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Quali-quantitative evidence on water quality by a governance process with payment for environmental services in a water supply watershed

Evidências quali-quantitativas da qualidade da água por um processo de governança com pagamento por serviços ambientais em uma bacia hidrográfica de abastecimento de água

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ABSTRACT

For the efficient management of water and soil conservation, quality and quantity aspects must be integrated. However, there is still a lack of studies with this synergy including governance processes. The present research evaluated for ten years (2010-2019) quality and quantity aspects of a water supply source and the Payment for Environmental Services (PES) implementation to investigate public policy efficiency and its effect on water resources. We used statistical analyses for comparing means, graphical analyses (trends, time series, duration curve, standard deviation), and correlation and multivariate analysis to evaluate parameters' behavior after the PES implementation. Results showed that there was a significant reduction in turbidity, COD, and total suspended solids. Furthermore, water flow rate, total nitrogen, total phosphorus, and dissolved oxygen remained stable after the implementation of conservation practices, as confirmed by the multivariate analysis. Water quality index (WQI) between "Good" and "Great" and chemical and hydrobiological parameters below the maximum allowed values reflected on the water quality maintenance. Participative decision-making based on dialogue between stakeholders and trust in PES were key elements for success.

Keywords: Water and soil conservation; WQI; PCA; Cluster; Water policies.

RESUMO

Para uma gestão eficiente da conservação da água e do solo, os aspectos de qualidade e quantidade devem ser integrados. No entanto, ainda faltam estudos com essa sinergia incluindo o processo de governança. Avaliamos aspectos de quali-quantidade (2010-2019) por 10 anos em um manancial de abastecimento de água e a implementação de Pagamentos por Serviços Ambientais (PSA), para entender a eficiência da política pública na área ambiental e seus efeitos sobre os recursos hídricos. O processo de governança foi investigado e análises estatísticas usadas para comparação de médias, análises gráficas (tendências, série temporal, curva de permanência, desvio padrão), correlação e multivariada para avaliar o comportamento dos parâmetros, após implementação do PSA. Nossos resultados mostraram que houve uma redução significativa na turbidez, DQO e sólidos suspensos totais. Além disso, a vazão, nitrogênio total, fósforo total e oxigênio dissolvido permaneceram estáveis, após a implementação de práticas de conservação, corroborada pela análise multivariada. O índice de qualidade da água (IQA) entre "Bom" e "Ótimo" e os parâmetros químicos e hidrobiológicos abaixo dos valores máximos permitidos, refletiram na manutenção da qualidade da água. A tomada de decisão participativa com base no diálogo entre as partes interessadas e a confiança no PSA foram os elementos-chave de sucesso.

Palavras-chave: Conservação do solo e da água; IQA; ACP; Cluster; Políticas de água.

INTRODUCTION

Traditionally, many studies have addressed the quantitative aspect of water resources management in watersheds (Ouyang, 2012). However, not always such research integrates its analysis with qualitative aspects. In the context of soil conservation management and water quality, the sediment input into water bodies increases through the inadequate planning or even lack of management of land use and cover (Figueiredo et al., 2019; Pereira et al., 2019; Oliveira et al., 2019; Fang, 2021; Kumarasiri et al., 2021). Nevertheless, there is still a lack of studies with this synergy including the governance process and regulatory approaches.

The main findings of studies highlight that incremental regulatory and governance actions end up being constantly needed, and more than just implementing the zoning of areas and restrictions, the actions and programs must be effective.

Water quality deterioration is higher depending on the type of soil use and cover. Especially in priority areas for public supply the consequences are more serious due to the human health risks (Mokondoko et al., 2016). Randhir et al. (2001) suggest that protection decisions on land use, such as preservation of forest areas and habitats essential for wildlife, planning of leisure and recreation areas, and use of (ecological-economic) zoning are the solution. In the USA, Conway & Lathrop (2005) showed in their study that measures of control, zoning, and delimitation of areas for protection or flooded areas do not substantially limit negative impacts, especially on the water.

Primavesi et al. (2002) and Donadio et al. (2005) assessed water quality in areas with different types of land use in the southeast of Brazil, identifying that springs with riparian forest tend to improve the water quality. The parameters with perceptible differences were color, turbidity, electrical conductivity, alkalinity, pH, chemical oxygen demand (COD), nitrogen, and dissolved oxygen (DO). Fernandes et al. (2011) found that areas in the southeast of Brazil occupied by secondary forests provided better water quality. The bare soil influenced negatively turbidity and total solids.

In southern Brazil, in the last 60 years, EMATER/RS-Ascar[1] carried out several soil conservation actions with research entities and public and private companies, to share technologies and best practices with farmers. Classic methods, from construction of terraces, contour bunds, outlet channels, and plant methods, to soil correction, level terracing, use of cover crops, direct planting, flood containment in crops and roads, reforesting, and waste management, aiming at reducing water erosion, improving the water quality of fountainheads, and increasing agricultural productivity, were adopted. They obtained greater productivity and reduced loss of soil by erosion (Olinger, 2007; Streck, 2012). However, these actions and programs require incentives with funding for conservation practices.

The Payment for Environmental Services (PES) implementation by the Water Producer Program is an alternative applied in Brazil by the federal government for soil and water conservation (Mamedes et al., 2023). Created in 2021, the National Payment Policy for Environmental Services provided for payment contracts for environmental services. Although the policy had been made after this study, it reveals the maturation of public policies valuing ecosystem services, especially as to water security, which is the focus of the present research. The biggest challenges in developing mechanisms for PES programs have been the slow process in building confidence between that who pays and the one who receives, as well as being clear on additional gains between the parties (Asquith et al., 2008). Furthermore, holistic monitoring that deals with the ecosystem as a complex socio-economic system is necessary (Lima et al., 2021). In the Brazilian Midwest, in the Guariroba Environmental Protection Area, preliminary results showed that the baseflow tended to increase and soil conservation practices reduced the soil erosion by a quarter, results which were positive for water availability and considering the particularities of land use combined with water supply characteristics of the reservoir (Sone et al., 2019). However, there is still a worldwide need for information about the effects on water quality, integrated with quantitative aspects, and for considering how this governance process occurred so that it is implemented in other river basins and conservation units.

The literature about river basins water resources protection using the PES presents some studies (Asquith et al., 2008; Mokondoko et al., 2016; Jujnovsky et al., 2017; Tantoh & Simatele, 2018) indicating important aspects for obtaining effectiveness, such as (i) engagement of the basin institutions and actors; (ii) existence of a governance process for conserving the soil and water resources; (iii) integration between regulatory and non-regulatory actions; (iv) integration of local, state, and federal efforts; (v) existence of institutional and legal structure; and (vi) confidence between who pays and who receives. Few studies present quali-quantitative monitoring data for a long period (ten years or more) or include in their analyses a governance description containing the actions of actors (stakeholders) and legal and institutional aspects, bearing in mind the promotion of this engagement and confidence process in other river basins, and considering social, economic and environmental aspects. Despite the recognition that water security relates to quality, quantity, and social factors as such governance, discussions focus only on one or two of those aspects (Gunda et al., 2019).

In this context, the present study aimed to assess the water quality changes after the implementation of conservationist practices, including quantitative aspects (flow rate and precipitation), and to characterize the governance process built with different actors of the location in the adoption of PES at a Conservation Unit (Environmental Protection Area) that holds a water supply watershed.

CASE STUDY

Delimitation and location

The study area consists of the Guariroba Stream Basin, which is an Environmental Protection Area (APA), named APA of Guariroba (Figure 1), from the Brazilian savannah and integrating the Paraná basin, with an area of approximately 360 km^2. The APA's territory is characterized essentially by rural properties with activity aimed at extensive livestock farming. About 82% of its territory is occupied by artificial pastures (Prefeitura Municipal de Campo Grande, 2012).

[1] Acronym for Rio Grande do Sul Association of Technical Assistance and Rural Extension Enterprises – Rural Credit and Assistance Association of the South, which is a Brazilian organization that provides assistance in agricultural matters.

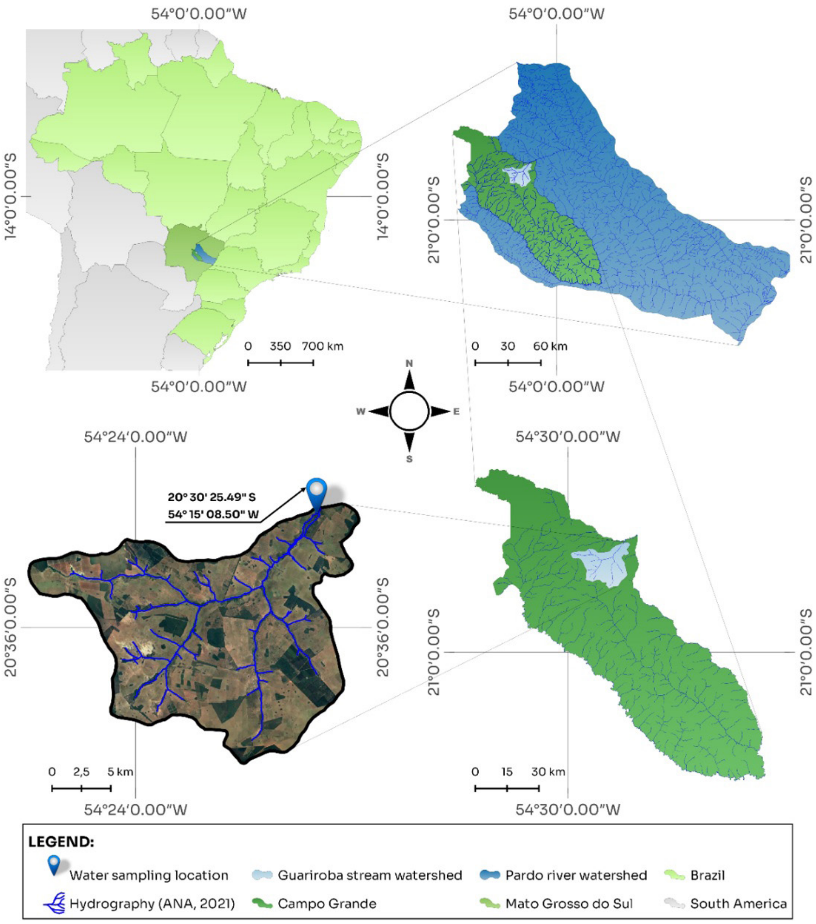

Figure 1. Location of the Guariroba water supply watershed (Environmental Protection Area).

The Guariroba APA was instituted by the municipal government through the decree n. 7,183, from September 21, 1995, from the need for recovery and conservation of the main raw water producing system for public water supply of the city of Campo Grande.

Currently, the water supply agency Águas Guariroba, Inc., makes the collection of approximately 4,433 m3.h^{-1} destined for public supply. The system accounts to approximately 35-50% of Campo Grande's water supply system depending on the time of the year, which is also served by the Lajeado and Desbarrancado superficial systems (~15% of the production of water) and a wide set of approximately 150 wells exploring groundwater resources (35-50% of the production of water) (Prefeitura Municipal de Campo Grande, 2012).

History of governance actions in the APA of Guariroba[2]

In this area, Management Plan and the PES program, named Water Producer Program (PPA), created and funded by National Water Agency (ANA), were implemented in 2008 and 2009, respectively. The PPA funded the implementation of conservationist practices - mechanical (level terracing), plant-based (commercial forestry), and restoration of permanent preservation areas – in the rural properties. Those practices comprised an area of 7,600 ha.

The Guariroba basin rural landowners, dialoguing with the rural union, intended to receive financial return from PES, but, without internalizing responsibilities or costs. In this context, in 2009, there was the mobilization of diverse actors: producers; Rural Union of Campo Grande; Municipal Government of Campo Grande (PMCG) through the Municipal Environment Secretariat; state government through the state environmental body, Public Prosecutor's Office, and technical assistance and rural extension; federal government by the National Water Agency (ANA); Águas Guariroba Inc.; and moreover the support of parliamentarians, which made a technical staff available to effect the recovery and conservation actions of the basin, through projects and fundraising for their development.

Additionally, positive experiences with the PES implementation in Extrema (MG, Brazil) and Nova York (USA) municipalities and the fact that other Brazilian states were implementing PES for protecting springs contributed to driving producers. This also led the public entity to internalize efforts to provide the means to make the spring's recovery and conservation viable, as well as PES. Furthermore, approximation to ANA and Brazil's The Nature Conservancy (TNC) occurred in several meetings, where clarifications needed for decision-making were presented.

[2] Prefeitura Municipal de Campo Grande (2012).

In December 2009, there was the appointment of a Working Group constituted by technicians from the mentioned institutions designated for the elaboration of projects for the raising of funds through ANA. Against this backdrop, "Program for Degraded Areas Recovery and Conservation of the Guariroba Stream Watershed" was submitted and approved.

In 2010, the sum for environmental actions necessary to the spring reached R$ 23.5 million for application in ten years. This value was needed to the recovery and conservation of the five sub-basins defined in the project. Funds from ANA corresponding to R$ 800,000 were released for application in the first phase of the Manancial Vivo Program (MVP, Programa Manancial Vivo), and funds from PMCG at the value of R$ 88.000, as an offset, and its application conditioned to the PES implementation to rural landowners opting to adhere to the program.

Without sufficient fund for complete execution of the program, from studies made available in the Management Plan of the Guariroba sub-basin that holds an area of 7,600 ha, 16 properties (Figure S1, Supplementary Material) totally or partially located in the basin were prioritized for the recovery, conservation, and PES pilot project implementation.

The convincing of the parties, still in the year 2009, of the importance of the PES implementation resulted in 2010 in an initial effort to legally institutionalize PES and provide funding necessary to its maintenance, associated with the studies. After all, the fund initially made available, R$ 888,000, was exclusively for the execution of works and services, and for implementing the PES, additional resources would be needed. Thus, a gap remained. Where would the funds for PES to producers come from? All discourses pointed to the company Águas Guariroba Inc., which should bear the cost, however, without the transfer to the consumer.

Decree n. 7,884/1995, which instituted the PES as an environmental management instrument within the Municipal Environment Fund (FMMA), through discussion with local society (councils, regulatory agencies, and legislative power), set the means for the raising of funds to provide the PES. Thus, this funding may be obtained, preferably, via concessionary companies of sanitation and electric power generation and distribution, enterprises installed within the watershed, funds that originate from laws or contracts, as well as other funds allocated in FMMA for diverse actions.

In addition, the decree provides for the funding derived from transfer determined in the budgetary allocation of the municipality, environmental license rates, fines for environmental or urban infractions, donations, legacies and contributions of companies, earnings and investment in the financial market, as well as funds aimed at environmental projects and programs, subsidies and grants and other transfers from federal and state governments, environmental compensations, and the Ecological taxes.

Figure 2 contains a summary with the main actions in the study area.

Simultaneously the Municipal Environment and Urban Development Secretariat (SEMADUR) published the Resolution n. 004, creating the Manancial Vivo Program (MVP) in the municipality of Campo Grande, the SEMADUR Resolution n. 06, which created the Project's Management Unit (PMU) in the Conservation Unit's Management Council, and Public Notice n. 001/2010, which set

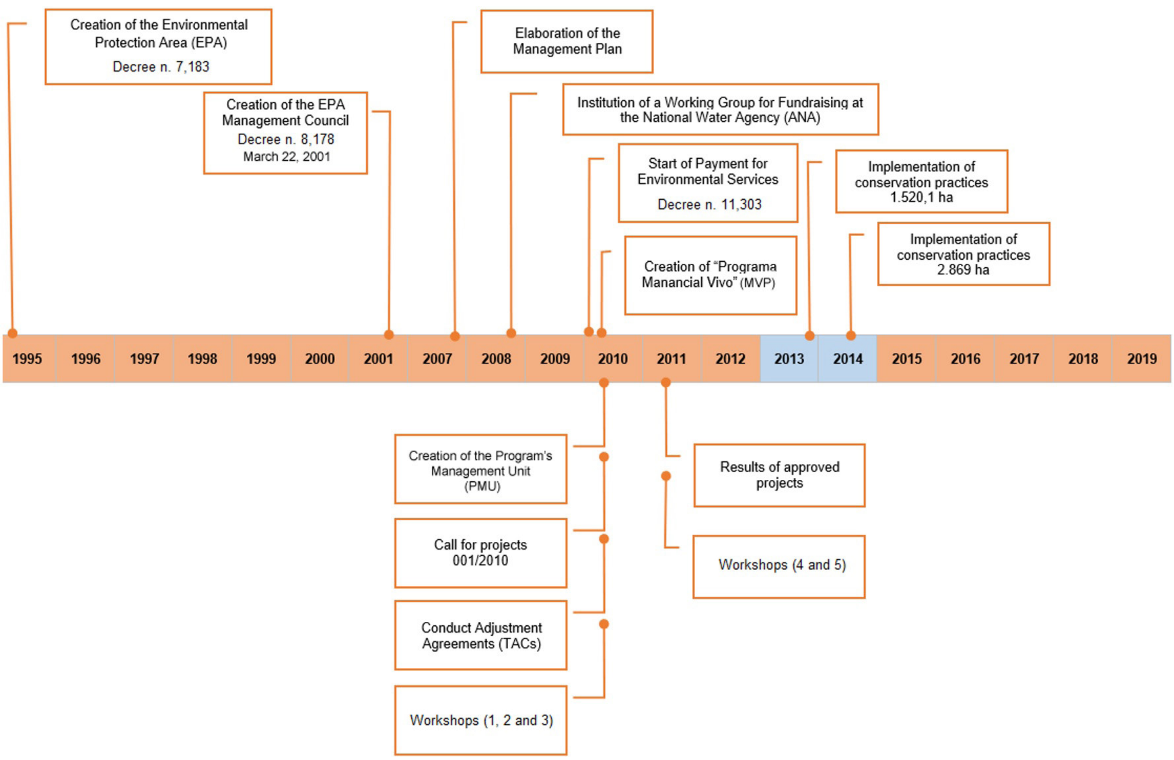

Figure 2. Timeline of governance actions in the Guariroba Basin (water supply watershed and Environmental Protection Area named "APA of Guariroba").

the rules for the accreditation of rural landowners aiming for the selection of proposals relative to the conservation of soil, water, and forests and the receipt of PES in the municipality of Campo Grande, legally structuring MVP and PES.

The State Prosecutor's Office (MPMS) acted directly and indirectly. The office targeted funds toward PES, which originated from consent orders, and initiated 57 proceedings, among civil investigations and administrative proceedings (consent orders and public civil actions) in the APA. Some properties were found to have only 30 meters wide destined for APA, while the Management Plan determines that it must be 50 meters. Practices aimed at soil conservation were also not found.

MATERIAL AND METHODS

The conservation unit governance actions

The governance analysis in the study area was carried out by collecting official documents available to the public, from different actors (stakeholders) who participated in actions in the location. Stakeholders were mapped and data collection was carried out following the actions chronological order. We present the timeline in item 2.2.

Water quality data: physicochemical, microbiological parameters and heavy metals

For evaluating water quality through WQI (Companhia Ambiental do Estado de São Paulo, 2018) we used quarterly data obtained from the Águas Guariroba company regarding samples collected throughout the period 2015-2019, from which we analyzed physical, chemical, and microbiological parameters of interest for the public supply of water. Complementarily we used the physical, chemical, and microbiological parameters data (Kofanovski, 2016) for the period 2010-2019. The sampling point was the same (Figure 1) and it was not possible to calculate WQI for the period before 2015 because of the inconsistency (lack of data) in the water quality monitoring before the conservation practices implementation.

Parameters analyzed were: dissolved oxygen (DO), total phosphorus, total nitrogen, nitrate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, turbidity, total solids, total dissolved solids, temperature, ammoniacal nitrogen, nitrate, *Cryptosporidium, Giardia*, *E. Coli*, and chlorophyll A. Monthly data of the parameters chlorophyll A, microcystins, cyanobacteria, total chloride, dissolved aluminum, dissolved iron, total manganese, zinc, and total chrome were also gathered. Data about *Cryptosporidium, Giardia*, enterovirus, and glyphosate were obtained from results of biannual analyses provided by the Águas Guariroba company.

Analyses followed recommendations for sampling, storage, and analysis, in accordance with Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 2012). Parameters' values below the analytical methods detection limit (DL) were replaced by the value corresponding to the respective DL for statistical analysis.

WQI – Water Quality Index

The water quality index (WQI) calculation followed the recommended by National Sanitation Foundation, considering the adaptation made by São Paulo State Environmental Company (Companhia Ambiental do Estado de São Paulo, 2018).

Nine parameters were considered as representative for water quality. The WQI holds values between 0 and 100 and is divided into five groups: 0-19, weak; 20-36, poor; 37-51, acceptable; 52-79, good; and 80-100, great. As shown in Equation 1, i-th weighted product (qi) for each variable increases according to the respective weight (wi) (Companhia Ambiental do Estado de São Paulo, 2018).

$$WQI = \prod_{i=1}^{N} qi^{wi} \tag{1}$$

Qi was obtained considering each parameter's concentration. Wi corresponds to a weight attributed to the parameter due to its importance for quality. The sum of wi is equal to one, on the basis of Equation 2:

$$\sum_{i=1}^{n} wi = 1 \tag{2}$$

Before 2015 it was not possible to calculate WQI because of the lack of data of all parameters making up the index.

Statistical analysis: rainfall, flow rate, and water quality

Monthly data for precipitation in the municipality of Campo Grande between 2010 and 2019 were obtained from the Weather, Climate, and Water Resources Monitoring Center of Mato Grosso do Sul (CEMTEC).

Flows rate for the period 2010 to 2019 in the upstream section of collection was estimated through a regionalization study of flow rates from the Pardo River sub-basin (station code: 63900001; latitude -20:26:29 and longitude -53:43:5) using the Hydrological Information System application, web version 3.0 from 2018, of the National Water Agency (ANA).

The statistical analysis initially consisted of the time series analysis for the following parameters: temperature, pH, dissolved oxygen (DO), BOD, total solids, turbidity (NTU), total nitrogen, total phosphorus, and *E. coli*, highlighting the period before and after the conservation practices implementation. The averages (before and after the conservation practices implementation) were compared by the Tukey test at 5% level of significance ($p <0.05$). Chemical and hydrobiological parameters were indicated by the mean values.

For analysis of the behavior of solids after the conservation practices implementation, as well as WQI, including drought and rain periods, vertical bar graphs with averages, standard deviation, and trendlines were used.

Additionally, water quality parameters multivariate analysis was carried out taking into consideration, firstly, correlation analysis and subsequently principal component analysis (PCA) and cluster analysis (CA), with the intention of understanding the behavior and effects after the conservation practices implementation, according to Shrestha & Kazama (2007), Osei et al. (2010), and Gibson et al. (2018) for quantifying the significance of variables (PCA); and Vega et al. (1998) and Kazi et al. (2009) for assessing homogeneity or heterogeneity between the data in the clusters formed (CA).

Pearson correlation coefficient (r) was used to measure the degree of linear correlation between two quantitative variables ranging from -1 to 1 (Pearson, 1895), following studies evaluating the correlation between water quality and its variables (Parizi & Samani, 2013; Yu et al., 2016).

Regarding flow rate and precipitation quantitative data, time series, trendlines, and frequency curves (flow rate and COD) were used, and calculation of organic load (COD and BOD), that is to say, taking into consideration the product of flow rate and concentration, relating quality and quantity.

RESULTS AND DISCUSSION

An analysis of the conservation unit governance actions

In the APA of Guariroba, there was the engagement of institutions relevant in creating partnerships to solve problems of the watershed where the spring lies, especially of rural landowners, through the APA's Management Council and was motivated by the following aspects:

- The diagnosis presented in Management Plan showing that the damages arising from the poorly conducted management of soil and livestock did not impact only water quality and quantity for public supply but also the loss of soil in rural properties, which indicated their economic infeasibility in the long term (Prefeitura Municipal de Campo Grande, 2008);

Sensitive environmental areas are often the subject of discussions. It is often thought that rural development, agriculture, forestry, and pastures will undergo deceleration. Thus, technical tools, such as management plans with detailed diagnoses and analyses, which identify areas with pollution, degradation, or at greatest risk, should be created, and deal with (i) the interrelationships between environment and economy and (ii) with the local community and stakeholders, for effective proposals that (iii) include local, state, and federal efforts in an articulated and integrated way (Steiner et al., 2000). This has happened via:

- The State Prosecutor's Office participation, with the elaboration of consent orders for the Legal Reserve and Permanent Preservation areas recovery, constraining the landowners to obey the law under penalty of a fine (Prefeitura Municipal de Campo Grande, 2012).

In Brazil, research reveals how the partnership between the Public Prosecutor's Office (Public Ministry – local) and other institutions helps in the governance process, and improves control and monitoring mechanisms, providing information to the population and stimulating actions to recover areas and solve environmental problems (Carvalho et al., 2021; Magalhães Filho et al., 2021).

The APA's Management Council, with the participation balanced between environmental bodies from the three government levels (SEMADUR – municipal; SEMA/IMAP – state; and IBAMA – federal), the non-governmental organizations (Association of Farmers of the Guariroba Basin; Rural Union of Campo Grande; Brazilian Bar Association, Mato Grosso do Sul section; and Municipal Environment Council), and private sector (TGB and Águas Guariroba), promoted the interventions conception in the watershed through programs.

This process created a possibility of receipt for the provision of environmental services (payment for environmental services - PES), with the trust of rural producers, which constitutes extra income (additional gain) to that obtained in the economic activities developed in the rural properties (Prefeitura Municipal de Campo Grande, 2012).

Jujnovsky et al. (2017) propose a tool for managing water resources that involves economic and social components. They present basic guidelines for the involvement among actors, control, participation, (quali-quantitative) monitoring, trust and influence among stakeholders, to help decision-makers improve the governance process. These mechanisms provide a real opportunity to change public policies, especially in developing countries, which have little data, lack of qualified technical staff, and occupy areas with fewer resources.

The environmental service economic valuation from the leasing of pastures in the region (R$ 130.00 per hectare) allowed the rural landowners' easy understanding because this was a negotiation currency that they normally used (Prefeitura Municipal de Campo Grande, 2012).

The institutionalization of PES as an environmental management instrument in the scope of the Municipal Environment Fund, via Decree 11,303/2010, ensured legal support and budget structure for the raising and allocation of funds aiming for the implementation of programs in the APA of Guariroba (Prefeitura Municipal de Campo Grande, 2012).

Another aspect that deserves highlighting is the partnership with the Federal University of Mato Grosso do Sul, via development agency resource, for measuring the effectiveness of the program actions through hydrosedimentological monitoring, from the installation of a network of pluviographs and water level recorders in the basin (Prefeitura Municipal de Campo Grande, 2012). Such initiative allowed the monitoring of the program to occur from scientifically-measured data, conferring credibility on the achieved results.

The Manancial Vivo Program (MVP) socialization through the carrying out of workshops allowed technical, financial, and institutional information to flow in a continued and transparent way to the main actors in the implementation of the program. Furthermore, it brought producers closer to funding institutions, for example, Caixa Econômica Federal (Prefeitura Municipal de Campo Grande, 2012). This background differs from what was observed by Tantoh & Simatele (2018) in their study on the flaws and main challenges in the governance process. They were:

uncoordinated national development policies; weak institutional structures; top-down management, not allowing local autonomy; and the inability of water users to regularly contribute to the operation and maintenance of the water system.

The regular payment for environmental services to landowners that adhered to the program, on the basis of the verification and certification of achieved goals, created an environment of trust between who paid and that who received, so necessary in this type of relationship. Asquith et al. (2008) found that the biggest challenge in the development of mechanisms for payment programs for environmental services was the slow process in building trust between those who paid and those who received.

Behavior of water quality over the years (2010-2019)

Considering all parameters analyzed throughout the time (2010-2019), temperature, pH, and BOD showed an increasing trend in the period (Figure 3). But, temperature and pH had an increasing trend before the period of actions (2013-2015) and BOD did not surpass 4.0 mg.L^{-1}, which meets quality standards. Total Phosphorus was stable during the whole period, with greater variability in the period of actions in the basin, similar to Total Nitrogen. Turbidity, Total Dissolved Solids, COD, and *Escherichia coli* (*E. coli*) showed a falling trend, and Dissolved Oxygen remained stable.

In the statistical analysis for parameters before and after the actions in the basin, there was a significant difference for COD, BOD, pH, and Turbidity. The averages were compared by the Tukey test (Table 1), at the 5% significance level ($p<0.05$).

COD had an average result in the period of 5.79 mg.L^{-1}, with a falling trend, reflecting a decrease in the total number of oxidizable components, be they carbon or hydrocarbons, hydrogen, nitrogen (from proteins, for example), or sulfur and phosphorus from detergents, present in the water in the form of inorganic salts and small quantities of organic matter and dissolved gases by untreated domestic sewage. Agricultural areas are often susceptible to changes in water quality, particularly in COD and nutrients (N and P), through agrochemicals, fertilizers (Delgado et al., 2011; Sharpley, 2016), motor oil, fuel, and gear fluids from vehicles (Allen, 2005), especially in periods when the soil is disturbed, be it in preparation for agricultural crops or to implement conservation practices, and the water quality can deteriorate, changing the

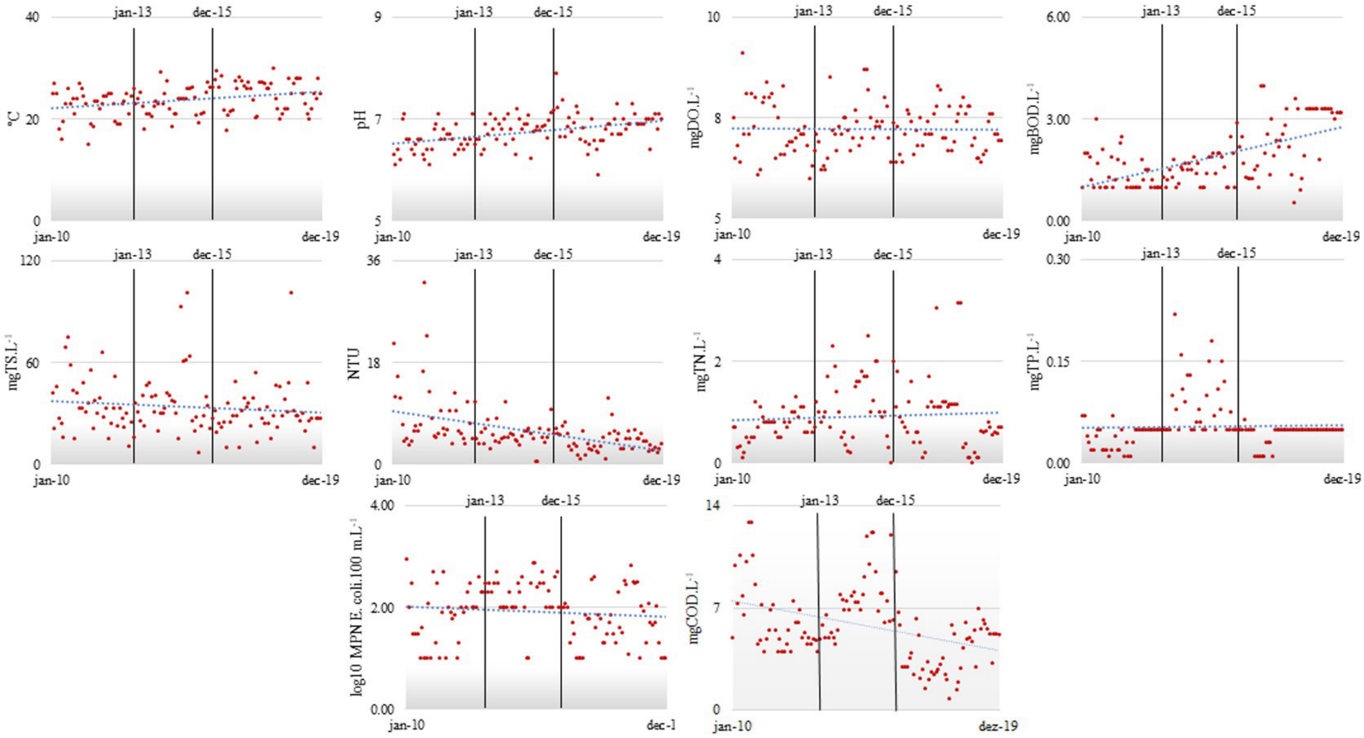

Figure 3. Behavior of the water quality parameters (2010-2019). Highlight to the period of the PES actions in the watershed (2013-2015).

Table 1. Statistical analysis (Tukey test) for the water quality parameters before and after the actions in the basin (period before January 2013 and after December 2015).

Period	COD	Total Nitrogen	pH	DO	Turbidity	Total Phosphorus	BOD	E.coli
Before Jan-13	6.47 a	0.73 a	6.56 b	7.21 a	9.03 a	0.04 a	1.41 b	149.51 a
After Dec-15	4.28 b	0.93 a	6.87 a	7.20 a	4.20 b	0.04 a	2.49 a	105.04 a

Means followed by the same letter (columns) do not differ by the Tukey test ($p>0.05$).

dynamics of lakes, ponds, and reservoirs - lentic environments (Straskraba & Tundisi, 2013).

It is important to highlight that the average result of BOD in the period 2010-2019 was 2.34 $mg.L^{-1}$, characteristic of little polluted water bodies in rural zones, where the oxygen demand is largely due to leaves and other debris carried to water (debris BOD).

The falling trend of Turbidity, Total Solids (TS), and COD possibly captures the effects of the terracing carried out in the APA properties in 2013 and 2014. Although there was a statistical difference for Turbidity and COD after the period of implementation of the practices, the same did not occur for Total Solids (TS). As the water source has a low solids load, the more sensitive parameter is Turbidity than Total Solids (TS) and this explains the significant difference. When analyzing TS and separating Suspended Solids (SS) from Dissolved Solids (DS), it is possible to notice the high variability (standard deviation). From a practical point of view, the average concentration of TS at almost 60 $mg.L^{-1}$ and SS above 20 $mg.L^{-1}$ (in 2015) is below 40 $mg.L^{-1}$ and 10 $mg.L^{-1}$ (in 2019), respectively, which results in reduced operating costs at Water Treatment Plants and increases water security. Total and suspended solids decayed throughout the period while the dissolved remained at the average of 31 $mg.L^{-1}$, as per Figure 4.

The Turbidity and Suspended Solids consistent decay throughout the period possibly resulted from the conservation practices – mechanical (level terracing) and plant-based (commercial forestry) and permanent preservation areas restoration – largely implemented in the properties in 2013 and 2014. In that regard, the soil conservation promotes adequate control of the input of sediments into the water body.

Behavior of other chemical and hydrobiological parameters

Total Chloride, Dissolved Aluminum, Dissolved Iron, Total Manganese, and Total Chrome parameters remained below the maximum allowed value in most months (Table S1, Supplementary Material). Total Chloride reached 25 $mg.L^{-1}$ extreme value in January 2015, Dissolved Aluminum reached 0.18 $mg.L^{-1}$ in May 2016, and Dissolved Iron recorded 0.5 $mg.L^{-1}$ in January 2016. Another result that draws attention is the value of 9.0 $mg.L^{-1}$ for Oils and Greases in January and February 2019. Souza et al. (2014), in southern Bahia state (Brazil), also found values considered above the standard and suggested that the source of pollution would be the washing of diverse domestic materials, the disposal of food remains on the banks of the river, and chemical products such as detergents, containing oils and greases, common in rural areas.

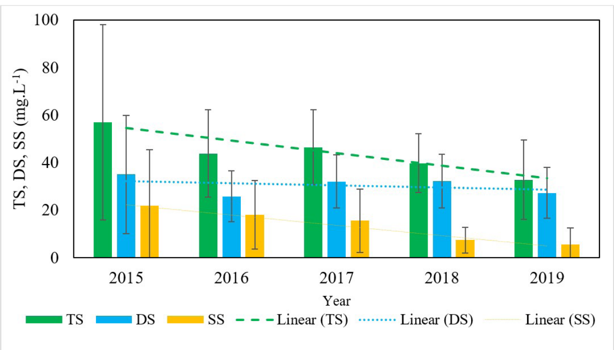

Figure 4. Behavior of Total (TS), Dissolved (DS) and Suspended (SS) Solids - 2010-2019.

The Chlorophyll A hydrobiological parameter, considered the main indicator of the trophic state of aquatic environments, recorded an atypical value only in September 2017, of 3 $\mu.L^{-1}$, and Cyanobacteria recorded the highest values in February, April, and December 2019, 8,564, 7,323 and 8,368 cell.mL, respectively, all the same below the maximum allowed value of 50,000 cell.mL (Companhia Ambiental do Estado de São Paulo, 2013). Microcistin values when reported were always below the quantification limit of 0.5 ppb.

Cryptosporidium, *Giardia*, and Enterovirus were absent in most biannual samples, except for first and second semesters of 2018 and 2019, all the same below the quantification limit. *Cryptosporidium* and *Giardia* are agents that have cysts resistant to conventional water treatment and are characterized by causing serious morbidities in immune-compromised individuals (Cacciò et al., 2005). The enterovirus is disseminated in oral secretions, feces, and sometimes, is present in the infected patient's blood. The infection is generally transmitted by direct contact with oral secretions or feces but may be transmitted by contaminated environmental sources, for example, water (Romero, 1999).

Results obtained for Glyphosate in biannual analyses in which this parameter was evaluated did not surpass the maximum allowed value of 65 $pg.L^{-1}$. The glyphosate, the most utilized active ingredient in Brazil, is a non-selective, systemic, post-emergent herbicide highly efficient in the monocotyledonous and dicotyledonous weed elimination (Amarante Junior et al., 2002).

Behavior of WQI over the years (2015-2019)

In Figure 5 WQI is observed to keep in the classification denominated "Good", above 70 in all years analyzed. In the year 2016, WQI achieved its highest value for the period, just after the actions in the basin, having a decrease in 2017 and 2018, and increasing again in 2019. Before 2015 it was not possible to calculate WQI because of the lack of data of all parameters making up the index.

As for seasonality (dry and rainy season), 2015, 2016, and 2017 showed the highest WQI values for the dry period and, in 2019, WQI was higher in the rainy period (Figure 5). In the period of analysis, the highest WQI value was in July (drought) 2018 (85 - Great) and the lowest in May 2015 (70 - Reasonable).

This reveals that even with the rain, carrying and transporting sediment into water bodies, in 2018 and 2019, after the conservation practices implementation, there was no decrease in the index, revealing a positive effect of the implementation of those actions on the watershed. Even because the decrease in solids results in less organic matter, nutrients and pathogens, which have higher weights in the index – WQI (Von Sperling, 2007; Di Bernardo, 2002).

Periods of drought showed better WQI than rainy periods in the study of Figueiredo et al. (2019) for an Environmental

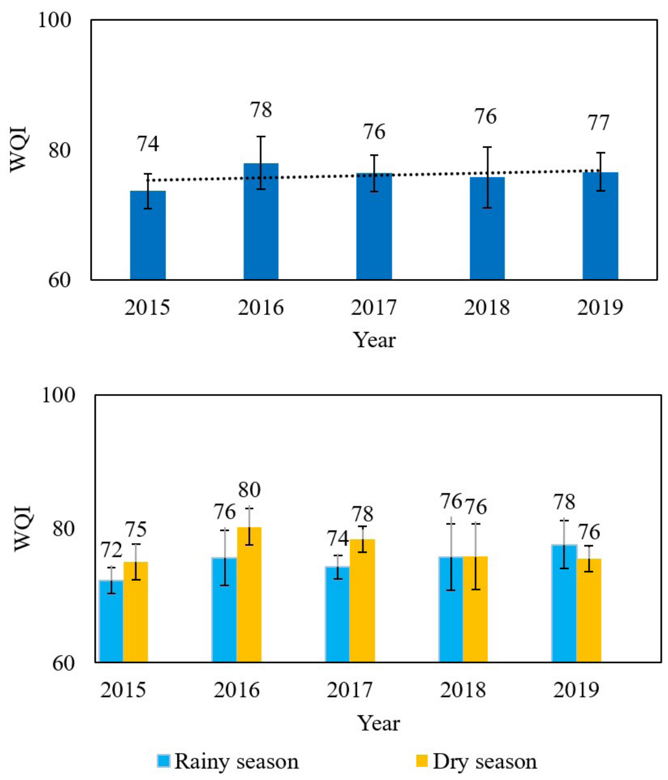

Figure 5. Water Quality Index (WQI) in the 2015–2019 period, drought and rain seasons.

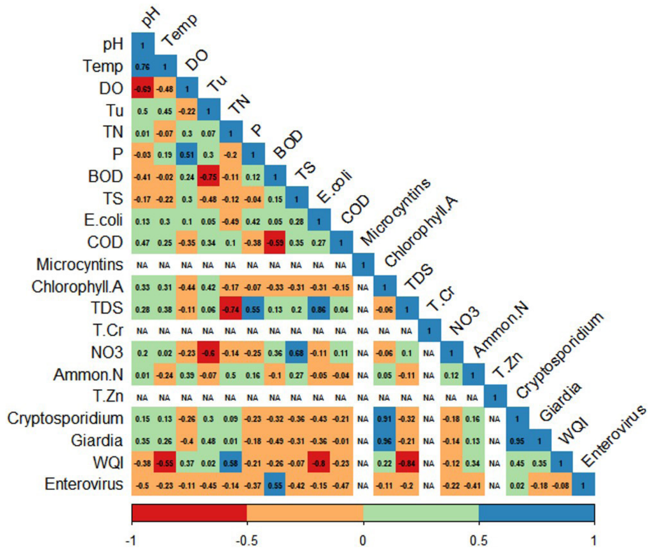

Figure 6. Correlation matrix between the analyzed parameters. Temp: temperature (ºC); DO: Dissolved Oxygen; Tu: Turbidity (NTU); TN: Total Nitrogen; P: Phosphorus; BOD: Biochemical Oxygen Demand; TS: Total Solids; E. coli: *Escherichia coli*; COD: Chemical Oxygen Demand; TDS: Total Dissolved Solids; T.Cr: Chrome; NO3: Nitrate; Ammon.N: Ammoniacal Nitrogen; T.Zn: Zinc.

Protection Area, of the same municipality, which is also a water supply spring. This explains the need for protected areas, which promote the degradation of the pollutant in the soil (Holloway & Dahlgren, 2001) and increase in the water bodies flow rate, which decreases the concentration of pollutants in the water (Pereira et al., 2019). The authors observed that in periods of rain, there is transportation of pollutants to some points of the watershed, reducing the WQI value, but in some cases there is the dilution of the pollutants, which increases oxygen values and decreases *E. coli*. Additionally, in dry periods, with lower flow rate, the concentration increases, as the volume is lower, and this decreases the WQI value. Therefore, WQI must be used thoughtfully. By and large, one notes the water quality maintenance after the implementation of the Water Producer Program with the Payment for Environmental Services.

Correlation, principal component analysis, and cluster

In the correlation matrix (Figure 6), red and blue colors correspond to negative and positive correlations, respectively. Light colors represent lower-intensity correlations and white color represents parameters with data without minimum standard deviation, not being possible to evaluate the correlation.

Parameter interrelation between 0.01 and 0.96 was found. Significant correlations ($p<0.05$) occurred between temperature and WQI (-0.55), TDS and WQI (-0.84), and *E. coli* and WQI (-0.80). These results indicate that the temperature, total dissolved solids (TDS), and *E. coli* parameters are the most representative for the WQI decay, which is in conformity with the finding of Figueiredo et al. (2019), in which the temperature caused the reduction of the WQI, significantly. Furthermore, periods of higher temperature were observed to show higher pH values (temperature-pH, 0.76) and are periods that decrease the WQI. In this way, climatic changes projected of increase in temperature may negatively influence the local water quality (Delpla et al., 2011). In this sense, plans must include the effects of climate change, as temperature will be responsible for the deterioration of water quality.

Chlorophyll A (algae indicative) is related to an increase in the *Cryptosporidium* and *Giardia* pathogens (0.91; 0.96, respectively), as the multiplication of algae may raise pH, which is more favorable to the proliferation of bacteria, as verified in Minas Gerais, Brazil (Gomes, 2008). Moreover, organic matter is related to increased pathogens (Enterovirus-BOD, 0.55), in that it demands the consumption of DO for its degradation and may transform the environment into anaerobic or cause it to have a low dissolved oxygen concentration, which reduces the water body's self-purification capacity. Nonetheless, there is a direct relationship between nutrient inputs, organic matter, and pathogens deriving from sewage and effluents (Von Sperling, 2007).

In the PCA analysis (Figure 7) we can identify the variables of greatest influence and relations between them, that is, the water quality behavior (including all parameters), as well as indications of grouping between the samples (similarity), including the cluster analysis.

The *E. coli* and DO parameters hold the greatest contribution, above 15%, and are considered variables of high contribution. The TN, P, temperature, pH, and turbidity parameters had medium

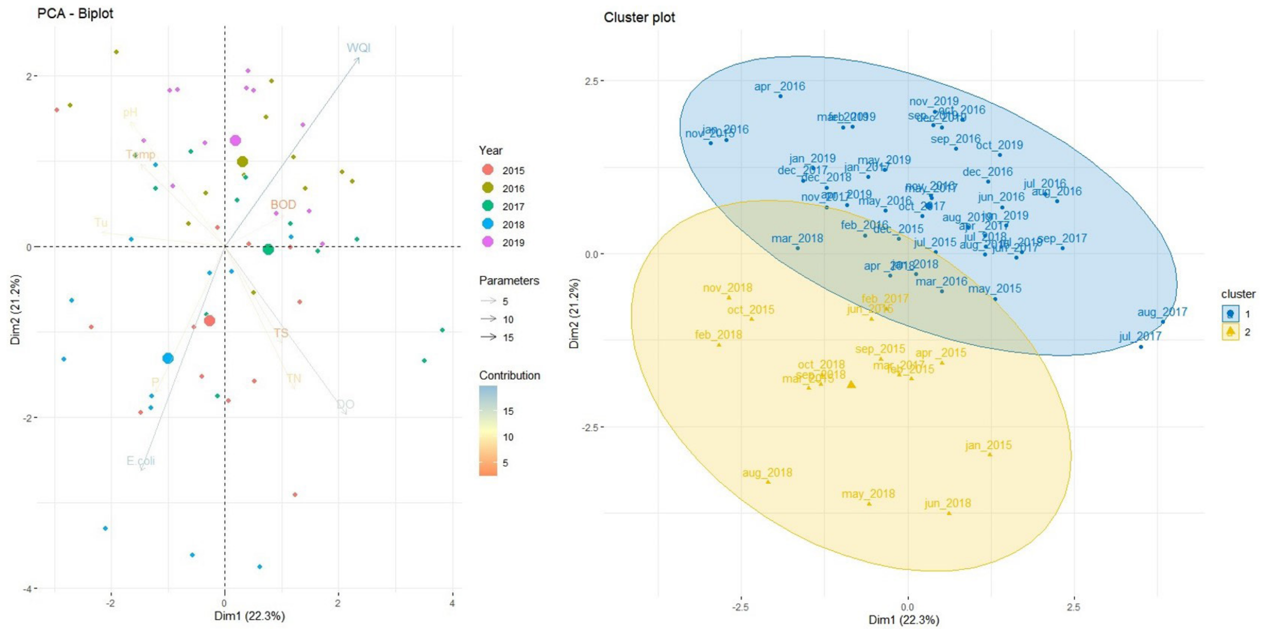

Figure 7. Principal Component Analysis (PCA) and cluster analysis by k-means clustering.

values and BOD and TS a low contribution, of less than 5%. This may be a result of low BOD values, as was presented, and the fact of *E. coli* and DO having the highest weights in the composition of the index (WQI). Pereira et al. (2019) evaluating water quality by multivariate analyses in different types of land use and occupancy have also observed this pattern.

Investigating the behavior of parameters over time, 2015 does not differ from 2018 and 2016, 2017, and 2018 show similarities. The cluster analysis corroborates this behavior by suggesting two clusters and made grouping in a similar way (Table S2, Supplementary Material). Therefore, although the water quality is considered as "Good" by WQI, when evaluating all parameters, distinct behaviors show for some years, which occurs precisely after the actions implemented in the basin (2015). This can be seen when analyzing Figures 3 and 5, as some parameters such as pH, BOD, COD, and NTU decrease after 2015 and then tend to increase. The WQI (dry/rainy season) increases after 2015 and then decreases again (on average). This indicates an overall positive effect on water quality, while continuity and maintenance of those actions are needed, as in 2018 one has again some similarity with 2015. It was possible to classify sites into groups by the cluster analysis - clean and polluted regions (Varol, 2020) – and also evaluate the behavior pattern of the parameters over time (years), revealing the need to keep the programs and actions to maintain water quality. As in Varol (2020), the study allows inferring by the PCA that the parameters responsible for water quality variations are mainly associated with suspended solids, nutrients, and organic matter.

Solids, nutrients (TN and P), DO, and pathogenic organisms (*E. coli*) are characteristic and representative parameters in the samples regarding 2015. For the following years, from 2016 to 2019, characteristic parameters were *E. coli*, turbidity, pH, temperature, and BOD. This reveals that after 2015 there was a decreased concentration of nutrients and solids and maintenance of the oxygen dissolved in the water. Yet, a variation in turbidity (suspended solids), which is common due to periods of drought and rain, still occurred. This parameter is fundamental for water treatment because it demands higher addition of chemical products, such as coagulants, flocculants, and agents for pH correction. Moreover, it requires higher input of solids into filters, increasing maintenance, with greater use of backwashing, water, and energy in the process (Di Bernardo, 2002; Fundação Nacional de Saúde, 2014). That being so, eventually the reduction in the water treatment costs is not significant. As precipitation patterns change, water pollution increases, and water is intensively exploited, it will be imperative to ensure water security. Successful water management practices should consider the quantity-quality-society nexus. Currently, emerging opportunities (socio-hydrology and data science) capture synergies and interactions pertinent to water resources management decisions. Cross-sectoral and cross-scalar dynamics using interdisciplinary methods and providing guidance on successful implementation of water management practices are necessary for safe water plans and equity and access guarantee (Gunda et al., 2019).

In evaluating the relation between parameters by the PCA analysis, we note similarities with the correlation analysis (Figure 6), which corroborates the relation between phosphorus and the presence of algae, which is measured by Chlorophyll A, and pathogens, measured with *E. coli*, *Cryptosporidium* and *Giardia*, and turbidity (suspended solids), in addition to the relation of temperature to pH and total nitrogen to total solids (Straskraba & Tundisi, 2013).

Behavior of the quantity aspects: rainfall and flow rate characteristics

Figure 8 contains data for rainfall and flow rate over the period from 2012 to 2019. Average rainfall in the period was 121.9 mm. January 2016 was the rainiest month (382.6 mm) and

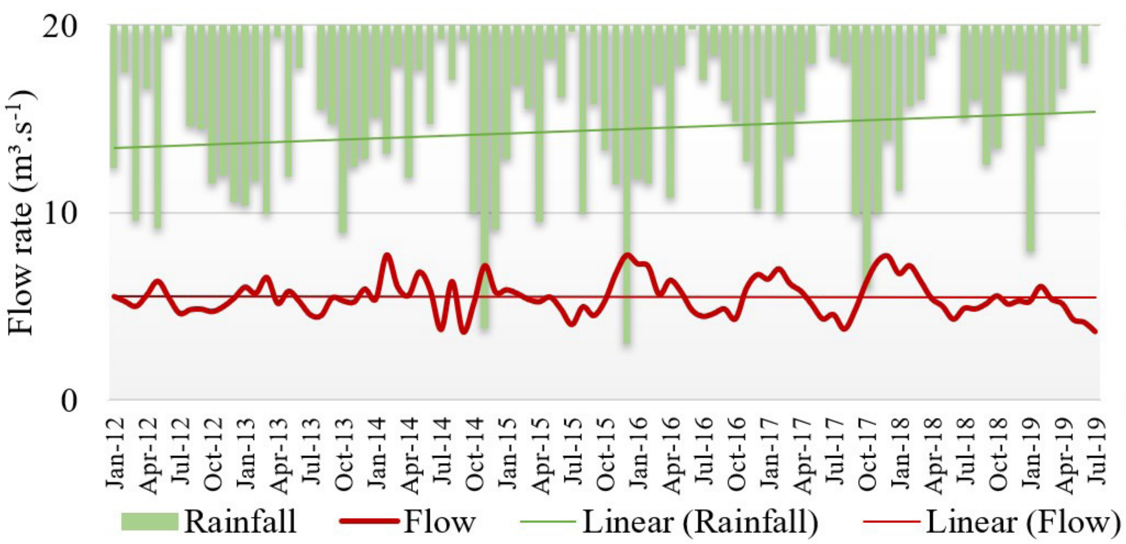

Figure 8. Characterization of the study area: rainfall and flow rate (2012-2019).

August 2013 the driest (0.0 mm). Regionalized flow rate for the basin had an average value for the analyzed period of 5.67 $m^3.s^{-1}$, peak in March 2011, of 14.45 $m^3.s^{-1}$, and the minimum value in October 2014 (3.63 $m^3.s^{-1}$).

In the enlarged period from 2010 to 2019, flow rate and rainfall showed a falling trend. In March and April 2011 there were extreme flow rates, 10 and 14 $m3.s^{-1}$ (Figure S2, Supplementary Material), however, rainfall and flow rate curves for 2012 to 2016 followed what Sone et al. (2019) have pointed out, decreasing trend for precipitation and mild increasing for flow rate (but without significant difference at a 5% level of significance ($p<0.05$), indicating at best the maintenance of the volume available.

Flow rate and COD duration curves and behavior of organic loads over the years (2010-2019)

The flow rate and COD duration curves for the period from 2010 to 2019 (Figure 9), along with the segmentation for the period 2010 to 2014 and 2015 to 2019 reveal signs of changes with the Water Producer Program and PES implementation, which was greater on water quality, by the COD parameter, than on the quantitative aspect (flow rate). At any rate there is maintenance of the flow rate available in the spring.

The evolution of biodegradable organic load, considering the BOD and the flow rate in the period (Figure 10), has an increasing trend due to increase in concentration (Figure 3), although results are below 5 $mg.L^{-1}$. But, in the total organic load evolution, considering the COD and the flow rate in the period (Figure 10), there was a decreasing trend, while the most significant reduction was in the period after PES. In the period of 2010 and between 2014 and 2015, in which flow rates above the average occurred and period of the conservation practices implementation, the COD load values were high, showing a decrease only after 2016 (after actions in the basin).

While BOD is associated with the organic matter biodegradable fraction (carbohydrates, proteins, lipids), COD

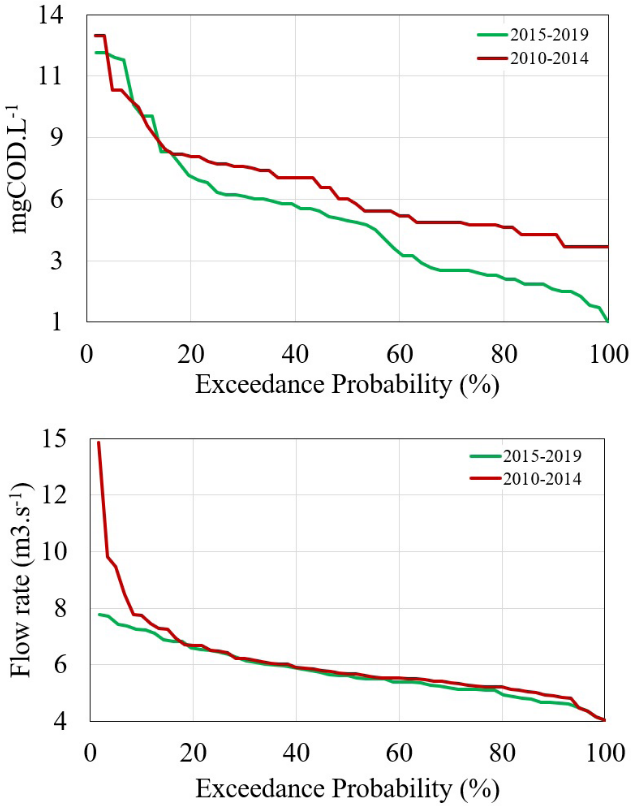

Figure 9. Flow rate and COD duration curves (2010-2014 and 2015-2019), before and after actions in the basin.

includes the inert, inorganic, and non-biodegradable fraction (Von Sperling, 2007). The reduction in COD organic load is related to turbidity and solids decay (Figure 3), according to the associated inert, inorganic, and mineral components fraction.

Dai et al. (2017) found variations in COD relative to the type of soil use and occupancy. They observed that water bodies

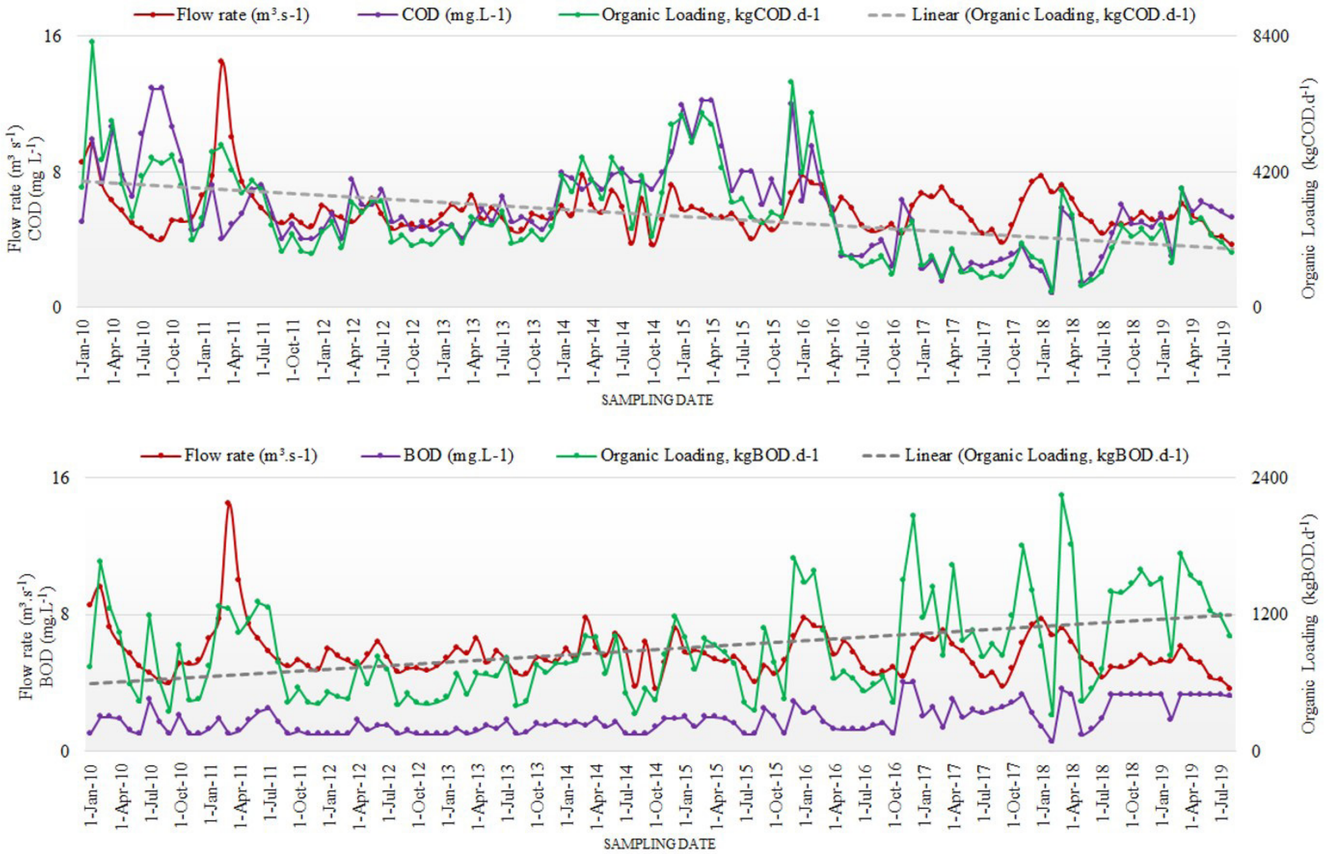

Figure 10. BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) organic loading (OL), 2010-2019. Highlight to the period of the PES actions in the watershed (2013-2015).

in agricultural areas are more susceptible to the water quality decay, especially for the COD and nutrients (phosphorus and nitrogen) parameters. Fertilizers, agrochemicals, and effluents are the main sources and the implementation of conservationist practices tends to improve the water quality. These actions may significantly reduce pollution in water bodies, preventing surface runoff, which transports pollutants, reducing soil erosion and absorbing those contaminants (Rao & Cui, 2008).

CONCLUSIONS

The soil conservation practices, through well-established governance, with conservation unit, Management Plan, councils and the payment for environmental services (PES) program, ensure the adequate quality of water for public supply. Continuity in water availability was also observed, while the flow rate in the basin was stable, and precipitation records showed a decreasing trend. This process has to do with greater forest restoration and improvement in soil conservation by strategies of incentive to the rural producer and confidence between the actors of the basin.

The effectiveness of the creation of the conservation unit (Environmental Protection Area), of the elaboration of its Management Plan, and of the PES implementation as instruments promoters of the improvements observed in the Guariroba basin, both for water quality and quantity, can be attributed to the following reasons (or observed factors):

- The decision-making process to solve the problems of the basin occurred from the dialogue and exchange of information between rural producers, public authorities, and supply company, mediated by the City Hall of Campo Grande, in the scope of the APA's Management Council;
- The disposition of the Public Prosecutor's Office in signing consent orders for recovering protected areas and the financial incentive provided by PES proved to be effective in encouraging rural landowners to adhere to the program;
- The efforts on a local, state, and federal level, both in terms of financial resources and informational and institutional, integrated under the leadership of the municipal government with the participation of landowners and the ANA (National Water Agency) were effective, as well as the actions of non-governmental organizations;
- The existence and functioning of the APA's Management Council and the legal institutionalization of PES (Payment for Environmental Services) are important aspects for the legal and institutional structuring needed for the success of the program's implementation; and
- The transparency conferred by the publication of results of audits and rendering of accounts, by means of indicators easy to be understood, measured, assessed, and reported, helped build trust among the actors of the program.

The WQI between "Good" and "Great" reflects water quality maintenance amid the improvements related to conservation practices in the water supply watershed between 2015 and 2019, especially for turbidity and COD parameters. In this context, suspended solids decrease by the decreased soil loss.

Chemical and hydrobiological parameters (such as Total Chloride, Dissolved Aluminum, Dissolved Iron, Total Manganese, Total Chrome, Chlorophyll A, Cyanobacteria, Microcystins, *Cryptosporidium*, *Giardia*, Enterovirus, and Glyphosate) remained below the maximum allowed values for most months or were absent in the largest number of samples (below quantification limits).

The temperature, total dissolved solids (TDS), and *E. coli* parameters are the most representative for the WQI decay. The highest-temperature periods showed higher pH value, which decreased WQI. That being so, the climatic changes of projections suggesting increase in temperature may have a negative influence on water quality as an indirect impact.

The PCA analysis revealed that after 2015 (after actions of implementation of conservation practices) there was decreased input of nutrients and solids, and maintenance of oxygen dissolved in water. However, still there was variability in turbidity (suspended solids) at some times of the year. There are similarities between the PCA (and cluster) results and the correlation analysis, which corroborates the relation between phosphorus and the presence of algae (Chlorophyll A), and pathogens (*E. coli*, *Cryptosporidium*, and *Giardia*), and to turbidity, in addition to the relation between temperature and pH and total nitrogen and total solids. In summary, the water quality deterioration, when it occurs, it does so in a synergetic way. Thus, predicting actions for the control of erosive process, management and conservation of the soil allows for maintaining water quality and even improving some parameters (COD and solids).

We highlight the importance of improving the system of monitoring of data about water quality, with systematic and uniform sampling of parameters, especially those used for calculating WQI. The periodic disclosure of WQI is a simple and effective way of informing society about the quality of the water and guiding decision-makers on the effectiveness of the policies implemented in the basin. Yet, the index did not show this sensitivity to the perception of improvements. The use of data about the changes and improvements in the water quality and quantity through the payment for environmental services is of utmost relevance in assessing economic and socioenvironmental impacts of programs of this type and for keeping society permanently informed about the quality of the water that it is consuming.

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Frederico Luiz de Freitas Júnior: Worked on the methodology, formal analysis, data curation, visualization, writing - original draft paper and writing – review and editing.

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Cristovão Vicente Scapulatempo Fernandes: Worked on the methodology, formal analysis, visualization and writing – review and editing.

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Reginaldo Brito da Costa: Worked on the formal analysis, visualization and writing – review and editing.

Fernando Jorge Correa Magalhães Filho: Was responsible for the conceptualization, supervision, project administration, and funding acquisition, writing - original draft paper and writing – review and editing.

SUPPLEMENTARY MATERIAL

Supplementary material accompanies this paper.

Figure S1. Location of the Guariroba water supply watershed (APA Guariroba) and properties with (or no) implemented techniques.

Table S1. Hydrobiological parameters and other chemicals. Absen: Absence.

Table S2. Cluster analysis by k-means clustering.

Figure S2. Characterization of the study area: rainfall and flow rate (2010 – 2019).

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