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ASSESSMENT OF WATER QUALITY AND ENVIRONMENTAL SANITATION IN THE CONTEXT OF SDG 6: A STUDY OF AN URBAN STREAM IN CAÇADOR (SC), BRAZIL

AVALIAÇÃO DA QUALIDADE DA ÁGUA E DO SANEAMENTO AMBIENTAL NO CONTEXTO DO ODS 6: UM ESTUDO DE UM CÓRREGO URBANO EM CAÇADOR (SC), BRASIL

EVALUACIÓN DE LA CALIDAD DEL AGUA Y DEL SANEAMIENTO AMBIENTAL EN EL CONTEXTO DEL ODS 6: UN ESTUDIO DE UN ARROYO URBANO EN CAÇADOR (SC), BRASIL

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ABSTRACT
Water quality in urban environments constitutes one of the major challenges for environmental management due to intensified anthropogenic pressures associated with population growth, unplanned urban expansion, and insufficient basic sanitation. In this context, the present study aimed at assessing the water quality of a waterbody in the municipality of Caçador, Santa Catarina (Brazil), through the analysis of physicochemical and microbiological parameters, as well as the National Sanitation Foundation Water Quality Index (NSF-WQI). Sampling was conducted at six points distributed along the stream. In the laboratory, total solids, thermotolerant coliforms, biochemical oxygen demand, total phosphorus, nitrate, and turbidity were determined. Data were subjected to ANOVA, Duncan's test (5%), and Principal Component Analysis (PCA). The results revealed a progressive degradation gradient from upstream to downstream, with a significant increase in BOD, nutrients, turbidity, and thermotolerant coliforms, accompanied by a reduction in dissolved oxygen. The WQI ranged from "good" in the headwater region to "poor" in the more urbanized areas, demonstrating the strong influence of domestic effluent discharge and surface runoff. The correlation matrix and PCA confirmed the interdependence among

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indicators of organic pollution and eutrophication, indicating the low self-purification capacity of the stream. Overall, the findings show that the Cemitério Stream is highly vulnerable to anthropogenic pressures, requiring priority actions related to sanitation improvements, pollutant load control, and restoration of riparian vegetation. The study provides relevant insights for local water-resource management and contributes to advancing progress toward SDG 6.

Keywords: Water Quality. Water Resource. NSF-WQI.

RESUMO
A qualidade da água em ambientes urbanos constitui um dos principais desafios para a gestão ambiental, devido à intensificação das pressões antrópicas associadas ao crescimento populacional, à expansão desordenada e à insuficiência de saneamento básico. Nesse contexto, o presente estudo teve como objetivo analisar a qualidade da água de um recurso hídrico do município de Caçador (SC), por meio da avaliação de parâmetros físico-químicos, microbiológicos e do Índice de Qualidade da Água (IQA_{NFS}). As coletas foram realizadas em seis pontos distribuídos ao longo do curso hídrico. No laboratório, determinaram-se sólidos totais, coliformes termotolerantes, demanda bioquímica de oxigênio, fósforo total, nitrato e turbidez. Os dados foram submetidos à ANOVA, teste de Duncan (5%) e Análise de Componentes Principais (PCA). Os resultados revelaram um gradiente crescente de degradação no sentido montante–jusante, com aumento significativo de DBO, nutrientes, turbidez e coliformes termotolerantes, associado à redução do oxigênio dissolvido. O IQA variou de “bom” nas cabeceiras para “péssimo” nas áreas urbanizadas, evidenciando forte influência do lançamento de efluentes domésticos e do escoamento superficial. A matriz de correlação e a PCA confirmaram a interdependência entre os indicadores de poluição orgânica e eutrofização, indicando baixa capacidade de autodepuração do córrego. Sendo assim, conclui-se que o Córrego Cemitério apresenta elevada vulnerabilidade às pressões antrópicas, demandando ações prioritárias de saneamento, controle de cargas poluidoras e restauração da vegetação ciliar. O estudo fornece subsídios relevantes para a gestão hídrica local e para o cumprimento dos ODS 6.

Palavras-chave: Qualidade da Água. Recurso Hídrico. IQA_{NFS}.

RESUMEN
La calidad del agua en entornos urbanos constituye uno de los principales desafíos para la gestión ambiental debido a la intensificación de las presiones antrópicas asociadas al crecimiento poblacional, la expansión urbana desordenada y la insuficiencia de saneamiento básico. En este contexto, el presente estudio tuvo como objetivo analizar la calidad del agua de un recurso hídrico del municipio de Caçador (SC), mediante la evaluación de parámetros fisicoquímicos, microbiológicos y del Índice de Calidad del Agua de la National Sanitation Foundation (IQANFS). Los muestreos se realizaron en seis puntos distribuidos a lo largo del curso hídrico. En el laboratorio se determinaron sólidos totales, coliformes termotolerantes, demanda bioquímica de oxígeno, fósforo total, nitrato y turbidez. Los datos fueron sometidos a ANOVA, prueba de Duncan (5%) y Análisis de Componentes Principales (PCA). Los resultados revelaron un gradiente creciente de degradación en el sentido aguas arriba–aguas abajo, con un aumento significativo de la DBO, nutrientes, turbidez y coliformes termotolerantes, asociado a la reducción del oxígeno disuelto. El ICA varió de “bueno” en las cabeceras a “muy malo” en las zonas urbanizadas, evidenciando la fuerte influencia del vertido de efluentes domésticos y de la escorrentía superficial. La matriz de correlación y el PCA confirmaron la interdependencia entre los indicadores de contaminación orgánica y eutrofización, indicando la baja capacidad de autodepuración del arroyo. Por lo tanto, se concluye que el Arroyo Cemitério presenta alta vulnerabilidad a las presiones antrópicas, requiriendo acciones prioritarias de saneamiento, control de cargas contaminantes y

restauración de la vegetación ribereña. El estudio aporta información relevante para la gestión hídrica local y para el cumplimiento del ODS 6.

Palabras clave: Calidad del Agua. Recurso Hídrico. IQANFS.

1 INTRODUCTION

Water is an essential resource for sustaining life and maintaining ecosystem balance, playing a fundamental role in human health, social development, and economic activities (Mata et al., 2024). Preserving water quality is therefore a central concern across various sectors of society that seek to mitigate the negative impacts of human activities on the environment (Abrão et al., 2024; Dias et al., 2024). Among the multiple drivers of environmental degradation, water pollution stands out for compromising water quality - particularly downstream of urban centers - affecting both its availability and distribution processes (Rocha et al., 2025; Almeida et al., 2025; Campos; Pagioro, 2025).

Population growth and urban expansion observed in municipalities across Brazil exert direct pressure on aquatic ecosystems, altering their physicochemical and biological characteristics (Pereira et al., 2021; Baima et al., 2023; Rocha et al., 2023; Campos; Pavelski, 2025). The absence of adequate urban planning and basic sanitation infrastructure encourages the discharge of domestic and industrial effluents into water bodies, intensifying contamination and eutrophication processes (Novicki; Campos, 2016; Gadelha et al., 2022; Santos; Medeiros, 2023; Teixeira; Millan, 2024). In this context, water-resources management based on river basins is considered an essential instrument for territorial planning and environmental control, as it enables an integrated understanding of the interactions between human activities and the natural environment (Silva et al., 2021; Silva et al., 2024; Fanhaimpork; Freitas, 2025).

In urbanized areas, environmental imbalance is intensified by the accumulation of solid waste, soil impermeabilization, and changes in vegetation cover, resulting in modifications to the hydrological regime and water quality. Several studies indicate that increasing occupation of riverbanks, combined with insufficient wastewater treatment systems, has been one of the main causes of the degradation of urban water resources in Brazil (Durigon et al., 2015; Costa et al., 2021; Bezarra; Souza, 2021; Alves et al., 2023; Quaresma et al., 2024; Campos; Reichardt, 2025a; 2025b; 2025c; 2025d).

The Caçador River, located in the municipality of Caçador, Santa Catarina, is an important tributary of the Rio do Peixe and holds significant environmental and socioeconomic relevance for the region (Zago; Paiva, 2008). However, the intensification of agricultural, industrial, and residential activities near its course has resulted in increased pollutant loads (Campos; Kuhn, 2021; Campos; Barcarolli, 2023; Campos; Pavelski, 2025; Campos; Moretto, 2025; Campos, 2025), leading to changes in the physicochemical and biological composition of its waters (Lautert et al., 2019; Campos et al., 2025a; 2025b).

The improper discharge of sanitary and industrial effluents, as well as the input of contaminated stormwater, represents one of the main challenges for maintaining water-resource quality (Campos; Borga; Vazquez, 2017; Wendling et al., 2018; Tilha et al., 2019; Campos; Zir, 2024). Mitigating these impacts requires investments in sanitation infrastructure, the adoption of integrated and sustainable water-management practices, the restoration of degraded areas, and the strengthening of environmental enforcement policies (Campos; Borga; Mello, 2017). Nevertheless, one of the most effective strategies is the continuous monitoring of water quality, which enables the identification of degradation trends, supports decision-making, and promotes preventive and corrective actions (Araújo Junior et al., 2025).

Environmental monitoring therefore aims at assessing water quality and verify its suitability for different uses, as well as to identify critical areas that require targeted interventions (Plein; Leme, 2024; Rocha et al., 2025). Thus, systematic water-quality monitoring becomes an essential tool for the sustainable management of water resources (Sousa et al., 2025). In this sense, the present study aims to analyze the water quality of the Caçador River by determining physicochemical and biological parameters.

2 METHODOLOGY

The study was conducted in a stream located in the municipality of Caçador, in the state of Santa Catarina, Brazil. This stream is a tributary of the Peixe River and forms part of the Peixe River Hydrographic Basin. Sampling activities were carried out in March 2024 during three sampling campaigns, encompassing six points distributed along the watercourse, as shown in Figure 1 and described in Table 1.

Figure 1

Location of the study area, Stream, Caçador, SC, Brazil

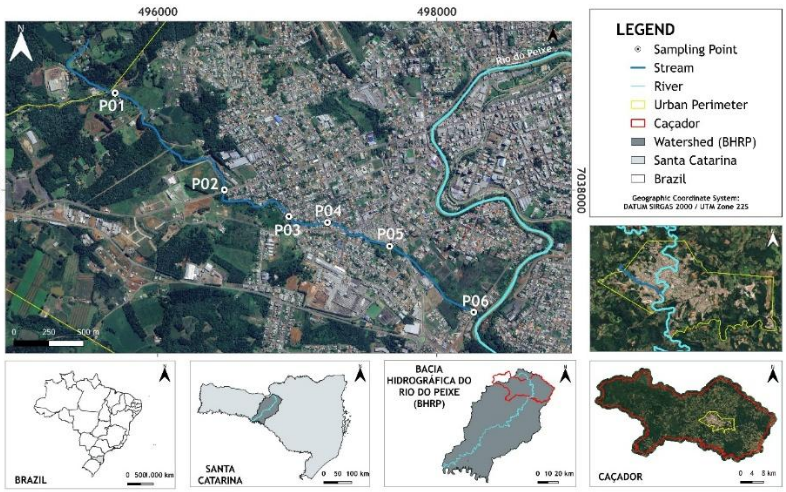

Table 1

Sampling points for water quality analysis

COORDINATES			
Sampling Points	**Longitude (W)**	**Latitude (S)**	**Altitude (m)**
SP 01	26°46'23.08"	51° 2'35.93"	943
SP 02	26°46'45.66"	51° 2'7.55"	926
SP 03	26°46'51.85"	51° 1'50.97"	909
SP 04	26°46'53.26"	51° 1'40.80"	899
SP 05	26°46'58.80"	51° 1'24.66"	894
SP 06	26°47'14.12"	51° 1'2.84"	886

Water samples were collected in 1-liter amber glass bottles during morning hours (between 6:00 and 8:00 a.m.), following the recommendations of NBR 9898 (Brazilian Association of Technical Standards – ABNT, 1987). Three sampling campaigns were conducted between February and April 2024.

In situ analyses included pH, temperature (T), and dissolved oxygen (DO), measured using a multiparameter probe (model AK88, AKSO). Turbidity (TU) was assessed with a digital turbidimeter (model Tu430, Mylabor). In the Chemistry Laboratory of the Alto Vale do Rio do Peixe University (UNIARP), the following parameters were analyzed in triplicate: total solids (TS), thermotolerant coliforms (TTC), total coliforms (TC), total phosphorus (TP), biochemical oxygen demand (BOD), nitrite (NO_2^-), and nitrate (NO_3^-), following the methodologies described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

For environmental monitoring, the Water Quality Index (WQI) proposed by the National Sanitation Foundation (NSF-WQI) was applied, as described by Brown et al. (1970) (Equation 1). This index integrates the parameters DO, BOD, T, TP, NO_3^-, TU, TS, and TC, as presented in Table 2.

$$\mathbf{WQI} = \prod_{i=1}^{n} \mathbf{qi^{wi}}$$

$$\mathbf{WQI} = (q_{BOD}/100)^{W}BOD{*}(q_{OD}/100)^{W}OD{*}q_{N}/100)^{W}N \ldots \quad (1)$$

Where:

WQI: Water Quality Index, a value ranging from 0 to 100;

q_i: quality rating of the i-th parameter, ranging from 0 to 100;

w_i: elative weight assigned to the i-th parameter (ranging from 0 to 1), according to its importance in the overall water quality assessment.

Table 2

Relative weights of the parameters used in the calculation of the NSF-WQI

PARAMETERS	*RELATIVE WEIGHT (wi)*
Dissolved Oxygen (DO_	*0,17*
Thermotolerant Coliforms (TC)	*0,16*
pH	*0,11*
Biochemical Oxygen Demand (BOD)	*0,11*
Total Phosphate (TP)	*0,10*
Temperature (T)	*0,10*
Nitrate (NO_3^-)	*0,10*
Turbidity (TU)	*0,08*
Total Solids (TS)	*0,07*

Source: Brown et al. (1970).

Based on the calculated values, the results were compared with the water-quality classification of the receiving water body that receives industrial effluents, as defined by the NSF-WQI and categorized according to Table 3.

Table 3

Water quality classification according to the NSF-WQI

CATEGORY	WEIGHTING
Excellent	$80 < WQI \leq 100$
Good	$52 < WQI \leq 79$
Fair	$37 < WQI \leq 51$
Poor	$26 < WQI \leq 36$
Very Poor	$0 < WQI \leq 25$

Source: Brown et al. (1970).

The results were compared with the standards established by CONAMA Resolution No. 357/2005 (Brazil, 2005) in order to classify the water body according to its quality status. For each analyzed variable, comparisons between group means were performed using analysis of variance (ANOVA), followed by Duncan’s multiple range test at a 5% significance level. Principal Component Analysis (PCA) was applied to identify the main sources of variation and the relationships among parameters. Axis decomposition and biplot construction were performed using XLSTAT (Addinsoft, 2024).

3 RESULTS AND DISCUSSION

3.1 PHYSICOCHEMICAL AND MICROBIOLOGICAL PARAMETERS

The descriptive results of the physicochemical and microbiological parameters evaluated in the Nhozinho Stream are presented in Table 4, which shows the mean values and respective standard deviations obtained from the six sampling stations during the

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summer and winter periods.

Table 4

Physicochemical and microbiological parameters of the Nhozinho Stream (mean ± standard deviation) by sampling point. Mean values followed by the same uppercase letter in the subscript do not differ significantly from each other according to Duncan's test ($p \leq 0.05$)

PARAMETER	UNIT	SP 01	SP 02	SP 03	SP 04	SP 05	SP 06
pH	-	6.10 ± 0.20 ^{A}	6.53 ± 0.12 ^{B}	6.55 ± 0.20 ^{B}	7.10 ± 0.21 ^{C}	7.70 ± 0.33 ^{D}	7.37 ± 0.03 ^{E}
T	°C	19.10 ± 0.50 ^{A}	19.91 ± 0.40 ^{B}	19.10 ± 0.32 ^{A}	20.00 ± 0.42 ^{B}	19.10 ± 0.47 ^{A}	20.00 ± 0.02 ^{B}
OD	mg/L	7.30 ± 0.22 ^{D}	7.20 ± 0.21 ^{D}	6.50 ± 0.17 ^{C}	6.52 ± 0.10 ^{C}	6.00 ± 0.20 ^{A}	5.41 ± 0.70 ^{B}
ST	mg/L	0.90 ± 0.11 ^{A}	1.10 ± 0.40 ^{A}	2.35 ± 0.59 ^{B}	2.50 ± 0.45 ^{B}	3.80 ± 0.31 ^{C}	3.77 ± 0.49 ^{C}
CT	MPN/100mL	18.00 ± 3.46 ^{A}	805.00 ± 14.00 ^{B}	950.00 ± 42.00 ^{C}	990.00 ± 68.00 ^{C}	1850.00 ± 62.00 ^{D}	1912.00 ± 0.00 ^{E}
CTT	MPN/100mL	60.00 ± 8.00 ^{A}	482.00 ± 10.00 ^{B}	680.00 ± 30.00 ^{C}	920.00 ± 50.00 ^{D}	2480.00 ± 70.00 ^{E}	2626.00 ± 28.83 ^{F}
PT	mg/L	0.89 ± 0.20 ^{A}	1.55 ± 0.27 ^{B}	2.30 ± 0.35 ^{C}	3.25 ± 0.43 ^{D}	3.80 ± 0.57 ^{E}	5.14 ± 0.23 ^{F}
PO_4^{3-}	mg/L	1.22 ± 0.21 ^{A}	1.96 ± 0.10 ^{B}	1.99 ± 0.28 ^{B}	2.21 ± 0.43 ^{B}	3.10 ± 0.20 ^{C}	3.17 ± 0.12 ^{C}
DBO	mg/L	1.65 ± 1.10 ^{A}	2.35 ± 0.50 ^{A}	2.76 ± 0.10 ^{B}	2.69 ± 0.44 ^{B}	3.96 ± 0.60 ^{C}	3.63 ± 0.30 ^{C}
NH_4	mg/L	1.10 ± 0.15 ^{A}	1.25 ± 0.29 ^{A}	1.32 ± 0.48 ^{A}	2.40 ± 0.10 ^{B}	2.97 ± 0.74 ^{C}	3.08 ± 0.10 ^{C}
NO_2^-	mg/L	1.52 ± 0.11 ^{A}	1.71 ± 0.42 ^{A}	1.63 ± 0.12 ^{A}	1.72 ± 0.25 ^{A}	1.40 ± 0.63 ^{A}	2.00 ± 0.01 ^{A}
NO_3^-	mg/L	1.01 ± 0.14 ^{A}	1.20 ± 0.10 ^{B}	1.36 ± 0.08 ^{C}	1.45 ± 0.10 ^{C}	1.50 ± 0.20 ^{C}	1.88 ± 0.05 ^{D}
TU	NTU	9.48 ± 0.45 ^{A}	11.67 ± 0.58 ^{B}	15.00 ± 1.01 ^{C}	17.91 ± 0.96 ^{D}	19.76 ± 0.31 ^{E}	24.10 ± 0.89 ^{F}
WQI	**Score**	**68.98 ± 3.13 ^{A}**	**56.89 ± 4.16 ^{B}**	**44.53 ± 3.03 ^{C}**	**38.12 ± 3.96 ^{D}**	**27.64 ± 3.95 ^{E}**	**3.82 ± 0.35 ^{F}**
	Classification	**Good**	**Good**	**Fair**	**Fair**	**Poor**	**Very Poor**

Source: Prepared by the authors (2025).

The results obtained for the physicochemical and microbiological parameters of the Cemitério Stream revealed a progressive gradient of environmental degradation along the watercourse, with significant variations among the sampling points and a strong association with the pattern of adjacent urban occupation. Among the parameters that exhibited highly significant spatial variation ($p < 0.001$), the most notable were pH ($p = 4.64\times10^{-6}$), total solids ($p = 4.27\times10^{-6}$), total phosphorus ($p = 7.71\times10^{-8}$), PO_4^{3-} ($p = 3.89\times10^{-6}$), NH_4 ($p = 5.40\times10^{-5}$), NO_3^- ($p = 3.61\times10^{-5}$), turbidity ($p = 1.77\times10^{-10}$), and WQI ($p = 3.41\times10^{-10}$).

Bacteriological indicators also showed marked contrasts along the stream, with total coliforms ($p = 6.48\times10^{-15}$) and thermotolerant coliforms ($p = 2.08\times10^{-17}$) exhibiting extremely significant differences between upstream and downstream regions. Parameters such as dissolved oxygen ($p = 1.23\times10^{-4}$), BOD ($p = 4.97\times10^{-3}$), and temperature ($p = 0.015$) also varied in a statistically significant manner, although with less intensity. Only nitrite showed no significant differences among the sampling points ($p = 0.386$), suggesting limited sensitivity of this variable to local anthropogenic pressures.

The upstream sites (P1 and P2) demonstrated better water quality, characterized by adequate dissolved oxygen concentrations (> 7 mg L^{-1}), reduced turbidity (9 to 12 NTU), low total phosphorus (0.69 to 1.55 mg L^{-1}), and thermotolerant coliform values within or close to regulatory limits. These patterns were statistically confirmed by lower means and superior groupings in Duncan's test. In contrast, the midstream and downstream sites (P3 to P6) showed progressive increases in organic and microbiological loads, particularly for BOD (2.25 to 4.56 mg L^{-1}), total phosphorus (1.95 to 5.41 mg L^{-1}), turbidity (14 to 25 NTU), and thermotolerant coliforms exceeding 2,000 MPN 100 mL^{-1} at P5 and P6. These changes were associated with highly significant p values ($p < 0.001$). Such patterns reflect the cumulative effects of domestic wastewater discharge, sewage leakage, clandestine connections, and surface runoff from urban areas, consistent with findings reported by Von Rückert et al. (2024) and Siqueira et al. (2023).

When compared with the standards of CONAMA Resolution No. 357/2005 for Class 2 rivers, several parameters exhibited noncompliance, especially in downstream stretches. Although BOD remained within the permitted limit of 5 mg L^{-1}, total phosphorus (limit of 0.1 mg L^{-1}) and thermotolerant coliforms (limit of 1,000 MPN 100 mL^{-1}) greatly exceeded recommended levels at all sampling points, with severe deterioration at P5 and P6. Dissolved oxygen also fell below the minimum required concentration (5 mg L^{-1}) at P6, reinforcing the condition of advanced degradation. Turbidity remained within the legal limit of 100 NTU, although the increasing trend indicates ongoing deterioration of aquatic habitats and enhanced sediment input.

The WQI demonstrated a pronounced decline from upstream to downstream, ranging from 68.98 at P1 (good) to only 3.82 at P6 (very poor). The extremely low p value ($p = 3.41\times10^{-10}$) confirms that this decline is not random but rather reflects the influence of urban pressures and continuous inputs of organic matter, nutrients, and pathogenic microorganisms. Similar patterns have been documented by Campos and Pavelski (2025) and Rocha et al. (2025), who observed that densely urbanized regions - especially in medium-sized municipalities - tend to develop critical zones of water-quality degradation in their downstream segments.

Variations in pH were also significant ($p = 4.64\times10^{-6}$), shifting from slightly acidic conditions at P1 (6.10) to neutral or slightly alkaline values at P4 to P6 (reaching 7.37). This trend indicates increased alkalinity associated with microbial activity and nitrification processes, as documented by Pakoksung et al. (2025) in tropical basins strongly affected by human activities.

The negative effects of urban land use in Caçador have been consistently identified in several local water bodies, with clear alterations in physicochemical and microbiological patterns (Lautert et al., 2019; Campos et al., 2025a; 2025b). The main drivers of this environmental degradation include industrial and domestic wastewater discharge (Alves et al., 2017; Campos; Borga; Vázquez, 2017b; Campos; Borga; Garcia, 2017; Campos; Borga; Mello, 2017; Tilha et al., 2019; Campos; Barcarolli, 2023; Campos; Moretto, 2025; Campos; Pavelski, 2025; Campos; Oliveira, 2025; Campos et al., 2025c; 2025d), contamination from fuel stations (Campos et al., 2017), inadequate solid waste disposal (Campos, 2025), and discharges from the stormwater drainage system (Campos; Kuhn, 2021; Campos; Zir, 2025).

Taken together, the findings indicate that the Cemitério Stream exhibits progressive environmental degradation along its longitudinal profile, with multiple parameters deviating from current environmental legislation and statistically significant differences supported by very low p values. These results highlight the urgent need for structural interventions, improvements in sanitation infrastructure, and continuous monitoring to mitigate the observed impacts.

3.2 CORRELATION AMONG PHYSICOCHEMICAL AND MICROBIOLOGICAL PARAMETERS

The Pearson correlation matrix revealed highly significant associations ($p < 0.05$) among most variables, demonstrating strong interdependence between the physicochemical and microbiological parameters evaluated in the Cemitério Stream (Table 05). Dissolved oxygen showed a negative and very strong correlation with nearly all indicators of organic

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contamination, especially total phosphorus (r = –0.975), BOD (r = –0.899), NH_4 (r = –0.893), thermotolerant coliforms (r = –0.919), and WQI (r = 0.984). This trend confirms that increases in organic and nutrient loads reduce dissolved oxygen availability and compromise overall water quality, a pattern similar to that reported by Siqueira et al. (2023) and Rückert et al. (2024) in urban streams of southern and southeastern Brazil.

Total phosphorus, total solids, and turbidity exhibited nearly perfect positive correlations (r > 0.94), indicating that the mobilization of particulate material is one of the primary pathways for nutrient transport in the system. These findings reinforce the role of urban surface runoff as a diffuse source of phosphorus and organic matter, consistent with the observations of Pakoksung et al. (2025), who reported substantial increases in turbidity and nutrient concentrations in tropical basins exposed to intensive agricultural and urban pressures.

Total coliforms and thermotolerant coliforms showed strong correlations with BOD (r = 0.983), NH_4 (r = 0.891), and total phosphorus (r = 0.926), indicating that the discharged loads are predominantly of domestic and organic origin. This pattern is characteristic of systems lacking sewage treatment and exhibiting irregular occupation of riparian zones, where effluent inputs promote nutrient and microorganism enrichment. Campos and Pavelski (2025) similarly associated these correlations with the low self-purification capacity of urban streams in Caçador.

Nitrogen species displayed distinct behaviors: nitrate (r ≈ 0.97 with total solids and turbidity) showed strong correlations with turbidity and phosphorus, whereas nitrite exhibited weaker correlations (r ≈ 0.30 to 0.49) and a positive association with temperature (r = 0.799). This suggests partial oxidation of ammonia under conditions of elevated temperature and reduced oxygenation, as highlighted by Wei et al. (2025) in subtropical streams.

Overall, the correlations reveal a pattern of co-variation typical of environments affected by organic and nutrient inputs, where the upstream - downstream gradient reflects the progressive accumulation of contaminants. The inverse relationships of dissolved oxygen and WQI with the other parameters reaffirm the decline in water quality and the intensification of environmental stress, consistent with the PCA results. These findings underscore the need to control both point and diffuse pollution sources and to restore riparian zones in order to advance progress toward SDG 6 and SDG 15.

Table 5

Pearson correlation matrix among physicochemical and microbiological parameters and the Water Quality Index (WQI) of the Cemitério Stream. Values in bold are significantly different from zero ($p < 0.05$). Strong correlations are indicated by $|r| \geq 0.70$; moderate correlations by $0.50 \leq |r| < 0.70$; and weak correlations by $|r| < 0.50$

VAR.	pH	T	OD	ST	CT	CTT	PT	PO_4^{3-}	BOD	NH_4	NO_2^-	NO_3^-	TU	IQA
pH	**1**	0,227	**-0,841**	**0,931**	**0,934**	**0,926**	**0,890**	**0,952**	**0,947**	**0,957**	0,114	0,808	**0,887**	**-0,851**
T		**1**	-0,212	0,086	0,250	0,165	0,386	0,275	0,088	0,310	0,799	0,445	0,352	-0,375
OD			**1**	**-0,961**	**-0,919**	**-0,934**	**-0,975**	**-0,918**	**-0,899**	**-0,893**	-0,434	**-0,967**	**-0,981**	**0,984**
ST				**1**	**0,941**	**0,947**	**0,942**	**0,941**	**0,961**	**0,927**	0,201	**0,894**	**0,952**	**-0,930**
CT					**1**	**0,959**	**0,926**	**0,995**	**0,983**	**0,891**	0,300	**0,903**	**0,920**	**-0,932**
CTT						**1**	**0,930**	**0,975**	**0,955**	**0,938**	0,251	**0,882**	**0,925**	**-0,927**
PT							**1**	**0,937**	**0,887**	**0,946**	0,492	**0,982**	**0,999**	**-0,992**
PO_4^{3-}								**1**	**0,977**	**0,924**	0,299	**0,903**	**0,929**	**-0,935**
BOD									**1**	**0,883**	0,134	**0,842**	**0,887**	**-0,885**
NH_4										**1**	0,270	**0,870**	**0,943**	**-0,906**
NO_2^-											**1**	0,617	0,473	-0,538
NO_3^-												**1**	**0,979**	**-0,994**
TU													**1**	**-0,990**
IQA														**1**

Source: Prepared by the authors (2025).

These interrelations among the variables, evidenced by the Pearson correlation analysis, are further confirmed by the PCA, which synthesizes the joint behavior of the parameters and enables the visualization of water quality gradients in an integrated manner. The strong positive association among nutrients, suspended solids, ammonia, and coliforms - contrasting with dissolved oxygen and WQI - clearly defines the main axis of variation (PC1), reflecting the progressive increase in water degradation from upstream to downstream. This pattern indicates that the input of organic matter and nutrients exerts a dominant influence on the multivariate structure of the system, surpassing seasonal or physical variations.

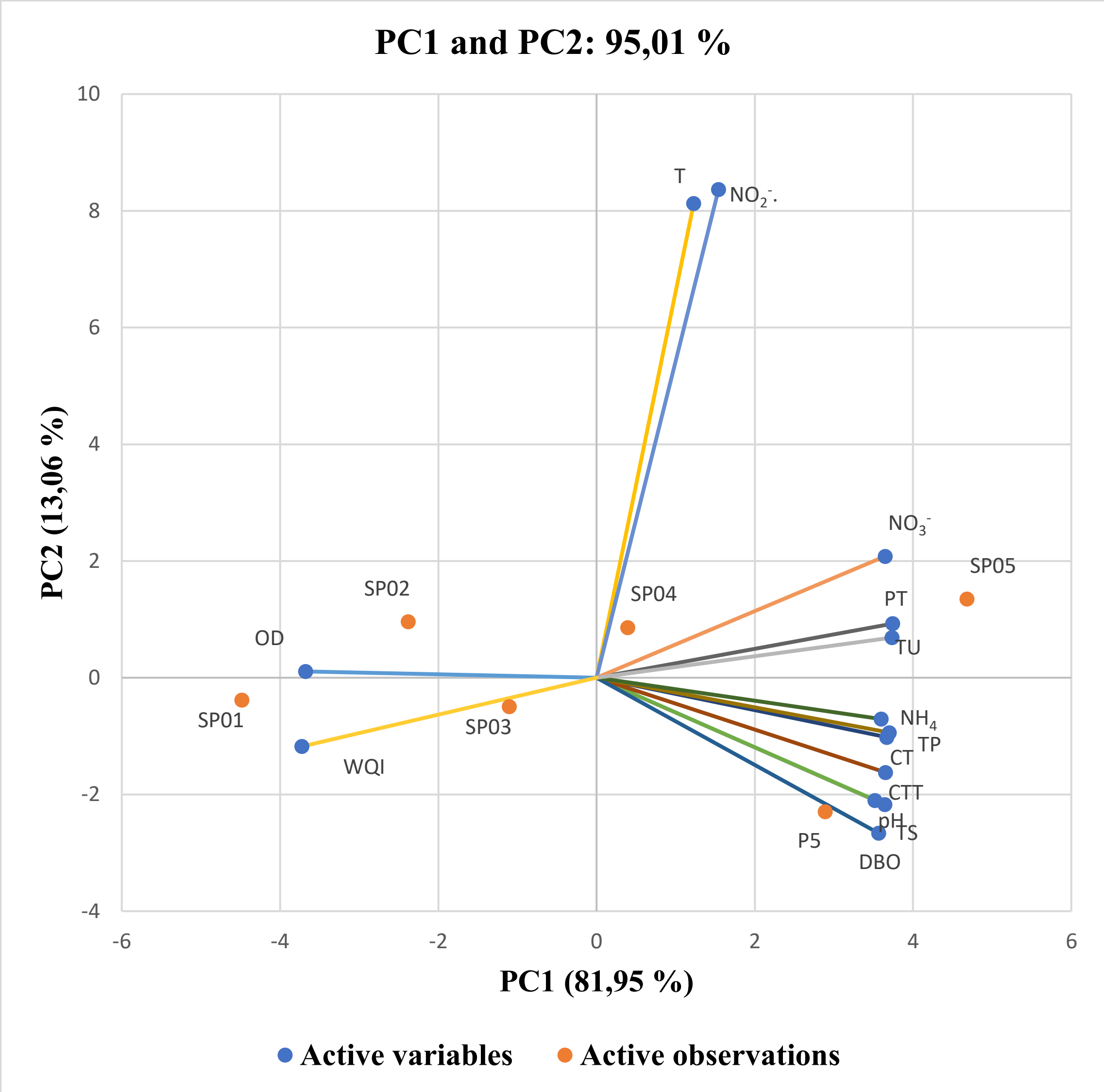
Thus, the PCA reinforces the findings of the univariate and bivariate analyses, consolidating anthropogenic pressure - particularly the discharge of domestic effluents and urban surface runoff - as the primary driver of spatial differentiation in the Cemitério Stream. Together, the evidence confirms that the system has a low self-purification capacity and high sensitivity to increases in organic load, highlighting the urgent need for environmental interventions and improvements in basic sanitation throughout the basin.

3.3 PRINCIPAL COMPONENT ANALYSIS (PCA)

Figure 2 presents the Principal Component Analysis (PCA) of the parameters evaluated in this study, along with the distribution of the sampling points.

Figure 2

Two-dimensional projection (A) and scores (B) of the physicochemical and microbiological parameters on the first two principal components (PC1 and PC2) obtained for the stream water samples



Source: Prepared by the authors (2025).

The PCA explained 95.01% of the total variance, with the first component (PC1) accounting for 81.95% and the second component (PC2) for 13.06%. PC1 clearly represented the water quality gradient along the Cemitério Stream, showing strong positive correlations with TP (0.989), turbidity (0.986), PO_4^{3-} (0.977), TC (0.969), TTC (0.965), NO_3^- (0.964), total solids (0.963), NH_4 (0.951), and BOD (0.942), and strong negative correlations with dissolved oxygen (–0.971) and WQI (–0.984). This pattern indicates that increases in organic matter, nutrients, and turbidity occur in opposition to dissolved oxygen availability and overall water quality, characterizing PC1 as an axis of organic pollution and eutrophication. Consequently, points P1 and P2, associated with higher values of dissolved oxygen and WQI, were positioned in the negative semiplane, whereas P4 to P6 clustered at the positive extreme, where high concentrations of phosphorus, suspended solids, ammonia, and thermotolerant coliforms prevail.

This behavior highlights the cumulative effect of anthropogenic inputs downstream, reflecting the advance of urbanization and the absence of effective riparian buffer zones. Similar results were observed by Rückert et al. (2024) in the Ipanema Stream in Minas Gerais, where the main PCA axis also reflected increases in ammonium, BOD, and suspended solids as markers of degradation in urban stretches. Likewise, Siqueira et al. (2023) reported in streams of southern Brazil that variables associated with organic load and turbidity are the main indicators of land-use influence on water quality, reinforcing the consistency of the patterns found in the present study.

PC2, which explained 13.06% of the variance, was mainly influenced by water temperature (0.857) and nitrite (0.882), forming a secondary axis related to thermal processes and nitrogen transformations. The association between temperature and nitrite may reflect local microvariations in sunlight exposure, flow, and oxygenation, influencing the partial oxidation of nitrogen compounds. Similar findings were reported by Pakoksung et al. (2025) in tropical basins, where temperature and nitrite represented local dynamics of decomposition and nitrification under strong anthropogenic pressure.

Overall, the PCA confirms that water degradation in the Cemitério Stream intensifies progressively from upstream to downstream, driven by nutrient enrichment and organic matter inputs, which reduce dissolved oxygen and sharply decrease the WQI. This pattern is consistent with the observations of Wei et al. (2025), who emphasized the determining role of physicochemical variables in structuring aquatic environments and defining their capacity to support sensitive biological communities. These results reinforce the need for strategies focused on restoring riparian vegetation and controlling domestic effluents as priority measures to mitigate impacts on water quality in the Cemitério Stream basin.

4 CONCLUSIONS

The monitoring of water quality in the Cemitério Stream revealed a clear degradation gradient from upstream to downstream, directly associated with the advance of urbanization and the insufficiency of basic sanitation infrastructure. The physicochemical and microbiological parameters showed a progressive increase in organic loads, nutrients, and turbidity, accompanied by a reduction in dissolved oxygen and a marked decline in the WQI, which shifted from “good” in the headwater section to “very poor” in the more urbanized stretches.

The Pearson correlation analysis indicated strong interdependence among the evaluated parameters, highlighting positive associations among total phosphorus, suspended solids, turbidity, ammonia, thermotolerant coliforms, and biochemical oxygen demand - patterns typically associated with environments receiving domestic wastewater and urban surface runoff. The PCA confirmed these trends by organizing the variables along a dominant axis of organic pollution and eutrophication and by grouping the most impacted sampling points according to this gradient.

Overall, the findings indicate that the stream has a low self-purification capacity and high vulnerability to anthropogenic pressures, especially the discharge of sanitary effluents and the inadequate occupation of its riparian zones. In this context, the implementation of measures aimed at controlling pollution sources, expanding basic sanitation coverage, restoring riparian vegetation, and promoting urban planning that considers watershed dynamics becomes essential.

From an environmental and social perspective, this study enhances the understanding of how land use and occupation influence water quality in urban basins, providing valuable support for public management and the development of policies aligned with the Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 15 (Life on Land). Continuous monitoring of these systems is crucial to mitigate the identified impacts and to promote more sustainable management of water resources in the municipality of Caçador, Santa Catarina.

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