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Spatial and Temporal Evaluation of Water Streams Using Quality Indexes: A Case Study

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Abstract: The present study aimed to analyze the spatial–temporal variation of water streams using Quality Indexes of the Minas Gerais Institute of Water Management (WQI-IGAM), compared with physical–chemical and biological variables established by the CONAMA Resolution 357/2005 employed for water classification. A water stream in the city of Cachoeira-Alta, State of Goiás, Brazil was used as a case study. Four sampling points along the water course were planned; at each point, the variables of dissolved oxygen (DO), temperature (T) and hydrogen potential (pH) were analyzed, using portable equipment, and samples were collected for laboratory analyses of the variables total phosphorus (TP), biochemical oxygen demand (BOD), total nitrogen (TN), turbidity (Turb), total residues (TR) and thermotolerant coliforms (TC). The waters were classified as of poor quality in relation to the variables TP and TC. The water course was classified as class 3 for the results of TP, class 2 for the results of BOD and TC and class 1 for the results of the other variables, according to CONAMA Resolution 357/2005. It is expected that the watershed management bodies will have a greater concern in the supervision of these resources, requiring greater protection of riparian forests and adequate management of watersheds.

Keywords: watershed; land use; water quality; anthropogenic activity

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1. Introduction

Water is one of the most important resources for the survival and maintenance of all life on Earth. With the increase in the human population, there has been a greater demand for consumption in recent decades and, as a consequence, natural resources, especially aquatic ecosystems, are thoroughly exploited to supply the various production activities such as industry and agriculture, in addition to water use in domestic activities [1]. From the beginning of time to the present day, humans have always depended on this resource for life support and for economic and social development [2]. However, there is unequal distribution of water in countries, where there are regions with an abundance of surface and underground water resources and others with scarcity. Although the Brazilian situation is one of the places with the highest water concentration in the world, land use and cover directly influence the quality of water resources and, in this case, change the conception of water as an inexhaustible resource [3,4]. Therefore, the use influences the dynamics of natural systems, and water quality also depends on other factors, such as the combined surface and underground compartments, and on the natural processes that occur, such as rain, runoff, infiltration, temperature, among others [5].

The transformations that water resources undergo as a result of use can be diagnosed through the monitoring of these waters. Thus, water quality evaluation is a tool to assess the influence of the various forms of land use and cover on water resources [6–8]. For this, in the last 30 years, there have been some improvements in national and international programs and policies, and one example is the United Nations (UN) General Assembly, which foresees sustainable development as the objective of the 2030 Agenda, with careful use of water resources, aiming at minimizing the impacts on the environment, as highlighted elsewhere [9]. In order to comply with the current water resource legislation, studies related to the water quality index began to constantly be carried out in waterbody monitoring programs. This monitoring seeks to describe the qualitative characteristics of water resources as a function of time. It is important to remember that environmental indices and indicators have emerged as a result of growing social concern with the environmental aspects of development, a process that requires a great amount of information in increasing degrees of complexity [10]. The evaluation of waterbodies is one of the main instruments to support a policy of planning and management of natural resources, which functions as a sensor that enables the monitoring of the use of water resources, presenting its effects on the qualitative characteristics of water, aiming to provide a basis for environmental control actions [11].

The classification of waterbodies becomes a great ally in the management of water resources, either by economic activities or by local communities. In this context, due to the use and deterioration of the aquatic environment, in 1970 a study was conducted by the National Sanitation Foundation (NSF) of the United States; this used several parameters of analysis to develop the Water Quality Index (WQI), based on an opinion consultation of 142 experts in water quality management, through the Delphi method. The WQI developed by NSF ranges from zero (poor quality) to 100 (excellent quality) and uses nine attributes: hydrogen potential (pH); nitrate (NO_3); total phosphorus (TP); turbidity (Turb); temperature (T); dissolved oxygen (DO); total residues (TR); thermotolerant coliforms (TC) and biochemical oxygen demand (BOD), with their respective relative weights (wi) [12]. In addition, these parameters and indices were adapted to several countries and states. In Brazil, according to information from the National Water Association (ANA) [13,14], the WQI began to be used by the São Paulo State Environmental Company (CETESB) from 1975, and from 1997 by the Minas Gerais Institute of Water Management (IGAM). IGAM uses the same parameters (except for total nitrogen, which is replaced with nitrate) and classification intervals as the WQI-NSF, but with modifications in the w values of each parameter. The WQI adopted by IGAM in Brazil was based on temperate climates, with adaptation for tropical climates by CETESB. In this case, nitrate was replaced by total nitrogen and phosphate by total phosphorus, keeping the weights and curves of each parameter [15,16].

Currently, studies using the WQI include the monitoring of 17 Brazilian hydrographic regions, involving the states of Minas Gerais, Alagoas, Mato Grosso, Mato Grosso do Sul, Paraná, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, Bahia, Ceará, Espírito Santo, Goiás, Paraíba, Pernambuco, São Paulo, Distrito Federal and Tocantins, under the management of their respective environmental or water resources management bodies. According to the Minas Gerais Institute of Water Management [17], the variables analyzed follow the proposal of the NSF-United States, and in this study, nitrate was replaced by total nitrogen. The calculation of WQI-IGAM provides results represented by (q_i), indicating class intervals ranging from 0 to 100: very poor quality from 0 to 25; poor quality from 26 to 50; medium quality from 51 to 70; good quality from 71 to 90; and excellent quality from 91 to 100. Although from the results of WQI it is possible to evaluate the quality of raw water for public supply, after treatment, this index has both advantages and disadvantages in its application. The advantage is related to the fact that it sums up the interpretation of nine variables into a single number, facilitating the understanding of the situation for the lay public. The disadvantage is that it has limitations, since it does not enable the analysis of the parameters of toxic substances, such as heavy metals, pesticides or organic compounds, in addition to pathogenic protozoa and substances that interfere in the organoleptic properties of water (color, texture, odor, flavor, brightness), requiring the survey of other variables and use of other indices, such as the Raw Water Quality Index for Public Supply Purposes (RWQI-IAP) proposed by CETESB, which considers, in addition to the variables mentioned, variables that indicate the presence of toxic substances and those that affect organoleptic quality, to better characterize a waterbody. Overall, the WQI-IGAM is widely used for river waters influenced by urban areas. However, it was shown in this work that this methodology can also be efficiently employed for river waters of rural and agricultural areas. In this sense, WQI-IGAM and the CONAMA Resolution No. 357/2005 are useful to indicate possible pollution sources derived from feedstock and agriculture. However, there may be need to adapt some studies to specific lotic environments. From this context, the objective of this study was to analyze the spatial–temporal variation of the water quality in the Matriz Stream in Cachoeira-Alta/GO, Brazil, according to the water quality index proposed by the Minas Gerais Institute of Water Management (WQI-IGAM) by monitoring physical, chemical and biological parameters. The possibility of using this study to evaluate other water supplies around the world was also estimated.

2. Material and Methods

2.1. Area Description

The Matriz Stream microbasin is located in the municipality of Cachoeira-Alta/GO (Figure 1), in the Southwestern Region of Goiás, Brazil. It has an area of 66.19 km^2, corresponding to 12.43% of the basin of the Barra dos Coqueiros Hydroelectric Power Plant (HPP), being the second largest sub-basin.

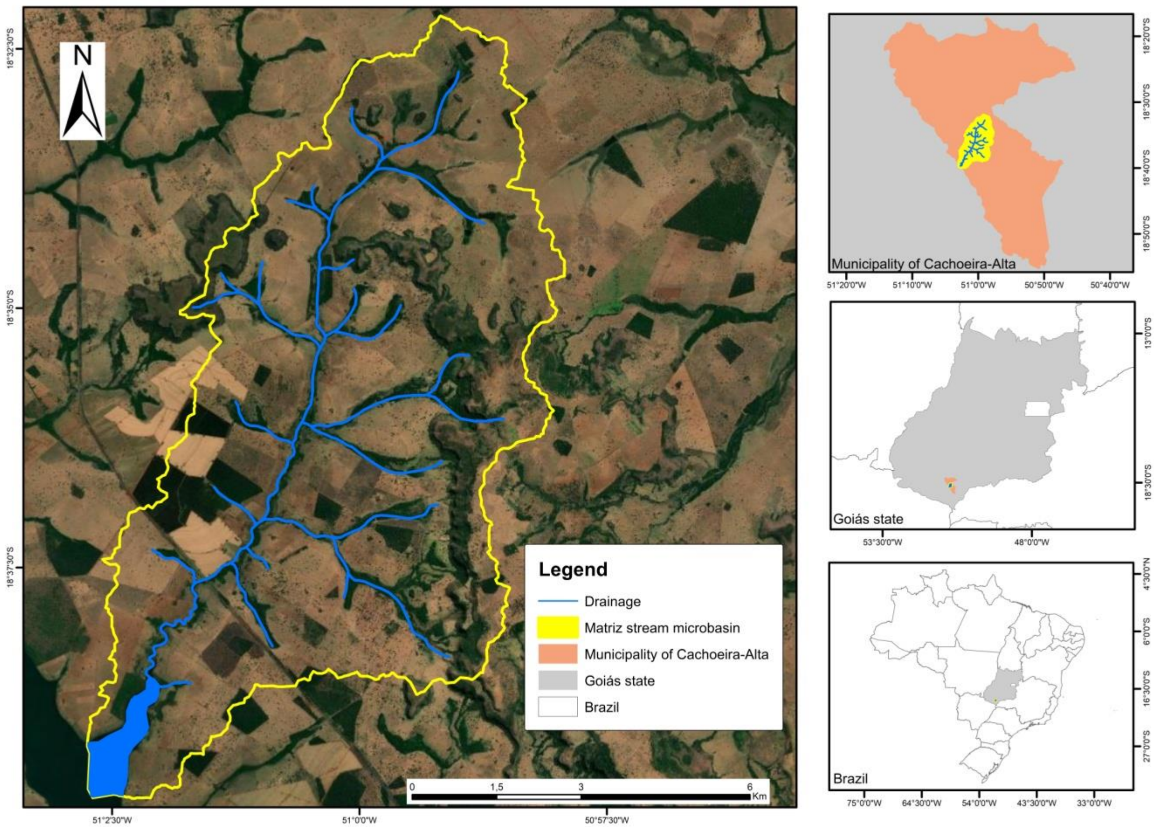

Figure 1. Location of the Matriz Stream microbasin, in Cachoeira Alta (GO), Brazil. Created in the Projected Coordinate System: Sirgas 200, UTM, Zone 22S.

The Matriz Stream microbasin has the presence of two relief units: Regional Planation Surface RPSII B and Regional Planation Surface RPSIII B. RPSII B occupies 7.85% of the entire watershed, and this proportion is related to its elevations of 600 and 730 m, developed on the rocks of the Paraná Basin, with flat plateaus generated on sedimentary rock, of the Marília Formation. The RPSIII B unit is present throughout the watershed, occupying 92.15% of the area. It has a relatively irregular character and erodes mainly from the basalts of the Serra Geral Formation and Vale do Rio do Peixe Formation. Its relief is characterized by gently undulating features and weak dissection [18].

Geologically, the Matriz Stream microbasin has three geological formations (Figure 2), being composed of the Marília and Vale do Rio do Peixe formations belonging to the Bauru Group and Serra Geral Formation, of the São Bento Group.

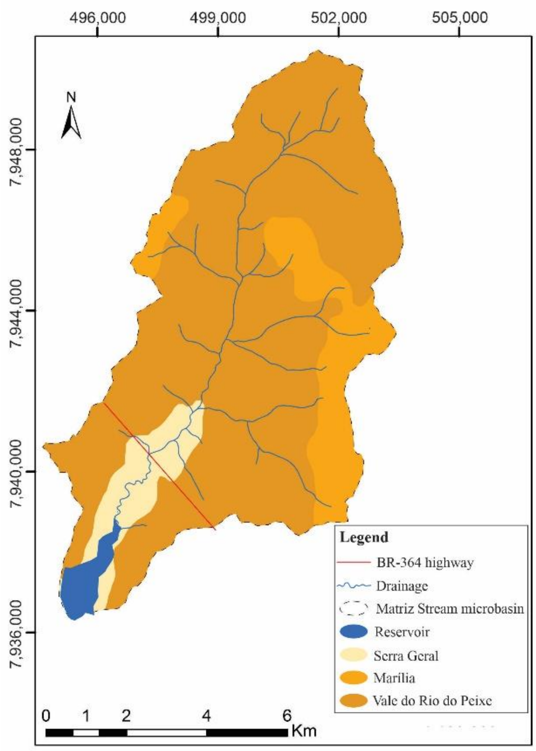

Figure 2. Geological formation of the Matriz Stream microbasin, Goiás, Brazil. Created in the Projected Coordinate System: Sirgas 200, UTM, Zone 22S.

The Vale do Rio do Peixe Formation rests directly on the basalts of the Serra Geral Formation [19]. Its sandstones have the characteristics of the very fine to fine type, pinkish to orangish light brown, moderate to good selection and with plane-parallel and cross stratification, occupying an area of 53.73 km^2 in the watershed. The Marília Formation is composed of conglomeratic sandstones, poorly selected, red, fine to coarse, with a large amount of calcium carbonate in its structure [19,20]. They are residual reliefs, flat and derive from these sandy rocks and soils of medium texture, occupying 6.54 km^2 of the area of the watershed. The basaltic rocks of the Serra Geral Formation occupy 6.16 km^2 of the area, are of volcanic origin, and are embedded in older lithostratigraphic units, often exhibiting a massive aspect, dark gray color, fine to medium phaneritic grain size, with fractures [21]. In the Matriz Stream microbasin, there is a predominance of Oxisols (LVd). These soils are directly related to the depositions of the Serra Geral Formation. According to works described elsewhere [22], they are soils with a low base saturation ($V < 50\%$) in most of the first 100 cm of the B horizon and favor greater resistance to erosive processes. The second largest area of the basin is formed by Red-Yellow Dystrophic soils (LVAd), followed by an area with Red Latosols-Oxisols (LVp), Ultisols (PVd) and Inceptisols (CXd) as presented in Figure 3.

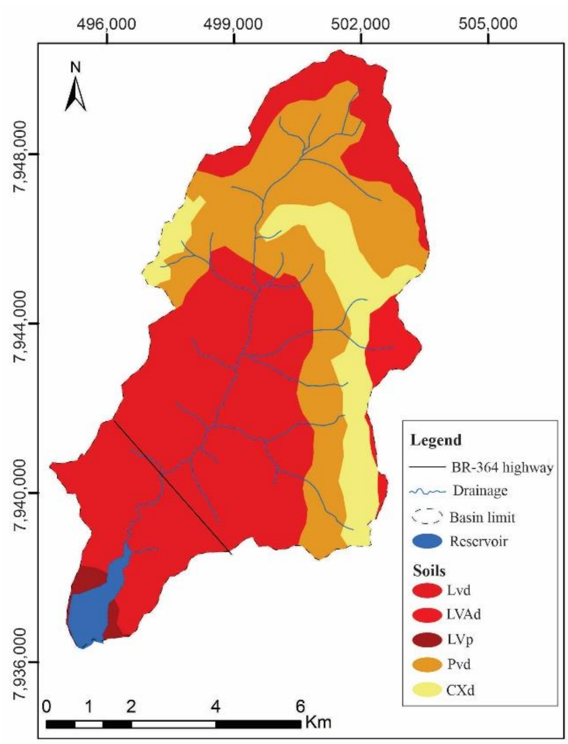

Figure 3. Pedological formation of the Matriz Stream microbasin, Goiás, Brazil. Red-Yellow Dystrophic soils (LVAd), followed by an area with Red Latosols-Oxisols (LVp), Ultisols (PVd) and Inceptisols (CXd). Created in the Projected Coordinate System: Sirgas 200, UTM, Zone 22S.

Precipitation and air temperature vary seasonally throughout the year, with two distinct seasons: from May to September, the least rainy period predominates (dry season); and from October to April, there are heavy rains (wet season) [23,24]. The average annual temperature varies from 16.9 to 30.0 °C and the average annual precipitation from 1400 to 1600 mm.

Land use and cover resulting from anthropic activities significantly alter the physical, chemical and biological processes of water resources. The processes that occur within the basin ultimately influence water quality, and this can be evaluated by monitoring surface water quality so as to ensure environmental preservation, both for the conservation of ecosystems and for future generations [11]. Some works pointed out that inadequate land use can cause impacts on the environment, such as erosive features, floods, silting of water resources, among others; that is, anthropic activities directly affect water production, and this factor is one of the most relevant to be considered in the management of watersheds [25]. These activities are related to urbanization, pasture for cattle and horses, agriculture, mostly for soybean and corn, sugarcane, eucalyptus and mahogany forestry, as well as enterprises such as pig and poultry farms and dams intended for hydroelectric power plants.

According to the classification carried out in 2015 (Figure 4) in the microbasin under study, diversified use was observed: 46.18 km^2 of the area are represented by pasture; 1.39 km^2, by forestry for coal production; 19.28 km^2, by Cerrado; 1.52 km^2, by the lake of the reservoir of the Barra dos Coqueiros HPP; and 0.77 km^2, by sugarcane for alcohol and sugar production. The predominance of pasture in the Matriz Stream microbasin is mainly related to steeper relief, which hinders agricultural mechanization, and for having soils with low fertility [26]. This type of land use requires simple practices of soil conservation, for the maintenance of pasture and control of erosive processes, such as contour ridges, micro dams (*barraginhas*), fertilization of pastures, etc. That is, the Latosols (Oxisols) in general are great for agricultural production and are easily corrected for base saturation (by adding limestone) and fertility (through fertilization). Therefore, the main factors that influence the type of use in the basin are the steep relief and the other types of soil.

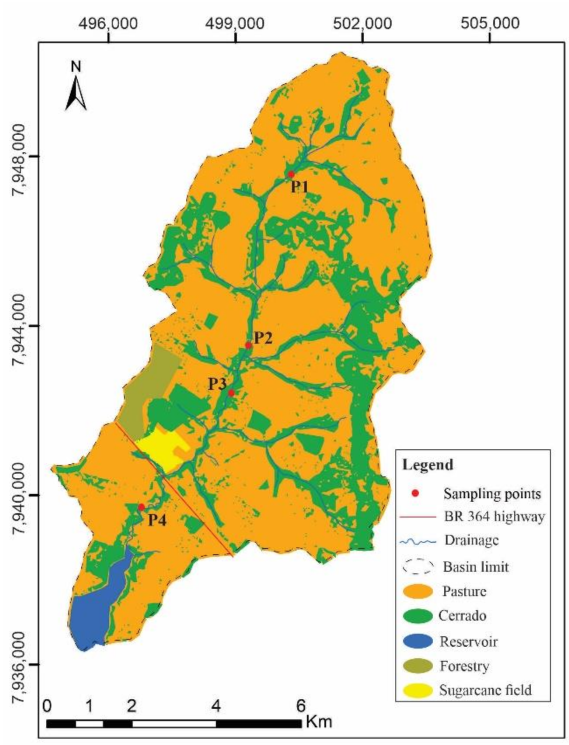

Figure 4. Land use and cover in 2015 and geo-spatialization of sampling points, in the Matriz Stream microbasin, in Cachoeira Alta/GO, Brazil. Created in the Projected Coordinate System: Sirgas 200, UTM, Zone 22S.

2.2. *Definition of Sampling Points and Data Collection*

Four sampling points, called point 1 (P1), point 2 (P2), point 3 (P3) and point 4 (P4), were defined in the watercourse. The samples were collected in four campaigns, named campaign 1 (C1), campaign 2 (C2), campaign 3 (C3) and campaign 4 (C4), the first in June 2015, the second in September 2015, the third in December 2015, and the fourth in March 2016. The water samples (from 500 to 600 mL) were collected on the surface layer of the watercourse under known temperatures and nutrient contents [15], stored in polyethylene bottles containing sulfuric acid, and left at 4 °C prior to TR, Turb, TP and TN analyses. BOD was monitored using water samples stored in polyethylene bottles covered with aluminum sheets, whereas thermotolerant coliforms (TC) were monitored using water samples stored in non-toxic autoclavable polyethylene flasks covered with aluminum sheets.

Overall, the analyses were performed as follows: DO, T and pH using an Oakton PCD 650 multiparameter probe; TP by the vanadomolybdate method; BOD by the method of incubation for five days at 20 °C ($BOD_{5,20}$ method); TN by the N-(1-naphthyl)-ethylenediamine (NTD) method; Turb by the nephelometric method; TR by the gravimetric method; and TC by the filter membrane method. These experiments were performed according to the methodologies proposed by Apha (1998) and Standard Methods for Examination of Water and Wastewater [27], with quality assurance based on five replicates and significance level of 95% ($p < 0.05$).

2.3. *Flow Measurement*

For the flow measurements, the float method was used according to the proposal described elsewhere [28]. Flow rate was calculated using Equation (1):

$$Q = \frac{A.L.C}{T} \quad (1)$$

in which Q is the flow rate (m^3/s), A is the mean of the two areas of the upper and lower section (m^2), L is the length of the measuring area (m), C is the coefficient or correction factor (0.8 for rivers with stony bottom or 0.9 for rivers with muddy bottoms), and T is the time (s) taken by the float to move along the length L.

2.4. Classification of the Waterbody

The waterbody was classified based on the CONAMA Resolution 357/2005 [29] by using parameters described in Table 1.

Table 1. Water quality standards of class 1, 2, 3 and 4 for freshwater, according to CONAMA Resolution 357/2005.

Water Quality Parameters	Limits (Class 1)	Limits (Class 2)	Limits (Class 3)	Limits (Class 4)
T (°C)	-	-	-	-
pH	6 to 9	6 to 9	6 to 9	6 to 9
Turb (NTU)	40	up to 100	100	-
TR (mg/L)	500	500	500	-
BOD (mg/L)	3	5	10	-
TP (mg/L)	0.1	0.1	0.15	-
TN (mg/L)	2.18	2.18	-	-
DO (mg/L)	≥6	≥5	≥4	>2
TC (MPN/100 mL) *	200	1000	4000	-

Legend: T: temperature; pH: hydrogen potential; Turb: Turbidity; TR: Total residues; BOD: biochemical oxygen demand; TP: total phosphorus; TN: total nitrogen; DO: dissolved oxygen; TC: thermotolerant coliforms; NTU: nephelometric turbidity unit; MPN: most probable number. * in 80% or more of at least 6 samples, collected during the period of one year, with bimonthly frequency.

2.5. Calculation of Quality Indices

WQI (water quality index) was calculated using the method proposed by the Minas Gerais Institute of Water Management [17] according to Equation (2). The relative weights are shown in Table 2:

$$WQI = \prod_{i=n}^{n} {q_i}^{w_i} \quad (2)$$

in which w_i is the relative weight of the i-th parameter, and q_i is the value of the index relative to the i-th parameter.

Table 2. Parameters, with the respective units of measurement, followed by final weights according IGAM 2005.

Parameter	Weight
Dissolved Oxygen (mg/L)	0.17
Hydrogen Potential-pH	0.12
Biochemical Oxygen Demand (mg/L)	0.10
Nitrogen (mg/L)	0.10
Phosphorus (mg/L)	0.10
Temperature (°C)	0.10
Turbidity (NTU)	0.08
Total Residues (mg/L)	0.08
Thermotolerant Coliforms (MPN/100 mL)$^{-1}$	0.15

The qualitative analysis applied to classify the waterbody is presented in Table 3.

Table 3. Classification of water quality according IGAM 2005.

Quality Level	IQA Interval
Excellent	91–100
Good	71–90
Medium	51–70
Poor	26–50
Very Poor	0–25

3. Results and Discussion

In the months referring to the rainy season (October to April), precipitation values ranged from 113.3 mm to 249.32 mm, while the average temperature ranged between 26 and 28 °C (Figure 5). In the dry season, precipitation was less than 50 mm in the months between June and September, except for May, with precipitation close to 92 mm. The highest average temperature occurred in April in the dry season, 26.8 °C, and in October in the rainy season, 28 °C.

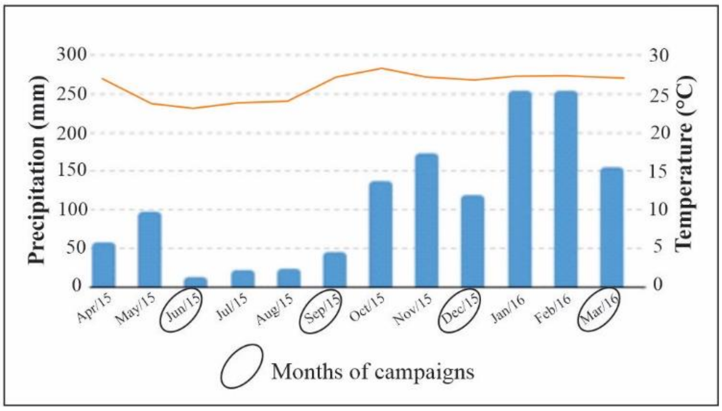

Figure 5. Data of precipitation and temperature in the Matriz Stream microbasin, GO, Brazil.

The minimum temperature values really seem to coincide with those of precipitation. However, the maximum values on the graph seem to occur in different months, at least visually: Maximum precipitation in January 2016 and February 2016, and maximum temperature in Apr and October 2015, February 2016 and March 2016 as well. The months of data collection revealed increasing values in relation to the amount of rain and average temperature in the month, influencing the results of water quality variables. The flow data (Table 4) show that in P1, (place closest to the source), the flow measurements had an average value of 0.03 m^3/s in the four campaigns. In P2, which was used for animal watering and also served as a passage for cattle, the average flow value in the four campaigns was 0.06 m^3/s. In P3, which refers to the most anthropized site due to the presence of animals (cattle trampling) and where the vegetation has little natural area, the average flow value in the four campaigns was 0.02 m^3/s. In P4, the place closest to the mouth of the microbasin, the characteristics are different from those of the other points; the watercourse is wider and the vegetation present is scarcer. The average result of flow measurements in this site was 0.04 m^3/s for the four campaigns.

According to the results of the variables from June 2015 to March 2016 presented in Table 5, it can be noted that many values are higher in the period with a higher concentration of rain, when there is an increase in surface runoff and a greater transport of substances to the watercourses. The variables that had lower results in the rainy season are related to the watercourse flow rate, because it has a diluting effect on the variables in the waterbody, that is, the flow directly influences the results of water quality [30]. In a study conducted in Senador Modestino Gonçalves in Minas Gerais were found results similar to those determined here, with inefficient self-purification in rivers that do not exceed 30 cm deep [31].

Table 4. Results of flow measurements in the four campaigns (June, September, December 2015 and March 2016).

	June 2015	September 2015	December 2015	March 2016	Final Average
Point 1	0.02	0.04	0.02	0.03	0.03
Point 2	0.70	0.01	0.02	0.10	0.06
Point 3	0.02	0.03	0.02	0.02	0.02
Point 4	0.02	0.04	0.03	0.04	0.04
Camp. Average	0.02	0.04	0.02	0.04	0.03

Table 5. Results of the variables in the dry and rainy seasons.

		Variables								
		Chemical					Physical			Biological
	Data	DO (mg/L)	pH	BOD (mg/L)	TN (mg/L)	TP (mg/L)	T (°C)	Turb (NTU)	TR (mg/L)	TC (100 mL)$^{-1}$
P1	C1	7.39	7.05	1.59	ND	0.001	21.80	2.80	4.17	121
	C2	7.43	6.18	4.49	ND	0.54	21.20	3.29	14.17	273
	C3	6.58	6.27	5.90	1.42	0.06	27.45	6.74	4.00	211
	C4	6.74	7.44	3.40	0.29	2.66	26.40	10.03	6.33	194
	Mean	7.07	6.66	3.95	0.15	0.30	24.10	5.02	5.25	202.5
P2	C1	7.66	7.65	1.86	ND	0.003	21.50	10.95	6.33	176
	C2	7.53	6.91	3.79	2.80	0.32	22.20	11.15	23.33	220
	C3	6.84	7.12	6.3	0.53	ND	25.90	10.38	8.33	431
	C4	6.81	6.94	3.30	ND	4.28	26.50	13.80	11.33	396
	Mean	7.19	7.03	3.55	0.26	0.16	24.05	11.05	9.83	308
P3	C1	7.49	7.77	1.78	ND	0.001	22.10	12.60	2.50	286
	C2	7.47	7.03	3.82	ND	0.53	22.30	13.40	22.83	334
	C3	6.77	7.25	6.10	1.26	0.10	26.10	11.15	10.50	343
	C4	6.88	6.95	3.50	0.49	2.80	25.60	20.60	14.50	185
	Mean	7.18	7.14	3.66	0.25	0.32	23.95	13.00	12.50	310
P4	C1	7.98	7.85	2.84	ND	0.001	22.10	13.45	1.50	198
	C2	7.28	6.45	3.63	ND	0.40	22.30	14.90	27.67	370
	C3	6.92	7.34	6.20	1.24	ND	26.10	17.65	12.83	334
	C4	7.07	6.99	4.80	0.14	1.05	25.60	27.80	23.67	141
	Mean	7.18	7.16	4.22	0.07	0.20	23.95	16.28	18.25	266

Legend: ND: Not detected; T: temperature; pH: hydrogen potential; Turb: Turbidity; TR: Total residues; BOD: biochemical oxygen demand; TP: total phosphorus; TN: total nitrogen; DO: dissolved oxygen; TC: thermotolerant coliforms; NTU: nephelometric turbidity unit.

Among the various physical–chemical parameters, CONAMA Resolution 357/05 does not establish any limit for the T of waterbodies. However, according to climatic conditions and anthropogenic activities, this variable can directly influence physical, chemical and biological reactions, and especially the concentrations of DO and pH [32]. The data in Table 6 show that the T variation was higher in the rainy season. However, a small variation between the points is noted. This observation can be explained by the different times of the campaigns. T influenced the concentration of DO, BOD and turbidity. CONAMA resolution 357/2005 states that good quality water should have a DO concentration above 5.0 mg/L.

Table 6. Average of the individual *qi* of each parameter per point of the results equivalent to the WQI-IGAM.

qi	Weights	P1	P2	P3	P4	Mean
DO	0.17	92.3	93.0	92.8	93.3	92.9
BOD	0.10	61.4	64.5	63.7	59.4	62.3
pH	0.12	84.4	91.7	92.2	92.3	90.2
TP	0.10	42.6	63.2	40.3	56.4	50.6
TN	0.10	98.8	97.8	98	99.4	98.5
Turb	0.08	87.9	75.4	71.8	66.8	75.5
TR	0.08	80.6	81.3	81.7	82.4	82.0
T (°C)	0.10	94.0	94.0	94.0	94.0	94.0
TC	0.15	33.4	29.8	29.7	33.9	31.7
WQI		**69.0**	**71.0**	**68.0**	**71.0**	**69.8**

Legend: DO: dissolved oxygen; BOD: biochemical oxygen demand; pH: hydrogen potential; TP: total phosphorus; TN: total nitrogen; Turb: Turbidity; TR: Total residues; T: temperature; TC: thermotolerant coliforms; 19 ≤ WQI < 36 (Poor—orange); 36 ≤ WQI < 51 (Medium—yellow); 51 ≤ WQI < 79 (Good—green); 79 ≤ WQI ≤ 100 (Excellent—blue).

According to the results presented in Table 5, all points had a DO concentration between 6.58 and 7.66 mg/L, above the minimum limit. It is important to mention that the DO concentration in natural waters can be influenced by temperature and the presence of nutrients such as phosphorus and nitrogen. The increase in temperature increases the solubility of dissolved oxygen; consequently, there is a reduction in concentration of oxygen, since its solubility decreases. Some works point out that the factors that negatively affect DO are due to the respiration of aquatic organisms, oxidation of metal ions and aerobic decomposition of organic matter [33]. The presence of nutrients such as phosphorus and nitrogen allows the growth and proliferation of aquatic plants and algae, which reduces the concentration of DO in water resources. BOD values make it possible to evaluate the biochemical oxidation of organic matter in the waterbody. According to the class 1 limit established by CONAMA Resolution No. 357/2005, BOD should not exceed 3 mg/L, and the only values that met this limit were those obtained in C1. In C2 and C4, the results were within class 2 of the said resolution, in which they cannot exceed the limit of 5 mg/L. In C3 in December, when the collection was performed in the rainy season, all values were classified as class 3, not exceeding 10 mg/L. Rain causes an increase in suspended sediments in the water, leading to a greater oxygen demand. In natural waters, pH variations are usually caused by the consumption and/or production of carbon dioxide (CO_2), by photosynthesizing organisms and by the phenomena of respiration or fermentation of all organisms present in the mass of water, producing organic compounds. Another variation in water pH is related to the natural characteristics of the study environmental site [34].

CONAMA Resolution 357/2005 determines that water intended for supply and human consumption must have pH within the range from 6.0 to 9.0. According to the results, as shown in Table 5, the pH of the water samples in the rainy season for both points is in accordance with the resolution mentioned above. The same was verified in all points for the dry season. Corroborating the observed data, it is important to highlight that the variations in pH in waterbodies may be related to several factors, for example, land use such as agricultural activities, soil types and the presence of organic matter, especially humic substances. These factors may explain the pH values found in P1 of the Matriz Stream and in the direction of the mouth, where the pH increases as the vegetation becomes sparser. Data presented in Table 5 also show a slight increase in pH due to the increase in precipitation between 2015 and 2016. These results may be related to the dissolution of rocks, absorption of gases from the atmosphere, oxidation of organic matter, among others.

Phosphorus (P) is an essential element for plants and animals. The main source of phosphorus is fecal organic matter and domestically used detergent powders, in addition to animal farming in the basin, or it may result from the application of agricultural pesticides and fertilizers [35]. Naturally, the presence of phosphorus can also have geological origin (eruptive rocks, such as the Serra Geral Formation, Figure 2), because the addition through rocks is natural and very important, because aquatic life needs phosphorus. Soil erosion has contributed to the P loads added to aquatic systems, either through surface runoff or leaching in the soil profile [36]. Although it is an important nutrient for aquatic biodiversity, phosphorus along with nitrogen in excess can cause an increase in the trophic status of waterbodies due to anthropic action [37]. This process compromises water quality and can cause damage such as fish mortality, clogging of water treatment and hydroelectric power plant systems, and poisoning of people and animals due to toxins produced by some water species. The data presented in Table 6 show a higher concentration of phosphorus in P2 during the rainy season. This increase can be justified by the presence of animal excrement in the collection period, also corroborating the TC data at that point. This increase in the variables may be related to the leaching of soils in the collection area [38].

Nitrogen is one of the most important elements in the metabolism of aquatic ecosystems, as it participates in the formation of protein, which is one of the basic components of biomass. When present at low concentrations, it may be a limiting factor for primary production in aquatic ecosystems [37,39]. In the same way as phosphorus, its source of pollution is related to industrial effluents and mainly domestic sewage, besides being added naturally from the atmosphere. For freshwaters of classes 1 and 2, when nitrogen is a limiting factor for eutrophication, under the conditions established by the competent environmental agency, the value of total nitrogen (after oxidation) should not exceed 2.18 mg/L for lotic environments, in the reference flow rate. According to the data in Table 5, nitrogen was found in both study periods, but the highest concentrations were found in the rainy season, and exceeded the limit value of 2.18 mg/L established by CONAMA Resolution 357/2005 for freshwater class 1 and 2 only in P2 in the second year, which may indicate compromised water, with amounts of nutrients from sewage sources and diffuse points in the area [40]. Similar results were observed elsewhere [38], that is, the highest values of TN and other parameters such as Phosphorus and BOD were found in the rainy/hot season, mainly in December, because of the heavy rains that preceded this collection and due to soil management and conservation in this period. The changes in TN are not related to the rainy season in studies conducted in Maringá Stream/PR [41]; these authors state that the changes that occurred are directly related to derivatives of anthropogenic sources, linked to the management of crops present in the basin. In a place with a predominance of the Amazon region climate, the dynamics of TN are consistent with that of the study area, in which a higher concentration of the nutrient was observed in the period with higher precipitation levels [42].

Turbidity represents the degree of interference of the passage of light through water and is a parameter adopted in the activities of control of water pollution, disposal of domestic effluents, solid waste and erosion, factors that favor the increase in turbidity [43]. Some studies verified that the increase in turbidity is related to the occurrence of precipitation [31,44]. In the present study, according to CONAMA resolution 357/05, turbidity data were below the maximum reference limit (100 NTU) in all points, in the different campaign periods. The main factors responsible for water turbidity, as well as radiation dispersion, are suspended particles (such as bacteria, phytoplankton, organic and inorganic debris) and to a lesser extent dissolved compounds [39]. In environmental terms, it is caused by suspended material, which prevents the passage of light in surface waters and can cause damage to fish and aquatic life. In addition, it can also retain bacteria and organic residues at the bottom of the watercourses, promoting anaerobic decomposition [45]. The TR parameter is also influenced by the same factors as turbidity.

According to the data in Table 5, the TR concentration was higher in the dry period when compared to the rainy period, possibly due to the higher deposition of organic matter (OM) in the dry season. After studying the Kelantan River basin in Malaysia, it was deduced that the decomposition of OM interfered with the results of TR and with the reduction of dissolved oxygen in water [46]. TC are only a sample of the group of total coliforms. As they are good indicators of water quality, TC have greater significance in the evaluation in terms of pollution related to the disposal of raw sewage of domestic origin or even activities such as cattle and pig farming. When analyzing other studies related to water quality analysis, it was observed that the results of TC are highly associated with the particularities of each site. Thus, the highest results in P1 and P2 were found in the dry season; and in P3 and P4, the highest results were found in the rainy season. Some authors, when conducting their analyses, realized that the high level of coliforms was linked to periods of drought, when the low flow results in a lower dilution of the raw sewage or animal waste [47].

Soil degradation is related to the removal of vegetation from the site, consequently exposing the soil, making it more vulnerable to cattle trampling and transport of sediments to the Matriz Stream. These sediments have leached materials of rocks and soils, as well as animal excrement, thus changing the physical, chemical and biological parameters of water and, consequently, water quality. When conceptualizing the quality of a given water, one should consider the relationship of the natural conditions of land use and cover in the basin, because this quality depends on the geological, geomorphological and vegetation cover conditions of the drainage basin, in addition to the behavior of terrestrial and aquatic ecosystems and human action, as well as changes in the water system [48]. The construction of the Barra dos Coqueiros HPP is an example of the implementation of a large hydraulic enterprise that, since 2010, has brought modifications to the Matriz Stream microbasin. On the other hand, these changes had beneficial consequences, such as the increase in PPAs in the microbasin under analysis. From this context, it is observed that the quality of water from a basin is not only represented by the analysis of its physical, chemical and biological characteristics, but also by the quality of the entire functioning of the ecosystem.

According to the analysis performed with the variables separately, the only ones that resulted in excellent quality are DO, TN and T, while the parameters pH, Turb and TR resulted in good quality waters in overall mean. The BOD variable, in all points, resulted, in general, in medium quality water, while the variables TP and TC resulted in poor quality waters. Although the stream has riparian and gallery forests, preserved throughout its length, it serves for animal watering, giving direct access of animals such as cattle, pigs, horses and others at many points, which defecate and urinate in these places, and which significantly alters the results presented by WQI-IGAM.

Figure 6 shows all the spatialized results during the four campaigns.

The first campaign carried out in June 2015 had precipitation of 7.3 mm, making the result of WQI show a good quality in the analysis at each point, where it had a variation from 76 to 81, being 76 in P3 and P4, 78 in P2 and 81 in P1. Thus, in this campaign good quality water was observed at all points, with the best value in P1, which is closer to the source. The second campaign carried out in September 2015 had precipitation of 40.7 mm, and one day before the collection it rained in the entire microbasin, which interfered in some parameters; thus, it was possible to observe that the quality of surface waters decreases with the rainy season [49]. The result of WQI was not bad; despite the increase, all points had a medium classification. Therefore, all points under analysis of this campaign resulted in WQI around 65 in Point 1 and Point 3 and 67 in Point 2 and Point 4. With precipitation of 113.3 mm in the month of collection of the third campaign, the WQI classification was better than in the campaign of September, with a variation of 73 in Point 3, 74 in Point 1, 75 in Point 4 and 76 in Point 2. Despite having a higher average precipitation compared to September, the third campaign had no interference of rains over the seven days prior to collection. Seasonality directly contributes to the enrichment of nutrients in the microbasin. The water monitoring is essential since the increase in precipitation causes changes, due to the major direct influence of surface runoff, thus transporting a large amount of organic matter to the drainage system [50]. Waters classified as of medium quality were observed in the Matriz Stream, in C4, with WQI-IGAM of 58 in P1, 55 in P2, 57 in P3 and 62 in P4. This result is related to the high phosphorus content present in water. Another factor that should be taken into account in this campaign is the lowest result of WQI in P2; in this point, there was a high level of TC (396 MPN 100 mL^{-1}). The improvement of BOD and TC results may be related to the dilution factor caused by the higher flow rate observed in the month of the collection of this campaign (Table 4).

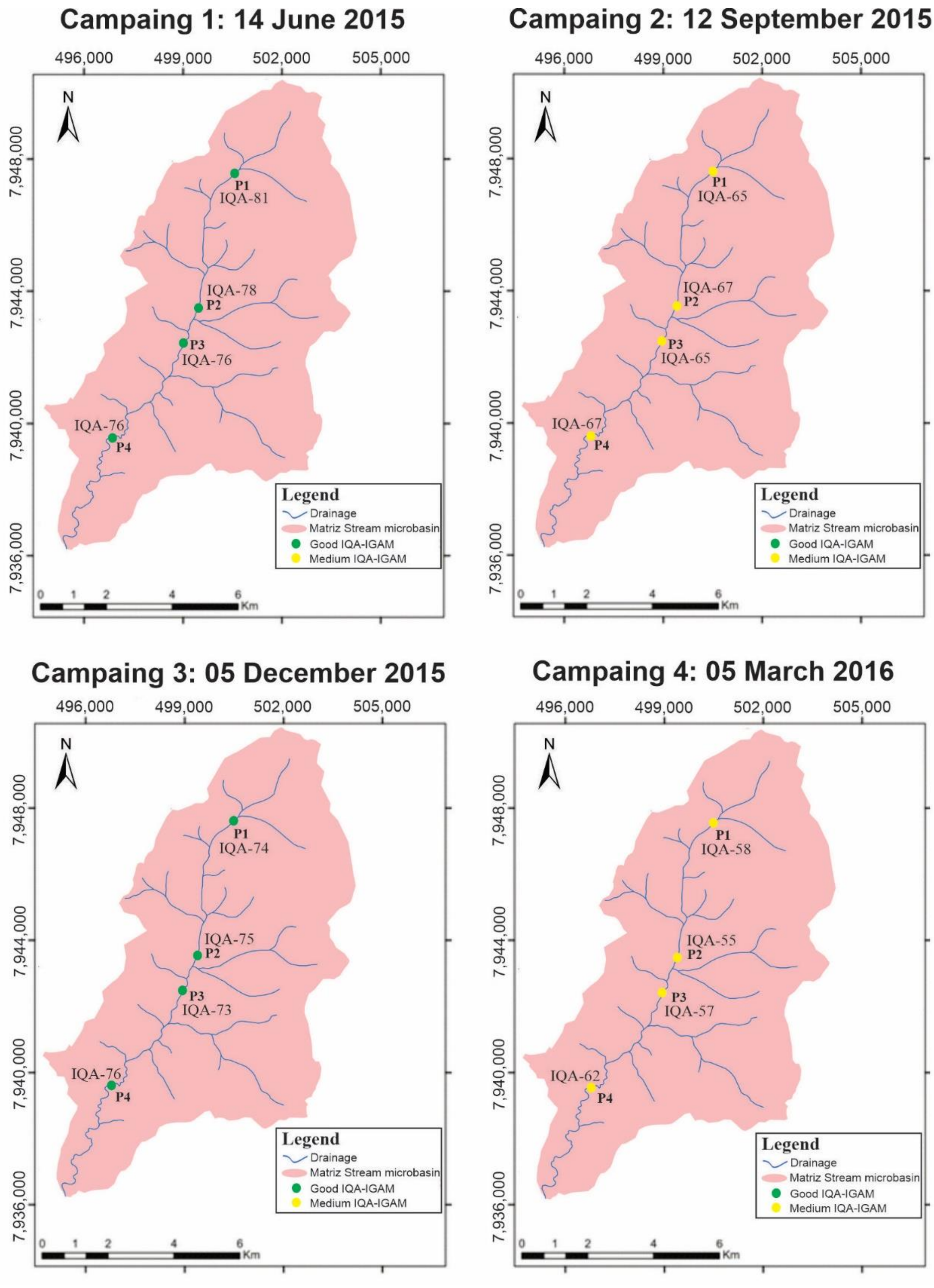

Figure 6. WQI results in the campaigns of June, September, December 2015, and March 2016. Created in ArcGIS 10.1 SIF Software at UTM position, Datum Sirgas 2000.

In addition to performing the analyses separately, it is important to evaluate each parameter (qiw) as a percentage of the maximum value that could be reached in P1, P2, P3 and P4. That is, to evaluate which parameter negatively influenced the final result of the WQI-IGAM, as presented in Figure 7.

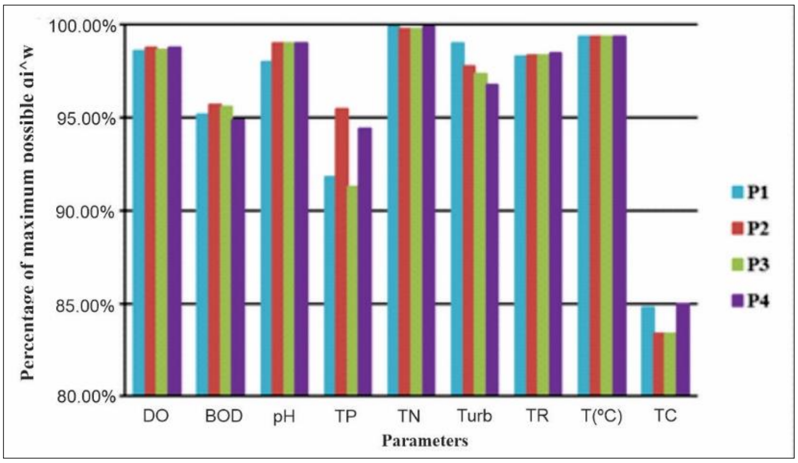

Figure 7. Percentage of qiw for each point. DO: dissolved oxygen; BOD: biochemical oxygen demand; pH: hydrogen potential; TP: total phosphorus; TN: total nitrogen; Turb: Turbidity; TR: Total residues; T: temperature; TC: thermotolerant coliforms.

It is observed that, at all points, the parameters that most negatively influence are first TC, followed by TP and BOD. If there was no influence of the high levels of these parameters, the results of WQI-IGAM would be better. Therefore, when taking the WQI as the main analysis of a basin, it is necessary to analyze each parameter alone, so as not to interpret that the surface waters are classified as of excellent, good, medium, poor or very poor quality for human consumption and other multiple uses, because the WQI often indicates waters with good quality and, when compared to the CONAMA Resolution 357/2005, some parameters show that this water has some degradation. This same observation was reported elsewhere, where the authors analyzed water quality in the Frades River basin in Bahia [48].

4. Conclusions

The parameters responsible for the degradation of the surface water quality of the Matriz Stream were biochemical oxygen demand, phosphorus and thermotolerant coliforms. There were parameters that indicated nonconformity with the classes 1 and 2, indicating that the Matriz Stream is mainly classified as class 3 by the CONAMA Resolution 357/2005. It means that this water requires conventional treatment to be used as a source of public supply. Low thermotolerant coliform values indicated a good quality water in the Matrix Stream when considering WQI-IGAM, with an average of 70 in the evaluation of the campaigns, confirming that this water could be useful for human consumption just after specific treatment. The CONAMA Resolution 357/2005 is useful for evaluating each environmental parameter individually; meanwhile, the WQI-IGAM is useful for indicating specific changes in an aquatic medium from the analysis of different parameters simultaneously. As the Matriz Stream under study is in a rural drainage basin area, the combination of phosphorus, thermotolerant coliforms and biochemical oxygen demand is relevant due to feedstock and agricultural activities. Generally, animal and agricultural residues impact on the watercourse in rural areas, needing adequate monitoring to maintain the water resources with satisfactory quality for human consumption and animal welfare. Thus, strategies for monitoring the water quality in rural and agricultural areas are important for the sustainable socio-environmental development. As a result of this study, it is expected that the watershed management bodies will have a greater concern in the supervision of these resources, requiring greater protection of riparian forests and adequate management of watersheds, with the objective of conserving the springs. Thus, more constant monitoring in the region is necessary, with a greater number of collection points, given the adverse conditions found in some sampling points. Studying water streams on drainage basins is important for planning a sustainable social and environmental development. Overall, the results obtained in this work were demonstrated as being useful for evaluating the water quality both in urban and rural areas. WQI-IGAM could be employed in future works for the monitoring of areas with high feedstock and agricultural activities by evaluating biochemical oxygen demand, phosphorus content and thermotolerant coliforms.

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