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Comparative Analysis of Concentration Time Calculation Methodologies: A Case Study of the Igapó Lakes Watershed in Londrina-PR

Análise Comparativa de Metodologias de Cálculo de Tempo de Concentração: Um Estudo de Caso da Bacia Hidrográfica dos Lagos Igapó em Londrina-PR

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Abstract

Concentration time is an essential hydrological parameter for various hydrological analyses and for the design of hydraulic infrastructures, and can be estimated using different equations. This study assessed which concentration time calculation methods are most suitable for the Igapó lakes watershed in Londrina, PR, considering its morphometric characteristics and land use and occupation. Initially, a review of the main available methods was carried out, identifying those applicable to the watershed in question. The selection of the Williams (1922), Haktanir & Sezen (1990), Desbordes (1974), Espey-Winslow (1966), and Federal Aviation Administration (1970) methods, considered the most representative for this watershed, was based on the watershed geomorphological characterization. Five methods theoretically compatible with its characteristics were analyzed. However, when comparing the results, a significant variation in the estimated values was observed. To determine the most appropriate method, the calculated concentration times were compared with the watershed's geomorphological and morphometric parameters. The results indicated that the Desbordes and Federal Aviation Administration methods are the most suitable for representing the Igapó lakes watershed's hydrological reality. However, there were no direct local validations.

Keywords:
Urban Watersheds, Morphometry, Hydrology, Precipitation.

Resumo

O tempo de concentração é um parâmetro hidrológico essencial para diversas análises hidrológicas e para o dimensionamento de infraestruturas hidráulicas, podendo ser estimado por diferentes equações. Este estudo avaliou quais métodos de cálculo do tempo de concentração são mais adequados para a bacia hidrográfica dos lagos Igapó, em Londrina – PR, considerando suas características morfométricas e o uso e ocupação do solo. Inicialmente, foi realizada uma revisão dos principais métodos disponíveis, identificando aqueles aplicáveis à bacia em questão. A seleção dos métodos: Williams (1922), Haktanir e Sezen (1990), Desbordes (1974), Espey-Winslow (1966) e Federal Aviation Administration (1970), considerados os mais representativos para esta bacia foi baseada na caracterização geomorfológica da bacia. Foram analisados cinco métodos teoricamente compatíveis com suas características, porém, ao comparar os resultados, observou-se uma variação significativa nos valores estimados. Para determinar o método mais apropriado, os tempos de concentração calculados foram confrontados com parâmetros geomorfológicos e morfométricos da bacia. Os resultados indicaram que os métodos de Desbordes e do *Federal Aviation Administration* são os mais adequados para representar a realidade hidrológica da bacia dos lagos Igapó, todavia não houve validações locais diretas.

Palavras-chave:
Bacias urbanas, Morfometria, Hidrologia, Precipitação.

I. INTRODUCTION

Phenomena such as soil infiltration, surface runoff, and evapotranspiration are directly influenced by the relationship between a watershed's hydrological cycle and geomorphological characteristics (Braga et al., 2017). These phenomena are related to the area, perimeter, slope, and extent of the channels of water bodies, which may or may not contribute to the surface runoff volume or to retention or infiltration capacity (Santos et al., 2012). A watershed's geomorphological characteristics directly influence its hydrological behavior, since they are correlated to its flow regime. Several hydrological parameters stand out among the main geomorphological attributes, such as drainage area, watershed shape, compactness coefficient, form factor, stream order, drainage density, and slope. These parameters can be obtained through the analysis of maps, aerial photographs, and digital elevation models generated from satellite images (Farias Júnior; Botelho, 2011; Braga et al., 2017).

Concentration time, among the various hydrological parameters influenced by geomorphological characteristics, stands out due to its relevance in hydraulic infrastructure design and in hydrological modeling. Concentration time is defined as the time it takes for rainfall at the furthest point in the watershed to reach the outlet, or for the entire watershed to contribute to the flow at the outlet (Mata-Lima et al., 2007, Fang et al., 2008; Mostarda Neto et al., 2023).

Concentration time is researched and used in hydrological studies, analyses, or projects that require at least one watershed response parameter. This parameter is chosen for these studies due to its diverse applications such as "implementation of flood warning systems, urban drainage projects, hydrograph separation, and definition of the hydrological monitoring interval" (Mota; Kobiyama, 2015; Salis et al., 2019; Mansour; Pinheiro, 2023).

Changes in land use and occupation directly influence concentration time. Urban growth leads to greater soil impermeability, reducing infiltration and intensifying surface runoff. This process causes rainwater to reach river channels more quickly, resulting in a decrease in concentration time of the watershed (Alvarenga et al., 2019).

Studying concentration time is fundamental to understanding the surface runoff dynamics, especially in areas subject to intense environmental transformations. In Brazil, extreme events such as increased rainfall in the south, prolonged droughts in the Amazon, and irregular rainfall in the northeast have been associated with climate change, impacting the hydrological regime and increasing the frequency of floods and droughts (Salvador et al., 2024).

An efficient way to calculate concentration time of a watershed is by using 3D hydrodynamic models; however, these models require high computational costs, extensive topographic detail, and land use and land cover data, in addition to having difficulty representing the initial diffuse surface runoff.

Since the Igapó lakes watershed lacks the necessary data detail for the use of a 3D hydrodynamic model, this research is limited to comparing experimental and analytical methods, resulting in empirical or semi-empirical equations that are adjusted to the physical and hydrological characteristics of the watershed used to develop the equations (Almeida et al., 2014).

Since the methods for calculating concentration time of a watershed are empirical, many errors can occur in concentration time estimation if these methods are not selected and applied correctly, significantly impacting peak flows or design flow. Therefore, the chosen method must be appropriate for a watershed with conditions similar to those in which the method was originally developed (Mostarda Neto et al., 2023).

The choice of an appropriate method for calculating concentration time directly influences the accuracy of hydrological analyses. A study conducted by Braga et al. (2017) in a rural watershed in the countryside of Ceará, characterized by high soil infiltration rates, illustrates this relevance. The authors compared three calculation methods – Kirpich, Temez, and Vem Te Chow –, and concluded that the Kirpich equation was the most appropriate for the watershed in question. The other two methods showed significant discrepancies in the results, with one estimating a concentration time 63% higher and the other almost half the value obtained by the Kirpich equation. This study highlights the importance of considering a watershed' morphometric and climatic characteristics when choosing the calculation method.

In the research developed by Mostarda Neto et al*.* (2023), the authors identified that the most suitable equation for the Itaim stream watershed was the Kirpich equation. Furthermore, they highlighted that most methods for calculating concentration time consider the thalweg length and the equivalent slope as variables. While the thalweg length has a directly proportional relationship with concentration time, the slope is inversely proportional.

The study conducted by Cargnin et al*.* (2023) analyzed ten methods for calculating concentration time in six watersheds in Rio Grande do Sul. The results showed that the Ventura equation was the most suitable for the Maquiné and Santa Maria watersheds, while the Kirpich method proved more appropriate for the Taquari and Camaquã rivers. For the Caí and Icamaquã rivers, the Giandotti equation presented the best results.

In a study conducted by Silveira (2005), 23 equations for calculating concentration time were assessed in 29 rural and 32 urban watersheds. The author concluded that some equations are excellent for rural watersheds but do not present satisfactory results in urban watersheds; other methods only presented good results for small watersheds. However, the author found no physical reason to explain the contrast among the values obtained by the different equations, but he states that this variation is directly related to roughness parameters and rainfall intensity. In other words, the choice of an appropriate method depends directly on the climate and morphological conditions of the watershed studied, and on the variables that each equation has, such as consideration of impervious area, which is fundamental for urban watersheds.

The method for calculating concentration time of a watershed is a choice left to the analyst's discretion. Various methods can be used, always respecting a watershed's morphological characteristics, in order to compare them and finally choose the one that best represents the watershed's hydrological reality. In other words, it is essential to verify the limitations of each model, whether regarding watershed land use characteristics (urban or rural), area, slope, the main thalweg length, eCt. (Silveira, 2005; Mata-Lima et al*.*, 2007; Fang et al*.*, 2008).

Therefore, studies that analyze equations for calculating concentration time should avoid classifying all equations into a single "ranking". Instead, they should provide indicators that allow for a conscious choice for each specific situation, taking into account the morphometric characteristics of each watershed. In general, these indicators are some morphometric and/or morphological characteristics of a watershed (Mostarda Neto et al*.*, 2023).

Although the geomorphological characteristics of a watershed remain relatively stable over time, the conversion of rural areas or native vegetation into urban environments significantly impacts concentration time. Urbanization leads to soil impermeability, reducing infiltration and intensifying surface runoff within the watershed. These changes directly influence the design of hydraulic structures, which may be subjected to high water loads in short periods of time. Thus, the inappropriate choice of method for calculating concentration time can result in over- or under-sizing of these structures, increasing construction costs and compromising their efficiency (Rocha et al., 2022).

In this context, the present research aims to assess which equations for calculating concentration time are most suitable for the Igapó lakes watershed in the municipality of Londrina, PR, taking into account morphometric characteristics and land use and occupation within the watershed, based on a bibliographic survey, where several methods for calculating concentration time were identified, as described by Silveira (2005), Mata-Lima et al. (2007), Fang et al. (2008), Salimi et al. (2017), Azizian (2018), Mostarda Neto et al. (2023) and Cargnin et al. (2023). These authors present a detailed mapping of available methods, indicating the physical characteristics that a watershed must possess to fit into each of them.

II. MATERIAL AND METHODS

Study area contextualization

Londrina, emancipated in 1934, experienced rapid growth driven by coffee production, especially between the 1930s and 1970s. Between 1950 and 1959, its population jumped from 20,000 to 75,000 inhabitants, a period in which the first Igapó lake was built (Londrina City Council, 2024). Currently, the municipality has 555,965 inhabitants, being the second largest city in Paraná and the fourth largest in the southern region (IBGE, 2023).

Londrina's urban landscape is the result of several landscape transformations that occurred in the municipality during a period of significant population growth. The three dams built on the Cambé stream are some of the main constructions that changed Londrina's landscape, creating water reservoirs popularly known as Igapó lakes.

Although the Igapó lakes are currently located in a highly urbanized region, this was not always the case, since Igapó lake I was inaugurated in 1959, and at that time the area surrounding the lake was far from the city's urban area. In 1976, a new dam was built on the Cambé stream, creating Igapó lake II, and at the end of the same decade, a third dam was built, giving rise to Igapó lakes III and IV, which, although popularly considered

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as two distinct lakes, are two parts of the same reservoir separated by a bridge (Bortolo; Fresca, 2011; Oliveira 2018).

Thus, considering that urban expansion and consequent soil impermeabilization can lead to a decrease in concentration time, that there are three dams in the Igapó lakes — one built in the late 1950s and the other two in the late 1970s — and that the population dynamics of the municipality of Londrina have changed significantly since then, causing the population to more than double from the construction of the dams to the present day (Arruda, 2018), the importance of knowing concentration time of this watershed is noted, since it directly impacts the calculation of the maximum flow at the outlet.

The research focused on the Igapó lakes watershed in the municipality of Londrina, a sub-watershed of the Cambé stream. To choose the most appropriate method for calculating concentration time for the Igapó lakes watershed, the following watershed morphometric characteristics were first mapped: total area; urbanized area; total perimeter; watershed diameter; main thalweg length; river channel vector length; total length of all watercourses in the watershed; and average slope. Since some models for calculating concentration time have restrictions regarding area, average slope, and main thalweg length, these parameters served to guide the choice of methods. The QGIS 3.28.13 software was used to obtain the geomorphological parameters necessary for the calculations according to the chosen equations.

To better understand the impact of rainfall concentration time on a watershed, it is necessary to know the climate of the region where the watershed is located. Thus, according to the Köppen-Geiger climate classification, the municipality of Londrina is categorized as having a Cfa climate, a humid subtropical climate, with an average air temperature in the coldest month below 18 °C and an average temperature in the warmest month above 22 °C. The climate features hot summers and few frosts, with a tendency for rainfall to concentrate during the summer, but without a defined dry season (Alvares et al., 2013; Aparecido et al., 2016).

Urban expansion and soil sealing directly influence the watershed's concentration time, impacting the calculation of the maximum flow at the outlet. Considering that the population of Londrina, in the Igapó lakes' watershed area, has experienced intense growth since the construction of the dams, understanding this hydrological dynamic becomes essential (Arruda, 2018).

This allows for a better understanding of the land use patterns in the Igapó lakes watershed, located in the central region of Londrina (Figure 1).

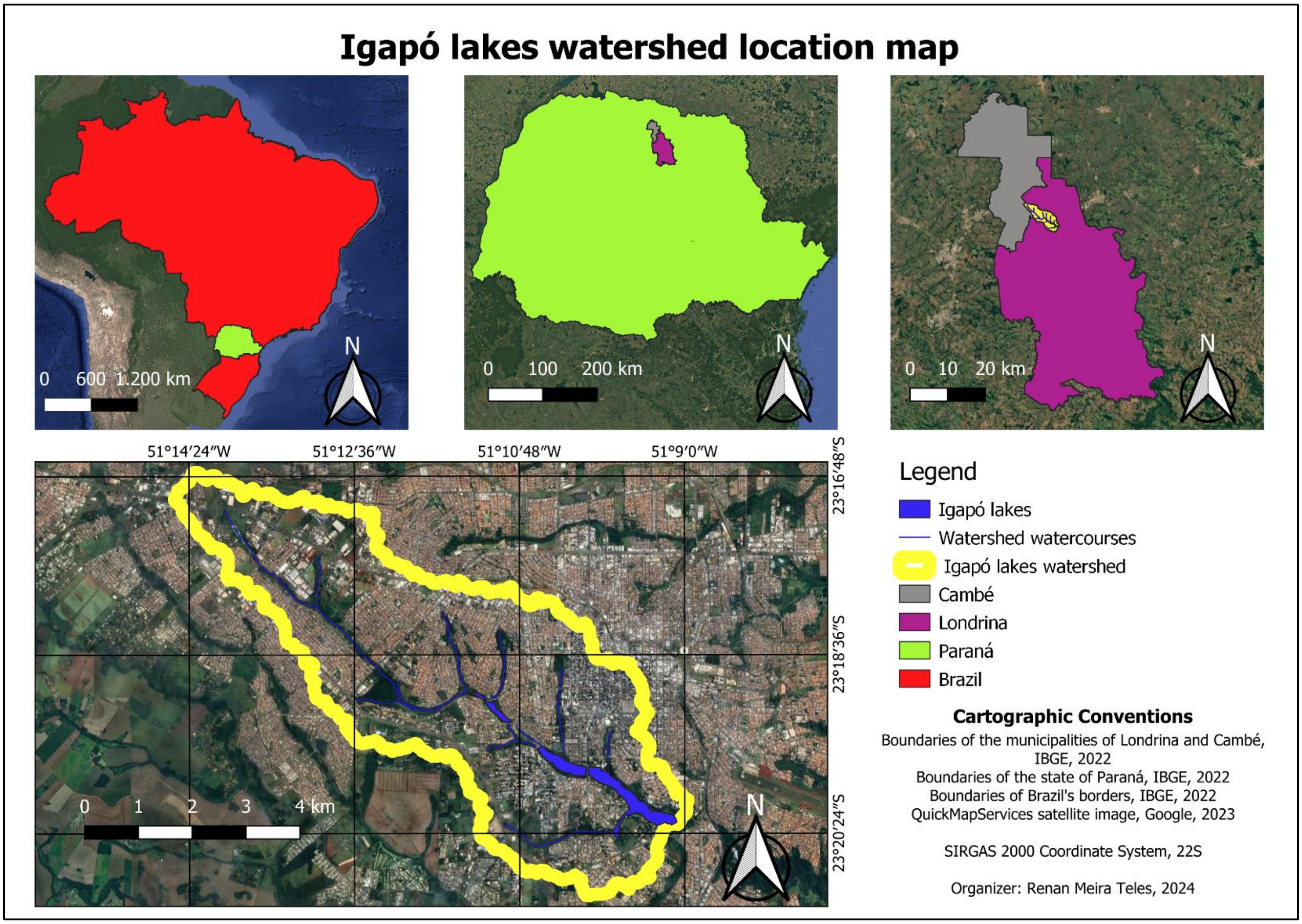

Figure 1 – Igapó lakes watershed location map. Source: Authors 2025.

Analysis of Figure 1 reveals that most of the Igapó lakes' watershed is located within an urban area. To better understand the degree of urbanization in this watershed, it is essential to examine the urbanization process of the municipality of Londrina.

Criteria for choosing a method to calculate concentration time

As previously described, a literature review was conducted, identifying several methods for calculating concentration time. Schaake, Debordes, Espey-Winslow, Federal Aviation Administration, Carter, and McCuen methods stood out, primarily due to their limited application to urban watersheds. However, this analysis also revealed methods that lacked specific information regarding the land use characteristics of their watershed. The next stage, using QGIS 3.28.13 software, was to obtain the following physical characteristics: total watershed area (km²); urbanized watershed area (%); total watershed perimeter (km); total watershed diameter (km); main thalweg length (km); fluvial channel vector length (km); total watercourse length (km); and average slope (%).

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These physical characteristics were then used to calculate a watershed' form factor, sinuosity index, compactness coefficient, circularity index, and drainage density (Bortolini et al., 2021; Braga et al., 2017) (Table 1).

Table 1 – Equations for physical characteristics

Hydrological parameters	**Equation**	**Equation number**	**Equations' terms**
Compactness coefficient (Cc)	$C_c = 0.28 * \left(\frac{P}{\sqrt{A}}\right)$	(1)	C_c – Compactness coefficient; A - Watershed area (km²); P – Watershed perimeter (km).
Form factor (Ff)	$F_f = \frac{A}{L^2}$	(2)	F_f - Form factor; A - Watershed area (km²); L – Watershed's main thalweg length (km).
Circularity index (Ci)	$C_i = 12.57 * \left(\frac{A}{P^2}\right)$	(3)	C_i – Circularity index; A - Watershed area (km²); P – Watershed perimeter (km).
Sinuosity index (Si)	$S_i = 100 * \left(\frac{L - L_{vetorial}}{L}\right)$	(4)	S_i – Sinuosity index (%); L – Total main thalweg length (km); $L_{vetorial}$ - Vector main thalweg length (km).
Drainage density (Dd)	$D_d = \frac{L_{total\ of\ rivers}}{A}$	(5)	D_d – Drainage density (km/km²); $L_{total\ of\ rvers}$ – Total length of rivers in the watershed (km); A - Watershed area (km²).

Source: Adapted from Soares and Galvíncio (2020) and Vendruscolo et al. (2020).

After calculating these five hydrological parameters, the next stage was to classify them in order to understand the Igapó lakes watershed's hydrological behavior. This classification was carried out based on reference values presented in Table 2.

Table 2 – Reference values for classifying hydrological parameters

Parameter	Unit	Limits	Class
Coefficient of compactness (Cc)	-	1.00 – 1.25 1.26 – 1.50 >1.50	High propensity for flooding Average tendency towards flooding Not subject to flooding
Form factor (Ff)	-	<0.50 0.50 – 0.75 0.76 – 1.00	Not subject to flooding Average tendency towards flooding Subject to flooding
Circularity index (Ci)	-	0.36 – 0.50 0.51 – 0.75 0.76 – 1.00	Elongated shape Intermediate form Circular shape
Sinuosity index (Si)	%	<20 20 – 29 30 – 39.9 40 – 49.95 >50	Circular shape Straight Wandering Winding Very winding
Drainage density (Dd)	Km/km²	<0.50 0.5 – 2.00 2.01 – 3.50 >3.50	Low Average High Very high
Average slope (S)	%	0 – 3 3 – 8 8 – 20 20 – 45 45 – 75	Flat Gently wavy Wavy Strong wavy Mountainous

Source: Adapted from Vendruscolo et al. (2020).

After performing the morphometric characterization of the Igapó lakes watershed, the next stage was to map which equations are suitable for these watershed characteristics. For this, we used the mappings of methods for calculating concentration time carried out by Silveira (2005), Mata-Lima et al. (2007), Fang et al. (2008), Salimi et al. (2017), Azizian (2018), Mostarda Neto et al. (2023), and Cargnin et al. (2023).

III. RESULTS AND DISCUSSION

To obtain a more precise dimension of how urbanized this watershed is, data from collection eight of the MapBiomas platform were used to create a land use and land cover map of the watershed, represented in Figure 2.

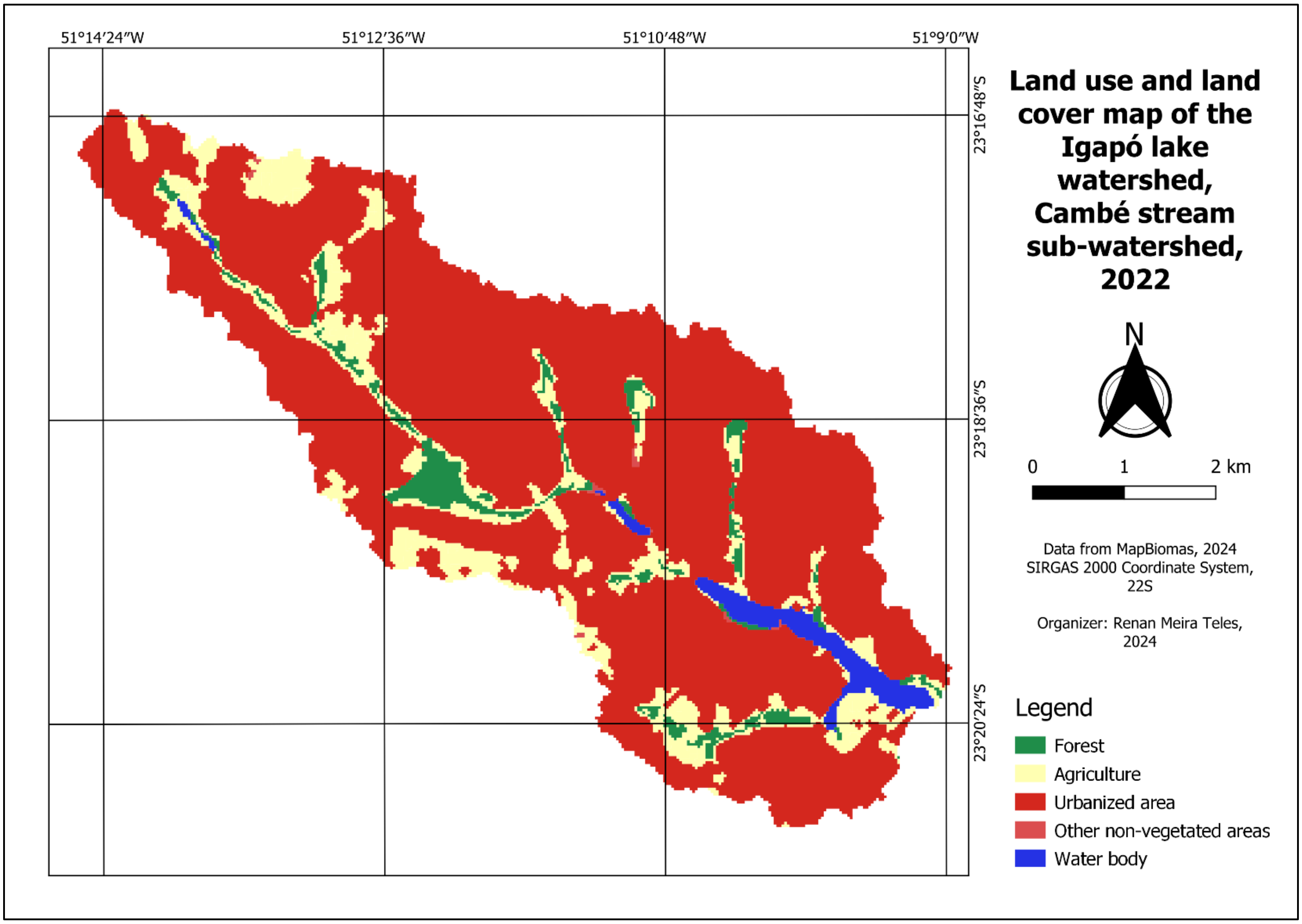

Figure 2 – Land use and land cover map of the Igapó lakes watershed. Source: MapBiomas, 2024.

Using QGIS version 3.28.13, the land use areas were delineated, allowing for the quantification of urbanization present in the Igapó lakes watershed, as well as land use and occupation distribution analysis in this region (Figure 2). Subsequently, each of the areas shown in Figure 2 were calculated using the same software used to create the map, as presented in Table 1.

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Table 1 – Land use and occupation distribution in the Igapó lakes watershed in 2022

Type	Area (km²)
Agriculture	4.169
Urban Area	24.593
Body of Water	0.786
Forest	1.237
Other non-vegetated areas	0.049
Total	30.834

Source: Authors, 2025.

Based on the map shown in Figure 2, several morphometric, geomorphological, and land use parameters of the watershed were calculated using the QGIS software and are presented in Table 3.

Table 3 – Igapó lakes watershed morphometric, geomorphological and land use parameters

Parameters	Value	Unit
Total watershed area	30,834	Km²
Perimeter	35,528	Km
Average slope	0,7	%
Total main thalweg length	11,285	Km
Vector main thalweg length	10,17	Km
Total length of all rivers	23,859	Km
Watershed diameter	6,266	Km
Watershed's impermeable area	80	%

Source: Authors, 2024

Hence, these data were applied to the equations presented in Table 1 for Igapó lakes watershed morphometric characterization, based on the reference values in Table 2. Table 4 presents the results obtained.

Table 4 – Calculated hydrological parameters

Hydrological parameters	Calculated value	Unit	Classification
Coefficient of compactness (Cc)	1.79	-	Not subject to flooding
Form factor (Ff)	0.24		Not subject to flooding
Circularity index (Ci)	0.31	-	Very elongated shape
Sinuosity index (Si)	9.88	%	Very straight
Drainage density (Dd)	0.77	Km/km²	Average
Average slope (S)	0.7	%	Flat

Source: Authors, 2024.

The calculated compactness coefficient (Cc) was 1.79, indicating that this watershed does not have a tendency to flood, which was supported by the form factor (Ff) found to be 0.24. These two calculated values of compactness coefficient (Cc) and form factor (Ff) suggest that the watershed does not have a circular shape, which is confirmed by the value obtained from the calculation of the circularity index (Ci) of 0.31, inferring that the Igapó lakes watershed is very elongated and not very susceptible to flooding.

The sinuosity index of 9.88% represents a very straight river channel, facilitating surface runoff. Drainage density resulted in 0.77 km/km², indicating that the watershed is moderately drained. The fluvial order of the watershed's main thalweg according to Strahler's classification (1957) is two, i.e., the tributaries of the main thalweg do not have other tributaries.

Although the watershed was classified as having no probability of flooding, this is not what happens after the intense urbanization of the area. In the Igapó lakes, there are several recent records of floods registered in 2007, 2011, 2013, 2016, 2017, and 2018, as reported by Vacario and Machado (2019). The authors also emphasize that the worst of these events were those of 2011 and 2016, when a fatality was recorded. Figures 3 and 4 show the overtopping of the dams of Igapó lakes I and II in 2011.

(a) (b)

Figure 3 – (a) Igapó lake I dam overtopping in 2011; (b) Igapó lake I dam in 2024. Source: Adapted from Vacario and Machado (2019, apud, Fantaussi 2011).

(a) (b)

Figure 4 – (a) Igapó lake II dam overflow in 2011; Igapó lake II dam in 2024. Source: Adapted from Oliveira (2018, apud, Lorenzo 2011).

The most recent flood recorded in the area was on February 4, 2025, when, after receiving more than 70 mm of rainfall, several flooding points were recorded in the city, including the Igapó lakes region, as reported by local media[1].

Among all the methods researched, the limiting factors considered were watershed area, average slope, main thalweg length, and the fact that it is an urban watershed. Based on these criteria, the studied watershed fit into five different methods for calculating concentration time: Williams (1922); Haktanir & Sezen (1990); Desbordes (1974); Espey-Winslow (1966); and Federal Aviation Administration (1970) (Table 5).

Table 5 – Methods for calculating concentration time suitable for the Igapó lakes watershed

Method	**Equation**	**Equation number**	**Equations' terms**	**Limiting factors**	**Source**
Williams	$C_t = \frac{0.272 * L * A^{0.4}}{D * S^{0.2}}$	(6)	Ct – Concentration time (hours) L – Main thalweg length (km) A – total watershed area (km^2) D – Equivalent watershed diameter (km) S – Average slope (m/m)	A < 129.5 km^2	Fang et al. (2008)
Haktanir & Sezen	$C_t = 0.7273 * L^{0.841}$	(7)	Ct – Concentration time (hours) L – Main thalweg length (km)	11 km^2 < A < 9867 km^2	Fang et al. (2008)
Desbordes	$C_t = \frac{0.0869 * A^{0.3039}}{S^{0.3832} * {A_i}^{0.4523}}$	(8)	Ct – Concentration time (hours) S – Average slope (m/m) A – Total watershed area (km^2) Ai – impermeable area (%)	A < 51 km^2 S < 7 % L < 18 km For urban watersheds	Silveira (2005 apud, Desbordes 1974)
Espey-Winslow	$C_t = \frac{0.343 * \phi * L^{0.29}}{S^{0.145} * {I_a}^{0.6}}$	(9)	Ct – Concentration time (hours) ϕ – Espey channeling factor L – Main thalweg length (km) S – Average slope (m/m) Ia – impermeable area (%)	A < 91 km^2 For urban watersheds	McCuen et al. (1984)
Federal Aviation Administration	$C_t = \frac{1.8 * (1.1 - C) * L^{0.5}}{i^{0.333}}$	(10)	Ct – Concentration time (hours) C – Rational method runoff coefficient L – Main thalweg length (km) i – Average slope (%)	Method used for urban watersheds	Mata-Lima et al. (2007 apud Chow et al., 1988)

Source: Organized by Teles (2024).

Finally, the values obtained by the five methods for calculating concentration time were analyzed for their compatibility with the watershed morphometric characterization results. Based on this analysis, the most suitable methods for estimating concentration time in the Igapó lakes watershed were determined. The results presented in Table 2 for concentration time were achieved by applying the different mapped mathematical models.

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[1] Information obtained from the local media outlet G1 Paraná (2025)

Table 2 – Concentration times calculated by different methods

Method	Calculated concentration time (hours)
Williams	5.208
Haktanir & Sezen	5.583
Desbordes	1.824
Espey-Winslow	0.488
Federal Aviation Administration	1.362

Source: Authors, 2024

Observing Table 2, it is possible to verify that although the five chosen methods fit in some way into the Igapó lakes watershed, it is important to consider how the chosen method was developed, as well as some characteristics of each method, such as the number of watersheds used for its development and the location of these watersheds, in order to understand if the chosen method was developed from watersheds that resemble the watershed for which concentration time will be calculated.

The Williams method was developed considering watersheds in India. The Haktanir & Sezen method was based on a study that analyzed ten different watersheds in Turkey. The Desbordes equation was developed from research that studied 21 distinct watersheds in France. The other two methods were developed in the United States, with the Espey-Winslow model considering 17 watersheds and the Federal Aviation Administration not disclosing a total number of watersheds.

The values obtained by Williams, Haktanirs & Sezen methods are high, with a concentration time exceeding five hours. However, although these methods are suitable for watersheds of various sizes, they do not yield satisfactory results for watersheds smaller than 50 km² (the watershed under study has an area of 30.834 km²), as presented by Fang et al. (2008) in their research. The five-hour runoff period does not reflect the Igapó lakes watershed's actual situation, since there are flooding problems at the watershed's outlet. This suggests that runoff occurs rapidly, hindering infiltration. Furthermore, considering soil impermeability, concentration time is less than five hours.

On the other hand, the Espey-Winslow equation resulted in a low value, where rainwater would reach the outlet very quickly, since concentration time of 0.488 hours (29.28 min) would result in a surface runoff velocity greater than 5.55 m/s, which represents a watershed with a high slope, or watersheds with areas smaller than 5 km². The Igapó lakes watershed has an average slope of only 0.7%, which characterizes a flat and gentle relief. Therefore, this method also does not represent this watershed's hydrological reality.

Therefore, it is possible to state that the most suitable methods for calculating concentration time for the Igapó lakes watershed, considering the watershed's hydrological parameters, are the Desbordes and Federal Aviation Administration methods, with values ranging from 1.8 to 1.3 hours. Both equations are consistent with geomorphological characteristics and land use (the analyzed watershed has 80% urban area), presenting results compatible with a watershed of low sinuosity and little tendency to flooding due to its low slope, which favors surface runoff, as demonstrated in the morphometric analysis performed in this study.

IV. CONCLUSIONS

Thus, it becomes evident that the chosen model must take into account not only the watershed's geomorphological characteristics, its urbanization or lack thereof, but also its morphometric characteristics, since these represent different particularities of relief, rainfall regime, soil types, among other characteristics that can impact surface runoff and soil infiltration.

Therefore, the recommended approach would be to find an equation developed from watersheds with the greatest possible similarity to the watershed for which the concentration time is to be calculated. However, a mathematical model with these characteristics is not always available. In these cases, it would be appropriate to calculate the concentration time using different methods and perform a weighting, or for a more reliable calculation, consider only the model that results in the most critical value, i.e., the one with the shortest concentration time, always respecting the watershed's physical and morphometric characteristics. Thus, for the Igapó lakes watershed, the equations that proved most suitable were those of Desbordes and the Federal Aviation Administration.

Although the hydrological parameters presented show that this is an elongated, flat, moderately drained watershed with little risk of flooding, there are still several reports of flooding in the Igapó lakes' vicinity, probably caused by soil impermeability in this watershed. Desbordes' and Federal Aviation Administration's methods are the most suitable for these watersheds because they combine morphometric the watershed characteristics in their equations while also considering soil impermeability. In the case of the Desbordes equation, it considers the watershed's total area, average slope, and impermeable area percentage. On the other hand, the Federal Aviation Administration considers the main thalweg length, the average slope, and the runoff coefficient of the rational method (which takes into account the impermeable area). Therefore, it is possible to state that these are the most appropriate methods for calculating concentration time of this watershed.

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V. REFERENCES

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