

Seasonality and criteria for concession of water in the Ivinhema basin
Sazonalidade e critério para concessão de água na bacia do Ivinhema
Estacionalidad y criterios de concesión de agua en la cuenca del Ivinhema

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Abstract

Global demand for water has been increasing per year due to population growth, economic development, and changes in consumption patterns, among other factors. This increase in water demand is expected to continue in the next decades. The objective of this work was to evaluate the use of different criteria to grant the use of water from the Ivinhema river basin, Brazil. Monthly periods were compared to annual periods to calculate the reference flows $Q_{7,10}$ and Q_{95} . The relative differences in water availability using different reference flow rates for water concession were quantified. The replacement of the annual criteria (standard in Brazil) for water concession by 50% of monthly $Q_{7,10}$ and 70% of monthly Q_{95} can potentially

increase the use and improve the management of water resources. The best criteria to award grants is the monthly $Q_{7,10}$, which despite being more restrictive, it allows higher flow rates when there is excess water, and lower rates in the months of low water availability.

Keywords: Water availability; $Q_{7,10}$; Q_{95} .

Resumo

A demanda global por água tem aumentado a cada ano devido ao crescimento populacional, desenvolvimento econômico, e mudanças nos padrões de consumo, entre outros fatores. Esse aumento na demanda de água é esperado nas próximas décadas. O objetivo deste trabalho foi avaliar o uso de diferentes critérios para garantir o uso da água na bacia do rio Ivinhema, Brasil. Períodos mensais foram comparados com períodos anuais para calcular as vazões de referência $Q_{7,10}$, Q_{95} . As diferenças relativas na disponibilidade de água usando diferentes taxas de vazões de referência para concessão de água foram quantificadas. A substituição dos critérios anuais (padrão no Brasil) para concessão de água em 50% do $Q_{7,10}$ mensal e 70% do Q_{95} mensal pode potencialmente aumentar o uso e melhorar a gestão dos recursos hídricos. O melhor critério para a concessão de outorga é o $Q_{7,10}$ mensal, que apesar de ser mais restritivo, permite maiores taxas de vazão quando há excesso de água, e menores taxas nos meses de baixa disponibilidade hídrica.

Palavras-chave: Disponibilidade hídrica; $Q_{7,10}$; Q_{95} .

Resumen

La demanda mundial de agua ha ido aumentando cada año debido al crecimiento de la población, el desarrollo económico y los cambios en los patrones de consumo, entre otros factores. Este aumento de la demanda de agua se espera en las próximas décadas. El objetivo de este trabajo fue evaluar el uso de diferentes criterios para garantizar el uso del agua en la cuenca del río Ivinhema, Brasil. Se compararon períodos mensuales con períodos anuales para calcular los flujos de referencia $Q_{7,10}$, Q_{95} . Se cuantificaron las diferencias relativas en la disponibilidad de agua utilizando diferentes caudales de referencia para la concesión de agua. El reemplazo de los criterios anuales (estándar en Brasil) para la concesión de agua en el 50% del $Q_{7,10}$ mensual y el 70% del Q_{95} mensual puede potencialmente incrementar el uso y mejorar la gestión de los recursos hídricos. El mejor criterio para otorgar una subvención es el $Q_{7,10}$ mensual, que a pesar de ser más restrictivo, permite mayores caudales cuando hay exceso de agua y menores en meses de baja disponibilidad de agua.

Palabras clave: Disponibilidad de agua; $Q_{7,10}$; Q_{95} .

1. Introduction

Global demand for water has been increasing approximately 1% per year (WWAP, 2012) due to population growth, economic development, and changes in consumption patterns, among other factors. This increase in water demand is expected to continue in the next decades (Unesco, 2018).

In the context of water resources management, minimum flows have received attention because they represent the conditions of a basin during the dry season, when the water supply is limited (Silva et al., 2017). For an adequate management of shared water resources, it is essential to precisely estimate the water flows (Li et al., 2010; Arai et al., 2012; Pinto et al., 2015). Commonly, the average minimum flow of seven consecutive days with return period of 10 years ($Q_{7,10}$) and the minimum expected flow in 90% or 95% of the time (Q_{90} or Q_{95} , respectively) are adopted as reference (Brodie et al., 2008; Tucci, 2012).

The procedure for water concession is based on the minimum reference flow, which corresponds to the conditions during the greatest water shortage in a given year. This annual value can restrict the water use. However, where the water demand is high, a larger volume of water could be granted in the concession, especially during rainy periods. Therefore, it is necessary to consider the seasonal nature for the granting criteria.

There is great water availability in Mato Grosso do Sul, Brazil. However, the management of water resources requires solutions that satisfy the increasing challenges of water security arising from population growth and climate change. The water catchment area of Ivinhema is the second largest basin in Mato Grosso do Sul. It provides water to approximately 26% of the state's population and supports the development of several municipalities.

To properly evaluate the water availability in the Ivinhema basin and to promote socioeconomic and environmental development, different criteria for water concession in the Ivinhema river basin were analyzed in this study.

2. Material and Methods

This research was carried out through quantitative methods, the collection of quantitative or numerical data was performed through the use of measurements of quantities and obtained through metrology, numbers with their respective units. These methods generated a set or masses of data, which were analyzed using mathematical techniques

(Pereira et al. 2018)

The Ivinhema basin is located in Mato Grosso do Sul and occupies an area of approximately 46,500 km². It is located between latitudes 20° 51' S and 23° 14' S, and longitudes 52° 21' W and 55° 57' O. The Pardo river basin is in its northern border, and the Amambai river basin in the southern. The Maracaju mountain range and the Republic of Paraguay are west of the Ivinhema basin, and the Paraná River is east of it (Arai et al. 2012). The main river of the basin is the Ivinhema river, and its main tributaries are the Dourados river on the right bank and the Vacaria river on the left bank. Twenty-five municipalities are part of the basin. Fifteen of them are integrally within the drainage area, and 10 only partially. According to the Köppen Geiger classification, the climate of the region is type Aw (Peel et al., 2007), with annual average precipitation and temperature of 1,425 mm and 23.6 °C, respectively.

To estimate the minimum reference flows ($Q_{7,10}$ and Q_{95}), data from nine fluviometric stations (Table 1) were gathered. These stations belong to the hydrometeorological network of the National Water Agency (ANA), and the data are available on its Hydrological Information System.

Table 1. Characterization of selected fluviometric stations. DA = Drainage Area; PRB = Port Rio Brilhante; FSJ = Farm São Joaquim.

Code	Estation	River	Latitude	Longitude	DA (km ²)*
64601000	Brilhante	Brilhante	21°37'57" S	54°59'13" W	3.759
64605000	PRB	Brilhante	21°55'00" S	54°30'00" W	9.180
64609000	Dourados	Dourados	22°23'50" S	54°47'31" W	5.817
64610000	Port Wilma	Dourados	22°04'08" S	54°13'43" W	9.059
64611000	Retriat Guarujá	Brilhante	21°54'03" S	54°03'14" W	20.714
64613000	Aroeira	Vacaria	21°38'29" S	54°25'19" W	4.468
64613800	FSJ	Vacaria	21°50'48" S	53°53'39" W	6.290
64614000	Farm Ipacaráí	Ivinhema	21°57'23" S	53°46'03" W	27.397
64617000	Ivinhema	Ivinhema	22°22'57" S	53°31'43" W	31.910

*The drainage areas were obtained by means of the digital elevation model generated in the GIS, therefore, it does not consist of ANA's fluviometric inventory. Source: Authors.

To estimate $Q_{7,10}$ and Q_{95} , years from 1973 to 2007 with more than 95% of the data were analyzed. To estimate the annual and monthly series of Q_7 for each station, log-normal

probability distribution functions, namely Pearson III, log-Pearson III, and Weibull, were analyzed with two and three parameters. The Kolmogorov-Smirnov adherence test was used to select a probability distribution that was adjustable for each historical series, with 20% probability. The adjustment of the parameters for each distribution was performed using the moments method. After selecting the probabilistic distribution with the best fit to the minimum flow data, the values of $Q_{7,10}$ were obtained. To calculate the $Q_{7,10}$ of seasonal periods, the events of Q_7 were obtained by restricting the data set to the seasonal period in question. To compute these flows, the Computational System for Hydrological Analysis (SisCAH, 2009) program was used (Sousa et al., 2009).

Q_{95} was obtained from the permanence curve of each fluviometric station, based on daily data. Q_{95} considers the portion of time during which a given flow is equalized or exceeded within the analyzed period. Therefore, the data series were organized in descending order, and the frequency associated with each flow rate was determined according to Eq. 1:

$$f_i = \frac{N_{qi}}{NT} 100, \quad (1)$$

Where N_{qi} is the number of events greater than or equal to the flow of order i ; and NT is the total number of data in the sample.

Through SisCAH, Q_{95} was obtained in monthly and annual scales for each historical series, according to the methodology described. To determine the permanence curve on a monthly basis, the same procedure as the one for the annual estimation was used, but with the data set restricted to a monthly scale.

Based on the estimated minimum reference flows, the monthly and annual flows were compared. The relative difference between water availability for concession based on monthly and annual minimum reference flows were calculated according to Eq. 2.

$$Dr = \frac{Q_{\text{seasonal}} - Q_{\text{annual}}}{Q_{\text{annual}}}, \quad (2)$$

Where Dr is the relative difference in water availability, %; Q_{seasonal} is the estimated flow on a monthly basis, m^3s^{-1} ; and Q_{annual} is the estimated annual flow, m^3s^{-1} .

The water catchment area of the Ivinhema River does not have a legislation regarding water concession. However, the basin management plan presents the estimated water balance

as a function of the minimum flows (Q_{95} e $Q_{7,10}$) (Imasul, 2015). Therefore, the maximum allowable flows for concession granted by the Federal Government (70% of annual Q_{95}) and by different Brazilian states (50% of annual $Q_{7,10}$) were compared.

For each fluvioimetric station considered in the study, the values of $Q_{7,10}$ and Q_{95} on monthly and annual bases were compared, in addition to the criteria for: 50% of $Q_{7,10}$, 50% of Q_{95} , 70% of $Q_{7,10}$, and 70% of Q_{95} ; in the different time scales analyzed. The monthly behavior of the estimates and the magnitude of the discharge according to the time scale were compared to the annual flows.

The relative difference between the criteria of maximum allowable discharge for annual and monthly bases was based on volumes and calculated using Eq. 3.

$$Dr_{\text{criterion}} = \frac{V_{70\%Q_{95}} - V_{50\%Q_{7,10}}}{V_{50\%Q_{7,10}}} 100, \quad (3)$$

Where $Dr_{\text{criterion}}$ is the relative difference between the criteria, %; $V_{70\%Q_{95}}$ is the maximum permissible water volume for concession considering the ANA criterion, $\text{m}^3 \text{ year}^{-1}$; and $V_{50\%Q_{7,10}}$ is the maximum permissible water volume for granting, considering 50% of $Q_{7,10}$, $\text{m}^3 \text{ year}^{-1}$.

Based on the flows considered for the monthly and annual concession, the total volume for each concession (annual and monthly) was calculated. The difference between the maximum permissible volume upon change from annual to monthly concession was calculated according to Eq. 4.

$$Dr_b = \frac{V_{\text{monthly}} - V_{\text{annual}}}{V_{\text{annual}}} 100, \quad (4)$$

Where Dr_b is the relative difference between the monthly and the annual criterion, %.

3. Results and Discussion

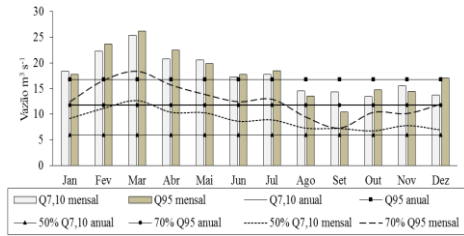
The monthly variations of $Q_{7,10}$ and Q_{95} throughout the year, the comparison with annual values, and the projection of different criteria for the concession (50% $Q_{7,10}$, and 70% Q_{95} monthly and annual basis) are presented in Figure 1.

On average, the annual Q_{95} was 35.0% higher than the annual $Q_{7,10}$. Considering the different flow criteria for concession in the nine stations evaluated, 50% of monthly $Q_{7,10}$ yielded a 75.9% higher flow for concession compared to 50% of annual $Q_{7,10}$. Moreover,

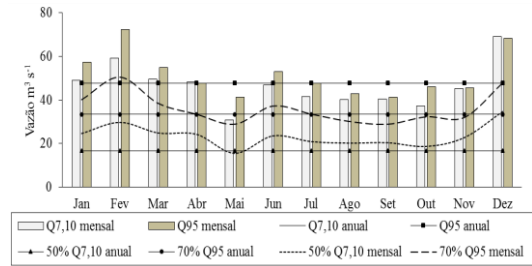
70% of monthly Q₉₅ resulted in a 32.0% higher result when compared to 70% of annual Q₉₅.

Figure 1. Q_{7,10} and Q₉₅ monthly variations and comparison with annual values.

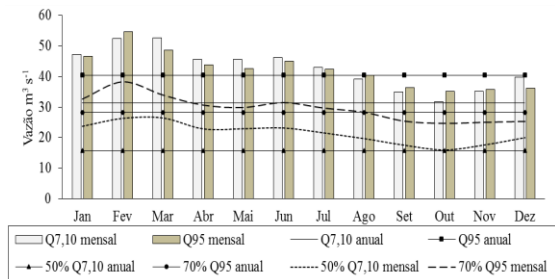
A) Brilhante station



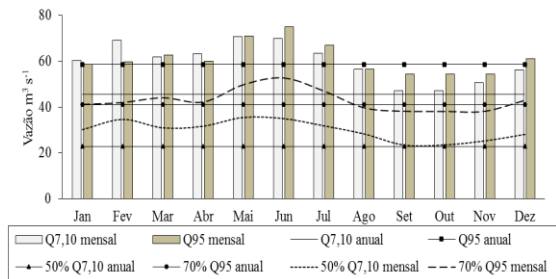
B) Port Rio Brilhante station



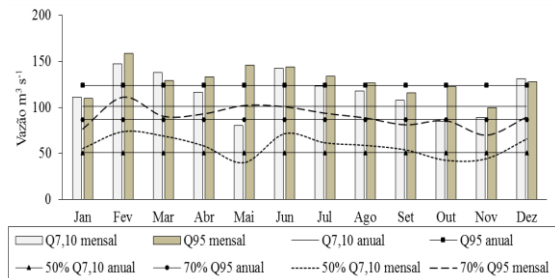
C) Dourados station**



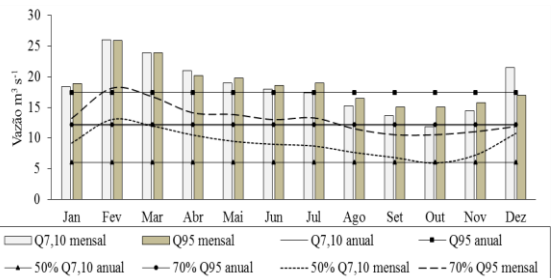
D) Port Wilma station**



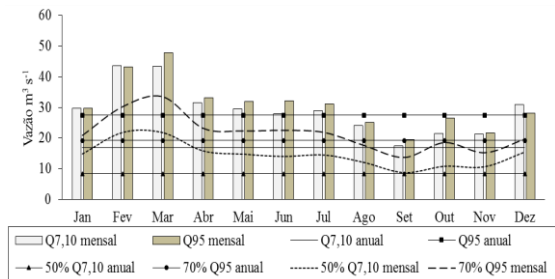
E) Retriat Guarujá station



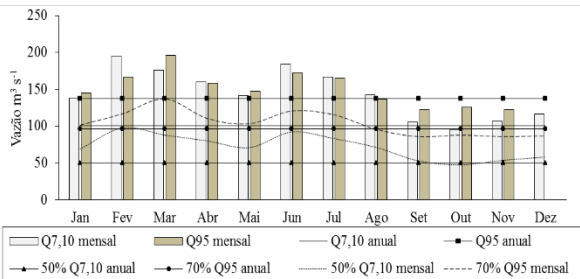
F) Aroeira station



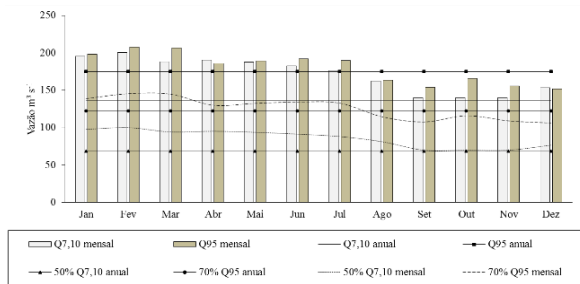
G) Farm San Joaquim station



H) Farm Ipacari station



I) Ivinhema station



Source: Authors.

For all studied stations, it is evident that, compared to the monthly criteria, the criterion corresponding to the concession of 70% Q_{95} per year is very permissible in the months with low water availability (September to November) and quite restrictive in the months with high water availability (Figure 1). At the Retriat Guarujá station (Figure 1E), 70% of annual Q_{95} and 70% of monthly Q_{95} present similar values for October and even higher results for May, compared to the monthly $Q_{7,10}$. These results indicate that annual flows may not be a satisfactory criterion for water concession in the region, as it may negatively affect water availability. According to Bof et al. (2013), these circumstances can increase the risk of occurrence of unfavorable conditions that may lead to the complete drought of a river. If the 70% Q_{95} annual concession was adopted, the river would dry in October of that year at Aroeira station (Figure 1F). However, if this same criterion is adopted on a monthly basis, the risk of river drought decreases.

The period from September to November is the most critical in terms of water availability. During these months, 70% of annual Q_{95} is close to the values of monthly $Q_{7,10}$. However, this risk of drought decreases if 70% of monthly Q_{95} is used. At Farm São Joaquim station (Figure 1G), 70% annual Q_{95} resulted in a value above the monthly $Q_{7,10}$ (10.3%) in September, which implies a high risk of river drought.

Overall, the criterion based on monthly flows leads to a more adequate water management plan, as it allows for a greater water use during the period of higher availability, and it imposes a more realistic restriction to critical periods. Bof et al. (2013) emphasizes the same argument in their paper about the Paracatu basin in Minas Gerais. Silva et al. (2011) state that seasonality in the granting process becomes increasingly essential in basins with high growth rates and potential conflict between users.

At the Aroeira and São Joaquim stations (Figures 1F and 1G), 70% of annual Q_{95} is greater than the annual $Q_{7,10}$. Therefore, the use of the former as the maximum permissible flow for concession would imply the complete drought of the river for seven consecutive days

at least once every 10 years, since $Q_{7,10}$ is the smallest and most restrictive reference flow.

Bof et al. (2013) compared the maximum permissible flows for concession in the Paracatu basin, considering the criteria used by the Minas Gerais Water Management Institute (IGAM) and ANA on an annual and monthly basis. They observed that at the Farm Limoeiro station, the annual Q_{95} was 47% higher than the annual $Q_{7,10}$. Therefore, 70% of Q_{95} would lead to a concession 3.4 times greater than the one based on 30% of $Q_{7,10}$.

A concession based on 50% of annual $Q_{7,10}$ would excessively limit the use of water resources throughout the year in the periods of high and low water availability. The change to 50% of monthly $Q_{7,10}$ would allow a higher amount of water to be used in periods with water surplus, and a lower amount in the months with lower water availability for all stations evaluated, as represented in Figure 1.

The permissible volume of water for concession is represented by the area under the curve (or line) relative to the criterion adopted. For the Ivinhema station (Figure 1I), 50% of $Q_{7,10}$ per year would allow the concession of a volume of 2,155.0 hm^3 . For 70% of annual Q_{95} , the volume would be 3,863.2 hm^3 , 50% of monthly $Q_{7,10}$ would reach from 2,206.1 to 3,159.8 hm^3 . For 70% of monthly Q_{95} , a maximum value of 4,591.6 hm^3 would be achieved. These maximum values are 1.8, 1.5, and 2.1 times higher than the maximum volume allowed by 50% of annual $Q_{7,10}$ (criterion assumed in several Brazilian states).

$D_{r_{\text{criterion}}}$ shows the relative percentage difference (%) of the total annual volume of water permissible for granting, between 50% of $Q_{7,10}$ and 70% of Q_{95} , on an annual and monthly basis, considering all nine fluviometric stations studied (Table 2).

Table 2. Percentage difference (%) of the total annual volume of water permissible for granting, between the criterion 50% $Q_{7,10}$ /70% Q_{95} , on annual and monthly basis, in the 9 fluviometric stations analyzed.

Code	Stations	Annual base	Monthly base
		50% $Q_{7,10}$ /70% Q_{95}	50% $Q_{7,10}$ /70% Q_{95}
64601000	Brilhante	98,4	41,7
64605000	Port Rio Brilhante	100,0	55,2
64609000	Dourados	80,0	38,3
64610000	Port Wilma	80,0	43,8
64611000	RetiroGuarujá	71,6	56,0
64613000	Aroeira	102,7	43,5
64613800	Farm São Joaquim	129,1	48,1
64614000	Farm Ipacará	90,8	44,5
64617000	Ivinhema	79,3	47,1

Source: Authors.

Considering the annual base, the volume of water granted based on 70% of Q_{95} is significantly higher than the one based on 50% of $Q_{7,10}$, the relative percentage varies from 71.64 to 129.10%. On the monthly basis, the differences are lower and vary from 38.3 to 56.0%. These results show that the monthly $Q_{7,10}$ and monthly Q_{95} are somehow similar.

Bof et al. (2013) obtained more expressive results for the Paracatu basin, since on an annual basis, the differences between permissible water volume adopted by ANA (70% of Q_{95}) and IGAM (30% of $Q_{7,10}$) ranged from 211.1 to 282.3%, and on the monthly basis this difference varied from 110.5 to 152.8%.

Table 3 shows the percentage relative difference (Drb%) for the nine fluviometric stations analyzed. It presents the changes in the granting criteria upon a shift from annual to monthly basis. These changes were higher for 50% of $Q_{7,10}$, whose monthly flows increased up to 73.6%. In contrast, the shift from annual to monthly 70% of Q_{95} resulted in a variation up to 12.3% in the flow granted. In this context, the annual values are more restricted because they are based on the period of greatest water shortage of the year. Whereas the monthly analysis represents the intrinsic characteristics of the flows during each month. The Drb% was smaller for 70% Q_{95} because the flows of monthly Q_{95} were smaller than the annual Q_{95} in some months.

Table 3. Percentage relative difference ($D_{rb}\%$) of the annual allowable total volume for granting between the monthly and annual criteria, considering the standards 50% $Q_{7,10}$ and 70% Q_{95} , in the 9 fluviometric stations analyzed in the study.

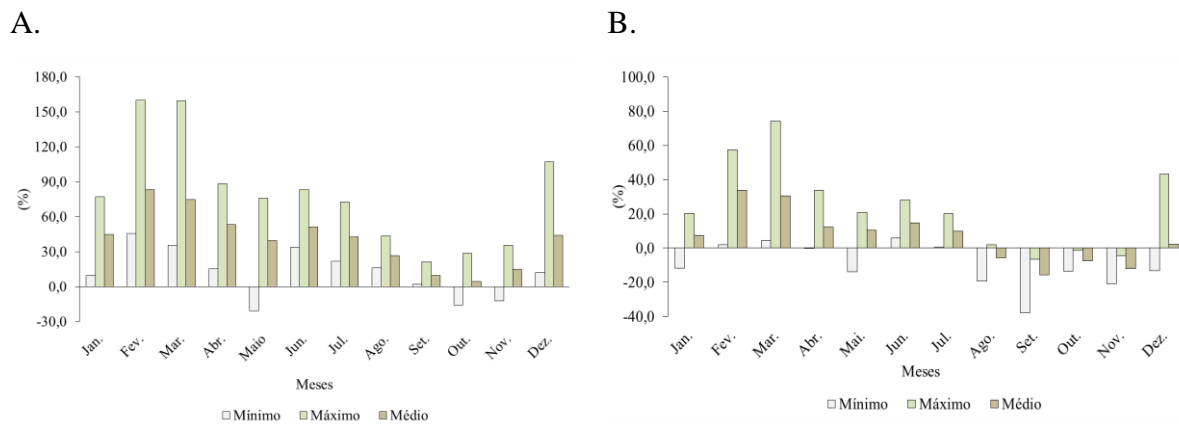
Code	Stations	50% $Q_{7,10}$	70% Q_{95}
64601000	Brilhante	50,5	7,5
64605000	Port Rio Brilhante	38,9	7,7
64609000	Dourados	36,1	4,5
64610000	Port Wilma	30,8	4,5
64611000	Retiro Guarujá	14,3	3,9
64613000	Aroeira	52,2	7,8
64613800	Farm São Joaquim	73,6	12,3
64614000	Farm Ipacará	42,8	8,1
64617000	Ivinhema	25,4	2,9

Source: Authors.

Bof et al. (2013) considered the change from the criterion by ANA (70% of annual Q_{95}) to 70% of monthly Q_{95} , which resulted in an increase in the maximum permissible volume for concession from 26.7 to 67.1%.

The graphs from Figure 2 show the amplitude of variation in the relative difference between monthly and annual $Q_{7,10}$ and Q_{95} flows, considering the fluviometric stations studied. The monthly $Q_{7,10}$ flows are higher than the annual $Q_{7,10}$ in all analyzed months, characterizing a potential increase in the allowable flow for concession. This potential is accentuated from December to April, when the increase is higher than 40%, except in the Retriat Guarujá station, where $Q_{7,10}$ monthly values were lower than annual $Q_{7,10}$ in some months.

Figure 2. Range of variation $Q_{7,10}$ monthly/annual (A) and Q_{95} monthly/annual (B).



Source: Authors.

For Q_{95} (Figure 2B), negative values of relative difference (flow values in which annual Q_{95} is greater than monthly Q_{95}) are observed from August to January and in May. Although they imply a reduction in the maximum allowable discharge for these months, the use of Q_{95} can increase environmental security, since the use of 70% annual Q_{95} leads to values approaching the monthly $Q_{7,10}$.

The use of estimated minimum flows on an annual basis restrict the water use for the whole year. Moreover, the period of highest demand for water resources does not always coincide with the period of lower water availability (Bof, 2013). Therefore, there should be more studies on the quantification of water availability. In this scenario, a change on the concession criteria from an annual to a monthly basis can potentially increase the maximum allowable flow rate.

4. Conclusions

1. The replacement of the annual criteria (standard in Brazil) for water concession by 50% of monthly $Q_{7,10}$ and 70% of monthly Q_{95} can potentially increase the use and improve the management of water resources.

2. The best criterion for concession is the monthly $Q_{7,10}$ because, despite being the most restrictive, it allows a higher withdraw in the periods with water surplus, and restricts the volume during the months with lower water availability.

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