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TIME OF CONCENTRATION IN AN EXPERIMENTAL BASIN: METHODS FOR ANALYSIS, BACKWATER EFFECTS AND VEGETATION REMOVAL

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Abstract: There are several empirical and theoretical formulas used for the estimation of the time of concentration (Tc). However, it has been shown that the Tc estimation may vary in several orders of magnitude depending on the method. In this study we compare 10 different methods for the estimation of the Tc using sub-basins and backwater effects to analyze those results. We also analyzed if the vegetation removal changes the *Tc* in the basin. The study area is the basin of the Federal University of Santa Catarina (UFSC) campus in Joinville with a significant part in a wetland and there is backwater effect caused by the Piraí river. Applying the empirical and theoretical equations found a significant variation of Tc estimates, the standard deviation in relation to the general average was around 65%. The influence of vegetation removal and drainage of a canal had an effect of reducing the Tc by 50%.

Keywords: time of concentration; backwater; erosion

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INTRODUCTION

The Time of Concentration (*Tc*) was first defined by Mulvany (1850) as the time required for the rain falling at the farthest point of the basin to get to the outlet, or even, the time required for the entire basin area to contribute to the discharge at the outlet (NRCS, 2010).

Most hydrological analyses require time parameters, among which the *Tc* is the most frequently used one. The *Tc* is applied, for example, in the rational method used for designing stormflow drainage systems. Therefore the *Tc* is essential for water resources management (McCuen *et al.,* 1984).

Sharifi & Hosseini (2001), Silveira (2005), Wong (2005), Kang (2008), Fang *et al.* (2008), Mota & Kobiyama (2011), Grecco *et al.* (2012), Gericke & Smithers, (2014), and others organized the main *Tc* formulas and evaluated their applicability in various conditions in an attempt to find the formula that better responds to the study basin.

Grimaldi (2012) showed that the estimated values of *Tc* often depend upon the resolution of the Digital Elevation Model (DEM), reporting one case where the variability of the *Tc* could be up to 500%. There is also a difference of *Tc* values found with six different methods proposed by McCuen *et al.* (1984). Furthermore, many authors showed a significant deviation between *Tc* estimated using empirical formulas and the hydrograph analysis method (e.g., Silveira, 2005; Gericke & Smithers, 2014; Malutta *et al.*, 2017b). While Almeida *et al.* (2016) proposed a model to estimate the *Tc* value by using only the hydrograph of an event without considering any rainfall data, Michailidi *et al.* (2018) showed that *Tc* is dependent on rainfall intensity.

There are several proposals to calculate *Tc* value. In addition to analyzing *Tc* calculation methods, it is also necessary to verify how human intervention in the basin or a natural phenomenon may change the *Tc*. Therefore, the objectives of the present study were: (i) to estimate the *Tc* values with 10 empirical and theoretical formulas; (ii) to estimate the *Tc* values for sub-basins with the 5 methods proposed by McCuen *et al.* (1984); (iii) to analyze backwater effects and groundwater on *Tc* in the sub-basin; and (iv) to analyze if the vegetation removal changes the *Tc* in the basin.

MATERIAL AND METHODS

Study area

The study area is the basin of the Federal University of Santa Catarina (UFSC) campus in Joinville (BHCUJ). With some hydrological studies in the BHCUJ, it would be possible to verify if this basin where the UFSC is going to implement its campus is a flood-prone area because of the physical characteristics such as the presence of elevated water-table level and the backwater phenomenon caused by Piraí river.

The BHCUJ (12 km²) is in the southern part of Joinville city (**Fig. 1**). According to the Köppen classification, the climate in Joinville is predominately the mesothermal and humid type without a dry season. According to Mello & Oliveira (2016) the mean annual rainfall is 2130.1 mm. January is the rainiest month and its mean monthly rainfall is 355.6 mm, reaching more than 600 mm. As reported by Uberti (2011), the main soils are Cambisols, Neosols and Argisols in the BHCUJ.

For a hydrological monitoring purpose, the BHCUJ is divided into five sub-basins. Two of them are delimited with the outlet at the Braço Comprido river, two others at Lagoa Grande river. The channel lengths from the monitoring point P2 (along the Braço Comprido River) to the Piraí River and from the P5 to the river Piraí are 4.5 km and 5.5 km, respectively (**Fig. 2**).

Precipitation, water-level and discharge monitoring

The monitoring points are located at the sub-basins outlets (**Fig. 2**). The rain gauge and the water pressure sensor were coupled to the EPOSMote-III (hardware and software system based on GPRS communication technology), and their monitoring data was transmitted to the Grafana platform in real time. The EPOSMote-III was developed by the Software/Hardware Integration Laboratory (LISHA) of UFSC. The hardware used in monitoring project and the system of monitoring installed in the basins are shown in **Fig. 3**. The detail information on the installation and monitoring in the sub-basins was described by Malutta *et al.* (2017a).

Table 1 presents the monitoring periods in each sub-basin. The locations of four discharge and two precipitation monitoring points are found in **Fig. 1** and **2**.

Calculation of parameters for *Tc* estimation

The *Tc* estimation with some formulas in the literature requirs the calculation of morphometric properties of the basin and also data about the land use and vegetation to estimate the Curve Number (*CN*), Manning Number (*n*) and the maximum rainfall intensity ($I_{\_max}$). For the morphometric analysis, the map available in the Georeferenced Municipal Information System (SIMGeo) of Joinville and geoprocessing tools were used.

The *CN* was estimated by using the land use and vegetation map of the basin presented by UFSC (2010). After an observation of the river, bed and banks, the *n* value was determined based on Chow (1959). Moreover, $I_{\_max}$ was calculated by the mean maximum

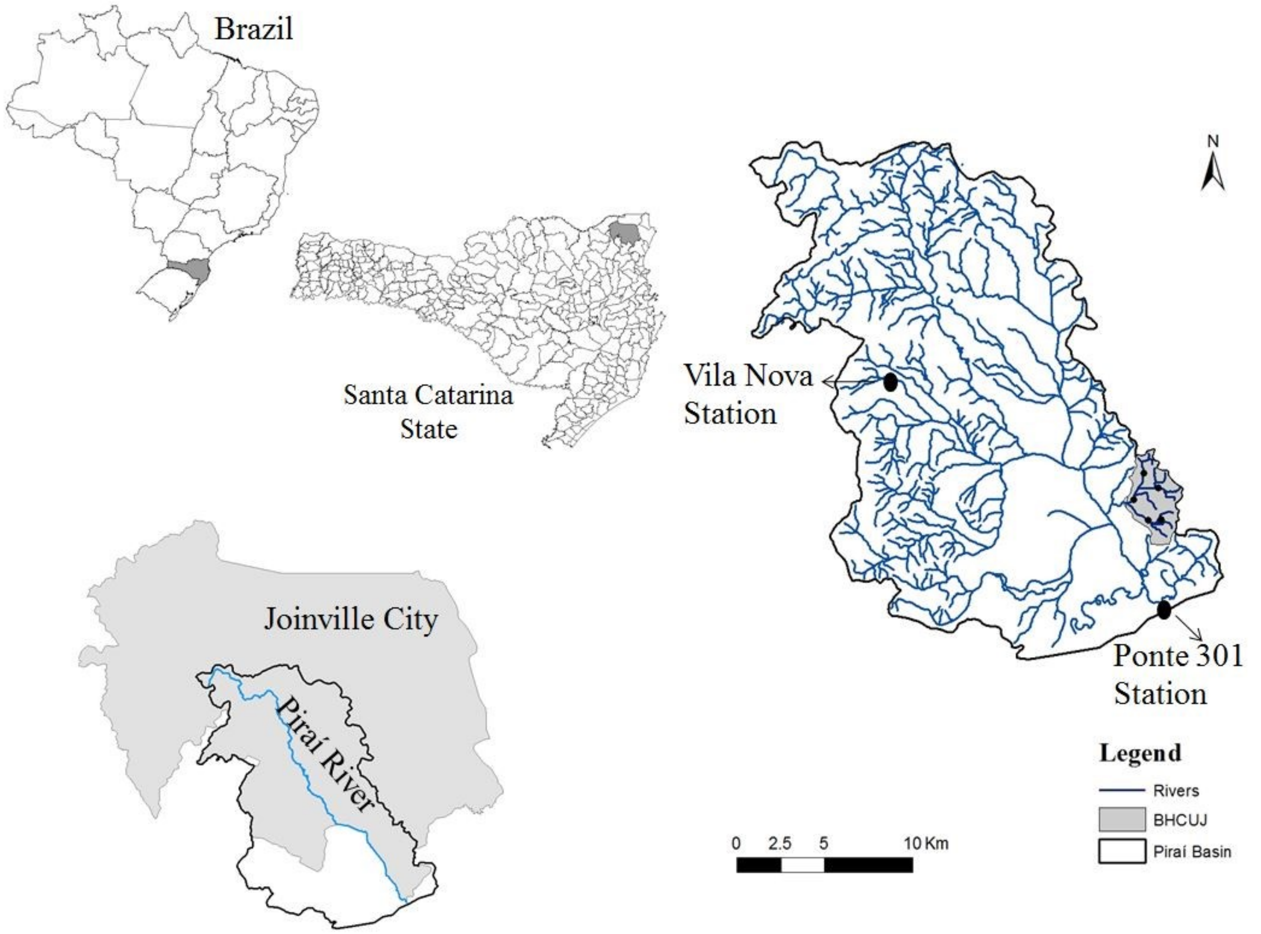

Fig. 1 Location of the Piraí River basin and the basin of the Federal University of Santa Catarina (UFSC) campus in Joinville (BHCUJ).

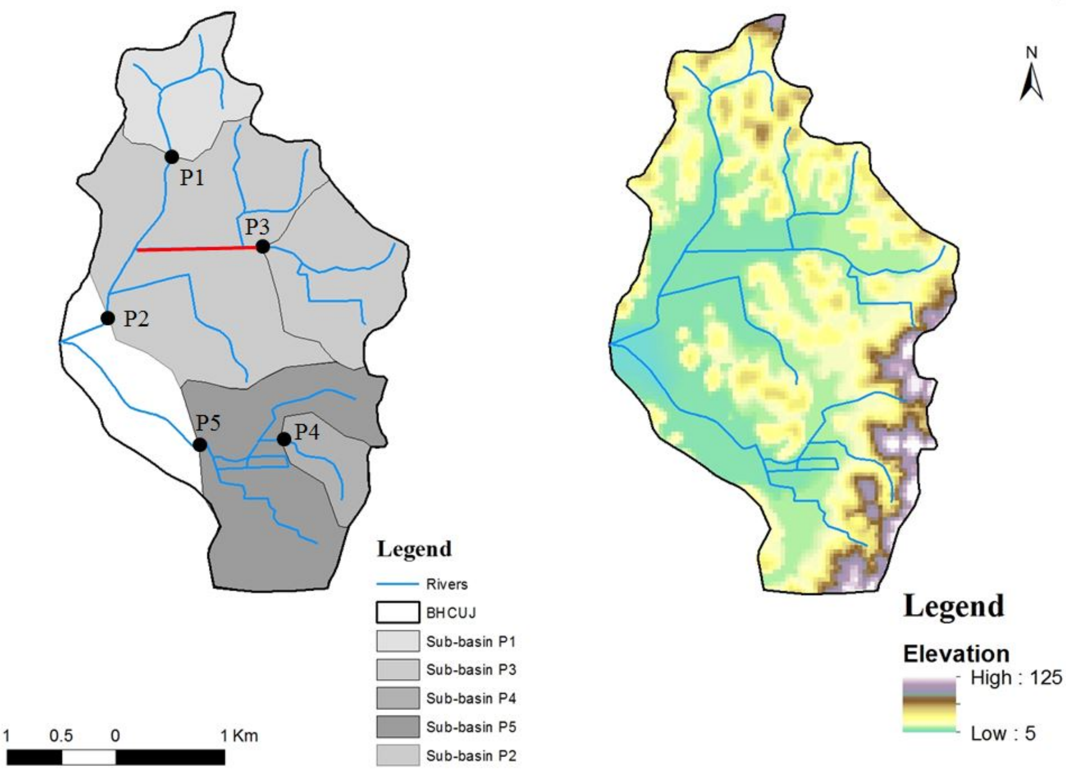

Fig. 2 Sub-basins and elevation in the BHCUJ. Note that the red line represents the dredged part of the river shown in Fig. 5

(a)

(b)

Fig. 3 Monitoring system installed in the basins: (a) EPOSMote-III; and (b) final layout.

Table 1. The monitoring periods for water level in river and precipitation at each sub-basin.

Sub-basin	Water level	Precipitation
P1	Jan/26-May/20/2017	-
P2	Fev/11-May/20/2017	Fev/11-May/20/2017
P3	Jan/18-May/20/2017	Jan/18-May/20/2017
P5	Apr/01-May/20/2017	-

intensity of all the events monitored during the period from January to April 2017.

Tc estimation

The equations below presents the empirical formulas used for the Tc estimation of each sub-basin. The summary of these formulas as well as their considerations were described by Silveira (2005). The basin morphometric parameters used in these formulas are: the drainage area A (km²), the main channel slope S (m/m), the basin length in a straight line from the outlet to the basin divide L (km), the basin mean elevation Hm (m), the main river slope Dt (m/m), the Manning coefficient n, and the maximum intensity of the analyzed events I_max (mm/5min).

The **Eq. (1)** is the Kirpich equation developed with data from six rural basins with reforestation (Kirpich, 1940).

$$tc = 0.62\left(\frac{L}{Dt}\right)^{0.8} \quad (1)$$

The **Eq. (2)** is the Pasini's equation developed for small basins and with little slope (Pasini, 1914).

$$tc = 0.108\cdot\left(\frac{\sqrt[3]{A\cdot L}}{\sqrt{Dt}}\right) \quad (2)$$

Eq. (3) called the Giandotti formula was developed with Italian basins (170 to 70,000 km^2) data (Greppi, 2005)

$$tc = 4\cdot\left(\frac{4\cdot\sqrt{A}+1.5\cdot L}{0.8\sqrt{Hm}}\right) \quad (3)$$

According to Johnstone & Cross (1949), **Eq. (4)** was developed based on data from 19 basins (64.8 and 4206.1 km^2) in the USA.

$$tc = 0.4623\cdot L^{0.5}\cdot S^{-0.25} \quad (4)$$

The **Eq. (5)** was deduced by Dooge (1956) based on studies by O'Kelly (1955) based on data from 10 basins (145 and 948 km^2) in Ireland.

$$tc = 0.3649\cdot A^{0.41}\cdot S^{-0.17} \quad (5)$$

The **Eq. (6)** is the Kerby-Hathaway's equation and was developed based on data from small basins where surface runoff is dominant (McCUEN *et al.* 1984). *N* is the surface type and in the present work is to 0.4 based on Kerby (1959).

$$tc = 0.6061\cdot\left(\frac{L\cdot N}{\sqrt{S}}\right)^{0.467} \quad (6)$$

The **Eq. (7)** is CHOW's equation and was based on data from 20 small basins (0.01 - 18.5 km^2) with little slope (9 - 0.51%) in the USA (CHOW, 1962).

$$tc = 0.1602\cdot L^{0.64}\cdot S^{-0.32} \quad (7)$$

The **Eq. (8)** is called the Papadakis & Kazan equation, developed from 84 rural basins with an area of less than 5 km^2 (USDA, 2010)

$$tc = \left(\frac{2.1539\cdot n^{0.52}+L^{0.5}}{i^{0.38}\cdot S^{0.31}}\right) \quad (8)$$

The **Eq. (9)** is the SCS lag equation developed with 24 basins (0.005 to 55 km^2).

$$tc = 0.3209 \cdot A^{0.5937} \cdot L^{-0.5937} \cdot S^{-0.1505} \cdot Sscs^{-0.3131} \quad (9)$$

$$\text{where } Sscs = \left(\frac{25400}{CN} - 254\right) \quad (10)$$

Tc estimation with the hydrographs and hyetographs analysis

By using hydrographs and hyetographs, McCuen (2009) mentioned six methods to estimate *Tc*, among which the present study used five ones described in **Table 3** and illustrated in **Fig. 4**. The M 1 is most commonly used. In this method, there is a possibility to have two cases: (a) 1 point of inflection; and (b) 2 inflection points (**Fig 4(b)**). Note that point A indicates the end of the surface flow, and B is considered the end of the subsurface flow.

Table 3. Description of the calculation the method proposed by McCuen (2009)

Method	Description
M 1	The time from the end of excess rainfall to the inflection point on the total storm hydrograph.
M 2	The time from the center of mass of excess rainfall to the center of mass of direct runoff.
M 3	The time from the maximum rainfall intensity to the time of the peak discharge.
M 4	The time from the center of mass of excess rainfall to the time of the peak of total runoff.
M 5	The time from the start of the total runoff to the time of the peak discharge of the total runoff.

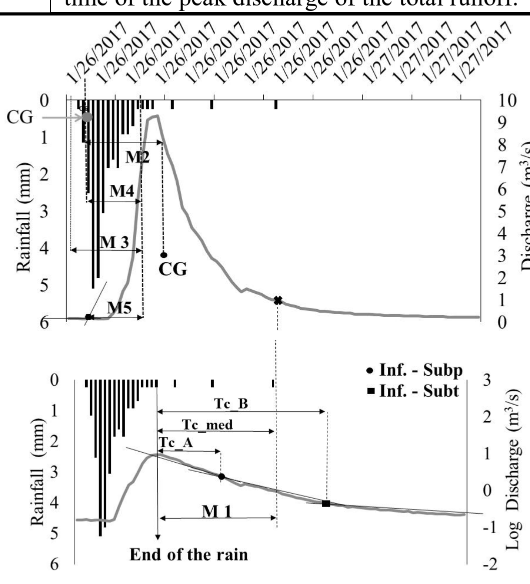

Fig. 4 Methods of calculating the time of concentration based on hydrographs and hyetographs: (a) Methods 2 to 5; and (b) Method 1.

RESULTS AND DISCUSSION

Precipitation, water-level and discharge monitoring

The discharge measurements were carried out mainly in the sub-basins 1, 2 and 3 (P1, P2, and P3). The discharge measurements at P4 and P5 have not started yet.

At P4, just after the installation of the physical frame to set up the sensors, the installation of the sensors was initiated. However, on January 17th, 2017 the installation of the pressure sensor at P4 was not possible. As shown in **Fig. 5a** an earthmoving work was carried out along the upstream part of P4. This earthmoving caused a sediment mobilization for the canal and ended up silting the channel, and consequently changing the flow section at P4 (**Fig. 5b**)

On January 22nd, 2017, the sediment deposition level reached 24 cm on the ruler at the P4 (**Fig. 5b**). When the ruler was initially installed, the zero on the ruler was set to the riverbed. Since the landscaping had not finished yet and the bed was continually changing, it was not possible to start the monitoring.

At the P5 the water-level measurement has been carried out. However, the stage-discharge rating curve has not been established yet.

Malutta *et al.* (2017a) described the stage-discharge rating curve analyzed at each monitoring point. There was an erosion event at P3, which required starting a new series of discharge measurements.

The bed erosion occurred due to a significant rainfall event on February 3rd, 2017. About one week before, dredging was done along a stretch between P3 and P2. Therefore, it may be thought that the

(a)

(b)

Fig. 5 Overviews of the P4 point at the sub-basin 4 outlet: (a) earthmoving; and (b) silting in the section vegetation removal caused this erosion (approximately 41 centimeters at the P3) and changed the bed along a stretch between P3 and P2 or/and because of a significant precipitation event. According to Rigotti & Pompêo (2011), the channel cleaning (or dredging) is a recurring practice in this stretch of channels.

Therefore, in the present study, the P3-1 is the denomination for the section before the cleaning on downstream in the channel and P3-2 is the denomination used for the new discharge measurements, topography, and stage-discharge.

Fig. 6(a) and **(b)** show the same channel stretch (note in the picture is the same tree in the margin). However, in the summer, rainy season in region, many channels are dredged. The red line in **Fig. 1** presents an extension of this dredging.

Fig.7 (a) show the stage-discharge relation at P3 and **Fig.7 (b)** show schematically the bed and banks of sub-basin 3, before and after erosion.

It is possible observed that the low level during the two periods the value of velocity was closed. Possibly, because in the bed of the river the Coefficient of Manning was not altered expressively.

However, in the higher level, the discharge in P3-2 is significantly larger, already in the upper level, with the withdrawal of vegetation, the margins became less resistant to the flow. Besides it is possible to perceive that the vegetation of the margins at P3-1 (almost at any point in the stretch between P2 and P3) starts at approximately 40 cm.

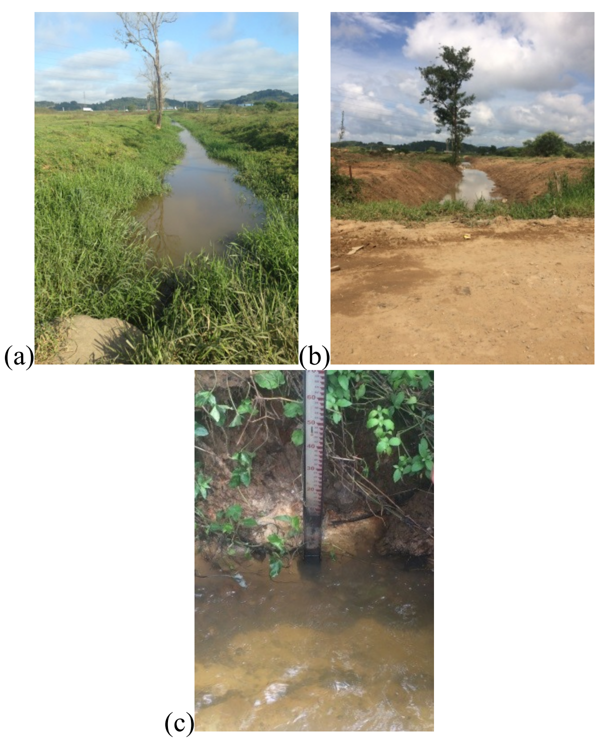

Fig. 6 Change in bed and banks channel between the point P2 and P3: (a) Natural, (b)"Cleaning" between P2 and P3 and (c) erosion at the point P3.

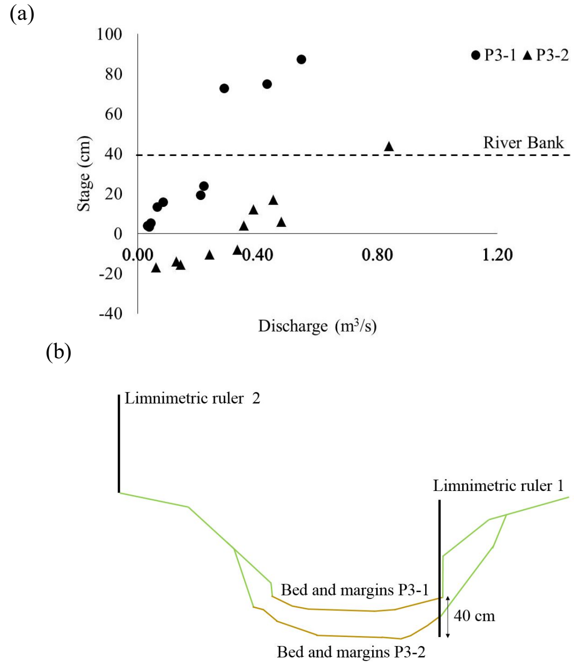

Fig. 7 (a) Stage-discharge P3-1 and P3-2, and (b) schematically the bed and banks River of sub-basin P3, before and after erosion.

To study the influence of the Piraí River basin on the BHCUJ was used the rainfall and levels monitoring stations of the basin located in **Fig. 1.**

Estimate the *Tc* with ten empirical and theoretical *Tc* formulas

Table 5 presents the estimation of these parameters for each sub-basin of this study, and **Table 6** and **Fig. 8** presents the results of the applications *Tc* equations for the sub-basins.

The empirical and theoretical equations were applied and the standard deviation in relation to the general average was around 65%. The Giandotti's and Johnstone's formulas presented the highest values of *Tc* for the sub-basins. It is not observed in Grecco *et al.* (2012) that found the highest *Tc* estimated by the

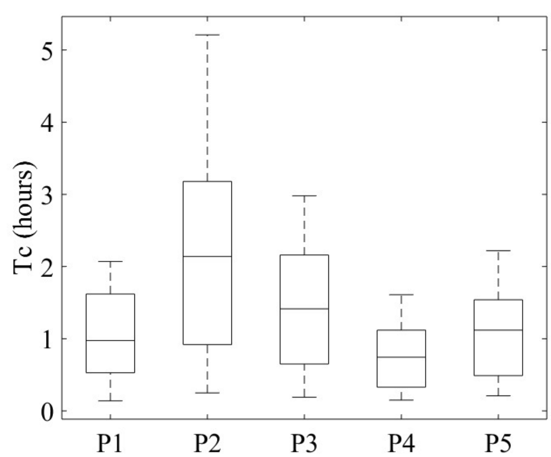

Fig. 8 Estimative of *Tc* based on equations

Table 5. Estimation of morphometric parameters for sub-basins

Parameter	Symbol	Unit	Sub-basin				
			P1	P2	P3	P4	P5
Area	A	km²	0.83	6.92	2.89	1.23	2.17
Main channel length	Lr	km	2.22	5.06	2.85	1.16	3.95
Straight length of basin	L	km	1.29	3.81	2.37	1.12	1.32
Altitude of outlet	He	m	10.80	10.00	14.30	14.50	10.00
Mean elevation	Hm	m	18.48	15.20	18.91	22.51	19.70
Mean slope of river	Dt	m/m	0.036	0.025	0.038	0.065	0.087
Mean slope of channel	S	-	0.004	0.004	0.006	0.014	0.005
Curve Number	CN	-			73		
Maximun Intensity	i_max	mm/5min			4.25		

Table 6. Results of the *Tc* equations for the sub-basins

Equation	Time of concentration (hour)				
	P1	P2	P3	P4	P5
Kirpich	0.29	0.79	0.46	0.20	0.21
Pasini	0.58	2.03	1.05	0.47	0.52
Giandotti	1.62	5.21	2.98	1.61	2.22
Johnstone	2.07	3.60	2.61	1.42	1.96
Dooge	0.86	2.07	1.36	0.82	1.22
Kerby-Hathaway	1.60	2.68	1.99	1.12	1.53
Chow	1.09	2.21	1.47	0.67	1.02
Morgali & Linsley (Kinematic wave)	1.64	3.18	2.16	1.04	1.54
Papadakis & Kazan	0.53	0.92	0.65	0.33	0.49
Simas-Hawkins	0.14	0.25	0.19	0.15	0.23

Chow's and Pasini's formulas. Since the Giandotti's formula was established for mountainous basins, it may not be appropriate for the present study.

The Simas-Hawkins's and Kirpich's formulas presented the smallest values. The results of Kirpich's formula can be considered underestimated, which coincides with the results obtained by McCuen *et al.* (1984) and Mota & Kobiyama (2012). Though the Simas-Hawkins's and Kirpich's formula were proposed by using basin events in areas similar to those in the present study, they may not show the same rainfall-discharge processes. It should be noted that Silveira (2005) observed that, the group formed by the formulas of Kirpich and Chow obtained good results for rural basins.

In the sub-basin P2, the difference of *Tc* values between the Simas-Hawkins's and the Giandotti's formulas is almost five hours. Fang *et al.* (2008) showed the mean differences of *Tc* estimated using the equations with the same set of basin parameters vary from -38 to 207%, whose absolute mean differences are from -3.0 to 2.8 hours.

Tc determination through the method of analysis of the hydrographs and hyetographs

Some events during the period from January to May of 2017 were analyzed for the sub-basins P1, P2, P3 and P5. The Sub-basin P4 did not have data enough to be analyzed yet due to the silting problem mentioned above.

The events were selected in the monitoring period of the basin to identify the *Tc* through hydrographs and hyetographs analysis. In sub-basin P1, P2 and P5, sixteen, twenty and nine events were chosen, respectively. As mentioned above, the sub-basin P3 had two periods of monitoring: P3-1 (the period before the bed erosion) and P3-2 (the period after the erosion).

Sub-basin P1

Figure 9 shows the *Tc* estimates for P1. In the sub-basin 1 the mean *Tc* was 1.86 hours, being the maximum and the minimum of *Tc* 7.92 and 0.25 hours, respectively.

The M1 estimated the highest median of *Tc*. The empirical formulas have the lowest *Tc* estimate. The extreme points that appear in M1 and M5 are the same event which occurred in May 2017. In this event the rainfall was well distributed and its duration was 10 hours, which caused the hydrograph to rise and to descend more slowly. Therefore the rainfall of this event presented its duration more significant than the other events. The short duration and high intensity of rainfall are characteristics of the summer. On the other hand, the rainfall in the region in autumn and winter are longer and less intense.

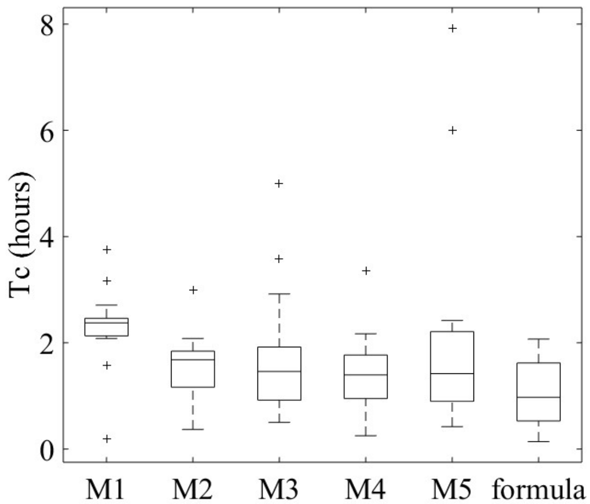

Fig. 9 *Tc* values in the sub-basin P1.

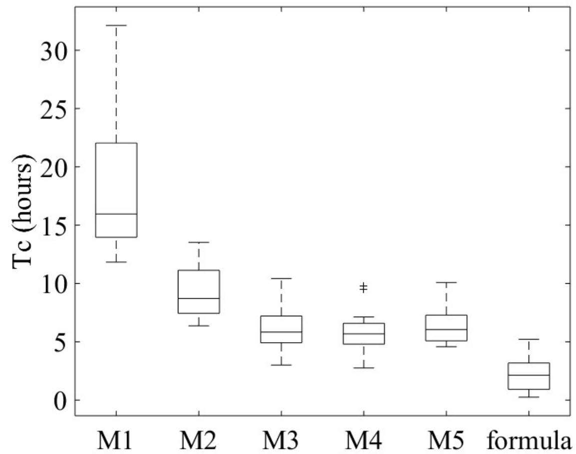

Fig. 10 - *Tc* values in the sub-basin P2.

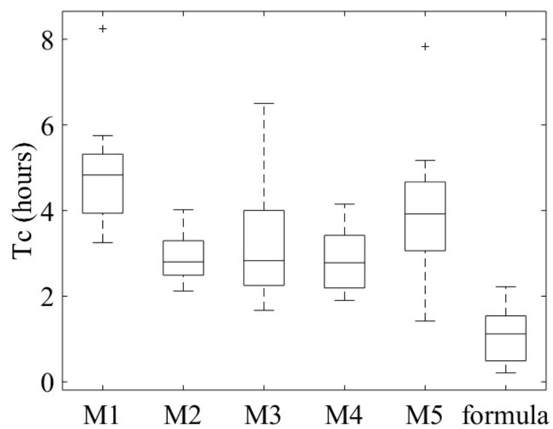

Fig. 11 *Tc* values in the sub-basin P5.

The M 5 where *Tc* was calculated between the start time of the event and the maximum discharge, the highest standard deviation was obtained (**Fig. 9**). This time depends much on the soil saturation conditions.

Sub-basin P2 and P5

The results of sub-basin P2 and P5 were analyzed together in order to compare if the events in these two sub-basins are effect by the Rio Piraí. In the sub-basin P2, the mean *Tc* was 9.21 hours, with the maximum of 32.13 and the minimum of 2.75 hours. The M1 estimates the highest median of *Tc* and the largest standard deviation (**Fig. 10**).

In the sub-basin P5, the mean *Tc* was 3.63 hours, with the maximum of 8.25 and the minimum of 1.42 hours. The M1 estimates the highest median of *Tc* meanwhile the M5 has the largest standard deviation (**Fig. 11**). The M5 is based on the time from the start of the total runoff to the time of the peak discharge. Bondelid et al. (1982) indicated that as much as 75% of the total error in peak discharge estimates could be ascribed to errors in the estimation of time parameters.

The observation of the events in sub-basins 2 and 5 permits to note that some events had a much larger falling limb than others. **Figure 12** illustrated (a) a "normal" event in P2 and (b) an event with the possible influence of the Piraí River in P2. **Fig. 13** showed the P2 on one of these days exemplified by **Fig. 12**.

Table 7 shows that in the sub-basins P2 and P5 there were higher *Tc* in some events (for example on day April, 17 to 19 that in *Tc* of P2 reached 32 hours). The events of sub-basin P2 and P5 are listed in **Table 7** which includes on the same dates the water-level of the Piraí River at the monitoring section Ponte 301 and the rainfall data of the Vila Nova rainfall station (located in **Fig. 1**). Nine events in the sub-basin P2 and three events in the sub-basin P5 are considered those probably suffered from the influence of the Piraí River backwater. In some events, it is observed that the total rainfall at Vila Nova Station was much larger than that at Ponte 301 Station.

The normal water-level in the section of Ponte 301 ranges from 35 to 60 cm. In the events listed in **Table 7**, the levels are higher than these values. Hence, the Piraí River may tend to dam the Braço Comprido River and Lagoa Grande river and this phenomenon are identified in P2 and P5 (with more intensity in P2).

It must be reported here that local residents often comment the influence of groundwater on a large area of the sub-basin P2. In rainy seasons it is possible to observe lakes formed in the extensive flat area of the sub-basin P2, which disappear in the dry period.

Sub-basin 3

In the sub-basin P3 which is the downstream of P2, the *Tc* values were estimated 4.19 hours for P3-1 (before the erosion in the channel) and 2.07 hours for P3-2 (after the erosion). With all the methods, it is clearly noted that a reduction of approximately 50% in *Tc* occurred (**Table 8**). Wong & Li (2009) showed that *Tc* could decrease to 4-39% of its original value when the basin is urbanized.

Table 7. Detailed calculation of *Tc* values for the sub-basins P2 and P5

Sub-basin		P2							P5									
N°	Event	M 1			M 2	M 3	M 4	M5	M1			M 2	M 3	M 4	M5	Rainfall (mm)		Level (cm)
		Tc_A	Tc_B	Tcmed					Tc_A	Tc_B	Tcmed					Vila Nova	Ponte 301	Ponte 301
1*	12-14/02/2017	16.58	40.33	28.46	12.60	6.00	5.65	5.25	-	-	-	-	-	-	-	70.6	31	160
2	23-25/02/2017	17.50	-	17.50	8.37	4.92	4.73	5.00	-	-	-	-	-	-	-	47.4	34	82
3*	01-03/03/2017	12.08	34.25	23.17	13.52	7.17	7.13	7.58								62.4	36.5	130
4**	03-04/03/2017	15.17	-	15.17	7.53	4.58	4.52	4.58	-	-	-	-	-	-	-	14	1	111
5**	04-05/03/2017	12.33	-	12.33	6.37	5.08	5.03	5.17	-	-	-	-	-	-	-	25.2	3.8	104
6*	05-07/03/2017	14.58	41.50	28.04	12.05	4.92	4.27	5.08	-	-	-	-	-	-	-	23.2	5.2	144.2
7*	08-10/03/2017	13.75	26.67	20.21	8.00	3.92	3.93	7.08	-	-	-	-	-	-	-	15.6	6.8	106
8	17-19/03/2017	15.17	-	15.17	10.20	7.17	5.70	6.42	-	-	-	-	-	-	-	61.6	25	102
9*	23-26/03/2017	12.83	35.67	24.25	12.20	10.25	9.78	10.08	-	-	-	-	-	-	-	70.6	25.1	216
10*	02-03/04/2017	12.17	23.42	17.79	9.03	5.08	6.38	7.50	3.75	-	3.75	2.12	2.25	2.23	2.25	41	9.5	148
11**	06-07/04/2017	16.00	-	16.00	9.83	8.00	6.58	6.75	4.00	-	4.00	2.80	5.00	4.15	5.17	23.4	11.4	119
12*	08-11/04/2017	20.92	43.33	32.13	12.18	3.00	2.75	7.92	4.83	-	4.83	3.07	2.33	2.08	4.42	101.2	13.8	198
13*	11-14/04/2017	14.17	27.67	20.92	10.10	4.33	4.87	5.92	8.25	-	8.25	4.02	2.25	2.75	3.50	48.6	4.6	223
14*	16-18/04/2017	11.00	18.42	14.71	9.82	10.42	9.47	9.67	-	-	-	-	-	-	-	48.6	11.4	126
15	19-20/04/2017	12.75	-	12.75	8.27	7.83	6.58	5.83	-	-	-	-	-	-	-	10.2	2.7	106.2
16	21-23/04/2017	14.42	-	14.42	7.03	5.83	5.38	6.67	-	-	-	-	-	-	-	6.2	-	-
17	26-27/04/2017	13.50	-	13.50	7.20	5.00	5.20	5.08	3.25	-	3.25	2.22	1.67	1.90	1.42	13	15.3	75
18	02-03/05/2017	12.67	-	12.67	7.33	6.00	6.08	4.83	5.75	-	5.75	3.12	3.67	3.88	4.50	2.6	4.7	40
19	04-05/05/2017	11.83	-	11.83	7.35	5.83	5.80	5.08	3.08	6.58	4.83	3.82	2.83	2.78	3.92	25.2	6.1	85.5
20	13-14/05/2017	15.92	-	15.92	8.40	7.25	6.93	6.17	4.67	-	4.67	2.68	3.58	3.27	3.33	8	7.6	27.5
21*	18-20/05/2017								5.17	-	5.17	2.58	6.50	2.85	7.83	261	133	196
Mean				18.35	9.37	6.13	5.84	6.38	-	-	4.92	9.37	6.13	5.84	6.38	-	-	-
(Without Events *)				14.30	7.99	6.14	5.69	5.60	-	-	4.46	2.99	3.29	3.18	3.75	-	-	-
Means (Events *)				23.30	11.06	6.12	6.03	7.34	-	-	5.33	2.89	3.38	2.64	4.27	-	-	-

* Events with influence fo Pirai River

** Events that are not sure of backwater infelucency

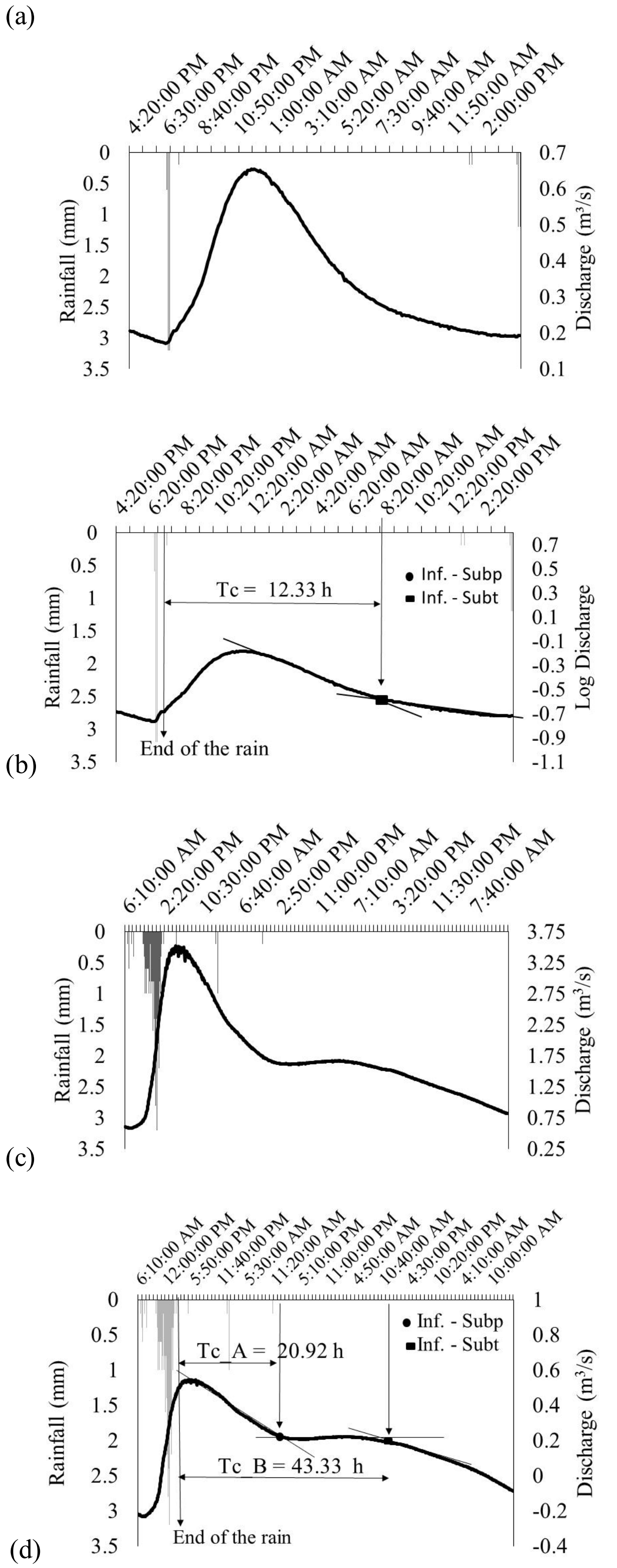

Fig. 12. Hydrograph and hyetograph in P2: (a) normal event; (b) *Tc* calculation of the normal event; (c) event with possible influence of the Piraí River; (d) *Tc* calculation of the event with possible influence of the Piraí River.

Fig. 13. Event in P2 with possible influence of the Piraí River.

Table 8. *Tc* values in the sub-basin P3 with two different situations (P3-1 and P3-2)

Sub-basin	Mean *Tc* (hours)					
	M1	M2	M3	M4	M5	Mean
P3-1	6.41	3.23	3.82	3.23	4.25	4.19
P3-2	2.83	1.87	2.19	1.66	1.78	2.07

The M2 and M3 were the ones that presented the most significant differences between the two periods (almost 60%). The M3 based on the difference between the maximum rainfall intensity and the hydrograph peak, possibly the fastest hydrograph peak due the removal of vegetation in the upstream section of station P3.

CONCLUSIONS

Since *Tc* is an important parameter of time and widely used in hydrological methods and in drainage design, the present study evaluated this value in various sub-basins inside the BHCUJ, Joinville city, Brazil.

Among the sub-basins, the highest *Tc* values estimated by the empirical formulas were for P2, which was already expected since this sub-basin has the largest area and small slopes. It was possible to notice that the falling limb in some events is much slower than in others. Analyzing the water-level data of another station Ponte 301, it was noted that there is a backwater effect of the Rio Piraí, thus damming the River Braço Comprido and the Rio Lago.

The *Tc* values in the sub-basin before and after vegetation removal in a stretch between P2 and P3 were evaluated. Based on the analysis of hydrograph and hyetograph methods, the mean reduction in *Tc* was around 50%. The M2 and M3 presented the biggest difference (approximately 60%) between the two periods. Therefore, it can be thought that the *Tc* is much more related to channel hydraulic parameters (Manning coefficient, water velocity and discharge) than morphometric parameters of the basin.

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