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Regionalization of the Q_{90} Steady Flows for the Japaratuba River Basin in the State of Sergipe according to its climatic regions

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Abstract

The reduction and resolution of conflicts involving the use of water, as well as the guarantee of compliance with its various uses, require the appropriate management of water resources, using the instruments foreseen in the pertinent legislation. Among the legal instruments used for the distribution of water, among the different uses and users, the granting of right of use stands out, which is provided as a function of demand and water availability in the requested water body. For the establishment of water availability in a river basin it is necessary to quantify the flows, which is done from the data collected in the fluviométricas stations. However, the Brazilian hydrometric network does not fully cover all hydrography, leaving parts of it without the necessary data for the estimation of flows. The regionalization of flows has been carried out with the objective of providing hydrological information in places with no data or with little information available, as long as they share similar characteristics. The hydrographic basin of the Japaratuba River, which is the object of the study, although it has the most complete hydrological monitoring network in the State of Sergipe, is characterized by great climatic variability (Tropical Humid, Agreste and Semi-Arid), resulting in a different hydrological behavior throughout this basin. Thus, the objective of this work is to determine the regionalization equations of the Q90 residence flow for this basin, which best fit its climatic hydro behavior, in order to *obtain a small variation between the actual and the calculated regionalization flow. In the determination of the Q_{90} permanence flow, the Traditional Method of regionalization was applied, having as independent variables the drainage area of the fluviometric station and its accumulated mean precipitation. The results show that the regionalization of the permanence flow when considering the average monthly precipitation characteristics to define the homogeneous regions presented results consistent with the hydrological reality of the basin rivers and good statistical adjustments to the flows observed in the fluviometric stations.*

Keywords: Hydrological regionalization; Water resources management; Climatology.

1. Introduction

The dissonance between water availability and population concentration in Brazil, coupled with the constant growth of demand over supply, are largely responsible for the occurrence of conflicts over water use in several watersheds. The false sense of water comfort has long justified the culture of waste in our country, in addition to its low valuation as a fundamental resource for the maintenance of ecosystems, resulting in the postponement of the investments necessary for the optimization and rationalization of its use.

The problems of water scarcity in Brazil result from the combination between the exaggerated growth of demands and the degradation of water quality, as a result of the disordered processes of urbanization, industrialization, and agricultural expansion. Santos (2001) and Pereira et al. (2016) state that the spatial and temporal distributions of water resources have been becoming more heterogeneous due to intense and unplanned anthropic action, the latter resulting in a degradation of natural systems and society itself.

The management of hydric resources in Brazil aims at harmonizing and solving conflicts resulting from the intensive use of water in the hydrographic basin, having as principles the rationalization of the use of water, the decentralization of the decision making process and the participation of the society in it. The administration of hydric resources has two basic lines of action regarding the management of the use of water: the management of water supply, by means of actions that aim at a greater quantitative and qualitative availability of this resource; and the management of demand, which seeks to discipline and rationalize its use. From the analysis of these problems should emerge a solution that involves the balance between the different uses of water and the conservation of the hydrological, biological, and chemical functions of ecosystems.

The establishment of water availability or surplus flows in a hydrographic basin is of fundamental importance to the management of the supply of water resources. To do this it is necessary to quantify the flows, which is done from the data collected at the river gaging stations found in specific sections of the hydrographic basins. Unfortunately, the hydrometric network does not completely cover the entire hydrography, leaving parts of it without the data needed to estimate the flows. In Brazil, for example, the hydrological monitoring network is reduced for basins with an area of less than 300 km² (Tucci, 2002).

According to Tucci (2002), the Brazilian hydrological network was installed in large hydrographic basins (above 2,000 km²), because its objective was to meet the energy needs, besides the fact that the costs of monitoring small basins are very high and the national territory is very extensive (8.5 million km²). However, it is through adequate knowledge of the flow rates of small hydrographic basins that one can establish the availability of water for the different uses of water and, historically, these studies have been carried out with little knowledge of the hydrological behavior (Tucci, 2002).

A technique used to estimate hydrological variables in places without data or with insufficient data is the regionalization of water levels, which consists of a set of tools that exploit the available data to the maximum in order to determine the water level at the point of interest, through a process of transferring information from one place to another with similar hydrological behavior. The studies of flow regionalization involve mathematical and statistical procedures relating hydrological processes with physical and climatic characteristics of a basin, for which the use of computer systems is indispensable.

The Secretary of State for the Environment and Water Resources (SEMARH) adopts the flow rate with 90% permanence over time (Q_{90}) as a reference for calculating water availability for granting water use right (Sergipe, 2010). Since the density of river gauge stations in the state is low, it is useful to use regionalized equations to estimate the water availability in each section of the water bodies.

Thus, this study aimed to determine the regionalized equations for annual and monthly Q_{90} for the Japaratuba River watershed that best fit its hydro-climatic reality, that is, equations that result in a small variation between the actual flow, observed at the river stations, and the flow calculated by the regionalization, as well as high values for the coefficient of determination R^2 and low values for residues.

2. Material and Methods

Initially, it was verified if all the stations in the basin were qualified to participate in this study. It was observed that the fluviometric stations presented historical series of at least 33 years and rainfall stations of at least eight years. With respect to the level of consistency, all fluviometric stations had their data already analyzed and adjusted by the State management agency; however, the historical series used for the rainfall stations were of data not yet analyzed and adjusted.

Schneider et al., (2017); Schneider and Mendes, (2015); Wolf et al., (2014) and Pruski et al., (2012) observed that the inclusion of mean accumulated precipitation as a second independent variable, in addition to the upstream contribution area, results in significant improvements in the results of the statistical parameters in the regionalization of flows. In view of this, the present study used as independent variables the upstream contribution area (km^2) and the average accumulated precipitation (mm) for the regionalized Q_{90} flow equation.

Since none of the river gauge stations used in this study collected and measured rainfall, we adopted rainfall stations closer to them, with greater influence on them, and with a more significant historical series in duration and number of failures. Having in hand the geographic coordinates of each measuring station, we made use of a geographic calculator in digital model of the National Institute for Space Research (INPE, 2015), to calculate the distances between the different rainfall and fluviometric stations used.

The regionalization of the permanence flow was carried out considering two distinct alternatives: the first grouped all the river gauging stations of the Japaratuba basin into a single homogeneous region, called Japaratuba Homogeneous Region (JHR); and the second discriminated two homogeneous regions, and their respective stations, according to the rainfall and climatological characteristics of the basin, thus defining the

Homogeneous Region I (HRI) and Homogeneous Region II (HRII). Thus, it was used, respectively, the geographic convenience and subjective groupings, pointed out by Hosking and Wallis (Figueiredo, 2013) and Bazzo et al. (2017), which state the importance of the division of homogeneous regions in hydro-climatological characteristics, as a methodology for defining homogeneous regions.

In Tables 1, 2 and 3 the river and rainfall stations were presented, as well as their code, the length of the historical series and the influence that the rainfall stations have on the upstream contributing area of the flow measurement stations for the JHR, HRI and HRII regions respectively.

Table 1. River and rainfall stations that make up the Japaratuba Homogeneous Region

Station nome	Code	Station type	history series	Distance (km)	Influence (%)
Japaratuba	50040000	River	1969 – 2005	-----	-----
Capela	1037009	Rainfall	1953 – 1998	14.2	45.0
Gracho Cardoso (Tamanduá)	1037016	Rainfall	1963 - 1999	38.2	40.9
Oteirinhos power plant	1036020	Rainfall	1963 - 1996	4.0	14.1
Pão de Açúcar farm	50042000	River	1973 - 2005	-----	-----
Aquidabã	1037003	Rainfall	1912 - 1997	19.4	100.0
Cajueiro farm	50043000	River	1973 - 2016	-----	-----
Cajueiro farm	1036063	Rainfall	1992 - 2017	3.9	100.0
Siriri (DNOCS)	50046000	River	1973 - 2005	-----	-----
Siriri	1037047	Rainfall	1963 - 1998	2.4	52.8
Nossa Senhora das Dores	1037036	Rainfall	1913 - 2000	14.4	47.2
Rosário do Catete	50047000	River	1973 - 2005	-----	-----
Siriri	1037047	Rainfall	1963 - 1998	13.8	27.1
Nossa Senhora das Dores	1037036	Rainfall	1913 - 2000	26.6	72.9

Table 2. River and rainfall stations that make up the Homogeneous Region I

Station nome	Code	Station type	history series	Distance (km)	Influence (%)
Japaratuba	50040000	River	1969 - 2005	-----	-----
Capela	1037009	Rainfall	1953 - 1998	14.2	45.0
Gracho Cardoso (Tamanduá)	1037016	Rainfall	1963 - 1999	38.2	40.9
Oteirinhos power plant	1036020	Rainfall	1963 - 1996	4.0	14.1
Cajueiro Farm	50043000	River	1973 - 2016	-----	-----
Cajueiro Farm	1036063	Rainfall	1992 - 2017	3.9	100.0

Siriri (DNOCS)	50046000	River	1973 - 2005	-----	-----
Siriri	1037047	Rainfall	1963 - 1998	2.4	52.8
Nossa Senhora das Dores	1037036	Rainfall	1913 - 2000	14.4	47.2
Rosário do Catete	50047000	River	1973 - 2005	-----	-----
Siriri	1037047	Rainfall	1963 - 1998	13.8	27.1
Nossa Senhora das Dores	1037036	Rainfall	1913 - 2000	26.6	72.9

Table 3. River and rainfall stations that make up the Homogeneous Region II

Station nome	Code	Station type	history series	Distance (km)	Influence (%)
Pão de Açúcar Farm	50042000	River	1973 - 2005	-----	-----
Aquidabã	1037003	Rainfall	1912 - 1997	19.4	100.0
Santa Rosa de Lima	50080000	River	1972 - 2005	-----	-----
Santa Rosa de Lima	1037049	Rainfall	1952 - 2017	1.0	100.0
Tourão Farm	50250000	River	1978 - 2005	-----	-----
Vila Isabel Farm	1037051	Rainfall	1963 - 1999	39.6	39.1
Samambaia	1038001	Rainfall	1963 - 1999	25.6	60.9
Inhambupe	50620000	River	1969 - 2005	-----	-----
Inhambupe	1138002	Rainfall	1948 - 2017	0.2	100.0

The SisCAH software was used for the processing of the historical flow series, a computational tool developed by researchers at the Federal University of Viçosa (Souza, 2009). The historical flow series from 1973 to 1996, with the exception of the Cajueiro farm station, in which the period from 1992 to 2016 was used, was considered for the determination of the permanence curve. A maximum percentage of up to 20% of failures was established, both for annual and monthly data. The data from the fluviometric stations were obtained from the HidroWeb database (ANA, 2006).

The SisCoRV software was used for the regionalization of Q_{90} (Souza et al., 2008). The Traditional Method of regionalization was employed, which adjusts the linear, potential, exponential, logarithmic and reciprocal regression models to the data series. It was established that the best regionalization equation would be the one that resulted in higher values of the coefficient of determination (R^2) and low values of standard error and residuals.

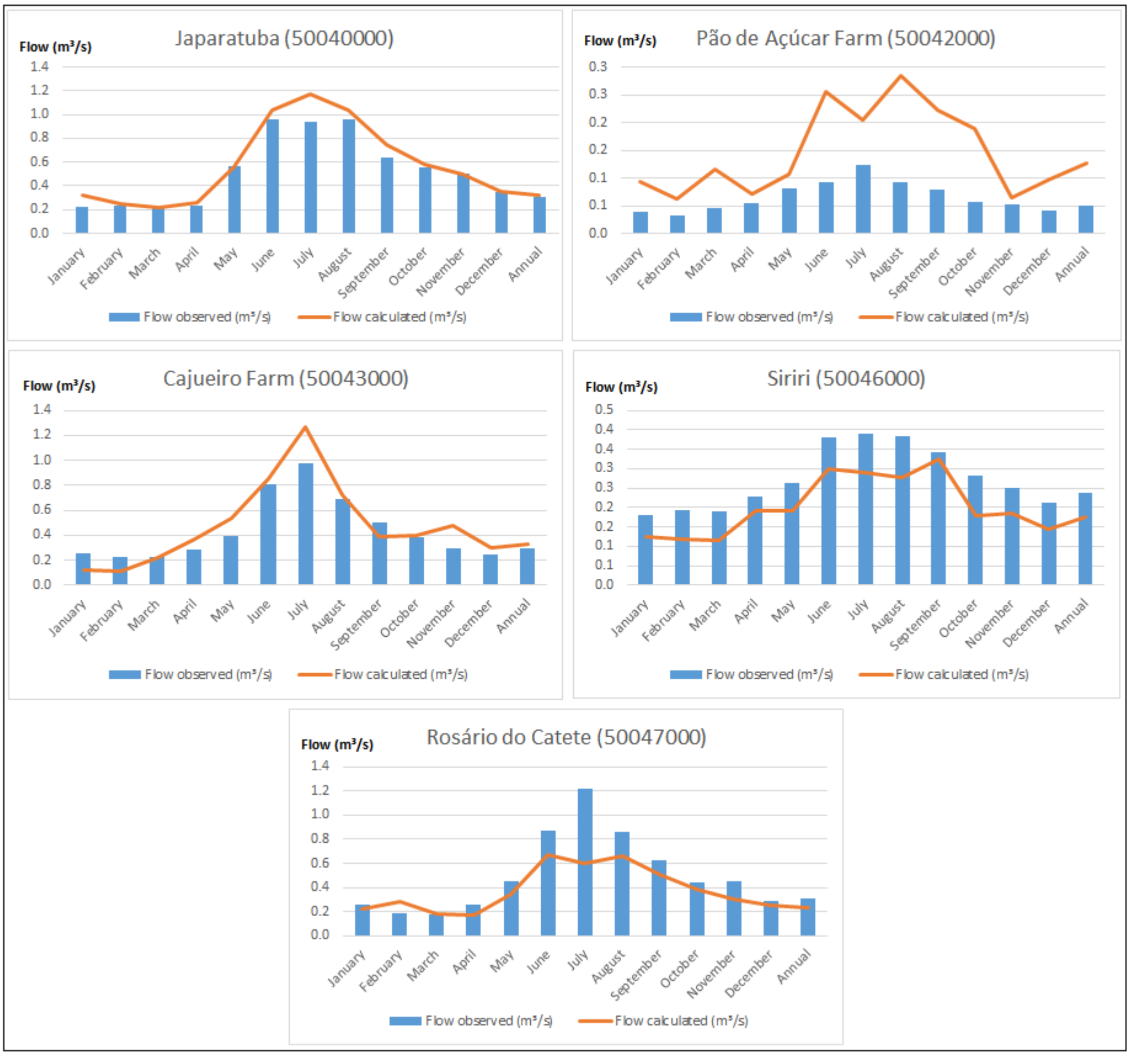
The definition of the homogeneous regions HRI and HRII was based on the variation of the accumulated annual precipitation in the State of Sergipe, which is decreasing in the East-West direction, reaching averages higher than 1,400 mm on the coast and only 400 mm in the semi-arid region. Thus, four of the five fluviometric stations present in the basin are located in the humid tropical zone - Japaratuba (50040000), Cajueiro farm (50043000), Siriri (50046000) and Rosário do Catete (50047000) -, which were gathered into the HRI. The station Pão de Açúcar farm (50042000) is the only station outside the humid tropical zone. Since SisCORV is limited to a minimum of four stations in the homogeneous region for data processing, stations from neighboring watersheds were included to form the homogeneous region HRII. This region then consisted of the stations Pão de Açúcar farm, Santa Rosa de Lima, Tourão farm and Inhambupe, located in the semi-arid region of the State of Bahia.

3. Results and discussion

3.1 Japaratuba Homogeneous Region (JHR)

Figure 1 shows the relationship between observed and calculated water levels for the JHR. There is a disparity between these flows, mainly due to the grouping in a single homogeneous region of stations with distinct hydro-climatic characteristics, given the spatial and inter-annual variability, with severe droughts and floods in different years, that the rainfall regime of Sergipe presents.

Figure 1. Observed and calculated flow rates for river stations in the JHR



The equations of monthly and annual Q_{90} and respective R^2 values of the regionalization for JHR are shown in Table 4 and the residuals obtained for the same region in Table 5.

Table 4. Regionalization equations for JHR, Q_{90} ($m^3 s^{-1}$), Precipitation (mm) and Area (km^2)

Station	Period	R^2	Equation
Japaratuba Pão de Açúcar farm Cajueiro farm Siriri Rosário do Catete	January	0.385	$Q_{90} = 0.04853 \times A^{0.61452} \times P^{-0.62414}$
	February	0.545	$Q_{90} = 2.22149E{+}20 \times A^{0.89914} \times P^{-13.31219}$
	March	0.524	$Q_{90} = 1.05760 + (0.07066) \times \ln A + (-0.29210) \times \ln P$
	April	0.814	$Q_{90} = 8.05139E{-}19 \times A^{0.16829} \times P^{7.90142}$
	May	0.848	$Q_{90} = 9.51061E{-}11 \times A^{0.71573} \times P^{3.44500}$
	June	0.848	$Q_{90} = -4.99948 + (0.42879) \times \ln A + (0.63486) \times \ln P$
	July	0.736	$Q_{90} = 6.8146E{-}09 \times A^{0.87150} \times P^{2.60840}$
	August	0.815	$Q_{90} = -4.46502 + (0.42267) \times \ln A + (0.58531) \times \ln P$
	September	0.730	$Q_{90} = -7.38804 + (0.24449) \times \ln A + (1.49627) \times \ln P$
	October	0.767	$Q_{90} = -1.34675 + (0.22726) \times \ln A + (0.11118) \times \ln P$
	November	0.839	$Q_{90} = 9.95753E{-}08 \times A^{0.69171} \times P^{3.09031}$
	December	0.793	$Q_{90} = -0.54842 + 0.00016 \times A + 0.03373 \times P$
	Annual	0.680	$Q_{90} = -3.13287 + (0.07174) \times \ln A + (0.42936) \times \ln P$

P = precipitation; A = area.

Table 5. Residuals (%) for the JHR

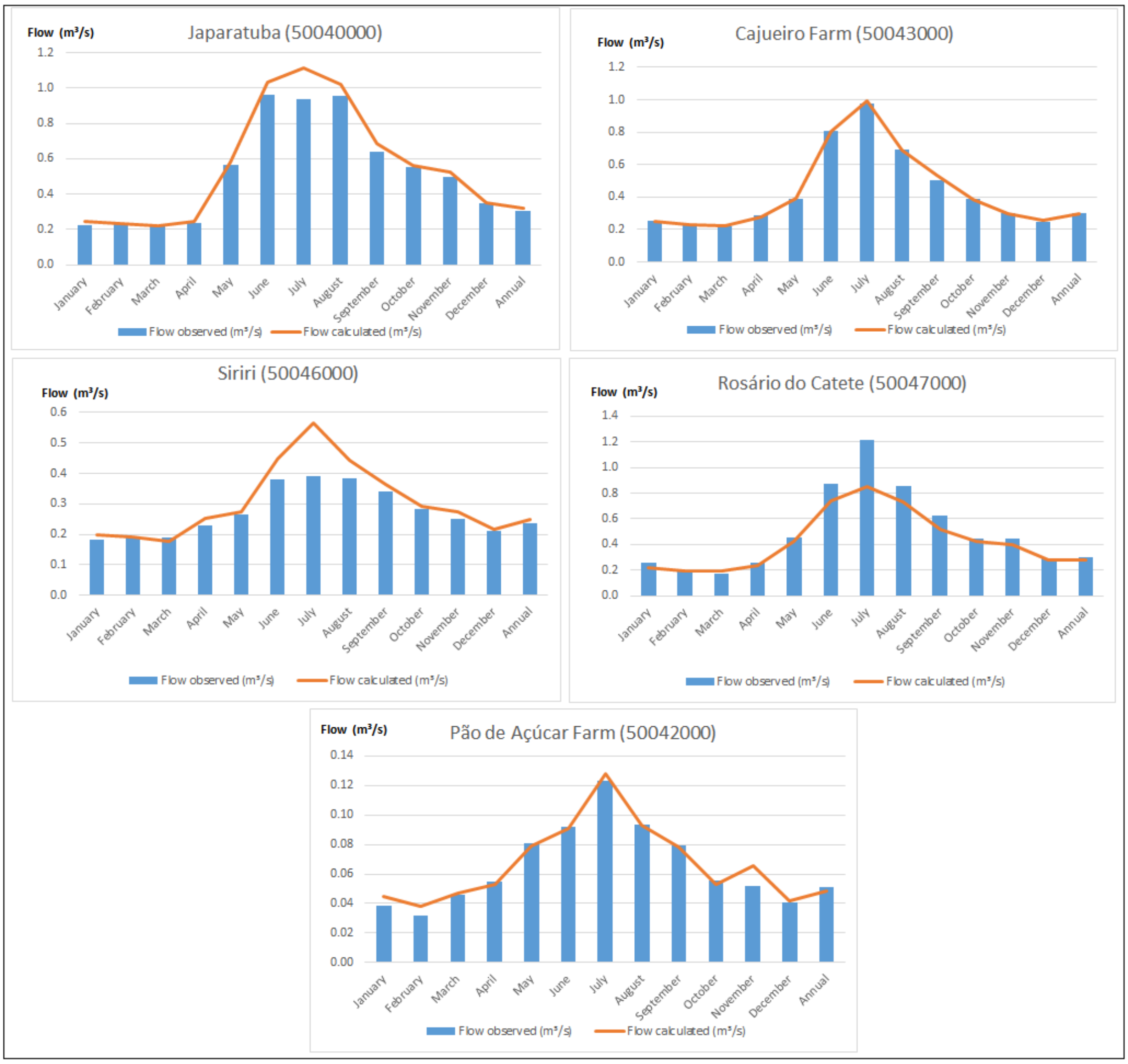
Period	River Stations				
	Japaratuba	Pão de Açúcar farm	Cajueiro farm	Siriri	Rosário do Catete
January	44.3	142.7	-51.3	-30.6	-15.4
February	5.9	95.2	-49.1	-37.7	52.4
March	-2.7	153.7	1.8	-38.2	2.2
April	11.0	28.9	28.0	-15.6	-35.3
May	-1.4	32.3	38.5	-27.4	-23.7
June	8.3	178.9	5.3	-21.5	-23.5
July	25.1	66.7	29.4	-25.4	-50.3
August	8.1	205.6	4.7	-27.9	-22.7
September	16.3	181.2	-22.4	-4.7	-19.0
October	4.3	238.4	3.1	-36.5	-14.7
November	-1.0	27.1	60.8	-26.0	-33.3
December	-0.2	144.1	18.6	-31.3	-12.9
Annual	5.3	147.6	11.7	-25.1	-22.2

The low values of the coefficient of determination and high residuals, especially in the dry seasons, are due to the difference in rainfall behavior between the stations grouped in the same homogeneous region. The results ratify the study of Bazzo et al. (2017), which show the need for the division of homogeneous regions based on the rainfall characteristics of the regions in which the river stations are located.

3.2 Homogeneous Region I and II

Figure 2 shows the relationship between observed and calculated flow rates for the river gauging stations in the HRI and HRII regions.

Figure 2. Observed and calculated flow rates for HRI and HRII river stations



The monthly and annual Q_{90} equations from regionalization for HRI and HRII are shown in Tables 6 and 7, respectively, and the residuals for the same regions in Table 8.

Table 6. Regionalization equations for HRI, Q_{90} ($m^3\ s^{-1}$), Precipitation (mm) and Area (km²)

Station	Period	R^2	Equation
Japaratuba	January	0.999	$Q_{90} = 0.06421 \times A^{0.10401} \times P^{0.19208}$
Cajueiro farm Siriri	February	0.711	$Q_{90} = (19.52264 + (-0.00013) \times \ln A + (-0.25990) \times \ln P)^{-1}$
Rosário do Catete	March	0.393	$Q_{90} = 0.33827 + 9.17E\text{-}05 \times A + (-0.00213) \times P$

April	0.982	$Q_{90} = -0.12859 + (-9.6E\text{-}06) \times A + 0.00268 \times P$
May	0.864	$Q_{90} = -0.07117 + (0.17295) \times \ln A + (-0.09508) \times \ln P$
June	0.459	$Q_{90} = -2.65268 + (0.33657) \times \ln A + (0.28917) \times \ln P$
July	0.881	$Q_{90} = -3.94228 + (0.33302) \times \ln A + (0.56493) \times \ln P$
August	0.812	$Q_{90} = -1.15877 + (0.33223) \times \ln A + (-0.00310) \times \ln P$
September	0.986	$Q_{90} = 24.15433 \times A^{0.36561} \times P^{-1.37012}$
October	0.923	$Q_{90} = -0.27737 + (0.15773) \times \ln A + (-0.05260) \times \ln P$
November	0.970	$Q_{90} = 1.43635 + (0.12536) \times \ln A + (-0.49515) \times \ln P$
December	0.751	$Q_{90} = 0.30243 + (0.09552) \times \ln A + (-0.18411) \times \ln P$
Annual	0.414	$Q_{90} = -0.44508 + (0.03788) \times \ln A + (0.07397) \times \ln P$

P = precipitation; A = area.

Table 7. Regionalization equations for HRII, Q_{90} ($m^3 s^{-1}$), Precipitation (mm) and Area (km^2)

Station	Period	R^2	Equation
	January	0.693	$Q_{90} = 1.04E\text{-}33 \times A^{1.34182} \times P^{17.44692}$
	February	0.992	$Q_{90} = 3.32845E\text{-}20 \times A^{0.89190} \times P^{9.15880}$
	March	0.547	$Q_{90} = 2.02E\text{-}30 \times A^{0.64612} \times P^{14.07550}$
	April	0.548	$Q_{90} = 7.6234E\text{-}13 \times A^{0.58153} \times P^{4.57234}$
Pão de Açúcar farm	May	0.715	$Q_{90} = 5.184E\text{-}11 \times A^{0.70059} \times P^{3.52002}$
Santa Rosa de	June	0.405	$Q_{90} = 1.52E\text{-}10 \times A^{0.63400} \times P^{3.44897}$
Lima	July	0.592	$Q_{90} = 3.33787E\text{-}07 \times A^{0.50909} \times P^{2.08880}$
Tourão farm	August	0.507	$Q_{90} = 2.599E\text{-}10 \times A^{0.64592} \times P^{3.62229}$
Inhambupe	September	0.926	$Q_{90} = 1.38E\text{-}08 \times A^{0.62727} \times P^{2.91047}$
	October	0.473	$Q_{90} = 6.85E\text{-}08 \times A^{0.46902} \times P^{3.00116}$
	November	0.986	$Q_{90} = 3.43611E\text{-}09 \times A^{-1.44493} \times P^{7.38736}$
	December	0.580	$Q_{90} = 2.84E\text{-}05 \times A^{-0.54074} \times P^{3.41084}$
	Annual	0.828	$Q_{90} = 1.15E\text{-}13 \times A^{0.47728} \times P^{3.60656}$

Table 8. Residuals (%) for the HRI and HRII

Period	**River stations**				
	Japaratuba	**Cajueiro farm**	**Siriri**	**Rosário do Catete**	**Pão de Açúcar farm**
January	10.3	-2.9	10.5	-15.5	15.4
February	-0.1	0.2	-0.3	0.3	18.9
March	-2.4	-0.7	-6.5	11.2	2.5
April	4.0	-4.1	10.9	-8.7	-3.7
May	2.0	0.5	4.2	-5.4	-2.4
June	7.2	-0.3	17.9	-15.3	-1.5
July	19.3	1.3	45.0	-30.2	4.4
August	6.4	0.3	15.5	-14.4	-0.3
September	7.6	5.3	6.6	-17.2	-1.3
October	1.7	0.1	3.2	-4.2	-5.5
November	4.8	-0.4	9.5	-10.4	27.2
December	1.5	2.2	2.1	-5.2	3.7
Annual	4.1	-1.1	5.4	-7.3	-5.4

The hydrological regionalization of the HRI and HRII regions presented results that were much more consistent with the hydrological reality of the basin studied, when compared to the regionalization obtained for the JHR. This was mainly due to the similar hydrological behavior between the stations that make up each of these two homogeneous regions.

We also observed a tendency for higher residuals to coincide with months of higher precipitation, due to the greater dispersion in rainfall data, which typically occurs in wet months.

4. Conclusion

The low density and poor distribution of river gauging stations in the basin made the application of the flow regionalization technique difficult, especially in the areas of the Agreste and Semiarid, far from the humid tropical zone of the coast. As it is the only fluviometric station in the Agreste, the Pão de Açúcar station had to be grouped with stations from neighboring watersheds with similar rainfall characteristics, which resulted in an increase in the error rate of the results.

The regionalization equations obtained in this study for the Homogeneous Regions HRI and HRII showed good statistical adjustment to the observed flows at the river gauging stations. The worst performance of the equations, regarding residuals, was observed in the month of July, marked by higher precipitation and, as a consequence, higher variance of flows, although the correlation coefficient in July was still high.

The monthly regionalization presented results that are coherent with the hydrological reality of the rivers of the basin, in which the rains are concentrated from March to August, causing higher flows in this period, and with low surface runoff from September to February, due to lower rainfall rates in this period. Thus, there is more water available for allocation in the fall and winter, which ratifies the importance of considering seasonality when calculating the maximum allowable flow rate for the region studied. Thus, seasonal allocation would positively influence the local economy, to the extent that it allows more consumptive demands to be allocated in the humid months, and environmental conservation, since it could encourage rational use of water in the drier months due to the lower availability of water for allocation. Such practice makes the application of the water use right granting instrument more coherent and contributes to the efficiency of water resource management.

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