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APPLICABILITY OF THE APPROXIMATE DELTA METHOD FOR DETERMINATION OF THE REAERATION COEFFICIENT IN SUB-BASINS IN THE CENTRAL REGION OF RIO GRANDE DO SUL, BRAZIL

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Abstract

The approximate delta method is a simplified experimental method easy to apply and low cost, it is based on the estimated surface reaeration, primary production, and respiration, basically using diurnal measurements of dissolved oxygen (DO). This study aimed to analyze the feasibility of applying this method to determine the reaeration coefficient (k_a*) in sub-basins of the central region of Rio Grande do Sul. The study was carried out in four sub-basins of the Vacacaí Mirim River, and one sub-basin of the Vacacaí River. In the fluviometric stations studied, one determined the values of velocity, depth, and flow rate, as well as the DO profile during the photoperiod. In three of the sub-basins, it was not possible to determine the *k_a* due to the occurrence of minimum DO deficit before solar noon and/or to the formation of an inappropriate DO profile curve. In the other two sub-basins, it was possible to determine the coefficient, although with some limitations that need to be better investigated since this method is an important alternative to the traditional ones.*

Keywords: dissolved oxygen, hydrodynamic characteristics, reaeration coefficient, water quality modeling.

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Introduction

A chronic problem of Brazilian urban rivers is the quality of its waters. The rivers, historically, are used as drainpipes of the effluents generated by the population. Most of these are not treated or inefficiently treated effluents, which turns the water body unavailable for bathing, supply, and maintenance of aquatic ecosystems (Von Sperling; Von Sperling, 2013). The Brazil Federal law N^{o}. 9433, January 1997 (Brasil, 1997), known as the Water Law, outlined a process for managing this vital resource for life support and allowed national and state councils to establish management tools. An important tool to develop management and planning measures of water resources in river basins are the models of water quality (Panagopoulos *et al.*, 2012), which has been widely used to assist water resource managers in planning and decision-making (Silva *et al.*, 2017; Gomes *et al.*, 2018; Lima *et al.*, 2018; Wrublack *et al.*, 2018; Kuchinski; Gastaldini, 2018).

The dissolved oxygen (DO) balance is essential in mathematical models of water quality based on self-depuration, such as Streeter-Phelps model (Streeter; Phelps, 1925), QUAL2E (Wang *et al.*, 2017), QUAL2K (Rehana; Dhanya, 2018), QUAL-UFMG (Gomes *et al.*, 2018; Lima *et al.*, 2018), SAD-IPH (Silva *et al.*, 2017), among others, in which the DO production is estimated by the reaeration coefficient (k_a) (Matos *et al.*, 2011). Empirical models or experimental methods can determine the k_a. Experimental methods, such as the gas tracer (Rathbun; Grant, 1978), soluble probe (Giorgetti; Schulz, 1990) and sound pressure (Morse *et al.*, 2007), require collections of samples, laboratory analyzes, and analysis of data, making the determination of the k_a an expensive and time-consuming task, which demand a large work team (Gonçalves *et al.*, 2017; Queiroz *et al.*, 2015). The tracer method is one of the most accurate to determine the k_a; however, it requires a specialized team, acquisition of materials, and the costs of field and laboratory analyzes are significant, leading to restrictions in its use (Costa *et al.*, 2015; Soares *et al.*, 2013). This becomes evident in the study carried out by Formentini (2010) in Vacacaí Mirim basin, who performed only two experiments using this method.

For this reason, empirical models are employed in studies to determine the k_a, such as O'Connor and Dobbins (1958), Churchill *et al.* (1962), Elmore and Buckingham (1962), Owens Edwards and Gibbs (1964), Tsivoglou and Wallace (1972), Parker and Gay (1987), Smoot (1988), Melching and Flores (1999), Jha *et al.*, (2001), Ojha and Bhatia, K.K.S (2001). These models are based on considerations of theoretical mass transfer and statistical correlation values of k_a with hydrodynamic characteristics, and they consist of equations that require the hydrodynamic characteristics of the river (Palumbo *et al.*, 2014). However, when using these equations to calculate the k_a in different locations from where they were drawn up, one can insert uncertainties in the process, since they are more accurate to the location where they were originated from (Queiroz *et al.*, 2015). Therefore, field investigations at the fluviometric station of interest would be the best way to estimate the k_a (Haider *et al.*, 2013).

The approximate delta method (ADM) (Mcbride; Chapra, 2005), developed from the delta method (Chapra; Di Toro, 1991), was proposed as a simpler alternative to experimental methods. This method requires few resources to determine the k_a, as a DO meter and meteorological data. Although the proposal is apparently easy to apply, it has not yet been widely used. Since the method is a low cost alternative applied in loco, the objective of this study is to analyze the feasibility of applying the ADM to determine the k_a, and understand why this method is not widely used. We applied the ADM in five sub-basins of the central region of Rio Grande do Sul, Brazil.

The technical note is organized in four Sections. Section 2 introduces the ADM to determine the k_a. Section 3 presents the applications of the method in five urban sub-basins in the central region of Rio Grande do Sul, and finally, Section 4 exposes the considerations and conclusions of the study.

Approximate delta method

The ADM can be defined as a simple procedure for the simultaneous calculation of k_a, primary production rate, and respiration rate in a river stretch using the DO diurnal profile. This curve indicates that both the minimum and maximum concentration of DO occur during the photoperiod, the first between sunrise and solar noon, and the second between solar noon (SN) and sunset, considering the appropriate DO profile (Mcbride; Chapra, 2005). We shall detail only the equations to determine the k_a, aimed of this study. More details about the method are found in McBride and Chapra (2005).

The k_a (days^{-1}) is determined as a function of the time between the minimum DO deficit (MDOD) and the solar noon, regardless the primary production rate and respiration, given by:

$$k_a = 7.5\left(\frac{5.3\eta - \Phi}{\eta\Phi}\right)^{0.85}$$ **Equation (1)**

where, Φ (hours) is the time between MDOD and SN, defined as:

$$\Phi = t_{min} - \left(\frac{f}{2}\right)$$ **Equation (2)**

with t_{min} being the time in which the MDOD occurs, f is the photoperiod duration (hours), and η is the correction factor of the photoperiod (dimensionless) given by the equation:

$$\eta = \left(\frac{f}{14}\right)^{0.75}$$ **Equation (3)**

In order to obtain the analytical solution, the temperature is taken to be constant (Mcbride and Chapra, 2005). The method is indicated for photoperiod between 10 and 14 hours, and k_a value lower than 10 d^{-1}. The photoperiod can be known in advance, but the k_a is determined by the ADM, justifying the purpose of this work.

Application of approximate delta method

The study was carried out in five sub-basins in the central region of Rio Grande do Sul (Figure 1). Four sub-basins belong to the Vacacaí Mirim River basin, namely: (i) Menino Deus II, (ii) Menino Deus IV, (iii) João Goulart, and (iv) RSC 287. The fifth sub-basin is Cancela-Tamandaí, belonging to the Vacacaí River basin.

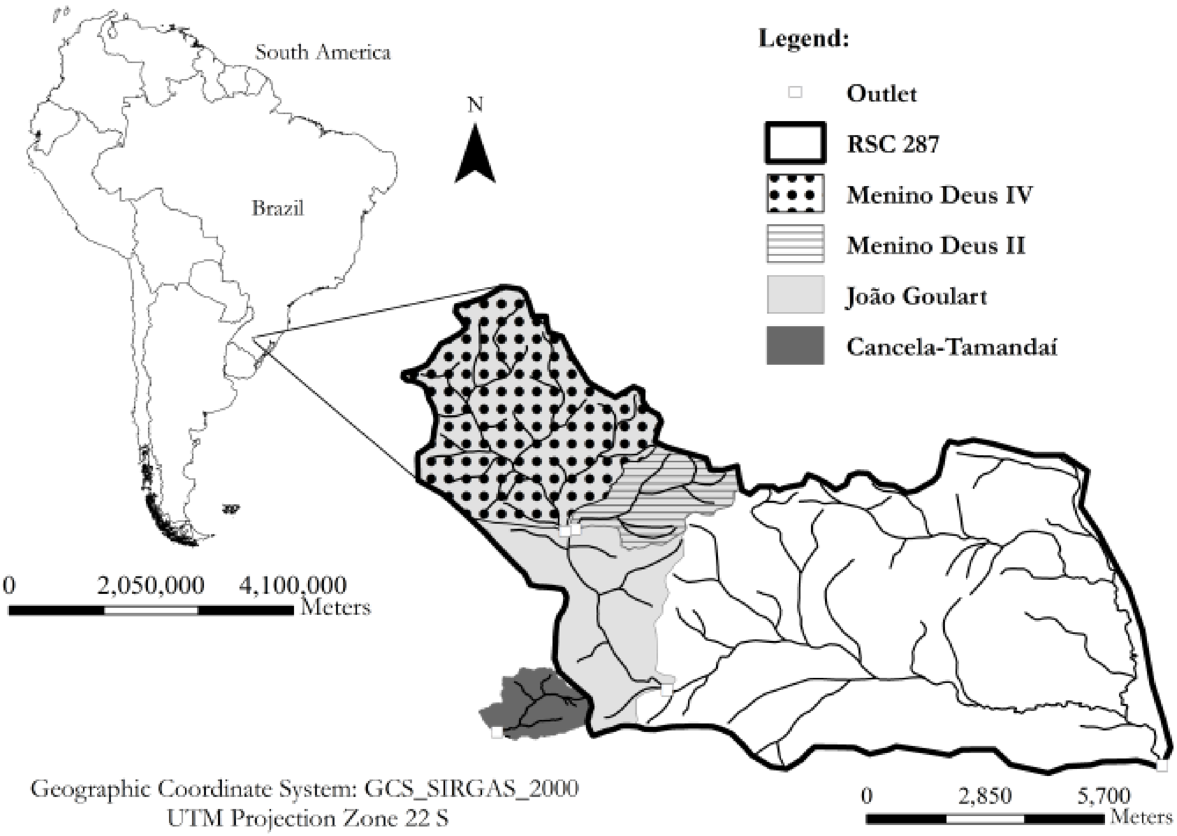

Figure 1. Location of the sub-basins.
Source: Authors.

An oximeter brand YSI Model 58 (precision of 0.1mg L^{-1}) was used to monitor the DO profiles (measured every 15min, except Menino Deus II and IV, where the DO was measured every

20min), while the f was obtained at the meteorological station of the National Institute of Meteorology – INMET, located in the Federal University of Santa Maria, with approximately 25km of maximum distance between monitoring stations (Graepin, 2016). Fluviometric stations were located in the sub-basin outlet (Figure 1).

Menino Deus II sub-basin

Menino Deus II sub-basin has 5.07 km², the second smallest sub-basin under study. This sub-basin is characterized as a headwater basin covered by arboreal vegetation (66%), pasture/crops (19%), urban area (7%), and exposed soil (8%). In the fluviometric station, located on that sub-basin outlet, we determine the DO profile curve by performing 13 field samplings. The average flow rate was 0.37m^3 s^{-1}, the average velocity was 0.70m s^{-1}, the average depth was 0.24m, the average water temperature ranged from 14.13°C to 22.57°C, and the biochemical oxygen demand (BOD) was 1.7mg L^{-1}. We performed only one field sampling to BOD.

The flow rate, depth, and average velocity are important characteristics to explain the values of k_a, and they were determined through rating curves. The flow rate rating curve used in this work was fitted by Souza and Gastaldini (2014). We fitted the depth and the average velocity rating curves using existing database (Souza; Gastaldini, 2014). Daily water levels were measured by thalimedes equipment (OTT Hydrometrie) in the fluviometric station. The water level was used in rating curves.

However, it was possible to determine the k_a using the ADM only in two field samplings (Table 1). The k_a values were 32.4d^{-1} and 49.3d^{-1}. The impossibility to determine the k_a has two main reasons: (i) the MDOD occurs before the SN, as shown in Figure 2(a) where the MDOD occurs at 12h10min, while the SN at 13h50min, which makes it impossible to determine Φ; or (ii) the non-formation of an appropriate DO profile, making impossible to obtain the time between MDOD and SN (Figure 2(b)).

Characteristics of this fluviometric station that may influence the determination of k_a are the turbulence and the water temperature variation (which was higher than 4°C in three field samplings). The presence of stones in the riverbed increases the roughness, combined with low-values of average depth produce a high rate of reaeration coefficient. The water depth, the velocity, and the channel bedside roughness are important to the surface reoxygenation phenomenon, interfering in the process of mass transfer in the air-water interface (Costa *et al.*, 2015). Low depths imply in high rates of reaeration coefficient due to atmospheric reaeration, turning the system unsuitable to apply the method as it is sensitive to small time intervals between MDOD and SN (Chapra, 1997).

Table 1. Weather characteristics, hydrodynamic characteristics, and k_a values in Menino Deus II sub-basin. NC - No curve; MD - MDOD before SN.

Menino Deus II

Date	Heather characteristics*			Water Temperature (°C)		Hydrodynamic characteristics			k_a (d^{-1})
		Temperature (°C)							
	Insolation (hours)	Average	Variation	Average	Variation	Flow rate ($m^3 s^{-1}$)	Depth (m)	Velocity ($m s^{-1}$)	
12/17/14	0.1	23.84	6.20	19.92	1.10	0.48	0.29	0.84	32.4
01/12/15	9.7	27.96	9.60	21.60	4.70	0.94	0.40	1.15	MD
02/04/15	8.8	26.16	7.40	22.57	2.60	0.56	0.31	0.89	49.3
02/12/15	8.9	26.20	10.40	21.64	6.30	0.49	0.29	0.84	MD
03/12/15	9.1	22.16	11.60	21.14	2.70	0.42	0.27	0.78	NC
03/20/15	8.0	24.56	16.40	21.99	2.60	0.15	0.16	0.48	NC
04/10/15	9.9	19.88	21.60	18.92	2.90	0.46	0.28	0.81	NC
04/24/15	6.5	18.56	10.50	18.16	1.60	0.44	0.27	0.80	NC
05/15/15	4.8	20.32	10.40	17.17	1.80	0.06	0.10	0.31	NC
07/01/15	0.5	12.36	5.80	14.40	2.10	0.15	0.16	0.48	NC
07/15/15	4.9	10.92	5.20	14.13	1.50	0.45	0.28	0.81	NC
08/06/15	7.6	26.16	12.80	17.90	5.10	0.16	0.16	0.49	NC
09/02/15	9.4	15.12	12.20	15.03	2.70	0.07	0.11	0.34	NC

Menino Deus IV

Date	Weather characteristics*			Water Temperature (°C)		Hydrodynamic characteristics			k_a (d^{-1})
		Temperature (°C)							
	Insolation (hours)	Average	Variation	Average	Variation	Flow rate ($m^3 s^{-1}$)	Depth (m)	Velocity ($m s^{-1}$)	
12/17/14	0.1	23.84	6.20	21.07	1.60	0.05	0.14	0.24	33.6
01/12/15	9.7	27.96	9.60	23.20	6.40	0.61	0.18	0.31	MD
02/04/15	8.8	26.16	7.40	24.70	5.20	0.30	0.14	0.36	MD
02/12/15	8.9	26.20	10.40	23.80	8.30	0.06	0.12	0.11	MD
03/12/15	9.1	22.16	11.60	23.01	4.30	0.04	0.08	0.20	MD
03/20/15	8.0	24.56	16.40	23.90	3.80	0.04	0.09	0.21	MD
04/10/15	9.9	19.88	21.60	19.80	5.30	0.18	0.17	0.19	MD
04/24/15	6.5	18.56	10.50	18.63	2.90	0.21	0.17	0.20	MD
05/26/15	0.0	17.12	3.00	17.50	0.60	0.07	0.08	0.18	174.3
06/19/15	0.5	6.36	5.80	11.40	2.40	0.66	0.18	0.31	MD
07/15/15	4.9	10.92	5.20	13.88	1.90	1.19	0.25	0.68	MD
08/06/15	7.6	26.16	12.80	18.70	6.60	0.26	0.16	0.27	MD
09/02/15	9.4	15.12	12.20	16.20	5.20	0.10	0.09	0.17	MD

Continue

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João Goulart

Date	Weather characteristics*			Water Temperature (°C)		Hydrodynamic characteristics			k_a (d^{-1})
	Insolation (hours)	Temperature (°C)							
		Average	Variation	Average	Variation	Flow rate ($m^3 s^{-1}$)	Depth (m)	Velocity ($m s^{-1}$)	
12/18/14	12.1	25.32	11.80	23.80	7.30	0.01	0.05	0.04	16.90
01/07/15	0.8	25.96	8.40	24.90	0.60	0.44	0.29	0.28	25.80
01/13/15	11.3	28.92	12.40	29.20	5.70	0.96	0.41	0.42	68.40
02/05/15	10.3	24.80	9.00	25.60	3.00	0.19	0.19	0.18	8.40
03/03/15	8.6	26.72	13.00	25.10	3.10	0.28	0.23	0.22	20.40
03/17/15	9.5	23.12	11.60	24.70	2.50	0.46	0.29	0.28	7.40
03/31/15	9.4	22.00	13.80	21.60	2.90	0.96	0.41	0.42	5.70
04/07/15	9.9	17.20	12.80	19.00	2.30	0.67	0.35	0.35	7.90
04/14/15	3.5	21.64	12.20	21.10	1.50	0.43	0.28	0.27	11.10
04/23/15	2.4	18.64	5.80	19.90	1.90	0.47	0.30	0.29	26.40
05/05/15	9.2	11.48	15.60	14.90	1.60	0.35	0.26	0.24	34.90
05/14/15	5.8	18.60	11.60	17.30	1.40	0.10	0.15	0.13	24.30
06/16/15	9.1	9.32	17.00	12.80	3.40	0.50	0.31	0.30	38.10
07/16/15	0.0	11.92	3.20	14.30	0.70	2.48	0.64	0.70	NC
08/12/15	7.8	23.72	12.60	20.00	2.70	0.01	0.04	0.03	42.60
09/15/15	8.4	22.12	19.80	17.10	3.80	0.06	0.12	0.15	25.00

RSC 287

Date	Weather characteristics*			Water Temperature (°C)		Hydrodynamic characteristics			k_a (d^{-1})
	Insolation (hours)	Temperature (°C)							
		Average	Variation	Average	Variation	Flow rate ($m^3 s^{-1}$)	Depth (m)	Velocity ($m s^{-1}$)	
09/30/15	9.8	16.64	10.80	17.38	4.10	6.4	1.45	0.25	NC
11/06/15	9.7	17.40	11.20	16.26	4.40	17.1	2.75	0.38	NC
12/07/15	11.9	19.68	16.00	21.67	5.20	2.05	0.75	0.10	11.01
12/10/15	11.1	23.72	11.00	22.03	3.30	3.64	1.24	0.10	9.47
01/19/16	5.6	26.4	7.80	21.56	6.80	Zero	-	-	NC
01/21/16	12.1	26.6	10.40	25.95	2.60	Zero	-	-	13.75
02/01/16	10.5	23.52	9.80	24.01	2.60	3.37	0.68	0.13	8.40
05/24/16	4.3	9.84	13.60	11.50	0.80	1.92	1.00	0.13	15.49
06/02/16	7.1	12.32	11.60	13.60	0.50	1.33	0.89	0.10	12.72
06/21/16	5.6	10.60	9.60	10.31	1.00	0.80	0.75	0.08	10.91
07/03/16	8.0	20.80	16.00	12.80	-	2.47	1.02	0.14	NC
07/19/16	8.9	7.28	10.20	10.70	-	1.94	0.96	0.13	NC
08/31/16	3.8	16.12	7.40	16.02	1.10	9.11	-	-	1.18
10/14/16	7.8	21.52	11.00	22.10	2.50	0.8	0.62	0.07	29.16

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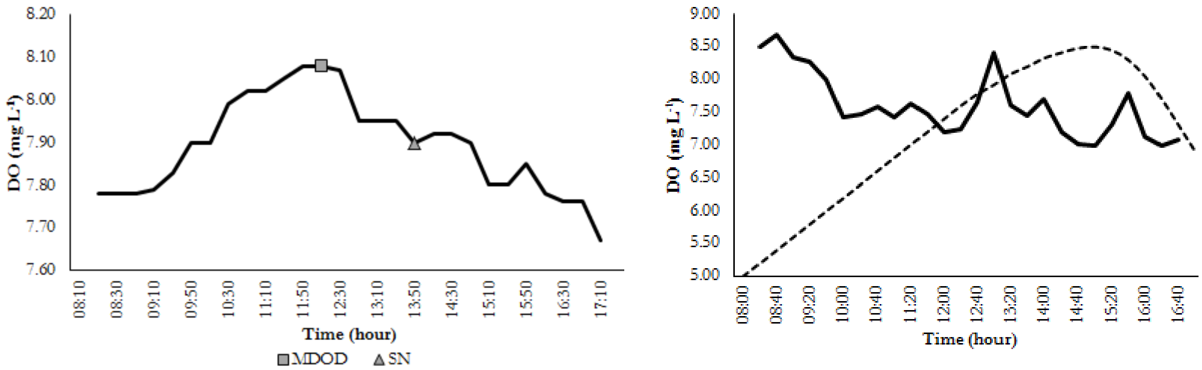
http://dx.doi.org/10.22201/iingen.0718378xe.2021.14.2.72711
Vol. 14, No.2, 714-727
6 de agosto de 2021

conclusion

Cancela-Tamandaí

Date	Weather characteristics*			Water Temperature (°C)		Hydrodynamic characteristics			k_a (d^{-1})
	Insolation (hours)	Temperature (°C)							
		Average	Variation	Average	Variation	Flow rate ($m^3 s^{-1}$)	Depth (m)	Velocity ($m s^{-1}$)	
11/04/14	8.4	19.12	6.20	19.84	6.90	0.19	0.23	0.25	NC
12/08/14	6.6	27.24	13.80	23.72	2.60	0.09	0.13	0.21	NC
02/03/15	11.0	26.64	9.60	23.49	4.40	0.14	0.19	0.23	NC
02/26/15	5.3	24.44	12.80	22.96	2.80	0.33	0.33	0.28	NC
03/18/15	8.9	23.08	13.40	22.82	2.50	0.13	0.18	0.23	NC
07/10/15	6.0	16.00	8.80	15.76	1.40	0.15	0.20	0.24	NC
10/23/15	8.3	19.44	7.80	17.73	7.30	0.21	0.25	0.25	NC

**Source: INMET*



(a) Appropriate behavior of DO profile. Minimum DO deficit (MDOD) before solar noon (SN).

(b) No DO profile. Dashed line defines the ideal behavior of the DO profile curve.

Figure 2. DO profile in Menino Deus II sub-basin.
Source: Authors.

Menino Deus IV sub-basin

The Menino Deus IV sub-basin has 19.70 km^2, and is a headwater sub-basin. Its land cover consists of arboreal vegetation (61%), pasture/crops (26%), exposed soil (7%), and urban area (6%). In the fluviometric station, located on the sub-basin outlet, we carried out 13 field samplings to determine the k_a. The field samplings in the sub-basin yielded average flow rate of 0.29m^3 s^{-1}, average velocity of 0.26m s^{-1}, average depth of 0.14m, average water temperature ranged from

http://dx.doi.org/10.22201/iingen.0718378xe.2021.14.2.72711
Vol. 14, No.2, 714-727
6 de agosto de 2021

11.40°C to 24.70°C, and BOD of 2.5mg L^{-1}. We performed only one field sampling to BOD. The flow was determined by the half-section method, and depth and average velocity by the equations (Santos *et al.*, 2001). The results of the field samplings are shown in Table 1.

In this sub-basin, we were unable to determine the k_a by the ADM in 11 field samplings. This impossibility was due to the occurrence of MDOD before SN, or by the formation of an inappropriate DO profile curve, similar to the Menino Deus II sub-basin behavior. Water temperature variation was higher than 4°C in seven field samplings.

In only two monitoring field samplings it was possible to determine the values of k_a. In one of them, the value was 33.6d^{-1}, and in the other, the value was 174.3d^{-1}. In this case, the oxygen curve profile presented the expected behavior; however, due to the sensitivity of the method to low-values of time between MDOD and SN, which was approximately 0.127hours, there was an overestimation of the k_a. The occurrence of MDOD before or close to SN is due to a high rate of the reaeration coefficient in the fluviometric station, caused by the characteristics of the section, similar to Menino Deus II sub-basin. We highlight that in the two cases where the k_a were calculated, the insolation was close to zero.

In sections with a high rate of reaeration coefficient (higher than 10d^{-1}), the method is not efficient (Chapra, 1997), indicating its infeasibility to determine the k_a in the Menino Deus IV sub-basin.

João Goulart sub-basin

The João Goulart sub-basin has 36.17 km^2, and it is downstream to sub-basins Menino Deus II and IV. The land use and land cover are characterized by arboreal vegetation (61%), pasture/crops (21%), urban area (11%) near the outlet, and exposed soil (7%). To determine the k_a, flow rate, depth, and average velocity, we performed 16 field samplings in the sub-basin outlet. The average flow rate in the field samplings was 0.52m^3 s^{-1}, the average velocity was 0.27m s^{-1}, the average depth was 0.27m, and the water average temperature ranged from 12.80°C to 29.20°C. We performed only one field sampling to BOD, indicating 21mg L^{-1} or 224.6kg d^{-1}. The hydrodynamic characteristics were established by rating curves. The flow rate rating curve was fitted by Teixeira *et al.* (2016). We fitted depth and average velocity rating curve using a previous database (Teixeira *et al.*, 2016). Table 1 shows the values found.

In this sub-basin, it was possible to determine the k_a using the ADM, once the DO profile curves show an appropriate behavior, except for one field sampling. This field sampling, in particular, occurred in a period of high flow rates, (2.48m^3 s^{-1}), approximately 500% higher than the average flow rate of the other field samplings; this could have influenced the non-formation of an adequate DO profile curve.

The values of k_a ranged between 5.7d^{-1} and 68.4d^{-1}, i.e., an amplitude of 62.7d^{-1}, and average value of 24.2d^{-1}. Variations in the k_a values for a same fluviometric station are considered normal since the variables that influence the values cannot be totally controlled (Queiroz *et al.*, 2015; Matos; Von Sperling, 2015; Omole *et al.*, 2013; Longe; Musa, 2013). We need to highlight that only at four field samplings the k_a were less than 10d^{-1}, and in two the water temperature variation was higher than 4°C.

For this fluviometric station, Formentini (2010) proposed an equation using the tracer gas method. The equation by Formentini (2010) was using and most of the values presented differences above 100%. This could be explained by the non-correlation between the k_a, velocity, and flow (lower than 0.123), input data in Formentini (2010) equation.

RSC 287 sub-basin

The RSC 287 sub-basin has 99.71 km^2, and it is downstream to the sub-basins Menino Deus II, Menino Deus IV, and João Goulart. The land use and land cover are characterized by arboreal vegetation (46%), pasture/crops (22%), urban area (16%), and exposed soil (16%). To determine the k_a, flow rate, depth, and average velocity, we conducted 14 field samplings in the fluviometric station, located in the sub-basin outlet. We obtained an average flow rate of 3.80m^3 s^{-1}, average velocity of 0.14m s^{-1}, average depth of 1.10m, average water temperature ranged from 10.31°C to 25.95°C, and BOD of 1.5mg L^{-1}. We performed only one field sampling to BOD. The hydrodynamic characteristics were determined by an ADCP (Acoustic Doppler Current Profiler) Sontek RiverSurveyor S5. Table 1 shows the values found.

In this sub-basin, it was possible to determine the k_a by the ADM in nine out of 14 field samplings. The values of k_a ranged from 1.18d^{-1} to 29.16d^{-1}, indicating an amplitude of 27.98d^{-1}, and average value of 13.88d^{-1}. The behavior was appropriate of the DO profile curve, with the increase and decrease in DO concentration, being the decline after SN, at 15h30min. However, in some monitoring field samplings, the appropriate profile was not observed, being similar to the DO profile curves of Menino Deus II and IV sub-basins. In four field samplings, the water temperature variation was higher than 4°C, and the formation of an inappropriate profile or unreliable k_a value could be derived from that. In only three field samplings the k_a was less than 10d^{-1}.

During the monitoring field samplings, the sub-basin had weather variabilities, which may have contributed to the formation of a non-adequate DO profile curve, as well as its use for irrigation of rice crops. An indicator of these factors is the variability of the hydrodynamic characteristics, such as flow rate, depth, and velocity, which ranged from zero (no flow and velocity, so the equipment does not measure depth) to 17.10m^3 s^{-1}, 2.75m, and 0.38m s^{-1}, respectively.

In this sub-basin, it was possible to determine the k_a by the ADM; however, there are uncertainties in the values due to the behavioral incompatibility of the coefficient with the hydrodynamic characteristics. This agree with Ávila (2014), which applied the ADM in this sub-basin checking the favorable and uniforms values of k_a; however, comparing the observed and calculated values through equations from the literature, there were differences between the results.

Cancela-Tamandaí sub-basin

The Cancela-Tamandaí sub-basin was the smallest sub-basin studied, with 2.70km^2, the only one outside the Vacacaí Mirim River basin. Its land use is composed of urban area (68%), arboreal vegetation (23%), pasture/crops (7%), and exposed soil (2%). To determine the k_a, flow rate, depth, average velocity and DO profile, seven field samplings were performed in the fluviometric station, located in the sub-basin outlet. In this sub-basin, we obtained average flow rate of 0.18m^3 s^{-1}, average velocity of 0.24m s^{-1}, average depth of 0.21m, and average water temperature ranged from 15.76°C to 23.72°C. We performed only one field sampling to BOD with 21mg L^{-1} or 308.4 kg d^{-1}. The hydrodynamic characteristics were determined by rating curves. The flow rate rating curve was fitted by Santos and Gastaldini (2016), and we fitted the depth and average velocity rating curve using a database (Santos; Gastaldini, 2016). Table 1 shows the values found.

In this sub-basin, the DO profile curve has not satisfied that of indicated by the method in any of the field samplings, making it impossible to determine the k_a. In all field samplings, the maximum value of DO occurred early in the morning, with a constant decline of its concentration throughout the photoperiod.

The DO profile curve presented by this sub-basin differs from others most likely because of high values of water BOD (308.4 kg d^{-1}), since it has essentially urban characteristics with disposal non-treated domestic effluents (Santos; Gastaldini, 2016). Thus, the constant decline of DO concentration is associated with the presence of liquid effluents with high levels of BOD (Nezlin *et al.*, 2016).

The inefficiency of the ADM in a station with high organic load can be explained by the joint assessesment of respiration, photosynthesis, and reaeration effects (Mcbride; Chapra, 2005). The BOD, associated with water temperature variability (between 1.4°C and 7.3°C), its no feasible the application of the method to the fluviometric station of the Cancela-Tamandaí sub-basin.

Considerations and conclusions

In this study,-we found the application of the ADM presented limitations in all sub-basins, some of them referred by McBride and Chapra (2005). The limitations observed in this study are related to the following factors: (i) the organic content present in the river section should be regular; (ii) in rivers with high rates of reaeration coefficient, the MDOD occurred before SN, or presented small values of time between MDOD and SN, causing an overestimation in the values of k_a; (iii) the high water temperature variability.

We could not determine the k_a in 54% of the field samplings. Among the sub-basins studied, João Goulart was the one that allowed a greater number of successes in determining the k_a. However, when the k_a was calculated, its values were unreliable due to no correlation with hydrodynamic characteristics, and incompatibility with the equation proposed by Formentini (2010). Then the ADM is not feasibility of applying in urban basin in the central region of Rio Grande do Sul. However, it is important to better explore the limitations of applying the ADM since the method is a low-cost alternative to experimental methods and empirical equations.

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