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WATER QUALITY ASSESSMENT IN RELATION TO THE SURROUNDING SOIL MANAGEMENT OF TWO RESERVOIRS IN PINDORAMA/SP - A PRELIMINARY STUDY

AVALIAÇÃO DA QUALIDADE DA ÁGUA EM RELAÇÃO AO MANEJO DO SOLO NO ENTORNO DE DOIS RESERVATÓRIOS EM PINDORAMA/SP - UM ESTUDO PRELIMINAR

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ABSTRACT

Soil management techniques applied by industrial farming have a profound impact on neighboring bodies of water, posing a threat to their aquatic biota. Therefore, water quality monitoring is essential to pinpoint areas of risk and propose remediation strategies. This preliminary study combined analysis of water quality physicochemical parameters and a trophic state index based on phosphorus concentration to characterize and compare two reservoirs in Pindorama/SP located in areas of distinct agricultural land management. Analyses showed that both reservoirs had total phosphorus concentrations above the federal threshold. It was then hypothesized that the excess of this nutrient was caused by the runoff of agricultural products from the surrounding area as no point sources of pollution were found. The first reservoir had a high density of floating macrophytes, which virtually covered the water surface, and was characterized as in a eutrophic state. The second reservoir, with lower macrophyte density and lower phosphorus levels, was characterized as in a mesotrophic state. These results evidenced that the overpopulation of macrophytes in the first reservoir may be a consequence of the eutrophication process. Furthermore, the presence of a more consolidated riparian forest which decreases the impacts of runoff in the second reservoir may explain its lower phosphorus levels. Finally, despite low turbidity, oxidation-reduction potential values in both reservoirs indicated low oxygen intake. The results demonstrate that these ecosystems are at risk of deterioration, thus strategies to improve the surrounding soil management and increase water circulation must be implemented.

KEYWORDS: Water resources management. Soil management. Diffuse pollution. Macrophytes.

RESUMO

As técnicas de manejo de solo aplicadas pela agricultura industrial têm um impacto significativo nos corpos d'água vizinhos, colocando a sua biota aquática em risco. Portanto, o monitoramento da qualidade da água é essencial para identificar áreas de risco e propor estratégias de remediação. Este estudo preliminar combinou análises de parâmetros físico-químicos da qualidade da água e um índice de estado trófico baseado na concentração de fósforo para caracterizar e comparar dois reservatórios de Pindorama/SP localizados em áreas de manejo agrícola distintas. Análises de fósforo total em ambos os reservatórios detectaram concentrações acima do limite federal, levantando-se a hipótese de que o excesso desse nutriente tenha sido causado pelo escoamento de produtos agrícolas do entorno já que não foram encontradas fontes pontuais de poluição. O primeiro reservatório apresentava alta densidade de macrófitas flutuantes, praticamente cobrindo sua superfície, e foi caracterizado como em estado eutrófico. O segundo reservatório, com menor densidade de macrófitas e menores níveis de fósforo, foi caracterizado como em estado mesotrófico. Esses dados evidenciaram que a superpopulação de macrófitas no primeiro reservatório pode ser uma consequência do processo de eutrofização. Além disso, a presença de uma mata ciliar mais consolidada que diminui os impactos de escoamentos no segundo reservatório pode explicar seus menores níveis de fósforo. Por fim, apesar da água apresentar baixa turbidez em ambos os reservatórios, os valores de potencial de oxidação/redução indicaram baixa entrada de oxigênio. Os resultados demonstram que estes ecossistemas estão em risco de deterioração, portanto devem ser implementadas estratégias para melhorar o manejo do solo no entorno e aumentar a circulação da água dos reservatórios.

PALAVRAS-CHAVE: Manejo de recursos hídricos. Manejo do solo. Poluição difusa. Macrófitas.

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INTRODUCTION

Water quality monitoring of surface waters is essential to obtain geological information of the associated ecosystem and detect variations that may lead to ecological imbalances. The use of physicochemical multiparameter probes, along with strategic analysis of eutrophication indicators has been used as an affordable alternative to the characterization of lentic water bodies by providing quantitative data of changes that may affect the biodiversity (MÉNDEZ-BARROSO et al., 2020). Water bodies are fundamental to the ecosystem that embodies it, and the contamination of their water can cause the loss of important ecosystem services provided by this body such as nutrient circulation, water supply, the keeping of the food chain, and the preservation of ecosystem biodiversity (HEINO et al., 2021; BARON et al., 2002).

The diffuse pollution of agricultural activity byproducts is a predominant cause of contamination of reservoirs and rivers in rural areas (SODRÉ, 2012). Considering this, the practice of intensive fertilization, the use of pesticides, and the management of the soil surrounding surface waters, especially those with lentic waters, can have a direct effect on the water quality, and thus, in the aquatic ecosystem (SODRÉ, 2012; TUNDISI; MATSUMURA-TUNDISI, 2011). Water contamination with nutrients related to agriculture practices, if not properly controlled, can lead to the process of anthropic eutrophication, which is characterized by an uncontrolled bloom of algae and cyanobacteria, the decrease of dissolved oxygen in the water, changes in the population of aquatic communities, the decrease of biodiversity and, in the most serious cases, massive death of fish (TUNDISI; MATSUMURA-TUNDISI, 2020). As phosphorus is usually a limiting nutrient in surface waters, its concentration can be used as an indicator of eutrophication according to the index defined by Lamparelli (2004). Eutrophic ecosystems can also present a bloom of aquatic macrophytes, high organic matter concentrations, increased toxicity, and the liberation of greenhouse and toxic gases (TUNDISI; MATSUMURA-TUNDISI, 2011). The monitoring of the occurrence of the aforementioned effects is also essential to detect the possibility of the eutrophication process when characterizing aquatic systems.

In addition to diffuse pollution, activities that pose a threat to the ecological balance of rural watersheds include deforestation, soil exposure, laminar and linear erosive processes, siltation, and the introduction of exotic species. According to Tundisi and Matsumura-Tundisi (2010), the removal of riparian forests and wetlands, especially when vegetation diversity is reduced, accelerates sedimentation and degrades the quality of superficial and ground waters, negatively impacting all ecosystem services. The removal of these forests along with the effects of urbanization and livestock production is one of the main causes of the recurrence of anthropogenic eutrophication (ÁLVAREZ et al., 2017). Considering that, the monitoring of watersheds becomes more valuable for statistical and limnological analysis when it integrates physicochemical, microbiological and biological (aquatic communities) variables, making possible the creation of more complete databases. Restoration initiatives for water bodies, especially well-monitored small reservoirs, must integrate the study of internal factors associated with the exosystemic dynamics (thermal stratification) as well as external factors (erosive processes, diffuse and point source pollution) for a complete analysis of the water quality of these ecosystems (LOPES et al., 2021).

This paper describes a preliminary study that uses a multiparameter probe and total phosphorus analysis to characterize two reservoirs located inside the Polo Regional Centro Norte of the Agência Paulista de Tecnologia dos Agronegócios (APTA), in Pindorama/SP. The study had the objective of evaluating the presence of the eutrophication process, identifying variables affecting the systems, and comparing the water quality in relation to the management of the soil surrounding these water bodies.

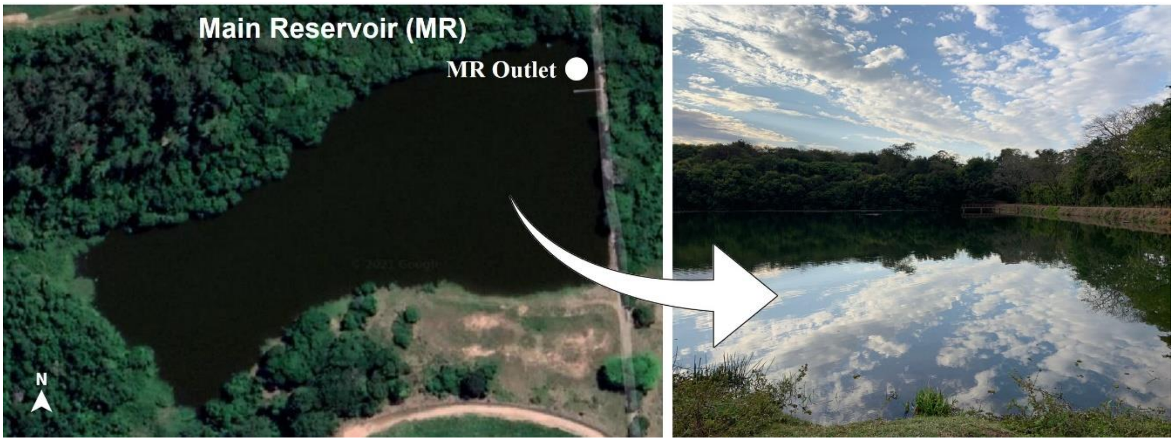
METHODOLOGY

Study Area Characterization

The two reservoirs studied in this paper belong to the Olaria Stream Watershed, located in the state of São Paulo, Brazil. The area is inside the regional research center of the Agência Paulista de Tecnologia dos Agronegócios (APTA) located in Pindorama/SP. The climate is defined as subtropical dry winter (Cwa) (ALVARES et al., 2013) and the predominant natural land cover is the seasonal semi-deciduous forest. The area has an average annual precipitation of 1340 mm, with temperatures varying near 18 °C in the coldest months (June-July) and usually above 22 °C in the hottest months (December-January) (LOPES et al., 2021).

The reservoir denominated as Main Reservoir (MR) was installed in the 1970s, being mainly used for conventional sprinkler irrigation on agricultural crops (Figure 1). Main Reservoir sub-basin covers an area of approximately 211 ha and the reservoir has a volume of 595726 cubic meters, an area of 37950 square meters, and a retention time of 123 days (LOPES et al., 2021). Its vegetation was anthropically changed over the years, and currently, the MR sub-basin has a natural riparian forest and is occupied by annual crops (corn, oats, beans, wheat, among others), perennial crops (peach, pupunha, among others), and sugar cane plantations.

Figure 1: Main Reservoir (MR).
***Figura 1:** Reservatório principal (MR).*



Source: satellite picture (Google Maps) and June 2021 photography.

The reservoir denominated Voçoroca Reservoir (VR) is a set of four interconnected reservoirs built to contain a gully using conservationist practices in 1998 and being in the state of natural regeneration ever since. The VR sub-basin covers an area of 70.5 ha and each reservoir has a volume of approximately 61250 cubic meters, an area of 2625 square meters and an average retention time of 60 days (LOPES et al., 2021). In 2011, riparian vegetation was planted along the drainage network surrounding the reservoir to work as a permanent preservation area. Besides this vegetation, there are pastures, sugar cane plantations, and annual soybean planting in the surroundings. Figure 2 provides a general view of the plantations surrounding both reservoirs.

Figure 2: General view of the areas of agricultural crops of sugarcane (left), peanuts (middle) and corn (right) installed nearby MR and VR.
Figura 2: *Visão geral das áreas de cultivo agrícola de cana-de-açúcar (esquerda), amendoim (meio) e milho (direita) instaladas nas proximidades de MR e VR.*

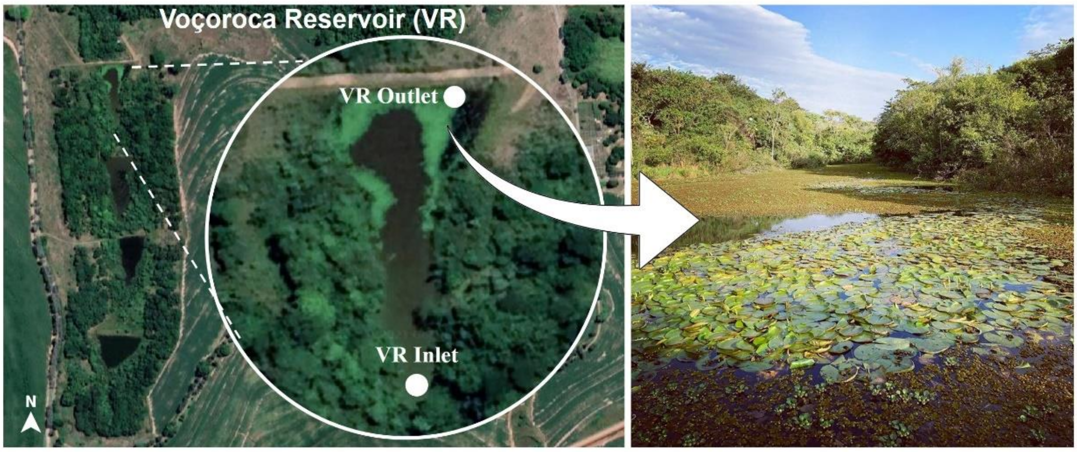
Source: June 2021 photographs.

Both reservoirs are fed by perennial springs located in forest fragments, and the soil in the reservoirs' area is classified as eutrophic argisol. The slope in the reservoirs' area varies from 2% at the elevation tops and floodplains, to 10% – 20% near the watercourses. There are not any point sources of pollution in any of the reservoirs. Floating aquatic macrophytes have taken the surface of the water in the last two reservoirs of VR since March 2021, which may indicate diffuse sources of pollution and a process of eutrophication. The dominant species of macrophytes in VR are *Salvinia* sp., *Eichhornia crassipes, Nymphaea* sp., and *Paspalum repens* (Figure 3).

Analysis of Chemical and Physical Parameters

In order to make a preliminary characterization of the water quality in both reservoirs, strategic sampling points were defined based on accessibility and the possibility of continuous monitoring in the future. At the MR, a sampling point was defined near the outlet of water (MR Outlet in Figure 1). At the VR, two sampling points were defined in the inlet and outlet water (VR Inlet and VR Outlet in Figure 3) points of the last reservoir, which is connected to the previous ones by concrete channels. The additional sampling point in VR was defined due to the amount of macrophytes in the water, which may absorb the nutrients and interfere in the results. Samples were collected on June 08, 2021, at the sampling points. Samples were taken with three repetitions for the calculation of standard deviations.

Figure 3: Voçoroca Reservoir (VR).
***Figura 3:** Reservatório da Voçoroca (VR).*



Source: satellite picture (Google Maps) and June 2021 photography.

Sample preparation for total phosphorus analysis was performed following EPA 3010A (1992) and the determination of this parameter followed SMWW, Method 3120B (23rd Edition, 2017). These results were used to calculate and classify the Trophic State Index (TSI) through the equation defined by LAMPARELLI (2004) for reservoirs. The pH, temperature, Oxidation-Reduction Potential (ORP), Electrical Conductivity (EC), Turbidity, and Total Dissolved Solids (TDS) parameters were also determined at the outlet sampling points using a multiparametric probe HORIBA U-50, model W23-XD. Sample collection and measurements with the probe were made ~ 0.15 m below the water surface for all points.

Water quality assessment in the reservoirs was based on the limits defined by CONAMA Resolution No. 357/2005 for lentic freshwater Class 2. The summary of quality standards recommended by this federal resolution are presented in Table 1.

Table 1: Summary of water quality standards defined by CONAMA 357/2005 regulation for Lentic freshwaters of Class 2.
***Table 1:** Resumo dos padrões de qualidade da água definidos pelo regulamento CONAMA 357/2005 para águas doces Lenticas da Classe 2.*

Parameters	CONAMA 357
Temperature (°C)	*
pH	6,0 to 9,0
Electrical Conductivity (EC)	*
Total Dissolved Solids (TDS)	≤ 500 mg/L
Dissolved Oxygen (DO)	≥ 5 mg/L
Turbidity (Tb)	≤ 100 NTU
Total Phosphorus (P)	≤ 0,03 mg/L

*No limits defined for this parameter. **Source:** CONAMA 357/2005.

RESULTS AND DISCUSSION

Table 2 summarizes the results of the physicochemical parameters analyzed at the sampling points in the reservoirs.

Table 2: Physicochemical parameters analyzed in sampling points at VR and MR.
Table 2: *Parâmetros físico-químicos analisados nos pontos de amostragem em VR e MR.*

	VR Inlet	VR Outlet	MR Outlet
Total Phosphorus (mg/L)	2,152	0,072	0,046
Temperature (°C)	-	19,7625 ± 0,0457	25,085 ± 0,2333
pH	-	7,460 ± 0,737	7,605 ± 0,148
ORP (mV)	-	107,75 ± 20,886	137,5 ± 3,535
EC (mS/cm)	-	0,13275 ± 0,001	0,192 ± 0,001
Turbidity (NTU)	-	1,15 ± 0,173	3,60 ± 0,141
TDS (g/L)	-	0,0865 ± 0,0010	0,1245 ± 0,0007

EC – Electric Conductivity; TDS – Total Dissolved Solids; ORP – Oxidation-Reduction Potential;
VR – Voçoroca Reservoir; MR – Main Reservoir.

It can be inferred from Table 2 that both reservoirs present similar values for physicochemical parameters, except for EC, TDS, and total phosphorus. The concentration of total phosphorus in both reservoirs was above the threshold defined by CONAMA Resolution No. 357/2005 for lentic freshwater Class 2. The results indicate that VR had a greater concentration of this nutrient than MR. According to the TSI defined by LAMPARELLI (2004), MR is in a mesotrophic state and VR is in a eutrophic state. Considering that VR had its surface filled with floating macrophytes and MR did not, these results evidence that the occurrence of the overpopulation of macrophytes in VR was a consequence of the greater phosphorus concentration and thus of the eutrophication process occurring in this reservoir. Voçoroca Reservoir (VR) is characterized as hypereutrophic in the inlet and eutrophic in the outlet, which demonstrates a decrease of 96,65 % of the phosphorus concentration between these sampling points, evidencing the role of macrophytes in the absorption of excess nutrients across the reservoir (POMPÊO, 2017).

Considering the non-existence of point sources of pollution and the numerous agricultural activities surrounding both reservoirs, it is hypothesized that the runoff and lixiviation of agricultural byproducts were the cause of the increased levels of phosphorus (SODRÉ, 2012). The results also indicate that this pollution affects more VR than MR. Such a fact may occur due to the greater area of sugar cane plantations closer to VR than to MR. These crops may lack proper practices for soil management and thus become a source of diffuse pollution. Main Reservoir (MR) also has a larger area of riparian forest in the surroundings and is about 25 years older than VR. Therefore, the riparian forest had more time to consolidate and expand, which could have contributed to decreasing the runoff of agricultural byproducts, thus decreasing the impact of diffuse pollution on the water quality (MILLER et al., 2014; PISSARRA et al., 2019). It is also important to note that MR has a water volume almost 3 times greater than VR, so a greater amount of phosphorus is needed to increase its concentration in these reservoirs. On the other hand, MR presents greater EC and TDS than VR. Such a fact may indicate that MR is affected by types of pollution other than phosphorus.

Main Reservoir (MR) is fed by 3 tributaries that have their sources near high-intensity sugarcane plantations and then flow into areas of natural forest and wetlands before reaching the reservoir. In this context, the wetlands would be able to decrease phosphorus concentrations in the incoming water to the reservoir but may not be able to decrease the concentration of some organic and inorganic contaminants that were lixiviated into the tributaries. In comparison, VR doesn't have tributaries in the same condition. This fact might explain the lower total phosphorus levels, but higher EC and TDS levels in MR (HAIDARY et al., 2013). Furthermore, the retention time of MR is about double the ones of each reservoir in VR, so MR is more likely to accumulate contaminants, offering another explanation for the difference in conductivity values.

The pH of both reservoirs was in the neutral range but leaning towards alkaline waters, which might be an indication of relatively low microbial activity. The sampling temperature in MR was greater than in VR. This was likely because VR samples were collected around 11 am, and MR samples were collected around 3 pm on the same day, a time when ambient temperatures are generally higher in the study area. All parameters except total phosphorus are within the limits established by CONAMA Resolution No. 357/2005 for lentic freshwater Class 2.

Both reservoirs presented low turbidity values, indicating waters that can have a high penetration of solar radiation, favoring autotrophic organisms. However, ORP values for both reservoirs were also low, indicating a reducing environment. ORP is a measurement of electrons availability in the water, with high positive ORP values indicating the presence of strong electron acceptors (oxidizing agents). Dissolved oxygen is strongly related to ORP as oxygen is a strong oxidizing agent. Therefore, low ORP values in VR and MR indicate that both environments may have low oxygen intake despite their low turbidities. In VR, the overgrowth of floating macrophytes is blocking the entrance of sunlight, which explains low oxygen intake due to reduced photosynthesis. MR, however, has a surface free of floating macrophytes, thus other factors might be the cause of low ORP. Floating macrophytes, unlike submerged macrophytes, have low oxygen exchange with the water; therefore, photosynthesis in these plants will not greatly affect dissolved oxygen (ATTERMEYER et al., 2016). Moreover, as turbidity levels in both reservoirs were low, it is unlikely that sediments affected the measurements made by the probe. Further investigation is necessary to identify what factors are contributing to making the reservoirs reducing environments as high concentrations of electron donors such as easily decomposable soil organic matter can also be the cause of the detected low ORP levels (INUBUSHI, 2018).

The results gathered in this study evidence the need for proper soil management in the crops surrounding VR and MR so that the environmental impact caused by agricultural activities can be reduced (SIMEDO et al., 2020; VALERA et al., 2017). Intensive practices could be taken in order to minimize the inlet of sediments and residues into the reservoirs. These include mechanical practices such as uneven terracing with adequate spacing between terraces, and cultural practices such as the implementation of no-till farming systems as these systems ensure greater soil porosity and, consequently, reduction of particle entrainment.

Considering the current state of both reservoirs studied, complementary actions could be taken to increase the water quality of these environments. First, natural protection systems could be increased through densification or increase in the extension of the riparian forest. Second, excess aquatic plants in VR could be physically removed, with an adequate destination. Finally, mechanisms that favor the circulation of water in the reservoirs, especially in the driest periods, and that reduce contamination could be structured. Examples of such mechanisms include the usage of sustainable aerators, the structuring of an intensive water quality monitoring plan, and the implementation of sustainable nutrient retention systems in the concrete channels of VR and in the tributaries of MR.

Future in-depth studies with higher quantities of samples and parameters analyzed are necessary to confirm the hypothesis presented in this study and evaluate the effect of other variables on the behavior of the water systems.

CONCLUSION

Analyses of physicochemical parameters were carried out in the reservoirs named Main Reservoir (MR) and Voçoroca Reservoir (VR) to characterize the trophic level of the systems and compare the water quality in relation to the management of the soil surrounding them. The results showed a concentration of total phosphorus above the federal threshold in both reservoirs, VR having higher levels than MR. Considering the non-existence of point sources of pollution and the numerous agricultural activities surrounding both reservoirs, it was hypothesized that the cause of the increased levels of phosphorus is the lixiviation and runoff of agricultural products. The results indicated a hypereutrophic state in the inlet of VR and a eutrophic state in the outlet of VR, while MR was characterized as in a mesotrophic state. These results evidence that the occurrence of the overgrowth of macrophytes in VR is a consequence of an advanced eutrophication process happening in this reservoir. Lower levels of phosphorus in MR may be explained by its morphological characteristics and the presence of a more consolidated riparian forest. Main Reservoir is fed by tributaries in areas of high agricultural activity and has a higher retention time than VR. Diffuse pollution in these tributaries may be the reason for the higher detected values for dissolved solids and electrical conductivity in MR compared to VR. Low ORP levels in both reservoirs might indicate low oxygen intake and the presence of easily decomposable soil organic matter.

In order to reduce the environmental impacts of the contamination in both reservoirs, complementary action could be taken to improve the water quality. Practices could be implemented focusing on developing better soil management practices in the surrounding plantations, increasing the water circulation in the systems, and containing the runoff/lixiviation of nutrients in the system through sustainable methods. Continued monitoring in these reservoirs along with future in-depth studies are necessary to confirm the hypothesis discussed in this study.

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