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Hydrological modeling using distributed rainfall data to represent the flow in urban watersheds

Modelagem hidrológica a partir de dados de chuva distribuída para representação do escoamento em bacias hidrográficas urbanas

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ABSTRACT

Hydrological models are one of the most effective ways of assessing water behavior and flood risk, although the quality of their results is determined by the input data representativity, especially rainfall. Normally, only rain gauge data is used, unable to represent rain spatial variability. Aiming to reduce the model's uncertainties, hydrological model performance was evaluated in determining the runoff based on distributed rainfall data applied in an urban watershed with macro drainage structures. A distributed rainfall data, derived from a conditional merging of radar and field measurements, was used as the hydrological model's input data, and led to very accurate runoff results. The analysis of the results demonstrated that to model urban watersheds with accuracy, distributed rainfall data is required, as well as knowledge about the sewage and drainage systems, reinforcing the need to use tools that are compatible with the site complexity.

Keywords: Hydrological modeling; Distributed rainfall; Model uncertainties; Water security; Radar measurements.

RESUMO

Os modelos hidrológicos são uma das formas mais eficazes de avaliar o comportamento da água e o risco de inundação, embora a qualidade de seus resultados seja determinada pela representatividade dos dados de entrada, principalmente pluviométricos. Normalmente, apenas dados pluviométricos são utilizados, os quais são incapazes de representar a variabilidade espacial da chuva. Visando reduzir as incertezas do modelo, avaliou-se o desempenho do modelo hidrológico na determinação do escoamento, com base em dados de chuva distribuída aplicados em uma bacia hidrográfica urbana com estruturas de macrodrenagem. Dados de chuva distribuídos, derivados de uma fusão condicional de medições de radar e de pluviômetros, foram usados como dados de entrada do modelo hidrológico e levaram a resultados de escoamento muito precisos. A análise dos resultados demonstrou que para modelar bacias hidrográficas urbanas com precisão são necessários dados pluviométricos distribuídos, além de conhecimento sobre os sistemas de esgoto e drenagem, reforçando a necessidade de utilização de ferramentas compatíveis com a complexidade do local.

Palavras-chave: Modelagem hidrológica; Chuvas distribuídas; Incertezas do modelo; Segurança hídrica; Medições por radar.

INTRODUCTION

Within the big cities, one of the biggest challenges is related to the water movement in the urban space, since this resource shapes the land surface, and in these environments, it must live together with the anthropic interventions, making each increasingly complex relationship between existing physical and human elements (Braga, 2022; Carvalho, 2020; Oliveira Rolo, 2019).

The cities' growth and population expansion increase the need for infrastructure, including the drainage system. Related to the edification, this system usually must be adapted to attend to the social demands, these new elements create alterations in the water runoff, which frequently cause local floods (Braga, 2022; Jha & Afreen, 2020).

This constant need for alterations and repair in the system, along with the current changes in the climate conditions, and the increase in population density in cities, raises the flood events' damage. Meantime those effects can be controlled by effective land use management, flood risk prevention policies, application of advanced geospatial tools, and decision support systems. Among the most effective ways of assessing the water behavior in the city and flood risk to people and infrastructures are the development and application of hydrological models (Jha & Afreen, 2020).

The hydrological model's development is directly related to the increase in computer capacity and the technology of data collection, as well as the quality of its results is determined by the representative of the input data (Singh, 2018). The scientists apply great effort to reduce the models' uncertainties, calibration methods, and parameterization (Gupta & Sorooshian, 2017; Zhou et al., 2012; Wagener, 2003; Klemeš, 1986; Gudmundsson et al., 2012; Döll et al., 2016; Clark et al., 2015; Ferreira et al., 2020).

In hydrological modeling, essential data are hydrographic network, topography, and precipitation. This is normally measured by rain gauges, which evaluate the intensity and duration of rain efficiently but have no spatial representation, even for a dense measurement network (Beck et al., 2017; Singh 2018; Rocha Filho et al., 2017).

The need for a better characterization of the spatial and temporal variations of climatic factors encouraged the development of data and tools that could provide this representation (Sokol et al., 2021). The use of radar rainfall data to explain the spatial distribution of rainfall to improve hydrological model input data has demonstrated applications worldwide (Obled et al., 1994; Schuurmans & Bierkens, 2007; Chen et al., 2017; Huang et al., 2019; Shakti et al., 2019; Wijayarathne et al., 2020).

Many studies are dedicated to analyzing the sensitivity of the spatial and temporal scales of meteorological radar data and to reducing the uncertainties produced by them, since there is a difference between what is read in the atmosphere and what is precipitated on the earth's surface. Shakti et al. (2019) emphasize that the hydrological response is more sensitive to spatial variation during convective rainfall events, these being best represented by resolutions ≤ 1km. Ghimire et al. (2022) state that the impact of temporal resolution is more significant in smaller basins (≤ 1000 km^2) and that in the flow forecast, an accurate representation of the volume of precipitation in the watershed is essential.

The reduction of uncertainties in the treatment of the data presents better performance with methods involving techniques that combine more than one data source, such as rain from radar and rain from rain gauges, and rainfall dataset and rainfall-runoff simulation in the grid (Lee et al., 2019; Rocha Filho et al., 2013).

Urban environments with high population density and high levels of soil sealing usually apply devices in their macro-drainage system to flood control. This configuration complicates the flow representation by the hydrologic model and increases the rainfall spatial distribution influence in its results.

Reduce model's uncertainties by using distributed and calibrated radar rainfall data as an input, improve this tool to perform better city management, reduce flood risks, and provide water security were the motivations for this work, which aims to evaluate the hydrological model performance in determining the surface flow based on distributed rainfall data applied in urban watersheds with macro drainage structures.

MATERIAL AND METHODS

The Pinheiros river basin in the city of São Paulo – Brazil was chosen to be the study site. This watershed is an example of a complex environment, with high population density, different land uses, the presence of micro and macro drainage devices, such as dams, pumping stations, and reservoirs, and the deterioration of its water resources, especially its main river (Baptistelli & Veras Neto, 2021).

Another important fact is that this area is covered by the São Paulo Meteorological Radar, the propriety of the Department of Water and Electricity – DAEE and operated by the São Paulo's Flood Alert System - SAISP, which is in the municipality of Biritiba-Mirim - São Paulo - Brazil, at the Ponte Nova Dam, headwater of the Tietê River (Rocha Filho et al., 2015, 2017).

The research steps included the compilation of radar rainfall data and flow field measurements, the setup of the area in the hydrological model, the calibration and validation of the model from the field measurements, the execution of annual hydrological simulations, and accuracy evaluation of the results, by comparing the estimated flow in the main river with the measurements in the outlet dam and in the pumping station.

Study site

The Pinheiros River Basin (Figure 1) covers approximately 265 km^2, with a population of approximately 3,317,676 inhabitants. Its occupation is diversified, with different occupation patterns, service offerings, and population vulnerability indexes. These different occupations reflect the urbanization process developed in the basin throughout its history (São Paulo, 2014; Companhia de Saneamento Básico do Estado de São Paulo, 2018).

The current scenario shows high rates of soil sealing, low rates of green areas per inhabitant, high population density, social inequalities, and difficulties in implementing sanitation policies throughout the area, resulting in frequent inundation events and pollution of streams and reservoirs (Baptistelli & Veras Neto, 2021).

The Pinheiros River is 25 km long, with its mouth in the Tietê River and its source in the Billings and Guarapiranga sub-basins. The channel consists of two main sections: the Lower and

Upper Channel (Figure 2). The lower channel is located between the Retiro Dam, at its mouth, and the Traição Pumping Station (E.E. Traição), it is about 10 kilometers long, with a total of 190 km^2, the most significant tributaries of this stretch are the Brooklin Drain, the Pirajuçara Stream, and the Jaguaré Stream (Águas Claras, 2017).

The Upper Channel, located between the Traição and Pedreira pump stations, has a length of 15.4 km and a drainage area of 80 km^2. The main tributaries on the left bank are the Morro do "S" stream and the Ponte Baixa stream (Águas Claras, 2017). The Guarapiranga reservoir is connected to the Pinheiros River by an artificial outflow channel used in emergency situations to control the reservoir water level. The Pinheiros River is a water body that provides multiple environmental services, such as flood control, effluent dilution, energy generation, and a landscape component (Águas Claras, 2017; São Paulo, 1992, 2010).

Pinheiros River's natural flow direction is from Billings Reservoir to the Retiro Dam, and from there to the Tietê River, and it's mostly observed on days with no rain. However, when the meteorological radar detects a rain that can elevate its water level by at least 0.2 m, the flood control operation is activated, the pump stations begin to work, and the natural flow is reversed. Alterations in these guidelines are made by system operator according to the eventual necessities (Águas Claras, 2017; Companhia Brasileira de Projetos e Empreendimentos, 2014, 2014; São Paulo, 1992, 2010)

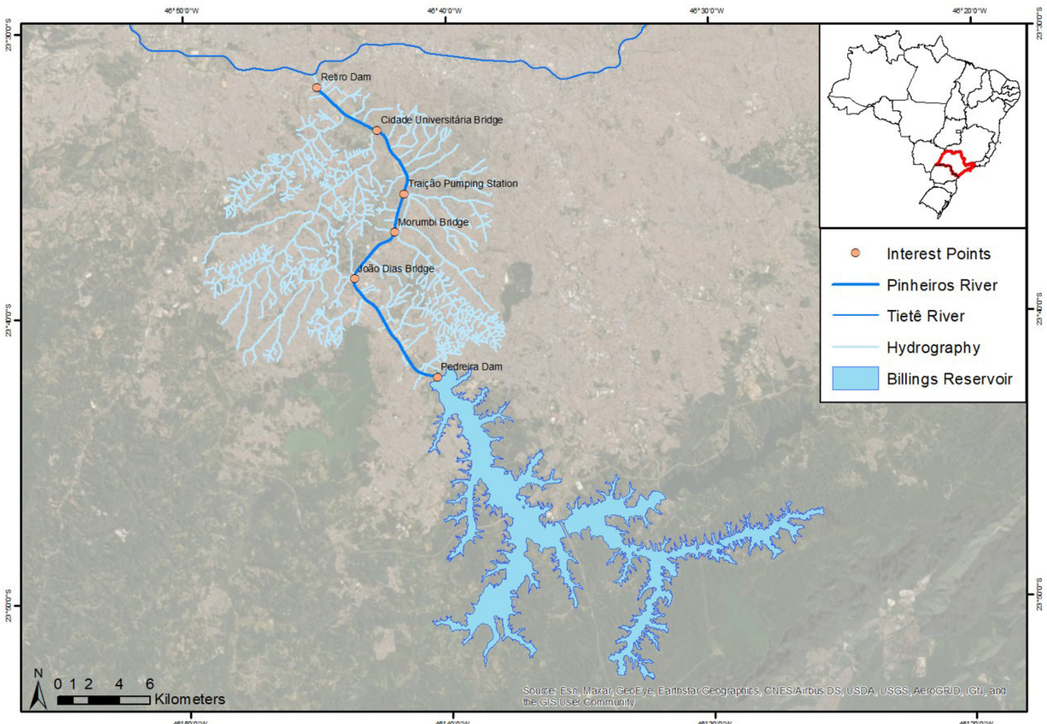

Figure 1. Pinheiros' river watershed.

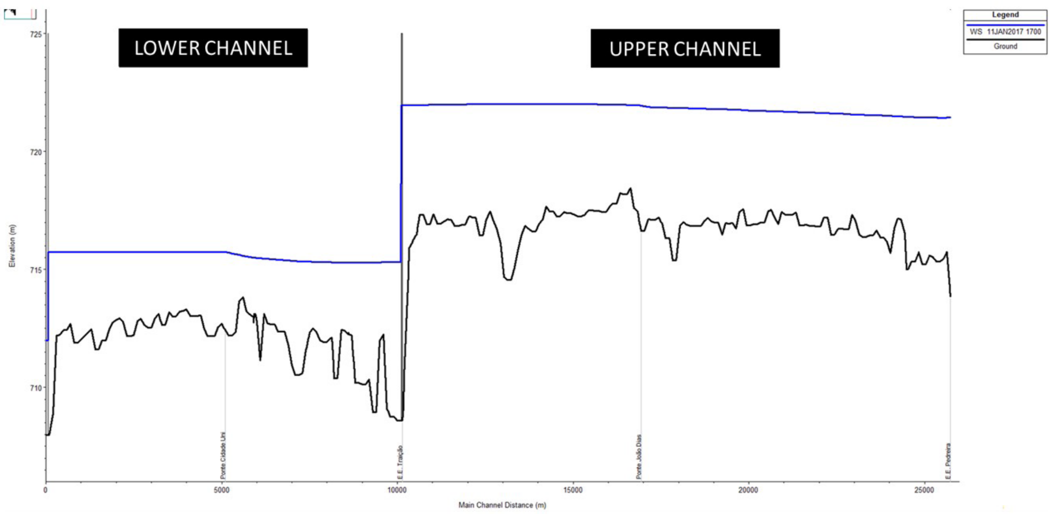

Figure 2. Pinheiros' river cross profile.

To reverse the natural direction of the flow three control structures were built in the river in 1939, namely (Águas Claras, 2017; São Paulo, 1992, 2010):

1. Pedreira Dam: controls the flow from Billings Reservoir to Pinheiros River. During precipitation events the Pedreira Pumping Station is activated to transpose the river waters to the reservoir (installed capacity of 395 m^3/s);
2. Traição Pumping Station: located approximately 15.45 km from the Pedreira Dam, it allows pump water from the Lower Pinheiros Channel and the Tietê River to the Upper Pinheiros Channel. This system allows the transfer up to 280 m^3/s;
3. Retiro Dam: retains the waters of the Pinheiros River in order to manage its water level and control the flow to the Tietê River. It can be operated in a way that allows the flow from the Tietê River to the Pinheiros River.

The implantation of this system, along with the city expansion and the watershed population growth, provoked impacts on the drainage network. To control its impacts, macro and micro drainage devices were built in the tributaries, and the main river receives bank protection and dredging works (Companhia Brasileira de Projetos e Empreendimentos, 2014; São Paulo, 1992, 2010).

In 2019, the Government of the State of São Paulo and its partners started the "Projeto Novo Pinheiros" aiming at the rehabilitation of the watershed. This project combines interventions in the sewage and drainage systems and a new approach to the watershed's planning and management (Baptistelli & Veras Neto, 2021).

As it is a watershed with many interventions, the main watercourse has bidirectional flow, multiple environmental functions, high population, its planning, and managing require knowledge of the system, field data, and adequate tools.

Hydrologic modeling

The software applied in the hydrologic modeling was CAbc (Software for Hydrological Simulation of Complex Basins), developed by the Center for Hydraulic Technology at the University of Sao Paulo (USP) and funded by Fundação Centro Tecnológico de Hidráulica (2002). It is a system of models intended for hydrological simulation using Soil Conservation Service (SCS), Unit Hydrograph methods or the SMAP method for flow generation (Lopes et al., 1982).

The CAbc model applies to all types of watersheds to manage urban and rural problems, especially those in a macro scale. The diversity obtained from rain distribution and land occupation can be considered through segmentation into sub-basins and makes it a differential for this model (Fundação Centro Tecnológico de Hidráulica, 2002).

In this study the method chosen for flow generation was SMAP (Soil Moisture Accounting Procedure), which is a mathematical method that performs rainfall-flow transformation (Lopes et al., 1982). It is a well stablished method with proven performance in many scales and recent studies still use it for its high reliability (Cavalcante et al., 2020).

In the daily basis conception, input data are the total daily rainfall, potential evapotranspiration and the drainage area values. To calibrate the parameters involved in the modeling, a historical flow series is necessary, including drought periods and flood events. In this way, the adjustment of the parameters must be done to minimize the discrepancy between the flow values calculated with the values observed in flow stations (Lopes et al., 1982).

Rainfall data

Rainfall is one of the key aspects to hydrology models. Understanding the precipitation in a watershed is very complex, as there are many variables involved, such as space and time. Precipitation hardly follows an identical physical pattern, such as quickly spatial variation changes, and the temporal variation is extremely random – rains can last from a few minutes to several hours or days and with a wide range of intensity (Marciano et al., 2018).

To represent the spatial and temporal distribution of rainfall in the study area, it was decided to use the rain data provided by the Department of Water and Electricity – DAEE radar and operated by the São Paulo's Flood Alert System - SAISP. The São Paulo Meteorological Radar is located in the municipality of Biritiba-Mirim (SP), at the Ponte Nova Dam, headwater of the Tietê River (Rocha Filho et al., 2015, 2017).

The radar operates on the S-band frequency and has a standard horizontal spatial resolution of 2 x 2 km, with a quantitative range of 240 km and a temporal resolution of 5 minutes. In this work, the CAPPI (Constant Altitude Plain Position) product will be used at the level of 3 km above sea level. The reflectivity fields are transformed into precipitation rates by the ZR relation of Marshall & Palmer (1948), Rocha Filho et al. (2015, 2017).

The method applied in the treatment of radar data consists of a conditional merging based on the method of Ehret (2002), in which radar measurements are used as a spatial boundary condition for an interpolated field from surface measurements (rain gauges).

This analysis consisted of the determination of a factor that relates the precipitation determined by the radar to the daily point accumulated value in each sub-basin for each rainfall event. From the data recorded in each pixel (1km) of the radar, the same data were compared with the terrestrial rain gauge, and a linear least-squares fit was made to represent the precipitation events in a consistent and validated way (Rocha Filho et al., 2015, 2017).

The CAbc software (Fundação Centro Tecnológico de Hidráulica, 2002) was used to determine the rain average point accumulated value in the basin, in which the accumulated precipitation plans extracted from the radar images obtained in the ASCI-Grid format were inserted (Figure 3). After the process of reading these files, the software computed the parameters of the distributed rain, with the daily accumulated being used for the hydrological simulation (Shakti et al., 2019; Ghimire et al., 2022).

Model configuration

The watershed representation into the software CAbc was made by inserting topographic, potential evaporation and hydrologic data, delimiting the watershed, its sub-basins, and the hydrographic network. For each sub-basin, parameters such as the sub-basins area, percentage of waterproof and permeable area, concentration time, stream length and slope were described.

A relevant data to the correct representation of the tributary flows to the Pinheiros River basin, were the effluent discharges. For this, SABESP provided information on the collected and uncollected sewage flows that are discharged into the tributaries of the Pinheiros River basin for the year 2018.

Model calibration

There were observed flow data available in the SAISP database for five streams: Pirajuçara, Jaguaré, Morro do S, Água Espraiada, and Zavuvus (Figure 3). For Pirajuçara and Água Espraiada, the monitoring points are positioned at the end of the river, so the whole sub-basin area and sewage discharge contribute to the generated flow, while for Jaguaré, Morro do S and Zavuvus sub-basins was necessary to calculate the exact area and sewage discharge which contribute until the monitoring point.

The calibration of the SMAP model can be done manually, through trial-and-error processes, or automatically, through mathematical optimization methods. Manually, it requires more experience from the modeler and constitutes a more laborious and subjective process. On the other hand, it has the advantage of total monitoring by the hydrologist to determine each parameter. The automatic calibration, in turn, facilitates the work and reduces the subjectivity of the manual process.

To achieve the calibration of the hydrological model, the adjustment of six parameters was sought, namely:

- Str - soil saturation capacity (mm);
- K2t - surface runoff recession constant (days);
- Crec - underground recharge parameter (%);
- Ai - initial abstraction (mm);
- Capc - field capacity (%);
- Kkt - base flow recession constant (days).

Bearing in mind that the purpose of the hydrological modeling was to provide data on inflows to the main watercourse (Pinheiros) with precision in temporal and spatial scales, the calibration process aimed to ensure that the volume drained during the day and the variation behavior of flows throughout the year (peaks and recessions) was well represented. For this, the averages, and the standard deviation of the simulated and observed flows were compared, minimizing the percentage difference between the flows and the average daily precipitation heights observed and calculated.

Continuous simulations

To perform hydrological simulations was necessary to characterize the calibration parameters to the other sub-basins where no observed flow data was available. In this process the land use, the slope, and geology of each sub-basin were analyzed, they were

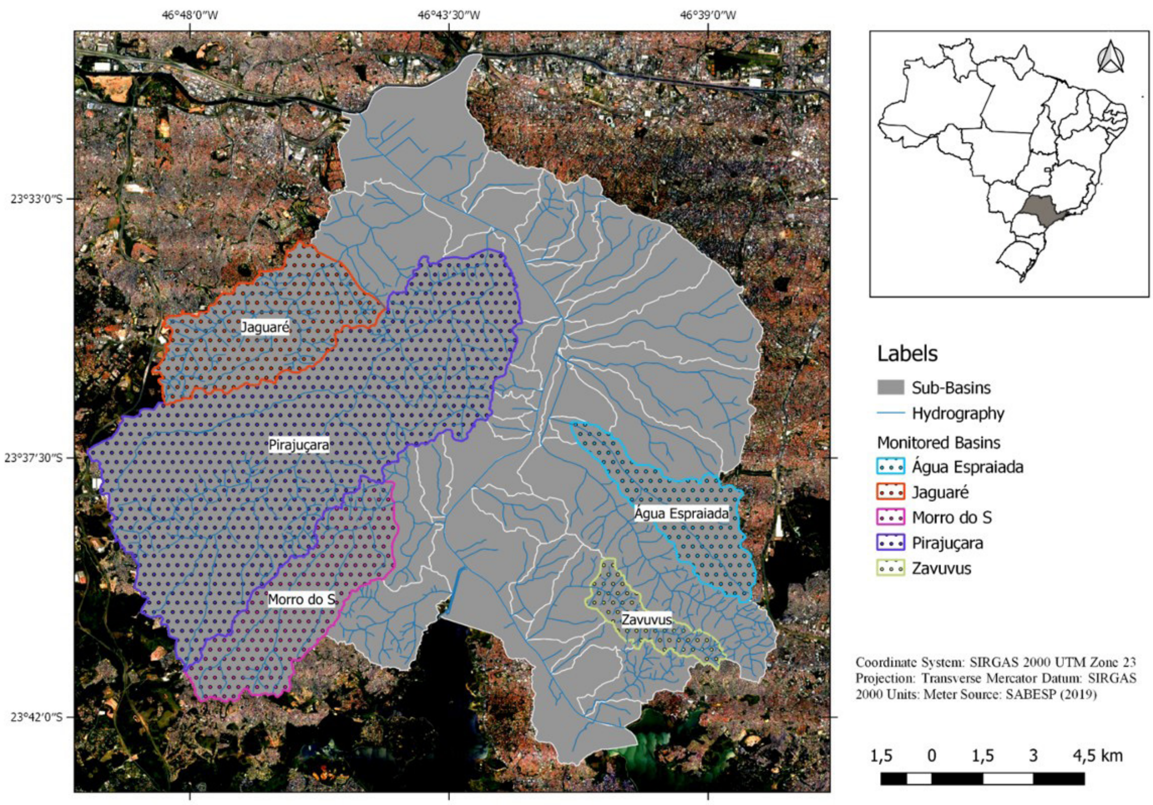

Figure 3. Pinheiros' river and the five sub-catchments used in the models' calibration.

compared with the calibrated sub-basins and the parameters were exported to them with adjustments related to the above characteristics.

With that annual hydrologic simulations were executed for the years 2017, 2018 and 2019 and the model's results performance in describing the flow along the year were evaluated by comparing with two different observed data, the first one is the flow discharged through the Retiro Dam to the Tietê River, which reflects the volume received by the main river during days with no rain, and the second one is the register from the pumping stations, which correspond to the volume transported during the rain events.

RESULTS AND DISCUSSIONS

Distributed rainfall data

The hourly data provided from the meteorological radar was applied as the boundary condition for precipitation in the hydrological model. According to the literature (Ghimire et al., 2022), watersheds smaller than 1000 km^2 are more sensitive to the rain spatial variation effects, in the case of the Pinheiros River watershed, it is crucial to correctly determine the amount of volume that will drain to the upper and lower channel, which in turn will affect the flood control operation and for that, the pumped volume.

Figure 4 represents the distribution of the annual rainfall accumulated data over the Pinheiros River watershed for the years 2016, 2017, 2018, and 2019. Is possible to observe that 2016, 2017, and 2019 have similar annual rain accumulate near 3100 mm year^{-1}, while 2018 is a drier year.

Related to the spatial distribution in all the four years the east portion of the watershed received more precipitation volume than the west, except by the Pirajuçara sub-basin headwater, that also receive greater amount of rain. The sub-basins of Pirajuçara, Jaguaré, and Morro do S are the ones with more accumulated rain difference between beginning and end of the watershed, two of them draining to the lower channel e one for the upper part.

Hydrological model calibration

In this project, the calibration in the SMAP model produced the simulated flow shown in the following pages. It is possible to observe that calibration presented a very good result in terms of flow when compared to the observed series. Some peaks of the observed data were not possible to be replicated for three reasons: (1st) observed flow is obtained in a 10-minute time step and then an average is made from the series, while accumulated rain is obtained in a daily time step which makes hard to reproduce peaks; (2nd) convective rains that act locally sometimes are not

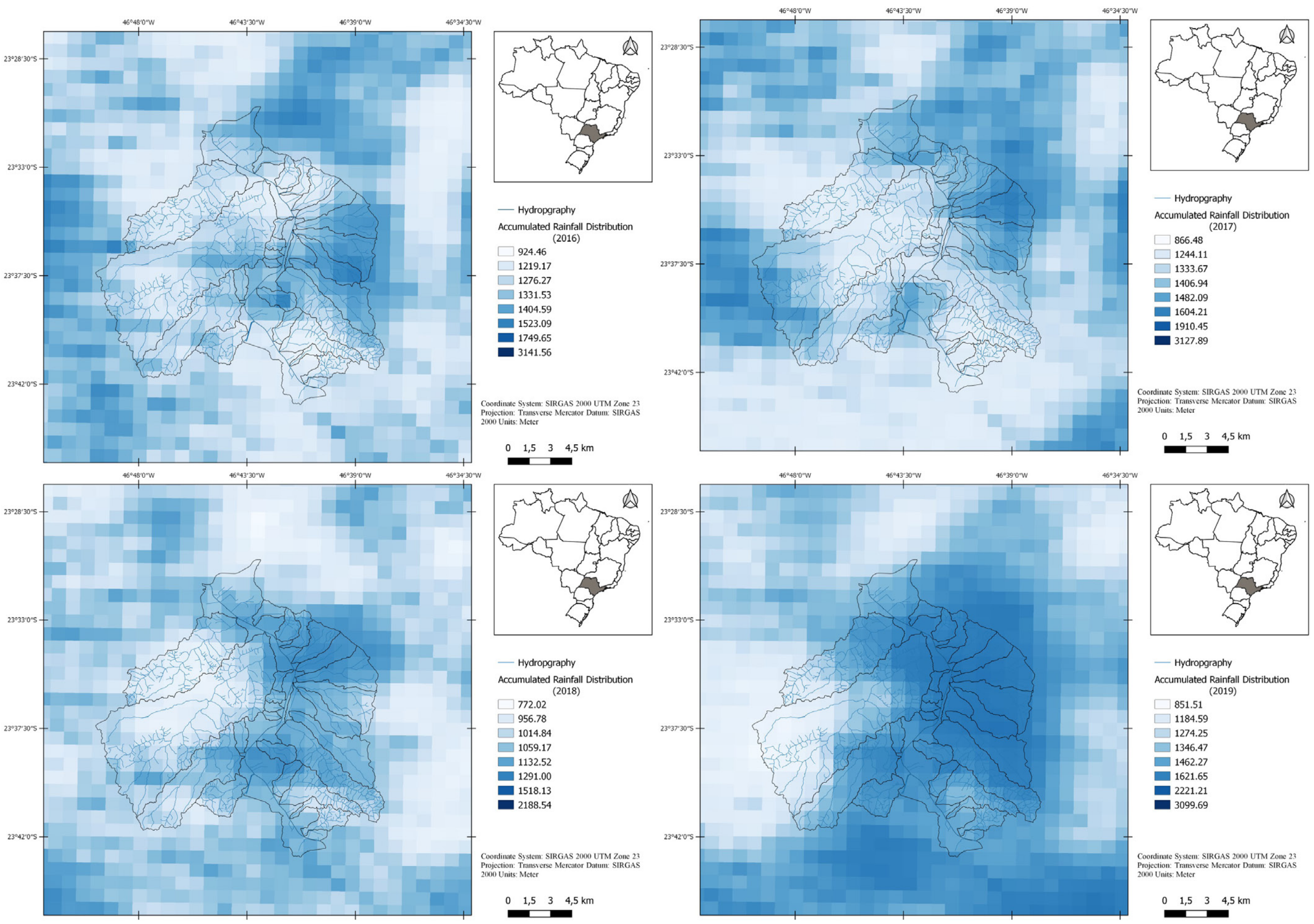

Figure 4. Distribution of the annual rainfall accumulated data over the Pinheiros River watershed.

well represented only with daily rain amount, and; (3rd) possible errors in the flow station.

After performing a consistency analysis in the observed flow data, excluding periods in which there were gaps or errors due to equipment maintenance, the intervals used to calibration and validation analysis were chosen. The Água Espraiada stream sub-basin had a calibration period from May to October 2019, and a validation period from November 2019 to February 2020. In the sub-basins of Jaguaré, Morro do S, and Pirajuçara streams, the year of 2017 for calibration and 2018 for validation. The Zavuvus stream sub-basin had 2016 for calibration and 2017 for validation.

Table 1 presents the parameters obtained in the calibration, there is a significant difference in the values between one sub-basin and another, especially in the parameter related to soil saturation, groundwater recharge and base flow recession constant. This variability of ranges of values of the calibration parameters is characteristic of complex basins, in which there is great diversity between the morphology and the use of soil of the sub-basins, in addition, the presence of drainage structures, with the reservoirs, which also influences the basic flow recession constant values.

Table 2 and Table 3 present the evaluation of the model's performance during calibration and validation. Note the good fit of the model in relation to the forecast of the average daily volumes drained, so that the percentage difference between the average daily flow calculated and observed is below 0.4% for all sub-basins. Most of the differences may be associated with the sewage flow adopted since the value used was the one estimated for the year 2018 and its variation during the day or year was not considered.

The observation of the comparisons highlighted in Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9 demonstrates the representation of the behavior of the flows generated by the model over a complete year and the Figure 10 shows the final results for the calibration parameters. Despite the individualities and complexity of the sub-basins, an accurate result was reached.

Assessments on model's performance

To evaluate the model's performance and results' accuracy two different approaches were made, the first one concerns the volume drained during the days without rain. It is represented by the flow discharged in the Retiro Dam, which transports the baseflow from the Pinheiros to the Tietê River.

Table 1. SMAP calibration parameters.

Parameters	Água Espraiada	Jaguaré	Morro do S	Pirajuçara	Zavuvus
Sat	30	120	100	250	30
k2t	0.2	0.2	0.2	0.2	0.2
Crec	50	4.6	4	20	0
Ai	0	1.1	1	3	0
Capc	0	0	4	0	0
Kkt	100	10	10	800	110

Table 2. Model performance during calibration.

	Água Espraiada		**Jaguaré**		**Morro do S**		**Pirajuçara**		**Zavuvus**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Observed flow (m^3/s)	0.93	1.237	0.57	0.414	0.76	0.877	3.03	0.598	0.19	0.125
Calculated flow (m^3/s)	0.93	0.906	0.57	0.655	0.76	0.89	3.02	1.033	0.18	0.121
Percentage Difference between Calculated and Observed Average Daily Flow	0.06%		0.35%		0.00%		0.05%		0.26%	
Difference between Calculated and Observed Average Daily Precipitation Height (mm)	0.0046		0.0080		0.0001		0.0019		0.0089	

Table 3. Model performance during validation.

	Água Espraiada		**Jaguaré**		**Morro do S**		**Pirajuçara**		**Zavuvus**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Observed flow (m^3/s)	0.93	1.237	0.49	0.361	0.5	0.492	3.05	0.519	0.26	0.255
Calculated flow (m^3/s)	0.93	0.906	0.49	0.411	0.5	0.506	3.05	0.534	0.26	0.311
Percentage Difference between Calculated and Observed Average Daily Flow	0.06%		0.06%		0.08%		0.09%		0.07%	
Difference between Calculated and Observed Average Daily Precipitation Height (mm)	0.0046		0.0014		0.0018		0.0035		0.0039	

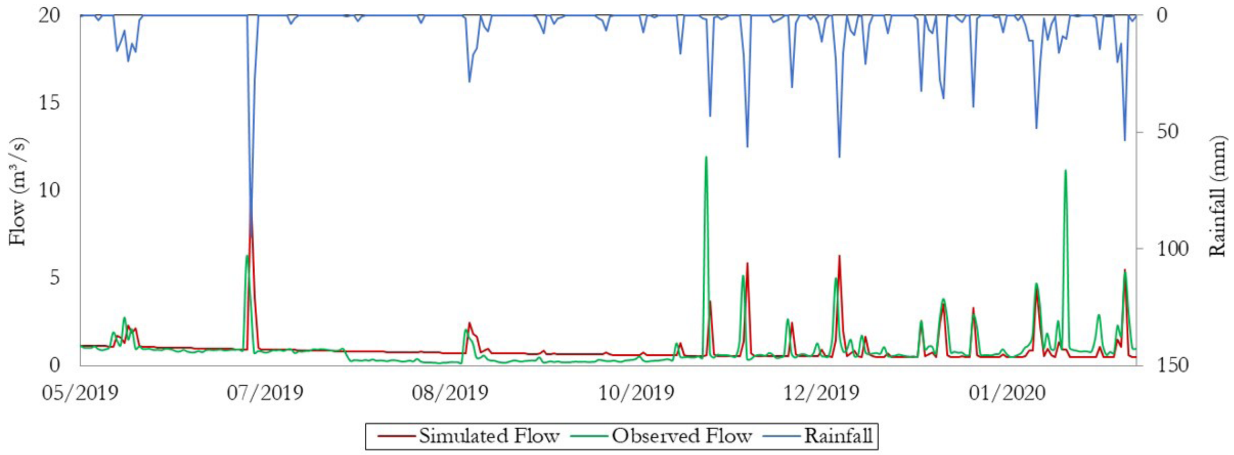

Figure 5. Calibration and validation series for the Água Espraiada stream – 2019-2020.

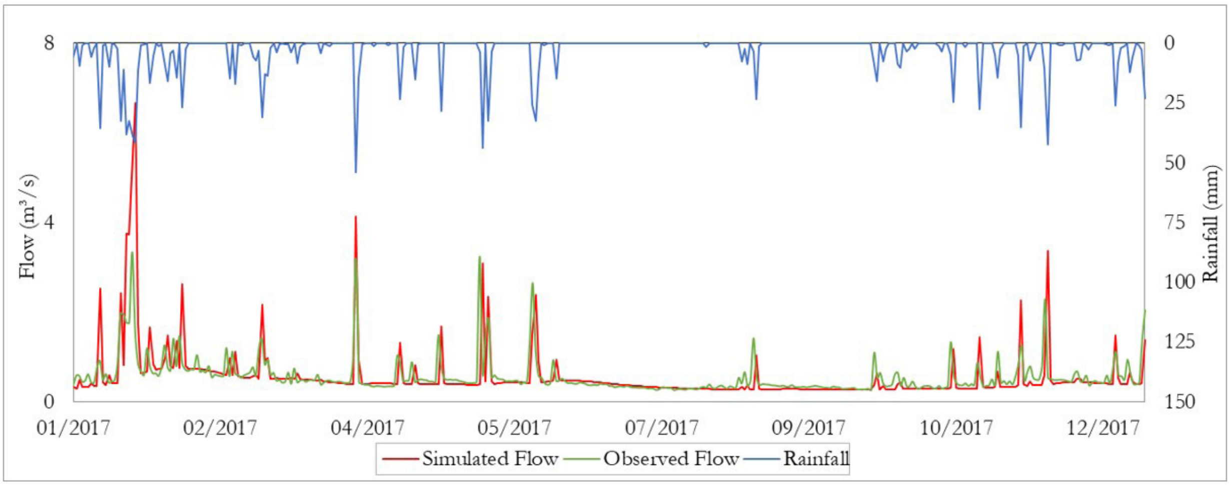

Figure 6. Jaguaré Stream calibration series – 2017.

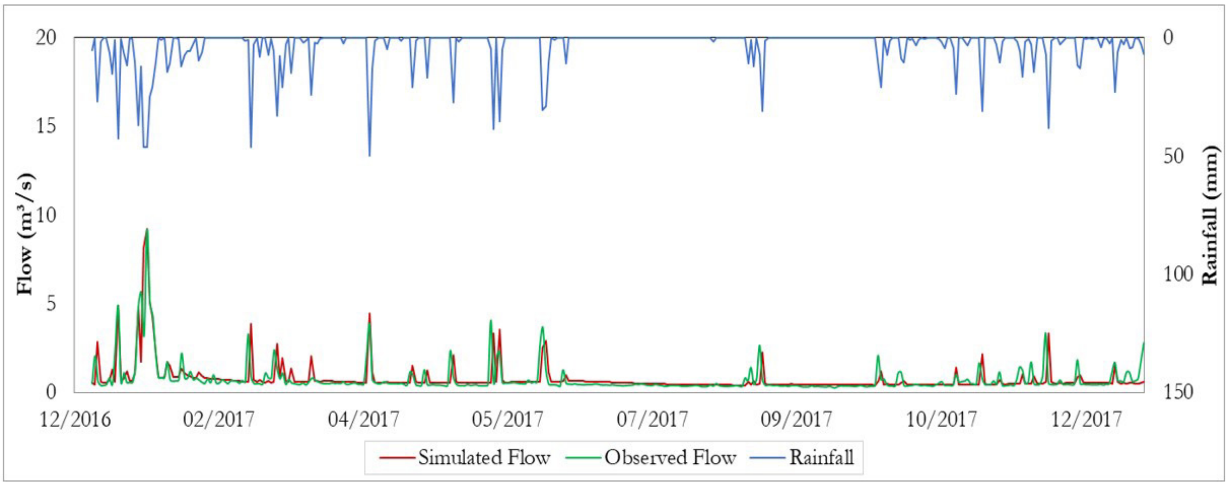

Figure 7. Morro do S Stream calibration series – 2017.

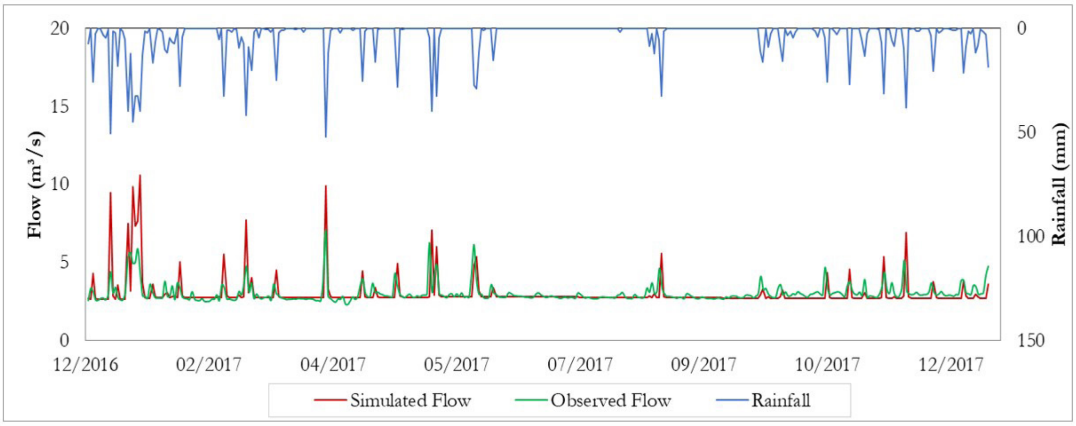

Figure 8. Pirajuçara Stream calibration series – 2017.

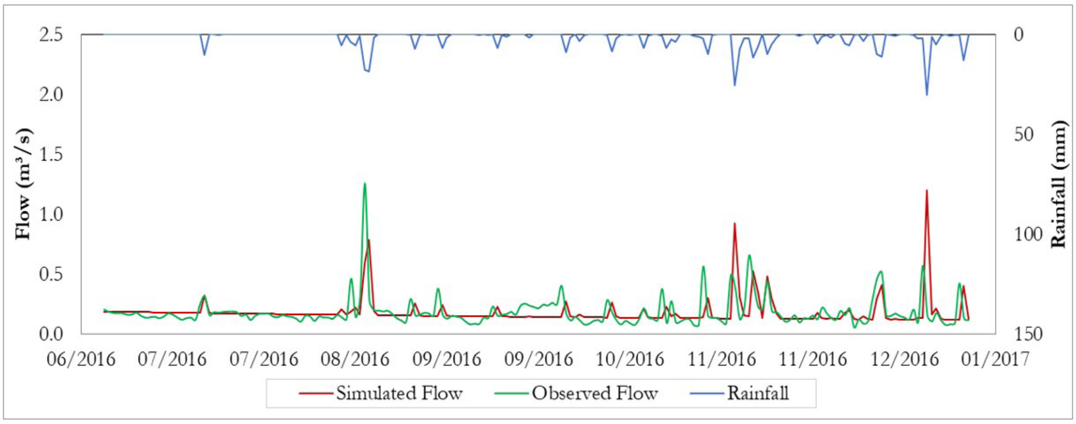

Figure 9. Zavuvus Stream calibration series – 2016.

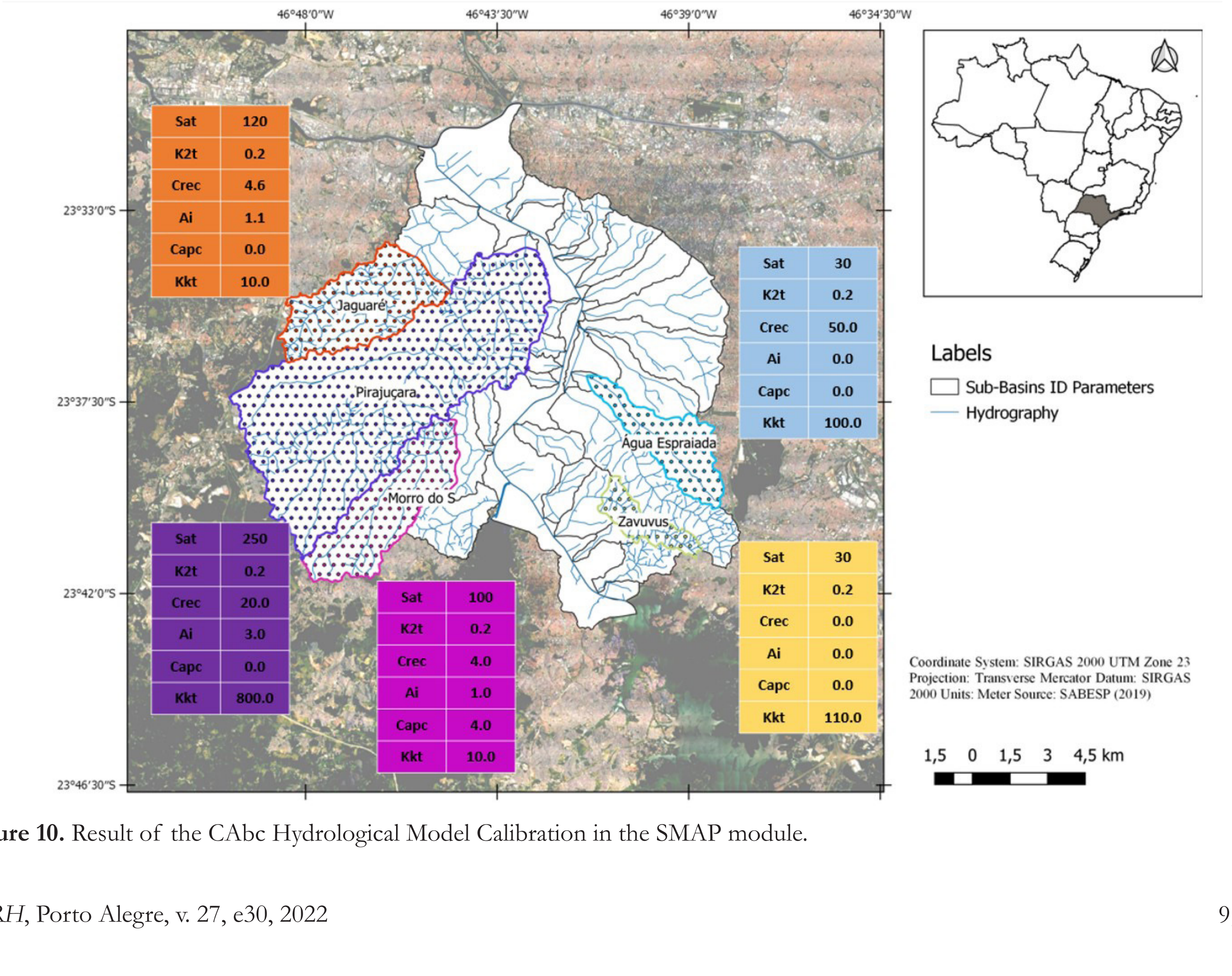

Figure 10. Result of the CAbc Hydrological Model Calibration in the SMAP module.

In this first analysis, the data from the Retiro Dam discharge was compared to the total flow generated by the hydrological model in the watershed's end (Figure 11, Figure 12, and Figure 13). It can be observed that the model reproduces the total baseflow generated in the watershed consistently during the year, attesting that the parameters adjusted in the calibration were correct.

An important data to be able to reproduce the base flow in this watershed was the sewage discharge on the streams. At this time, it represented almost half of the total baseflow drained in the area, so if they weren't considered it wouldn't be possible to correctly represent the daily drained volume.

The difference between the peaks on simulated results and observed data on Retiro Dam, for example, the ones highlighted in Figure 11, Figure 12, and Figure 13, is the exact volume that was pumped by the system. So, the total amount of drained volume is composed of the volume discharged in Retiro Dam and the ones pumped to the Billings reservoir.

To analyze the flow generated by the model during the rainy days the comparison was made between the peaks' volume on the total flow timeseries simulated and the total pumped volume on the pump stations. Tables 4, 5, and 6 show the comparison between monthly and annual volume pumped observed and simulated.

From the results presented, it is noted that the model can represent well the total pumped volume, it also reproduces the seasonal variations of pumping volumes, presenting similar values to the observed ones in almost every month, except for January. This situation is explained by the difficulty of representing this period in the hydrological model, due to the time required to adjust the volumes of the water balance.

The model was able to represent the runoff flow produced by the rain events and the total volume drained to the main river, regardless of the presence of 12 rainwater buffer reservoirs in the watershed, proving the model's capacity in representing the system.

The correct rainfall distribution was responsible for improving on the results, once only because of it, the model was able to determine the amount of volume going to the lower channel, that would be available to be pumped to the upper part in the reversing events, and the amount that would go to the upper channel to be transported to the Billings reservoir on each day of the rainy events.

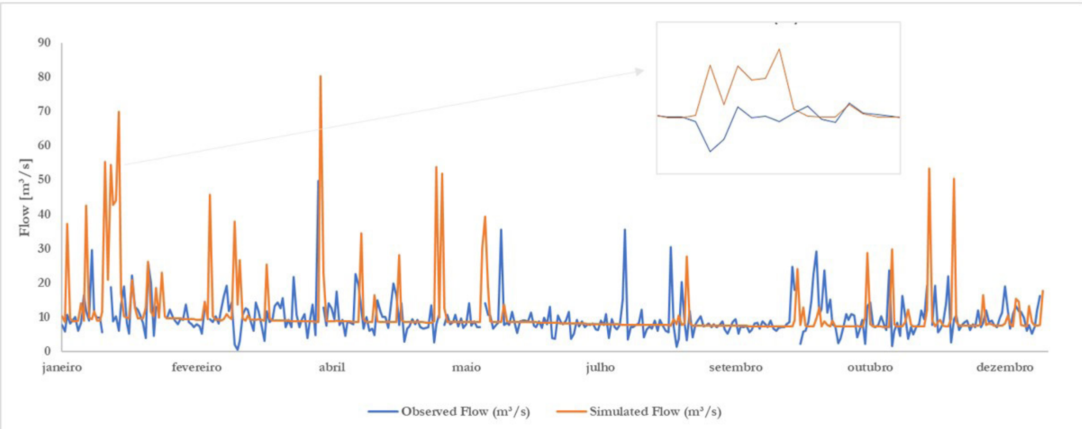

Figure 11. Simulated and observed total flow for the Pinheiros River basin – 2017.

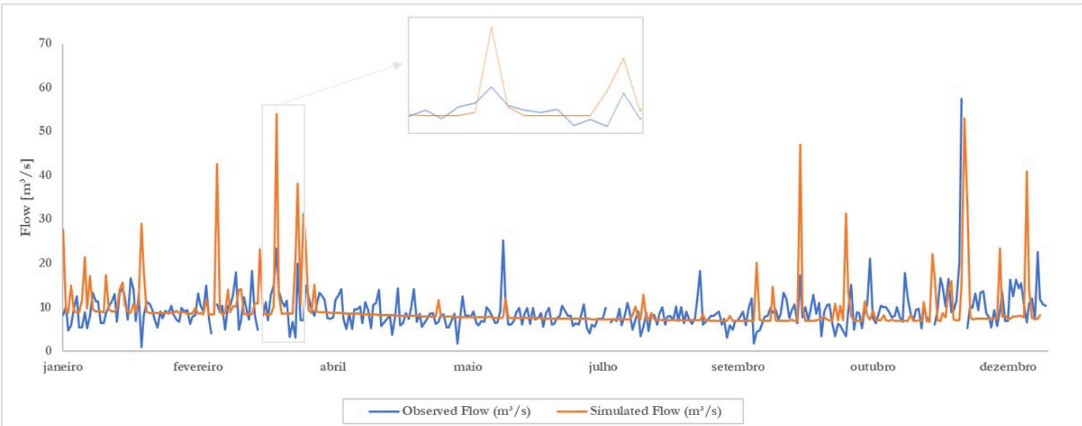

Figure 12. Simulated and observed total flow for the Pinheiros River basin – 2018.

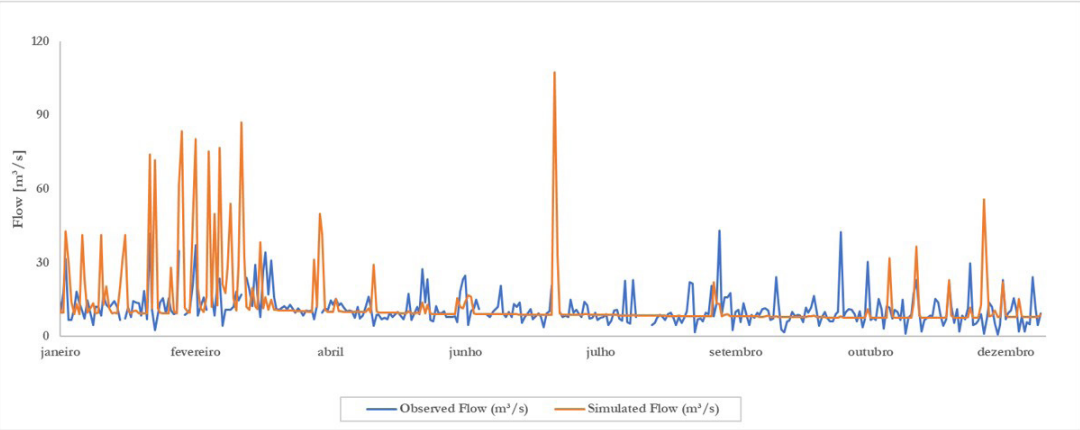

Figure 13. Simulated and observed total flow for the Pinheiros River basin – 2019.

Table 4. Comparison Sum of Monthly Flow and Total Monthly Volume - 2017.

	Volume Monthly Pumped (hm³)	
	Observed	**Modeled**
January	107.6	71.4
February	30.0	26.6
March	22.4	27.8
April	28.6	30.3
May	30.6	27.4
June	17.8	23.4
July	0.0	0.0
Agosto	9.4	12.9
September	2.7	6.3
October	13.5	20.3
November	35.2	41.7
December	18.5	28.3
	316.3	**316.3**

Table 5. Comparison Sum of Monthly Flow and Total Monthly Volume - 2018.

	Volume Monthly Pumped (hm³)	
	Observed	**Modeled**
January	27.2	17.2
February	14.2	9.6
March	48.7	52.6
April	6.3	3.2
May	2.0	3.0
June	0.0	3.7
July	2.7	4.7
Agosto	4.7	6.2
September	16.2	21.2
October	23.7	22.3
November	16.6	26.9
December	42.9	35.1
	205.0	**205.9**

Table 6. Comparison Sum of Monthly Flow and Total Monthly Volume - 2019.

	Volume Monthly Pumped (hm³)	
	Observed	**Modeled**
January	55.1	62.9
February	160.4	133.9
March	148.2	103.4
April	45.2	48.5
May	22.7	12.0
June	24.3	19.9
July	35.7	40.8
Agosto	0.0	0.0
September	5.9	22.0
October	0.0	5.1
November	15.8	37.0
December	26.7	55.5
	540.0	**541.0**

DISCUSSIONS

The use of hydrological models tends to grow even more due to the development of computers and data acquisition. Scientists say that it will have an even greater role in food, water, energy, health and ecosystem security, and sustainable development, especially in a future where climate change can be more severe. It is also said that the softwires will be friendly, and request less knowledge to operate them (Singh, 2018).

Nonetheless, to achieve this potential there is also the importance of input data, and how the models should develop to work with different types of data and be integrated into decision support systems. This type of technology will be responsible to provide accurate information to the cities' planners, and the challenge increases to extremely modified environments with a high-density of population, in which water needs to be available in quantity and quality for many uses but also needs to be controlled to prevent damage from flood events.

This work focused on the matter of rainfall input data as the need for it to be representative in terms of time and space. The radar data has been presented as an alternative to improve this matter, especially in places where rain gauges network present long periods with flaw in measurement or/and where spatial distribution is poor or not exists.

Urban watersheds with complex land use and drainage system showed a greater need to increase the reliability on hydrological studies, that can be provided by distributed rainfall input data, so the hydrologic model can be able to predict the correct volume and the runoff spatial distribution through the streams. It is important to highlight that using only radar data is not enough, but the conditional merging methods (or similar) where radar data is calibrated with field measures of the rain gauges, for example.

Another element that can be forgotten when modelers are describing the water balance in the basin is the sewage discharges. This research showed that, especially in the big metropolis in developing countries, in which water is transported between watersheds, and sewage is released or into the drainage systems or directly on rivers, this is a very important element to be quantified and considered in the model.

CONCLUSIONS

Hydrological models are a powerful tool for cities management and planning and will play a bigger role in society's future. However, to achieve results that are representative and accurate the input data are as important as the model itself, that is why the investigation on how to use geospatial technology in the data acquisition and models' execution is necessary for the development and the uncertainties reduction.

This work demonstrated that to model urban and complex watersheds with accuracy, rainfall distributed data is required, as well as knowledge about how the sewage and drainage systems interact with the multiple tributaries to the watercourses.

This research reinforces the need to use tools and data compatible with the complexity of the study environment and contributes to the field of hydraulics and water resources management. Furthermore, rainfall distribution in the hydrological model can be used as an underlying key aspect to assess nonpoint pollution modeling when it comes to qualitative aspects. This paper demonstrates the potential of using mathematical modeling as a tool to support management.

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Authors contributions

Lais Ferrer Amorim: Lead researcher of the project, worked in all stages of the work, from organizing field data to mathematical simulations, writing the text.

Ariel Ali Bento Magalhães: Researcher contributed to the hydrological modeling of the project, figures and paper revision.

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Fábio Ferreira Nogueira: Researcher contributed to the to the data acquisition for the project.

José Rodolfo Scarati Martins: Project supervisor, included in all parts of the work.

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