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Water quality and auto-purification in the Sapo stream in the urban area of Rio Verde - GO

Márcia Franco de Assis
Master, Instituto Federal Goiano – Campus Rio Verde, Brazil
marciafrancoassis@gmail.com

Édio Damásio da Silva Júnior
PhD Professor, Instituto Federal Goiano – Campus Rio Verde, Brazil
edio.damasio@ifgoiano.edu.br

ABSTRACT

The monitoring of water resources quality in urban areas is an essential tool to support municipalities in their proper sanitary management. This research aimed to determine the water quality in the Sapo stream, an urban area of Rio Verde city – Goiás state, and estimate its auto-purification capacity regarding to organic matter. During nine months, flow measurements, collections and laboratory analyzes of dissolved oxygen (DO) and biochemical oxygen demand ($BOD_{5,20}$) of water in the main water body and in its tributaries were carried out, for subsequent modeling of water quality, using the QUAL-UFMG model. The organic matter auto-purification capacity was obtained from four flow scenarios. The results indicated that the Sapo stream experienced greater imbalance in its natural conditions during low flow scenarios, particularly during the dry season. Additionally, it was observed that the tributaries with poorer water quality in the Sapo stream watershed were the Buriti stream, followed by the São Tomás de Baixo stream. The section with the highest capacity for oxygen reintegration and auto-purification of organic matter was located after the confluence of the main water body with the Barrinha stream. The Sapo stream showed satisfactory auto-purification capacity until the confluence with the Buriti stream, after which its auto-purification conditions were reduced, failing to restore its balance within the studied section. During the dry season, the water quality of the Sapo stream showed low indices (Class 3 or 4 for the most part), while during the rainy season, higher values were observed (primarily Class 2).

KEYWORDS: Mathematical modeling; QUAL-UFMG; water management.

1 INTRODUCTION

The world's accelerated population growth in recent decades has increased the demand for water, resulting in a considerable increase in wastewater production (Han et al., 2017). In this context, water bodies play a crucial role in the reception, assimilation, and transport of municipal, industrial and runoff wastewater from urban and agricultural areas (Castañé et al., 2015).

In the city of Rio Verde - Goiás, it is possible to observe that the Sapo stream and its tributaries are impacted by the presence of clandestine effluents originating from sanitary sewers and stormwater drains, as well as pollutants resulting from runoff and leaching in the watershed. Thus, it is noted that in the Sapo stream there are fishing activities, irrigation of vegetable gardens and animal drinking, besides, it became one of the largest tributaries of the river responsible for water supplying the city of Santa Helena de Goiás. Consequently, the water pollution can include fish and organism mortality, deterioration of aesthetic aspects, impairment of recreational use, generation of odors, risk of contamination, and the spread of waterborne diseases (Chapman, 1996).

Seeking to prevent environmental degradation of aquatic spots, it is important to understand the contamination process as well as the auto-purification capacity of water bodies, as this is directly associated with the ability of a watercourse to assimilate effluents (Von Sperling, 2011). The assimilative capacity of organic matter is determined by the natural concentrations and existing water quality standards (Jamshidi, 2019), making it important to understand the conditions to which the water body is subjected.

So, aiming to promote the conservation of water in the Sapo stream and enable its appropriate use for various activities established by Resolution No. 357/2005 of CONAMA

(National Environment Council), the study of auto-purification emerges as an important resource for the management of this water body. Through the mathematical modeling conducted in the study, critical areas that require intervention by public authorities can be observed and simulated, aiming to ensure water quality and preserve the balance of the local ecosystem.

2 OBJECTIVES

Evaluating the behavior of water quality in the Sapo stream in the urban zone of Rio Verde and its auto-purification capacity of organic matter.

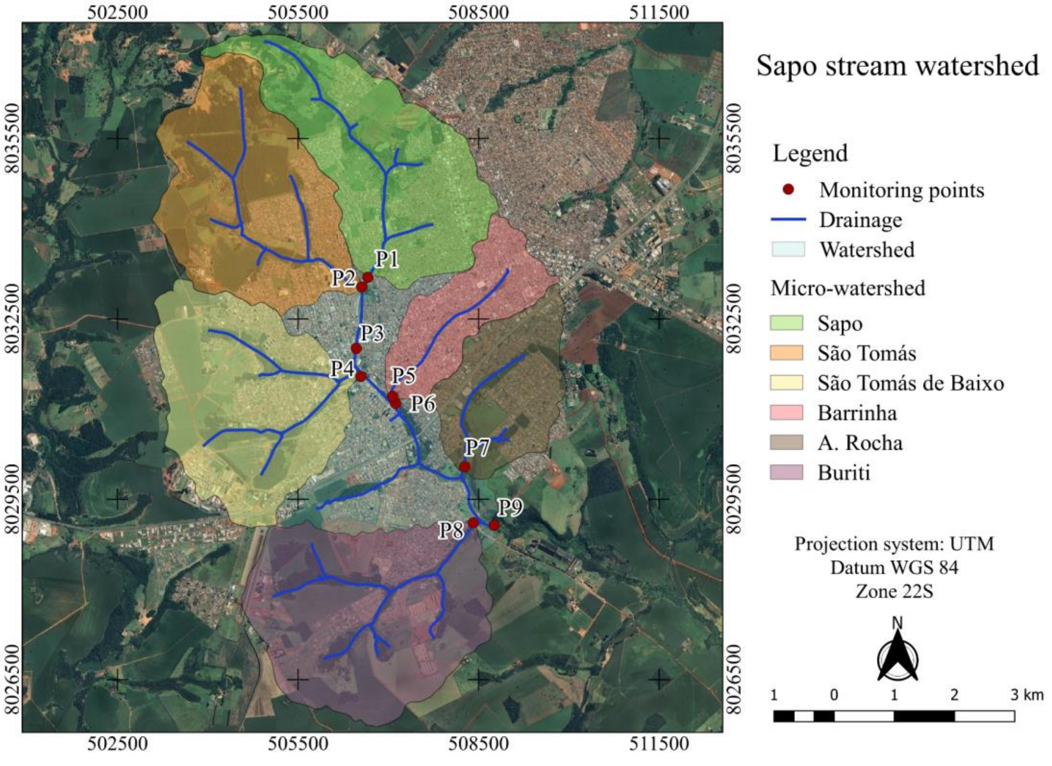
3 METHODOLOGY

3.1 Watershed and flow measurement

The present research has involved monitoring the water quality of the Sapo stream in the urban stretch of Rio Verde – Goiás, for over a period of nine months. The monitoring was carried out periodically from August 2020 to April 2021, at intervals of 14 days, covering both the dry and rainy seasons.

The water body monitoring was conducted at nine points, as shown in Figure 1, with four of them located in the main bed of the Sapo stream (P1, P3, P6, P9), and the other five points located upstream of the confluence with its tributaries (P2, P4, P5, P7, P8).

Figure 1 – Location of monitoring points.



Source: Author (2021).

In total, the complete section studied, between the first and the last monitoring point, corresponded to 6.1 km.

The flow in the cross sections of the monitoring points of the water body was obtained through the Lounchen ZM flowmeter, except in the points P3 and P6, which were used to calibrate the water quality model. As the conventionally flow meter is used to measure the flow in closed conduits, the device was calibrated so that it would be able to measure the flow in open conduits. In that process, a hydraulic bench was used in the laboratory, where a rectangular spillway was inserted, without lateral contraction, to calculate the water flow velocity.

The relationship between the velocity on the hydraulic bench and the measurement on the flowmeter was expressed by an equation with a coefficient of determination (R-squared) of 0.9278. Thus, using the flowmeter calibration curve, it was possible to correct all velocity and flow values of the water bodies studied.

Also, the studied water quality parameters were divided into four groups/ranges, based on the flow values at the outlet of the Sapo stream (P9), using the 25%, 50% and 75% percentiles of this set of flows. Each range presented a different scenario for water quality analysis.

Then, the flow limit values of the quartiles at point P9 were used to define the corresponding monitoring dates for each of the four flow ranges, as presented in Table 1, allowing for the segmentation of the other eight studied points.

Table 1 – Dates of the flow ranges studied.

Range 1 (0 – 25%)	**Range 2 (25 – 50%)**	**Range 3 (50 – 75%)**	**Range 4 (75 – 100%)**
08/22/2020	08/08/2020	12/12/2020	01/09/2021
09/05/2020	10/17/2020	01/23/2021	02/27/2021
09/19/2020	11/21/2020	02/06/2021	03/27/2021
10/03/2020	12/05/2020	03/13/2021	04/10/2021
11/07/2020	-	-	04/24/2021

Source: Author (2021).

During the research, the dates with occurrence of precipitation were verified through the data made available by the National Institute of Meteorology (INMET), based on the meteorological station 83470. Finally, the accumulated precipitation values for the five days preceding each monitoring date were observed.

3.2 Water quality parameters

The values of biochemical oxygen demand in five days at a temperature of 20ºC ($BOD_{5,20}$) and dissolved oxygen (DO) were analyzed, in addition to measuring the flow values of the Sapo stream and its tributaries. For the analysis of $BOD_{5,20}$ and DO parameters, the procedures described in section 5210 B and 4500-O G, respectively, of the book Standard Methods for Examination of Water and Wastewater (2017) were used.

A statistical analysis of the data was performed using the free software Jamovi, version 1.6.23. And the analysis of variance (ANOVA) was used to assess whether there were significant differences between the (independent) sample groups. Also, the Tukey's test was used to determine which groups differed, and a significance level (α) of 5% was considered, that is, ptukey values below 0.05 indicated the rejection of the null hypothesis, which considers the sample groups as equal.

3.3 Water quality modeling and model calibration

It is important to mention that this research adopted the QUAL-UFMG spreadsheets for water quality modeling of the Sapo stream in terms of DO and $BOD_{5,20}$ parameters. QUAL-UFMG is currently a widely used model in Brazil due to its simplicity of application and information visualization using spreadsheets (Von Sperling, 2014; Gomes et al., 2018; Lima Neto, 2018; Luz, 2018; Oliveira Filho; Riquieri, 2018; Silva et al., 2018; Medeiros, 2020).

The calibrated coefficients to achieve the best fit of the functions were: K_1 (deoxygenation coefficient), K_2 (reaeration coefficient), K_d (decomposition coefficient) and K_s (sedimentation coefficient). The Solver tool in Excel was used to maximize the coefficient of determination (CD) to find the best fit between the observed data and the data estimated by the model. The CD is a statistical indicator that measures the fraction of the total variance of the observed values, and the closer it is to "1", the better the fit obtained. According to Von Sperling (2014), CD is one of the most useful statistical indicators in the process of adjusting the estimated data from mathematical modeling to observed (real) data.

For the analysis of uncertainty and sensitivity in the four water quality modeling scenarios addressed in this research, the Monte Carlo simulation was used, and that technique is one of the methods adopted as reference for uncertainty analysis in water quality models (Costa et al., 2019).

This study conducted a thousand rounds of Monte Carlo simulation for each of the four water quality models. Therefore, in all scenarios, the outlet of the Sapo stream, point P9, was chosen for the application of the method.

Thus, the input values selected for the uncertainty analysis were the coefficients K_1, K_d, K_s and K_2, and their respective variation's ranger were obtained following a uniform distribution. For K_1 e K_s, a variation of 10% was adopted; for K_d, a variation of 20% was used, and finally, for K_2, an 80% variation was adopted. The fixed values used were those obtained in each of the models at the position of point P9, while the percentage variation around them was stipulated based on the values proposed by Von Sperling (2014) and the risk of variation associated with each coefficient, with the highest degree of uncertainty relating to the coefficient K_2.

The determination of the minimum, maximum, and input values for the simulation are given by Equation 1, Equation 2, and Equation 3, respectively.

$$\text{Minimum value} = \text{Fixed value} \times \left(1 - \text{Variation percentage} \div 100\right) \quad (1)$$

$$\text{Maximum value} = \text{Fixed value} \times \left(1 + \text{Variation percentage} \div 100\right) \quad (2)$$

$$\text{Value} = \text{Minimum value} + \text{Random value} \times \left(\text{Maximum value} - \text{Minimum value}\right) \quad (3)$$

So, aiming to analyze the output data, influenced by the variation of the K_1, K_d, K_s and K_2 coefficients, the thousand responses of the parameters DO and $BOD_{5,20}$ at point P9 were examined for each flow range studied in the research.

4 RESULTS

4.1 Analysis of flow ranges and water quality parameters

According to the Köppen-Geiger classification, the municipality of Rio Verde has a predominant tropical climate, with two well-defined seasons, a rainy season and a dry season (Castro; Santos, 2021). The months with the highest rainfall in Rio Verde typically occur from November to April, while the dry period predominantly occurs between May and October (Parreira et al., 2019; Brito et al., 2020; Lopes Sobrinho et al., 2020).

Thus, considering the accumulated precipitation data provided by INMET, it was identified that the lowest rainfall volumes were found between August and early December 2020, while the highest accumulated precipitations occurred between mid-December 2020 and April 2021.

Regarding to the water quality data obtained from the monitoring campaigns, the average values for the parameters of $BOD_{5,20}$ and DO, obtained for each point, and analyzed range are displayed in Table 2.

Table 2 – Average values per point and monitoring range.

Range	1		2		3		4	
Point	$BOD_{5,20}$ (mg/L)	DO (mg/L)	$BOD_{5,20}$ (mg/L)	DO (mg/L)	$BOD_{5,20}$ (mg/L)	DO (mg/L)	$BOD_{5,20}$ (mg/L)	DO (mg/L)
P1	11.52	5.30	5.95	4.68	1.86	5.33	1.89	4.56
P2	7.05	4.48	3.03	4.33	1.24	5.20	1.27	4.58
P3	11.38	5.78	3.82	5.15	2.35	5.50	2.61	4.96
P4	32.70	3.56	15.23	4.65	2.19	4.35	2.79	4.72
P5	13.37	9.18	6.26	8.20	2.84	6.75	2.15	6.26
P6	7.81	7.46	6.77	7.55	2.18	5.85	2.75	5.80
P7	24.36	4.75	7.34	5.60	3.33	5.80	4.85	5.48
P8	137.22	2.46	139.63	2.58	38.59	1.58	33.90	2.06
P9	36.24	5.00	31.80	5.15	7.14	4.15	7.31	3.60

Source: Author (2021).

Using analysis of variance (ANOVA) to compare the results among the $BOD_{5,20}$ samples, it was obtained that the p-value between the flow ranges was below the significance level (α) of 5%, indicating that the hypothesis of the treatments (ranges) being equal could be rejected. Through the Tukey test, it was observed that there was a significant difference in $BOD_{5,20}$ values among the following ranges: 1 and 3 (ptukey < 0.001), 1 and 4 (ptukey < 0.001), 2 and 3 (ptukey = 0.013), 2 and 4 (ptukey = 0.008). Therefore, the analysis indicated that there was a significant difference between the dry periods (ranges 1 and 2) and the rainy periods (ranges 3 and 4).

According to the results obtained in this research, it was found that the highest average values of $BOD_{5,20}$ were predominantly observed in range 1, followed by range 2. Thus, it was noted that the ranges exhibited lower flow values, in the period with no rain or low precipitation, were the same of those that showed the highest concentrations of $BOD_{5,20}$. This fact occurs due to the low dilution of pollutants by river waters in the dry period, in contrast to the rainy period, in which water bodies, due to their higher flows, have a greater capacity for diluting organic matter (Von Sperling, 2014).

Similarly, analysis of variance (ANOVA) was used to analyze the DO values, and again it was found that the p-value between the flow ranges was lower than the significance level (α) of 5%, allowing that the null hypothesis was discarded. Through the Tukey test, it was observed that there was a significant difference in DO values only between ranges 1 and 4 (ptukey < 0.049). Therefore, for all other pairwise comparisons between the ranges, no significant discrepancies were found in the behavior of DO.

Regarding to the DO variations presented between ranges 1 and 4, it is believed that they may have been influenced by the characteristics of land use and occupation in the watershed. Thus, the carrying of sediments to the bed of the water body during the rainy season, causing lower DO due to the decomposition of organic matter.

In the study conducted by Luz, Tomazoni and Pokrywiecki (2019), it was found that the most critical situations regarding water quality parameters occurred during winter, in campaigns with lower flow rates, while the best conditions were identified during autumn, in campaigns with higher flow rates. In the same way, the research conducted by Oliveira Filho and Lima Neto (2018) also indicated the vulnerability of water quality in water bodies under different flow conditions, with the worst behavior, in terms of DO and BOD, observed for low flow values.

According to Gomes et al. (2018), the highest BOD values in the study area (Rio Grande do Sul) were also observed during periods of lower flows in the spring/summer seasons, while higher concentrations of DO were found during seasons with lower concentrations of organic matter, specifically during autumn/winter.

Therefore, it can be seen that this research presented similar results regarding to the worst performance of $BOD_{5,20}$ concentrations in lower flow campaigns. Referring to the DO behavior, the statistical difference between the ranges was not significant, except for the comparison between range 1 and 4, as explained before.

By examining the statistical discrepancies between the sampling points, regardless of the flow rate categories, it was observed that for both parameters, $BOD_{5,20}$ and DO, Point P8 showed significant differences when compared pairwise with all other eight points, as determined by the Tukey test, with ptukey < 0.001 in all analyses. This location exhibited the highest values of $BOD_{5,20}$ and lower concentrations of DO, indicating the presence of organic matter due to the imbalance in the aquatic environment. It is worth noting that after the discharge of effluents into the water body, a degradation zone is formed, characterized by higher concentrations of organic load, and increased microbial population, leading to a higher consumption of DO in that region (Von Sperling, 2011; Molinari, 2015).

As for the differences in the mean DO values observed among the other points, except for P5, it was noted that P5 and P6 showed significant statistical differences when compared to almost all other points, as determined by the Tukey test, with ptukey ≤ 0.001. Point P5 was only not significantly different from P6 (ptukey = 0.332), while Point P6 was only not significantly different from P5 and P7 (ptukey = 0.070).

It must be noted that the highest DO values were exhibited by P5 and P6, respectively, and that they did not present relevant differences in the parameter, being the points closest to each other, with no probable sources of punctual pollution between them.

4.2 Water quality modeling

The results of the calibration of the coefficients K_1, K_2, K_d and K_s, obtained by the QUAL-UFMG model, are shown in Table 3.

Table 3 – Water quality coefficients obtained for each analyzed scenario.

Scenario/Range	**Coef.** (day^{-1})	**Section**							
		P1-P2	**P2-P3**	**P3-P4**	**P4-P5**	**P5-P6**	**P6-P7**	**P7-P8**	**P8-P9**
1	K_1	0.45	0.45	0.45	0.45	0.34	0.34	0.30	0.28
	K_d	1.00	0.95	0.95	1.67	1.21	1.21	1.57	1.90
	K_s	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	K_2 (20ºC)	7.97	7.62	7.62	5.85	58.94	58.94	47.75	37.84
2	K_1	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	K_d	1.68	1.47	1.47	2.12	1.83	1.83	2.04	2.26
	K_s	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	K_2 (20ºC)	4.69	4.61	4.61	5.26	49.51	49.51	43.59	34.94
3	K_1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	K_d	0.08	0.08	0.08	0.33	0.69	0.69	0.97	1.24
	K_s	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06
	K_2 (20ºC)	1.66	1.58	1.58	1.39	1.36	1.36	1.31	1.27
4	K_1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	K_d	0.08	0.08	0.08	0.40	0.72	0.72	1.07	1.41
	K_s	0.04	0.04	0.04	0.05	0.05	0.05	0.12	0.19
	K_2 (20ºC)	2.21	1.99	1.99	2.83	2.60	2.60	2.36	2.12

Source: Author (2021).

As proposed by Von Sperling (2014), the values of the carbonaceous BOD removal coefficients, K_1, K_d and K_s, were within the range of values proposed by the author for shallow water bodies with a depth of less than 1.0 m or 1.5 m and, it is worth noting that all monitoring points had a maximum water depth of less than 1.0 m.

The decomposition coefficient (K_d) was higher than the deoxygenation coefficient (K_1) for all eight sections studied in range 1 and range 2. As for range 3 and range 4, they were either higher or had the same values as K_1. It can be emphasized that the deoxygenation coefficient is influenced by temperature, the characteristics of organic matter, and the presence of substances capable of reducing the rate of chemical reactions (Von Sperling, 2014).

The behavior of higher values of K_d in relation to K_1 can be associated with the occurrence of sedimentation of organic matter and the removal of BOD by the sludge at the bottom of the water course (Chapra, 1997). Furthermore, in the rainy season, rainwater flows over the soil, causing the dissolution and dragging of sediments into the water body (Molinari, 2015; Tsuji, 2018; Rocha et al., 2019), favoring an increase in the decomposition coefficient, and that contemplates the decomposition of the organic load by the biomass present in the watercourse (Von Sperling, 2014).

It is emphasized that the highest values of K_1 and K_d were displayed in ranges 1 and 2, which presented the lowest flow values. Also, it was noted that shallow water bodies are more likely to have greater BOD decomposition, as the biomass in these channels is more influential due to lower flow rates (Von Sperling, 2014).

Regarding to the sedimentation coefficient (K_s), which refers to the ratio between the settling velocity of particulate material and the water depth (Von Sperling, 2014), it was found to be higher in ranges 1 and 2 compared to the values proposed by Von Sperling (2014) for watercourses receiving concentrated raw sewage. In both flow ranges, a value of 0.50 was obtained for K_s, which is consistent with the value presented by Chapra (1997) for shallow rivers with a depth of less than 1 m receiving raw effluent. And, according to Von Sperling (2014), water bodies with shallower depths tend to have higher values of K_s.

About the K_s values obtained for ranges 3 and 4, it is noticeable that they were considerably lower than those in the other flow ranges. The lowest values were observed in range 3, which had the highest flow rates. While in range 4, the second one to present the highest flow values, the maximum value of the referred coefficient was verified in the final section of the study "P8-P9". It is worth mentioning that during the field works, the presence of discharge of sanitary effluents was identified in that last location.

Concerning to the reaeration coefficient (K_2), which is associated with the oxygen production through reaeration in the water body (Von Sperling, 2014), it was corrected for the average temperature at each monitoring point, so the presented values are already adjusted. Thus, the highest values of K_2 in the study were presented in ranges 1 and 2 (lower flow values), after the confluence of the Sapo stream with the affluent water body of P5 (Barrinha), which presented a small water depth during carrying out this research, and still it had hydraulic ladders in its path.

The ranges 3 and 4 showed low values for the reaeration coefficient, which could be associated with their higher flow rates and less turbulence on the water surface. Water bodies with higher velocity and shallower depths tend to exhibit higher reaeration coefficients due to a greater tendency for mixing and the presence of turbulence in the surface layer (Von Sperling, 2014).

The values obtained for the coefficient of determination (CD), used for calibrating the mathematical model, are shown in Table 4.

Table 4 – Coefficient of determination for each flow range.

Range	**CD_{BOD}**	**CD_{DO}**	**$CD_{Average}$**
1	0.92	0.98	0.95
2	1.00	1.00	1.00
3	0.93	0.89	0.91
4	0.90	0.84	0.87

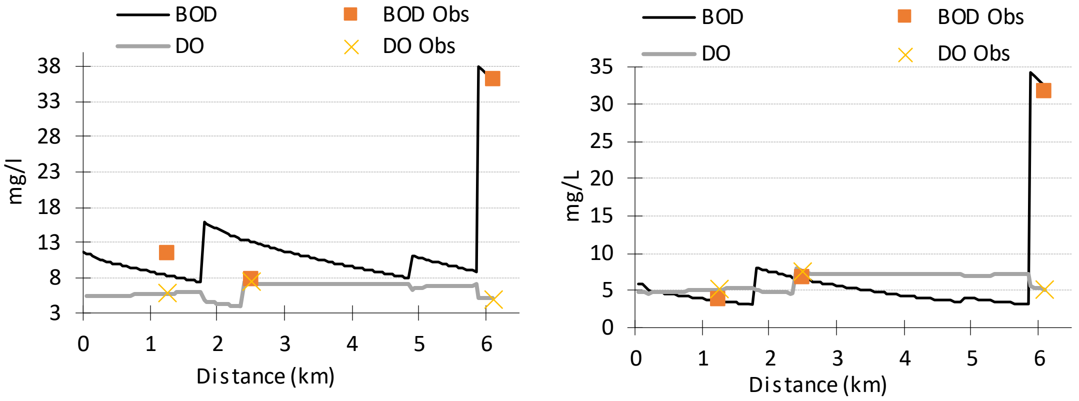
Source: Author (2021).

On analyzing the values presented by CD, it can be observed that the modeling for all four flow ranges had satisfactory fits, as all of them exhibited values higher than 0.84, both for

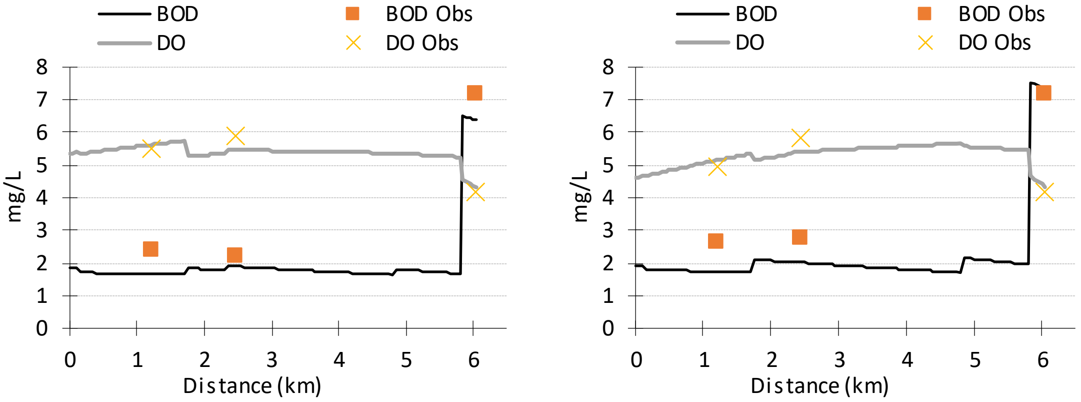
$BOD_{5,20}$ and DO. It is important to note that, according to Von Sperling (2014), values close to 1 indicate better model fits.

The auto-purification capacity of the Sapo stream, in the urban section of Rio Verde, referring to the parameters of DO and $BOD_{5,20}$, for each flow scenario, is displayed in Figure 2.

Figure 2 – Concentration profiles along the route studied.



(a) BOD5,20 and DO – Range 1 (b) BOD5,20 and DO – Range 2



(c) BOD5,20 and DO – Range 3 (d) BOD5,20 and DO – Range 4

Source: Author (2021).

After analyzing the concentration profiles of organic matter, it was observed that in all analyzed samples, there were significant increases in $BOD_{5,20}$ near kilometer 6.0 of the studied section (P8), accompanied by a reduction in DO. This behavior suggests the presence of pollutant discharges at that place, just initiating the degradation zone where there is a higher concentration of organic load and maximum consumption of DO. According to Von Sperling (2011) and Molinari (2015), when the aquatic environment is disturbed by effluent discharges, different zones of ecological succession are formed as part of the auto-purification process of the water body.

During the monitoring works, it was identified in the watershed of the P8 (Buriti) the release of sanitary sewage from residents of the region, in addition to the possible release of industrial sewage with inefficient treatment, coming from a dairy that dumps its effluents into the water body. It must be noted that the P8 exhibited, throughout the research, turbid water, with a grayish color and a bad smell. Even in the rainy season (ranges 3 and 4), when there is usually a higher dilution of organic matter, the concentrations of $BOD_{5,20}$ showed considerable growth when compared to the other monitoring points.

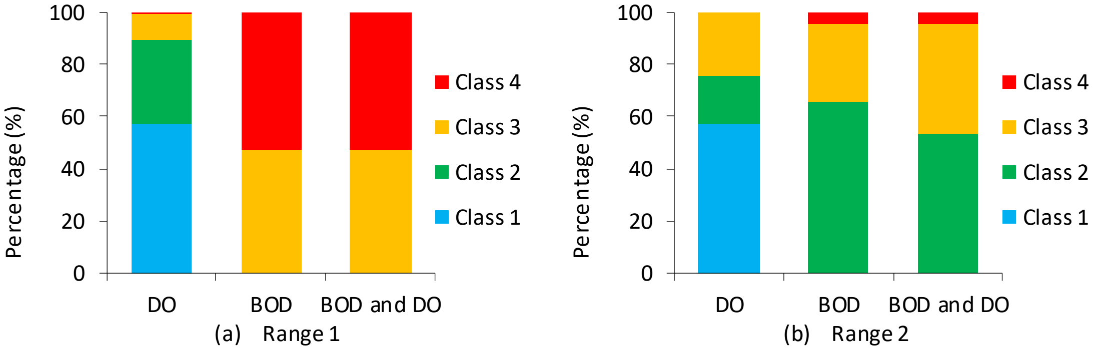
Besides of that, another point that stood out negatively, with an increase in $BOD_{5,20}$ and a reduction in DO, was P4 located close to kilometer 2.0. The worst values of the water quality parameters in that location were displayed in ranges 1 and 2, the driest period of the survey. This point is located downstream of a grain industry and a water dam, both of which may have contributed to the increase of nutrients in the aquatic environment, favoring the appearance of algae and the eutrophication process (Blaas; Kroeze, 2016).

The ranges 1 and 2 had an order of magnitude, in relation to $BOD_{5,20}$, about six times higher in the identified critical region than ranges 3 and 4. Additionally, it was noted that in the ranges with lower flow values, between kilometers 2.0 and 3.0 (P5), there was a significant increase in DO, indicating that during the dry season and low rainfall occurrence, this location had a great capacity for reoxygenation of its waters, which can be related to the low water depth and the presence of hydraulic steps along the Barrinha stream.

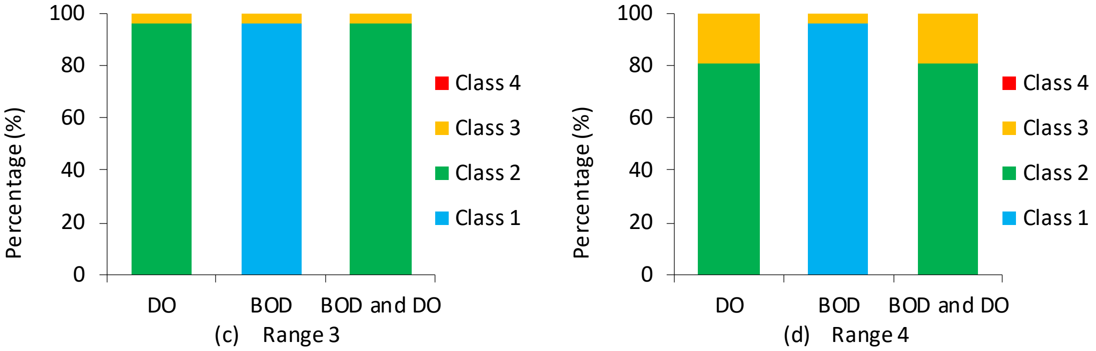
Evaluating the values of $BOD_{5,20}$ and DO throughout the Sapo stream, in the four flow ranges, it is observed that it has a good auto-purification capacity as until this moment it receives the affluent from point P8 (Buriti stream), and the curves experience jumps in $BOD_{5,20}$ concentrations and decreases in DO. Before the confluence with P8, the main water body presents reasonably balanced parameter values, and even though it shows water quality impairments after mixing with point 4, it manages to recover from the damages caused, returning to conditions like those before the mixing. However, due to the more prominent impacts of the mixing with the tributary from point P8, the auto-purification capacity of the Sapo stream is reduced, and it would only return to natural conditions downstream.

Thus, to evaluate the simulation obtained by QUAL-UFMG modeling together with the DO and $BOD_{5,20}$ standards, established for the classification of freshwater quality by CONAMA Resolution No. 357 of 2005, we can observe, according to Figure 3, that the two flow ranges with the longest stretch in linear extension with the best water quality classes were ranges 3 and 4.

Figure 3 – Percentage of extension in each class of water quality in the Sapo stream.



(a) Range 1 (b) Range 2



(c) Range 3 (d) Range 4

Source: Author (2021).

Range 1 was the most negatively impacted, as it did not have any section that could be classified as class 1 or 2 when considering simultaneous analysis criteria for $BOD_{5,20}$ and DO. Additionally, this range had the highest extension classified as class 4 (52.46%), followed by class 3 (47.54%). While range 2 had better water quality compared to range 1, as it had a lower extension classified as class 4 (4.10%) and a higher section classified as class 2 (53.28%) and 3 (42.62%).

Ranges 3 and 4 were not classified as class 4, and both had larger sections that fit the requirements of class 2 (95.90% and 81.15% respectively) when considering both $BOD_{5,20}$ and DO parameters. Therefore, it is evident that the water body had better quality in the higher flow ranges, and if these conditions were maintained during dry periods, more demanding water uses could be implemented.

Also, more recent studies addressing the water quality in water bodies through mathematical models can be found in works developed by Jamshidi et al. (2018), Soares (2018), Jamshidi (2019), and Nagisetty, Flynn and Uecker (2019).

4.2.1 Uncertainty and sensitivity analysis

The uncertainty and sensitivity analysis of the four water quality modeling scenarios was performed based on the output data of the Monte Carlo Simulation, shown in Table 5.

Table 5 – Monte Carlo Simulation output data.

Range	Parameter	Average	Standard deviation (sd)	Minimum value	Maximum value
1	DO	5.00	0.20	4.57	5.40
	$BOD_{5,20}$	36.13	0.04	36.06	36.21
2	DO	5.14	0.15	4.82	5.45
	$BOD_{5,20}$	32.47	0.04	32.39	32.55
3	DO	4.32	0.01	4.29	4.34
	$BOD_{5,20}$	6.38	< 0.01	6.37	6.39
4	DO	4.32	0.02	4.28	4.36
	$BOD_{5,20}$	7.33	0.01	7.32	7.34

Source: Author (2021).

It is observed that in none of the four streams, $BOD_{5,20}$ showed a significant change in its concentration, exhibiting a standard deviation of less than 0.04 mg/L in all cases. Regarding to the DO, it is noted that ranges 1 and 2 were more influenced by the variation of input coefficients. The uncertainty analysis shows that in ranges 3 and 4, the results were minimally influenced by changes in input values.

Analyzing the data presented in Table 5 and the provisions stated in legislation No. 357/2005 of CONAMA, it is evident that all simulations in ranges 1 and 2 would belong to class 4, with a minimum $BOD_{5,20}$ concentration exceeding 10 mg/L, while ranges 3 and 4 would still fit the criteria for class 3, with $BOD_{5,20}$ between 5 mg/L and 10 mg/L and a minimum DO exceeding 4 mg/L.

After performing sensitivity analysis on the four flow ranges using Monte Carlo simulation, the dataset of each model was divided into two groups of samples. The input values varied for the coefficients K_1, K_d, K_s and K_2. The criterion adopted to separate the samples was the magnitude of the DO parameter. Thus, the first group of samples consisted of the 500 lowest DO values (below the 50th percentile), and the second group was formed with the 500 highest DO values (above the 50th percentile).

Since ranges 1 and 2 were the most influenced by the input parameters of the model, the variation of each coefficient for these ranges was analyzed using a two-tailed Student's t-test, adopting a significance level (α) of 5%. Therefore, the important parameters for the model were those that had p-values below 0.05, indicating that the hypothesis that the means of the two sample groups are equal and should be rejected.

In ranges 1 and 2, the input coefficients that proved to be relevant in determining the output concentration of DO, showing significant differences in the two sample groups of the Monte Carlo simulation, were K_d and K_2, as both exhibited p-values below 0.05.

Recent research studies on water resources that adopted Monte Carlo simulation include works developed by Mahjouri and Abbasi (2015), Jamshidi et al. (2018) and Soares (2018).

5 CONCLUSION

The urban stretch of the Sapo stream in Rio Verde (Goiás) city presented satisfactory auto-purification capacity for organic matter along most of its length. The exception was after the confluence of that water body with the Buriti stream, which showed high pollution levels of organic matter and low levels of dissolved oxygen. Furthermore, after the confluence of these streams, the auto-purification capacity of the Sapo stream was significantly reduced, and it did not return to its natural conditions in the studied section.

In terms of water quality, there was considerable variation over the studied months, primarily due to the seasonal rainfall and its influence on the water body. Then, during the dry season or periods of low rainfall, the water quality of the Sapo stream showed low levels (mostly class 3 or 4), while during the rainy season, higher values were observed (mainly class 2).

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