cm), respectively, shows that the area of influence of these sites can be classified as impacted stretches of the Peri-Poçu Stream. Similarly, another study focused on water quality of streams, also registered high values of EC in sites under strong human influence (KREISCHER; GONÇALVES; VELENTINI, 2012).

DO and BOD were key factors that showed the decline in the quality of water downstream of the point of discharge. Dissolved oxygen is one of the most important parameters in determining the quality of surface water, because it assesses the effect of oxidizable loads in the water body (MACÊDO, 2005). When effluents are discharged into the aquatic environment, they demand oxygen for the stabilization of organic matter, which results in decreasing the amount of DO in the water and increase in BOD (ALVES et al., 2008; MACHADO, 2011). In this study, the concentrations of DO decreased downstream of the point of discharge, but, contrary to expectations in a process of self-purification, concentrations did not return to levels upstream of the discharge. Moreover, a significant increase was detected in the concentration of BOD in the longitudinal gradient, indicating the permanence of organic pollution in the watercourse. It is important to stress that the decrease in DO and increased BOD may be related to the lower flow, especially at the site downstream, which reduces the ability of the stream for purification. The increasing trend of BOD downstream of the discharge point seems to be a common pattern in streams receiving punctual sources of pollution (THEBALDI et al., 2011; RIBEIRO; SANDRI; BOÊNO, 2013).

Although pH was slightly higher in the sites of discharge and downstream, it is emphasized that the values of this parameter remained within the limits set by the CONAMA Resolution 357/05 (6.0 to 9.0). However, it is important to mention that pH is an indicator of the amount of organic matter in the aquatic environment, but may be influenced by the presence of photosynthetic organisms and the type of rocks (ESTEVES, 2011).

One of the steps of assessing the impact from the discharge of effluents into the water body and the effectiveness of control measures is the quantification of pollutant loads (VON SPERLING, 2005). In this study it was not possible to quantify the pollutant load for the industrial discharge, but the results suggest that the Peri-Poçu Stream lacks sufficient flow to dilute the effluent and hence reduce the pollutant load, since the load was not different between the discharge point and downstream. As the Peri-Poçu Stream has only about 5 km length, it is possible that all organic load is not degraded and also the oxygen balance is not restored, before flowing into the Vito-I-Cuê Stream. It is noteworthy that in the self-purification process is important to consider the assimilative capacity of the rivers to prevent the discharge of treated effluent with loads greater than that the water body can endure (THEBALDI et al., 2011).

The Peri-Poçu Stream was evaluated considering it as a Class II water body, since it still has no classification approved by the environmental agency of the Mato Grosso do Sul State. The classification of water bodies is the establishment of water quality goals to be achieved or maintained in a stretch of the water body in accordance with the intended uses, according to CONAMA Resolution 357/2005. In environmental licensing and in the application of other instruments of water and environmental management that have the classification as a reference for application, it should be considered, in surface water bodies not yet classified, the quality standards of the class corresponding to the preponderant uses more restrictive existing in the water body (ORTEGA; CARVALHO, 2013).

5 FINAL CONSIDERATIONS

The results of this study show the need for the government to focus efforts to improve management of water resources in the Mato Grosso do Sul State, especially those located in protected areas as in the case of the Peri-Poçu Stream, in order to prevent water pollution and conserve natural resources.

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