Toward resilient fish farming: water quality monitoring and environmental risk mapping in the Graminha reservoir.

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Abstract

The quality of water affects its various applications and can facilitate or prevent specific functions. In this context, fluctuations in water quality can adversely impact the productivity of fish farming operations. The objective of this study is to evaluate the characteristics of the Graminha reservoir, which is located in Caconde, São Paulo. To elucidate the dynamics of the reservoir, a meticulous sampling protocol was implemented, encompassing 14 sites from October 2024 to March 2025, complemented by samples from three additional fish farms. The study identified specific locations as being more susceptible to variations in water quality. Furthermore, certain parameters were found to be more prone to fluctuations, thus serving as reliable indicators of the reservoir's water quality. The parameters that demonstrated the most significant variation included temperature, turbidity, conductivity, pH, N-nitrite, and dissolved oxygen.

Keywords: Water quality, fish farm, environmental monitoring.

1. Introduction

The rapid expansion of cage-based fish farming in Brazil has raised concerns about the sustainability of aquatic ecosystems, particularly in reservoirs increasingly used for tilapia production. The Graminha Reservoir (Caconde, São Paulo) exemplifies this

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situation, wherein aquaculture activities coexist with significant environmental pressures, including land use changes, untreated domestic effluents, and natural vulnerabilities such as steep slopes and erosion-prone soils, especially in the watershed areas feeding the reservoir (Silva et al., 2025).

Monitoring tools are essential for tracking the reservoir's susceptibility status, and geotechnologies combined with spatial analysis play a crucial role in deepening the understanding of these processes, particularly in the reservoir's tributary watersheds. Consequently, this study was conducted to analyze the water quality in the reservoir. The objective of this study was to enhance the comprehension of land use dynamics and their influence on water-dependent activities, particularly fish farming.

2. Methods

The study was conducted in the watershed of the Graminha Reservoir, which is located between latitudes 21°33'49.83"S and 22°9'43.75"S and longitudes 46°41'27"W and 46°3'28.09"W, covering a total area of 258.96 km². The basin encompasses six municipalities in the state of Minas Gerais, with a combined population of 216,325 inhabitants (IBGE, 2024).

The initial phase of the study concentrated on identifying the key parameters to be evaluated, employing data from Info Águas (Cetesb, 2025) as a reference. The assessment encompassed a comprehensive array of water quality parameters, including dissolved oxygen, turbidity, pH, conductivity, and N-nitrite. The essential variables for fish farming, including temperature, alkalinity, hardness, and transparency, were also considered and analyzed (Lima et al., 2024).

The selection of sampling sites was conducted using the Copernicus browser and APA Script, through a temporal analysis dating back to 2016, identifying the locations most affected by algae blooms and where they were most persistent (Planet Labs, 2019). In addition to these sites, three fish farming locations were selected for monitoring purposes, with the objective of assessing the impact of aquaculture activities on the reservoir. It is imperative to acknowledge the limitation in the scope of the data available for Fish Farm 3, which is characterized by its incompleteness. This is attributable to the cessation of production during the months of October, November, and December, a decision precipitated by the occurrence of unprecedentedly low water levels at the site.

In situ measurements and water sampling for subsequent laboratory analysis were also conducted. The measurement of temperature, dissolved oxygen (DO), conductivity, and pH was conducted using a YSI ProQuatro probe. The assessment of turbidity was conducted by employing a Hach 2100Q turbidimeter. Alkalinity and hardness were determined using the titrimetric method, and N-nitrite was analyzed using the colorimetric method and a Hach DR 3900 spectrophotometer. All analyses were performed in accordance with the standards outlined by the American Public Health Association (Lipps et al., 2023) in 2023.

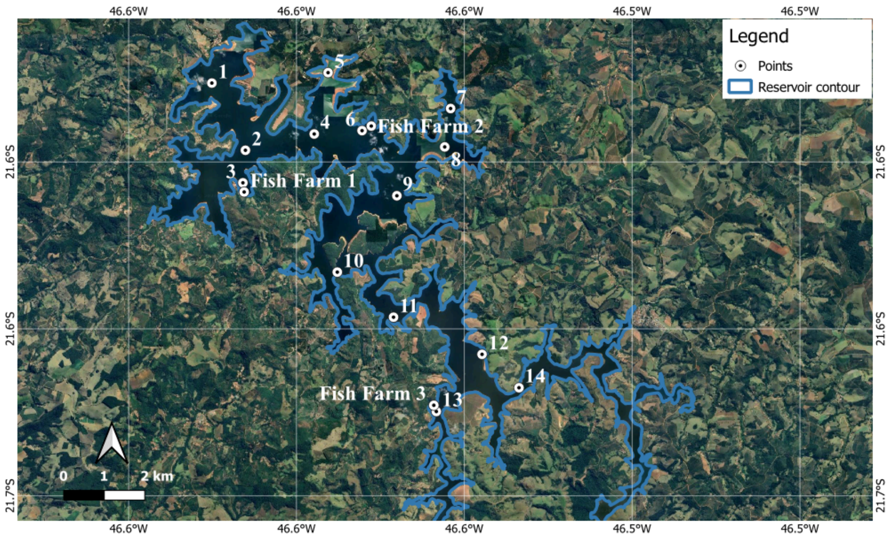

Figure 1. Map of the study area.

3. Results and discussion

The mean and standard deviation of temperature, dissolved oxygen, conductivity, pH, turbidity, alkalinity, hardness, N-nitrite, and transparency at the studied sites are presented in Table 1.

Table 1. Table with the average values and standard deviation of the collection points during the period.

Site	Temperature (ºC)	DO (mg/L)	Conductivity (µS/cm)	pH	Turbidity (NTU)	Alkalinity (mg/L)	Hardness (mg/L)	Nitrite (mg/L)	Transparency (cm)
1	27,98 (±1,18)	6,60 (±0,32)	61,55 (±3,25)	8,58 (±0,66)	4,51 (±1,86)	18,65 (±1,97)	16,37 (±2,48)	0,02 (±0,01)	172 (±80,76)
2	28,00 (±0,92)	6,77 (±0,70)	62,52 (±4,20)	8,7 1 (±0,76)	4,54 (±2,13)	19,78 (±2,17)	17,03 (±2,09)	0,02 (±0,01)	169 (±81,96)
3	27,83 (±1,20)	6,60 (±0,79)	62,07 (±3,60)	8,45 (±0,9)	4,76 (±2,29)	18,65 (±2,15)	16,34 (±1,22)	0,02 (±0,01)	154 (±96,05)
4	27,73 (±0,76)	6,80 (±0,54)	62,08 (±4,75)	8,63 (±0,69)	4,87 (±2,32)	18,49 (±2,62)	16,00 (±1,80)	0,03 (±0,01)	148 (±80,49)
5	27,93 (±0,91)	6,54 (±0,70)	63,17 (±5,99)	8,5 8 (±0,78)	5,21 (±2,88)	19,46 (±3,45)	16,18 (±1,04)	0,02 (±0,01)	151 (±84,51)
6	28,06 (±0,74)	6,95 (±0,70)	61,34 (±5,09)	8,81 (±0,61)	4,83 (±2,54)	18,06 (±0,53)	16,08 (±0,92)	0,02 (±0,01)	176 (±147,08)
7	28,48 (±0,52)	6,76 (±0,87)	61,36 (±5,19)	8,56 (±0,91)	3,77 (±2,06)	17,09 (±1,30)	16,47 (±1,59)	0,02 (±0,01)	184 (±135,94)
8	27,67 (±1,08)	6,61 (±1,09)	64,67 (±9,31)	8,47 (±0,93)	7,12 (±7,29)	20,59 (±4,22)	16,50 (±1,27)	0,04 (±0,06)	146 (±111,12)
9	27,75 (±1,23)	6,96 (±1,05)	64,90 (±8,51)	8,74 (±0,99)	6,69 (±5,46)	18,16 (±3,66)	16,14 (±1,93)	0,04 (±0,05)	138 (±81,69)
10	27,85 (±1,54)	7,17 (±1,40)	63,22 (±6,00)	8,58 (±1,10)	16,99 (±29,13)	18,00 (±1,54)	16,10 (±2,27)	0,06 (±0,06)	133 (±107,75)
11	27,28 (±2,27)	7,10 (±1,26)	59,80 (±4,93)	8,61 (±1,10)	19,22 (±31,45)	16,21 (±0,81)	16,59 (±2,43)	0,06 (±0,06)	136 (±113,13)
12	26,27 (±2,04)	6,32 (±0,91)	61,95 (±12,22)	7,86 (±1,16)	22,09 (±38,79)	16,37 (±1,77)	16,07 (±3,10)	0,08 (±0,08)	107 (±76,69)
13	26,52 (±2,13)	6,49 (±0,90)	68,32 (±21,67)	7,99 (±1,08)	60,76 (±132,41)	16,86 (±1,17)	17,74 (±4,51)	0,15 (±0,21)	90 (±67,31)
14	26,35 (±2,11)	6,18 (±1,14)	62,73 (±26,28)	7,90 (±0,84)	16,72 (±21,66)	19,14 (±6,03)	17,76 (±3,96)	0,14 (±0,28)	114 (±42,21)
Fish farm 1	28,23 (±1,34)	5,44 (±1,42)	61,88 (±3,54)	7,88 (±0,77)	5,28 (±2,49)	18,70 (±2,16)	16,54 (±1,20)	0,03 (±0,01)	157 (±97,92)
Fish farm 2	27,69 (±1,06)	5,16 (±1,20)	62,69 (±5,64)	7,77 (±0,86)	5,26 (±2,39)	18,92 (±2,89)	16,76 (±1,64)	0,03 (±0,02)	151 (±73,29)
Fish farm 3	26,98 (±1,38)	6,08 (±0,37)	61,37 (±9,36)	7,78 (±0,68)	7,93 (±3,56)	18,33 (±5,32)	16,52 (±2,69)	0,07 (±0,06)	111 (±56,45)

According to Table 1, sites 10, 11, 12, 13, and 14 exhibited the greatest standard deviations. It may be attributed to the proximity to diffuse and point-source pollution sites. However, beyond these sites, the reservoir's natural self-purification processes allow the water to recover. This results in more stable and improved water quality, which is favorable for tilapia farming. One contributing factor is the reservoir's retention time, which, on average, is 84 days historically (Agência Nacional de Águas, 2025).

Preliminary results indicate that the variables showing the greatest temporal variations across sites were turbidity, dissolved oxygen, N-nitrite, conductivity, and pH. These variables are interdependent and collectively influence water quality dynamics. One of the most prominent factors affecting water quality is reservoir volume, which may be observed in turbidity, dissolved oxygen and pH fluctuations, as a result of photosynthetic organisms blooming. This fact highlights the need for potential interventions, such as improved implementation and monitoring of best management practices, bioremediation measures, or even relocating the cages. Besides that, overall water quality parameters show that the reservoir is suitable for fish farming (Brasil, 2005).

The subsequent phases of the study entail the continuation of the analysis until the completion of the full 1-year monitoring cycle, the execution of remote sensing analysis of chlorophyll-a, and the comparison of this analysis with in situ results. Furthermore, the implementation of multivariate statistical analyses, including principal component analysis and clustering, is necessary for the purpose of comparing the dry and rainy seasons. Additionally, geostatistical analysis employing inverse distance weighting (IDW) will be conducted, and an assessment of the reservoir's carrying capacity will be made. Furthermore, the initiative will entail training sessions with local producers, spatiotemporal mapping of cage-based fish farming structures and earthen ponds within the surrounding sub-watersheds, and the mapping of aquaculture exclusion zones using geotechnologies.

4. Conclusion

The findings of this study demonstrated that sites characterized by more stable water quality were associated with enhanced safety conditions. The application of continuous monitoring and digital technologies (e.g., remote sensing, real-time data) is essential for maintaining both productivity and environmental integrity. Empowering water users and implementing evidence-based policies that balance environmental, social, and economic aspects are key to the long-term sustainability of aquatic resources.

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