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Modelo de Gestão Hídrica Para Rios Perenes: Outorga Sazonal - Brasil

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Resumo: O controle dos volumes existentes, a serem disponibilizados a partir de outorgas, deve passar por análises consistentes, onde os critérios devem estar bem definidos, visando beneficiar o maior número de usuários e reduzir ou mitigar os conflitos existentes em uma dada bacia hidrográfica. Logo, o objetivo deste trabalho está centrado na criação/construção de um método/mecanismo de gestão hídrica para alcançar a melhoria da oferta hídrica com segurança técnica. O método almeja realizar a atribuição temporal das vazões médias, associadas às vazões de pico. Os resultados mostram que é possível selecionar os meses com as maiores vazões, para permitir o aumento da disponibilidade hídrica em até 50%. Concluímos que na bacia hidrográfica do rio Paraguaçu é possível implantar um novo modelo de gestão hídrica, que prioriza a eficiência da produção, sem afetar negativamente a qualidade ambiental dos mananciais e fortalece a socioeconomia, por exemplo, a inclusão de comunidades tradicionais.
Palavras-chave: Atribuição temporal da curva de garantia; Hidrologia avançada experimental (HAE); Firmeza da garantia de vazões; Razão precipitação vazão (Rpv); Rio Paraguaçu.

WATER MANAGEMENT MODEL FOR PERENNIAL RIVERS: SEASONAL GRANTING - BRAZIL

Abstract: The control of existing volumes, to be made available through grants, must undergo consistent analyses, where the criteria must be well defined, aiming to benefit the greatest number of users and reduce or mitigate existing conflicts in a given river basin. Therefore, the objective of this work is centered on the creation/construction of a water management method/mechanism to achieve an improvement in water supply with technical security. The method aims to perform the temporal attribution of average flows, associated with peak flows. The results show that it is possible to select the months with the highest flows, to allow an increase in water availability by up to 50%. We conclude that in the Paraguaçu river basin it is possible to implement a new water management model, which prioritizes production efficiency, without negatively affecting the environmental quality of the water sources and strengthens socioeconomics, for example, the inclusion of traditional communities.
Keywords: Temporal assignment of the guarantee curve; Experimental advanced hydrology (EAH); Firmness of flow guarantee; Precipitation flow ratio (PFR); Paraguaçu River.

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INTRODUCTION

The current global context of climate change associated with extreme events demands the effort of academia to produce ideas, theories and solid positions in the face of the list of problems of daily life in rural and urban areas (aridity, droughts, prolonged droughts, floods, heat waves, etc.), especially when reflecting on the appropriation/exploitation of watersheds, through the construction of dams (B. Nyikadzino et al, 2020; Salviano et al, 2016; Coast et al, 2015; Portela, et. al 2011). The list of diverse aspects mentioned that motivated us in the incessant search to contribute technically to the resolution of issues associated with hydrological/hydrographic dynamics (e.g., river flow) and the management of freshwater resources.

According to Ferreira (2008), the main conceptual frameworks for water resources management are: a) hydrographic basin as a physical-territorial unit; b) delimitation of the basin; c) physiographic characteristics (shape, relief, drainage patterns, vegetation cover); d) thermal characteristics of the basin (latitude, longitude, altitude, vegetation, insolation time); e) land occupation and use of) water sources (surface, underground and rainwater).

The management of water resources in a semiarid environment requires an understanding of socioeconomic interventions and/or climate change that alter the hydrological/water balance and exacerbate water scarcity. The use/exploitation of waters, rivers in a predatory way, disregarding the physical-natural, socioeconomic, cultural, institutional aspects, etc., affects the river regime, mainly flows, interferes with water security, causes problems in the economy and environmental damage, sometimes irreversible (De Assis Cosso et al 2020; Santos, 2016).

The increase in the supply of surface water resources, due to water scarcity, increasingly requires the establishment of criteria allied to water security to achieve the most efficient management of water resources (Gomes, 2021; Mekonnen & Hoekstra, 2016; Denicola, 2015). The temporal allocation of flows is an alternative to obtain an increase in the supply of surface water, in a safe way, which is feasible to mitigate conflicts generated by the use of water, providing a more equitable distribution for all classes of users.

In the National Water Security Plan (PNSH), four dimensions are considered for water security - human, economic, ecosystem and resilience: the human dimension encompasses the guarantee of water supply for human supply; the economic dimension deals with water supply for development and productive activities; the ecosystem dimension refers to the quality of water compatible with multiple uses; the resilience dimension addresses vulnerability to drought events due to natural and artificial water stocks, such as reservoirs (ANA, 2022).

According to the concept of the United Nations (UN), Water Security exists when there is availability of water in sufficient quantity and quality to meet human needs, the practice of economic activities and the conservation of aquatic ecosystems, accompanied by an acceptable level of risk related to droughts and floods, and its four dimensions should be considered as guidelines for the planning of water supply and use in a country (ANA, 2020).

Gonçalves (2023a; 2023b and 2019) established criteria to classify/carry out the diagnosis of watersheds through the methodology called Advanced Experimental Hydrology (HAE), which allows the evaluation of periods of: greater or lesser water security; influence of drainage (influential, effluent or mixed); hydrological surpluses, surplus normals, deficit and deficit normals; amplitude of droughts and floods etc.

Studies related to the creation of a system of seasonal grants are recent. In 2006, Euclydes. H. P. et al., published the article entitled: "Seasonal grant criterion for irrigated agriculture in the state of Minas Gerais. Case Study". Nine years later, Da Silva et al (2015) discuss the "Influence of the seasonality of flows on the criteria for granting water use: a case study of the Paraopeba River basin".

The above-mentioned authors, respectively, investigated the hydrographic basins of the Grande and Paraopeba rivers, in the State of Minas Gerais, both in the Cerrado and Atlantic Forest biomes, referring to the problem of water supply for agricultural production, in a state similar to Bahia, which has a large territorial extension.

For the research in focus, the Paraguaçu River Basin (BHRP), in Bahia, was selected as an experimental model basin for the application of the methodologies "temporal attribution of flow guarantees" and "firmness of the water guarantee of flows", these methodologies aim to develop a water management model for perennial or perennial rivers, as well as to insert in the management of water resources the practice of seasonal granting.

The BHRP is located between the coordinates -11º 11'S to -13º 42'S South latitude and -38º 48'W to -42º 07'W West longitude, located in the Central-East region of the State of Bahia, totally inserted in Bahian territory. In the coding system of the National Department of Water and Electric Energy (DNAEE), it is included in Basin 5 - South Atlantic Basins - Eastern Section, being coded under number 51. In the State System of Water Resources of the State of Bahia, it is part of the Water Planning and Management Region – X, Paraguaçu. In the case of a basin with a spatial dimension of 54,873 km², there are numerous access options, for example, starting from the city of Salvador, the main access road is through the BR-324, until it reaches the city of Feira de Santana and the BR-242, following the path towards the city of Seabra.

It is noteworthy that, in this study, the concept of hydrographic basin was adopted, namely:

> "It represents a complex system of slopes, channels that drain a given area and transfer a volume of water, expressed in cubic meters (m³) or liters per second (L/s) until it reaches the outlet; being interrelated to the groundwater subsystem, both transformed by the list of political, socioeconomic, institutional, cultural and technological activities and actions. This system is understood as a unit of analysis, planning and management of water/environmental resources or a unit of spatial planning, when considering the interactions between physical-natural systems and human systems (Santos, 2017, p. 9).

Finally, the main objective is to evaluate the water availability in the Paraguaçu River basin, which is characterized by significant differences between the maximum and minimum flows, which directly influence the volumes made available to be granted, that is, the intention is to build a sustainable model of seasonal granting, which allows the flexibility and rational use of the grantable flows. It is intended to be a viable management model for water supply, security and guarantee, which are fundamental variables to achieve socioeconomic and ecologically sustainable development. Above all, it is essential to know, quantify, dispose of and rationally use the existing water resources in the BHRP, as this way it is possible to mitigate the main conflicts over the use of water, especially in the medium-high course.

METODOLOGY

In the first moment, the conceptual theoretical survey was carried out, in which some classic and contemporary authors were selected, who supported the development of the study, such as Huygens (1657), Gonçalves (2014), Nyikadzino (2020), Salviano (2016), Costa (2015), Portela (2011), Gomes (2021), Denicola (2015), among others.

Then, the flow data was collected and processed, filling in the gaps and consolidating the flow data. The data of this stage were obtained through consultations on the HIDROWEB website of ANA. The set of these data were systematized to support the elaboration of charts, tables, graphs through the Excell-2016 software, as well as maps, through the use and application of ARCGIS 9, that is, the careful performance of these steps ensures the production of consistent information.

It is understood that the lowest flow guarantees occur at the time when the highest flows occur, but focusing on the fact that the Q90 guarantee aims to allow the continuous use of water throughout the year, but limits the period of greater supply to very low withdrawal values. In this way, the evaluation of the existing flows in the bed of a perennial river is carried out to provide greater water security for the existing and projected demands. For the point flows described in the guarantee curve (CG) of a given period, the temporal assignment is made with the precipitation-flow ratio (Rpv), which is an average data and aims to make this correlation, so that it is possible to introduce the procedure capable of improving the water supply in perennial rivers.

The data used from the GC and the Rpv for the same acquisition period were acquired through consultations in journals published in Bahia (1999) and Brazil (2022). The expectation of flow was based on the work of Christiaan HUYGENS (1657) who published "De Ratiotiniis in ludo aleae" (The Reasoning of the Book of Games of Chance) which is considered the first book of probabilistic calculus, which contemplates the detailed study of the theories of Blaise Pascal (1623-1662) and Pierre de FERMAT (1601-1665), that is, introduces for the first time the concept of Expectation (probability of exceedance).

In the state of Bahia, the Q90 guarantee is used to allow the continuous use of water throughout the year, but it limits the period of greatest supply to very low withdrawal values, as it is calculated based on the probability of exceedance. With it, it is possible to identify the chance of occurrence of a certain flow. Therefore, we propose to re-read this methodology from the fifteenth century, to update the application and not the concept; for the flow expectation.

The methodology described below is part of a series of methodological procedures called Advanced Experimental Hydrology (HAE). HAE, developed by Gonçalves (2014), is based on the principle of conservation of energy (1st Law of Thermodynamics), which associated with the principle of action and reaction (Newton's Third Law) makes it possible to predict the behavior of a given water system, that is, it is possible to monitor precipitation (action) and evaluate the flows generated (reaction), aiming to understand the water dynamics of a given river basin.

That said, it is assumed that the "river basin" system cannot create or consume energy, but only store it. Thus, the following procedures were observed.

CHOICE OF RAINFALL AND FLUVIOMETRIC STATION

The selected rainfall station is located closer to the source of the Paraguaçu River basin, while the chosen fluviometric station should be located downstream of the first one (rainfall and fluviometric data were collected from websites). Armed with this data, they were organized, filling in the existing gaps.

It should be noted that the data were processed using the Microsoft Excel Spreadsheet Editor, 2016. On the other hand, the filling of the gaps in the flow elevations was performed by calculating the arithmetic progression (AP) or arithmetic mean. On the other hand, the flow data were filled in using the calculated key curve, in turn, if necessary, the precipitation data can be filled in by means of the weighted average Paulhus e Kohler (1952). Subsequently, the following were performed: the evaluation of the mean delay time (MRT); the permanence curve (PC); the guarantee curve (CG); the temporal allocation of flow guarantees (ATGV); the firmness of the water guarantee of flows (FGHV), for the continuation of hydrological analyses.

EVALUATION OF THE MEAN DELAY TIME (TRM)

The evaluation in question allows us to define/know the average time it takes for the water from a precipitation to contribute to the runoff in the outlet, or another point within it. According to Gonçalves & Torres (2019), it points to the existence of two types of watersheds: Type 1 (TRM<30 days), impermeable basins, characterized as those in which the average delay time is less than 30 days; and Type 2 (TRM≥30 days); permeable basins, which are those in which the average delay time is greater than or equal to 30 days (in these basins it is necessary to correct the TRM).]

The above classification is associated with the factors that interfere in the geoenvironmental dynamics of the basin, which were divided into Climatic and Physiographic. Climatic Factors consider the frequency, intensity, and duration of precipitation, as well as antecedent conditions. On the other hand, the Physiographic Factors are the area, shape of the basin, vegetation cover, permeability, infiltration capacity, geology, topography and socio-spatial interventions (e.g., the construction of tubular wells and dams).

GENERATION OF THE PERMANENCE CURVE (CP) GRAPH

The data involved in this step refer to the flows organized in descending order. These will be displayed in the form of percentages, so that the resulting graph displays the flow rate on the y axis and the percentage values on the x-axis. Thus, the graph shows the percentage of annual flow permanence within the analyzed period.

GENERATION OF THE GUARANTEE CURVE (CG) GRAPH

For GC generation, the flow data is organized in descending order and the guarantee is in an ascending manner (0% to 100%). Every ten (10) percentage points of the guarantee is associated with a flow value, so that the highest flow value will be associated with the 0% guarantee and the lowest value with the 100% guarantee. This graph will allow us to verify the percentage of guarantee of the flows analyzed at the station.

GENERATION OF THE PRECIPITATION-FLOW RATIO (Rpv) curve graph, WITH TRM CORRECTION (if applicable)

Curve generated from the average precipitation and flow data for a given period, over the months.

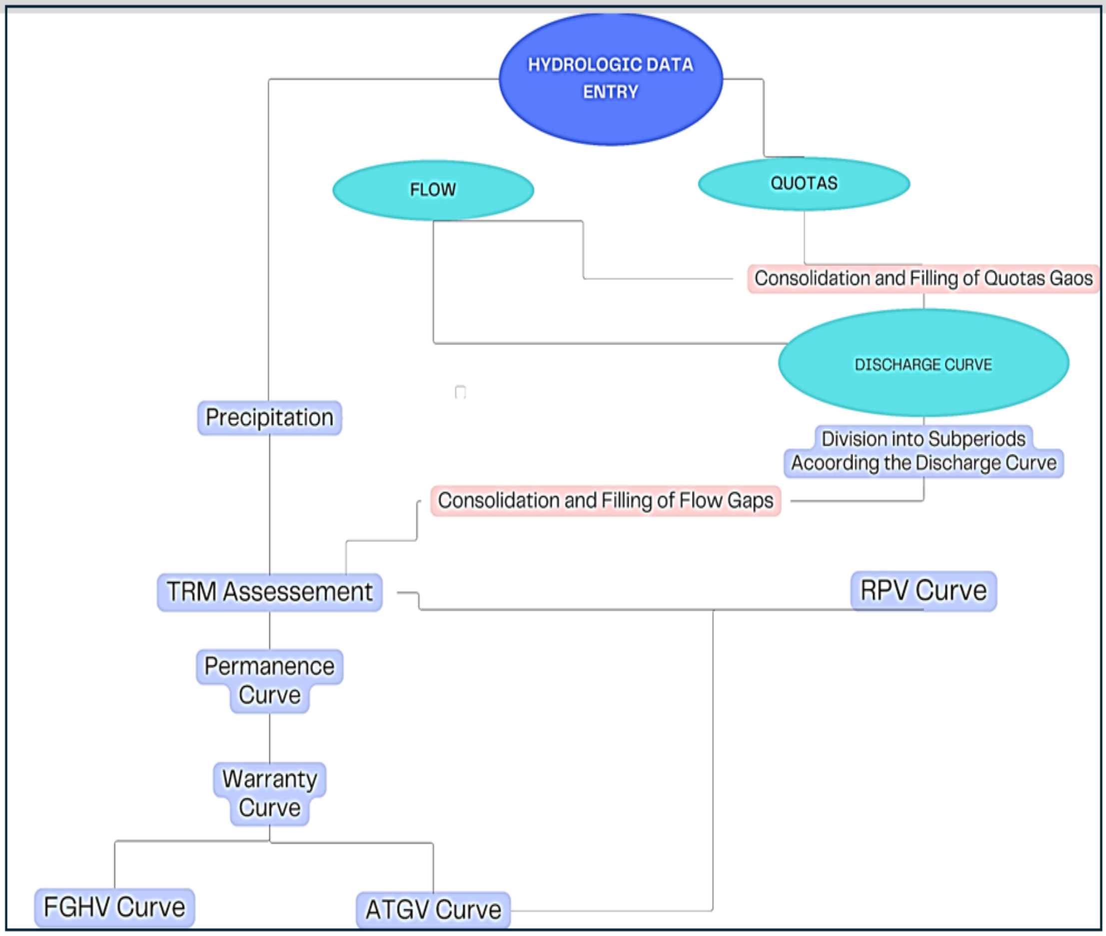
TEMPORAL ASSIGNMENT OF FLOW GUARANTEES (ATGV)

Curve generated from the union of the Rpv curve and the CG, for a given period, over the months.

FIRMNESS OF THE WATER FLOW GUARANTEE (FGHV)

It is a part of this methodology that makes it possible to assess whether the water guarantee has a reliability in a given fluviometric station of a river basin. It is the percentage representation of the value of the Q90 index relative to the Q0 index. The basic sequence for the development of the study is summarized in Figure 1.

Figure 1: Simplified flowchart of the methodology – 2024



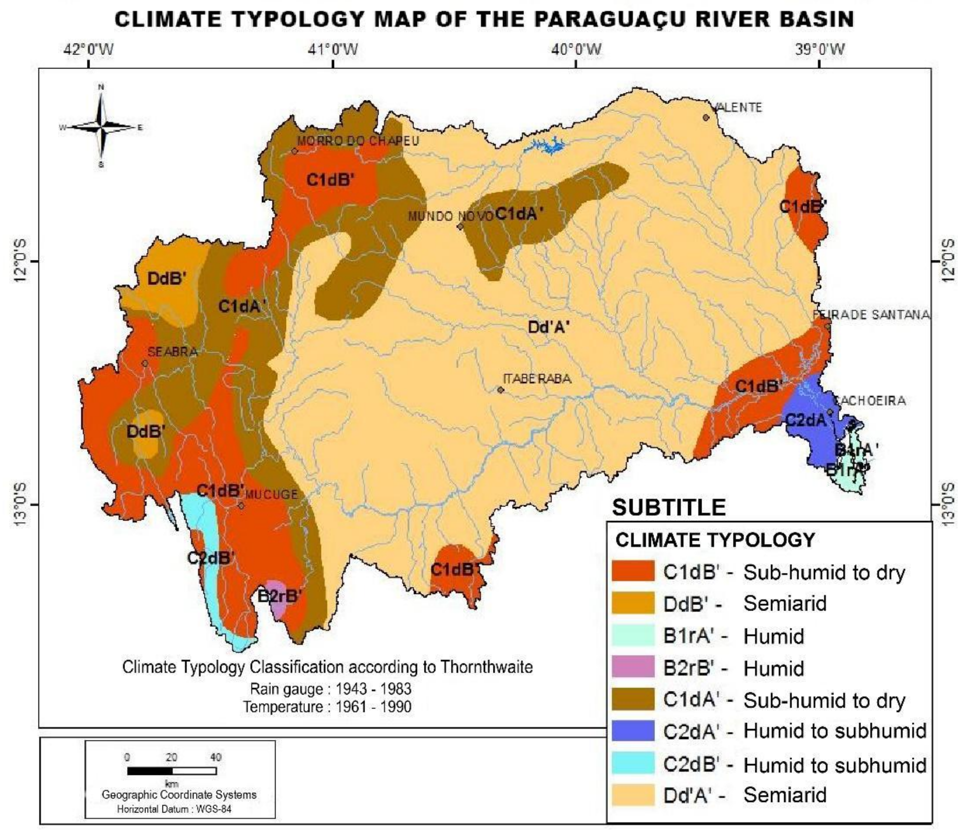
Source: The authors, 2024

RESULTS AND DISCUSSIONS

The climatic typology map of the Paraguaçu River basin makes it possible to understand the distribution of the drainage network, inserted in the context in which semiarid climates predominate and the dependence on precipitation for flow generation (Figure 2).

When comparing the permanence and guarantee curves between Stations 51120000 (Figure 3) and 51280000 (Figure 4), both in the period 1943-1981, on the Paraguaçu River, it can be observed that despite the marked difference in flows, the two curves have similar behaviors, indicating that the form of management proposed for one stretch of the basin can be implemented for another stretch, as long as their existing similarities and differences are observed

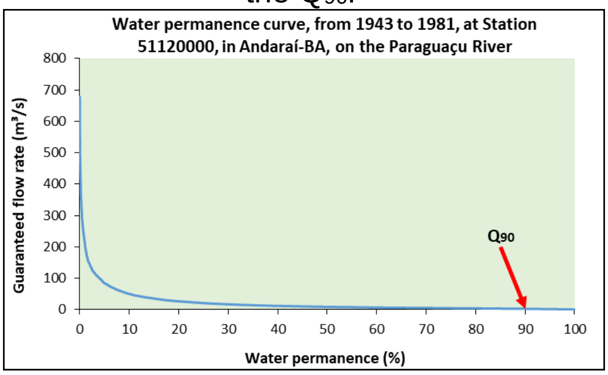
Figure 2: Climatic typology of the Paraguaçu river basin-Bahia, associated with the drainage network. 2024



Source: Adapted from Gonçalves 2014.

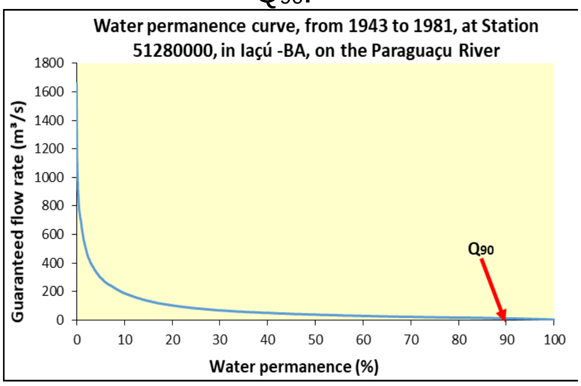
The permanence curve of Station 51120000 reveals the maximum flow Q0 = 678 m³/s, minimum flow Q100 = 0.3 m³/s, in addition to the value Q90 = 2.7 m³/s, while the permanence curve of Station 51280000 shows maximum flow values Q0 = 1660 m³/s, minimum flow Q100 = 3 m³/s, and the value Q90 = 12 m³/s. Indicating that there was an increase in the maximum flow (Q0) of +144.8%, the minimum flow (Q100) of 900%, and the Q90 value of 344.44%, between the two stations, for the same time interval.

Figure 3: Permanence curve at Station 51120000, in Andaraí, with indication of the Q_{90}.



Source: ANA, 2022. The authors.

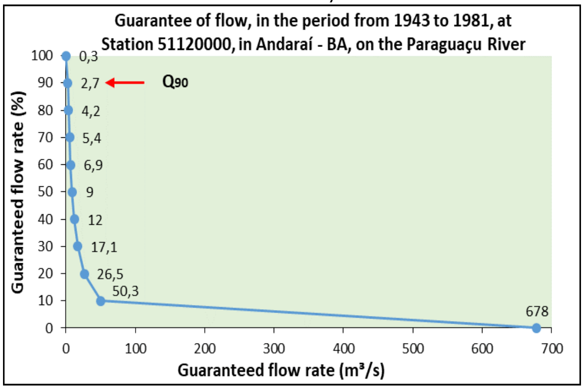
Figure 4: Permanence curve at Station 51280000, in Iaçu, with indication of Q_{90}.



Source: ANA, 2022. The authors.

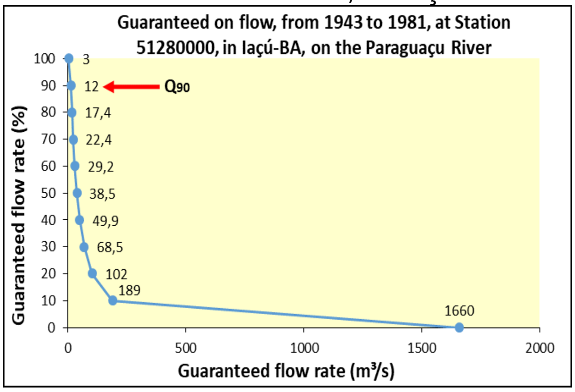
In Station 51120000 (Figure 5) the highest flow corresponds to 678 m³/s and the lowest is equal to 0.3 m³/s, while in the water guarantee curve of Station 51280000 (Figure 6) the highest flow is 1660 m³/s, while the lowest is 3.0 m³/s, indicating that there are no regulated flows in the stations.

Figure 5: Flow guarantee curve of Station 51120000, in Andaraí.



Source: ANA, 2022. The authors.

Figure 6: Flow Guarantee Curve of Station 51280000, in Iaçu.



Source: ANA, 2022. The authors.

According to Gonçalves (2019), the analyzed stretch of the Paraguaçu River basin based on rainfall in the region of the municipality of Barra da Estiva allowed the classification of TRM<30 days as Type 1, which characterizes this basin as being impermeable, with better water use through dams, since the highest average flows occur within the same month marked by the highest average rainfall.

By using the consolidated data of precipitation and average flow, the Precipitation-Flow Ratio (Rpv) was calculated. In this particular case, there was no need to correct the mean delay time (TRM), since the highest average rainfall value coincides with the highest average TRM flow < 30 days (Gonçalves, 2019). The values of precipitation and average flow, between 1943 and 1981, were used for this evaluation, because in this period the hydrographic basin of the Paraguaçu River did not have large dams built, so there was no significant influence of physiographic factors, such as the delay of water stored in dams.

In the comparison between the two stations, it is evident that at Station 51120000 (located in Andaraí), more millimeters of average precipitation are needed to generate 1 m³/s of average flow, due to the station being located upstream of Station 51280000 (located in Iaçu), for this reason, it has a smaller contribution area and, consequently, lower values of average flows for the same precipitation.

In both Stations, it is observed that the values are directly proportional, i.e., the highest value of average precipitation (155 mm) coincides with the highest value of average flow (43.8 m3/s), as well as the lowest average precipitation (30 mm) with the lowest average flow (6.1 m3/s). Table 1 shows the calculation of the Rpv and average precipitation (in Barra da Estiva) and the average flow (at the Andaraí Station) in the Paraguaçu River.

Table 1: Calculation of the RPV at Station 51120000, in the period 1943-1981, in the Paraguaçu River-BA and indication of the highest and lowest values of precipitation and flow

Month	Average rainfall (mm) Barra da Estiva Station in the period 1943 -1981	Average flow (m³/s) Andaraí Station (51120000) in the period 1943 -1981	Month	Rpv (mm / m³/s)
Jan	89.4	29.9	Jan	2.99
Feb	88.3	29.8	Feb	2.96
Mar	121.5	33.2	Mar	3.66
Apr	88.2	29.6	Apr	2.98
May	47.3	14.9	May	3.17
Jun	59.7	13.2	Jun	4.52
Jul	55.7	13.6	Jul	4.10
Aug	33.4	8.6	Aug	3.88
Set	30	6.1	Set	4.92
Oct	65.9	11.6	Oct	5.68
Nov	144.4	29.9	Nov	4.83
Dec	155	43.8	Dec	3.54

Source: BAHIA (1999); BRAZIL (2022). The authors.

Table 2 shows the calculation of the Rpv and the values of average precipitation in Barra da Estiva and average flow at the Iaçu Station, on the Paraguaçu River.

Table 2: Calculation of the Rpv, at Station 51280000, in the period 1943-1981, on the Paraguaçu River.

Month	Average rainfall (mm) Barra da Estiva Station in the period 1943 -1981	Average flow (m³/s) Iaçú Station (51280000) in the period 1943 -1981	Month	Rpv (mm / m³/s)
Jan	89.4	107.6	Jan	0.83
Feb	88.3	120.7	Feb	0.73
Mar	121.5	124.6	Mar	0.98
Apr	88.2	110.2	Apr	0.80
May	47.3	60.8	May	0.78
Jun	59.7	48	Jun	1.24
Jul	55.7	51.8	Jul	1.08
Aug	33.4	34.6	Aug	0,97
Set	30	22.7	Set	1.32
Oct	65.9	38	Oct	1.73
Nov	144.4	83.3	Nov	1.73
Dec	155	156.7	Dec	0.99

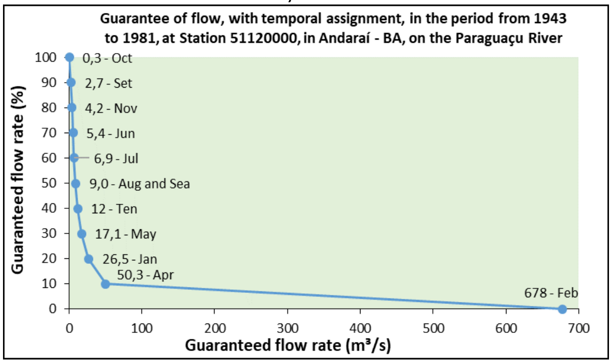
Source: Bahia (1999); Brazil (2022). The authors.

With the data of the GC curve and the RPV, it was possible to make the graph of the correlation of the GC with the Rpv, for the stations of Andaraí and Iaçu. The graph under analysis makes it possible to visualize in which month of the year the highest and lowest flow guarantees are recorded, with the temporal attribution of the GC.

Comparing the flow guarantee curves at Stations 51120000 (Figure 7) and 51280000 on the Paraguaçu River (Figure 8), from 1943 to 1981, it can be seen that despite the marked difference in the flows in the two curves, the month of February recorded the highest flow and the lowest precipitation-to-flow ratio (Rpv), so there is a lower demand for precipitation to generate 1m³/s of average flow.

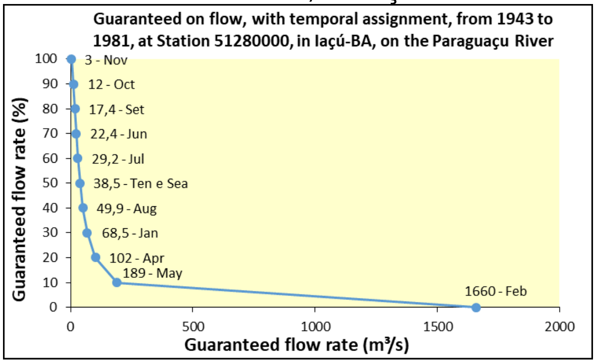
Figure 8, Station 51120000, shows the Q90 value of 2.7 m³/s, which represents a flow rate of only 0.4% of the Q0 flow rate (678 m³/s). Figure 9, Station 51280000, shows a value Q90 = 12 m³/s, representing a flow rate of only 0.72% of the flow rate Q0 (1660 m³/s). Figures 8 and 9 show guarantee curves with temporal assignment given by the Rpv. Therefore, these values allow us to affirm that there is an urgent need to develop effective methodologies, capable of ensuring better availability of these flows for production, in general.

Figure 7: Warranty curve at Station 51120000, in Andaraí.



Source: ANA, 2022. The authors.

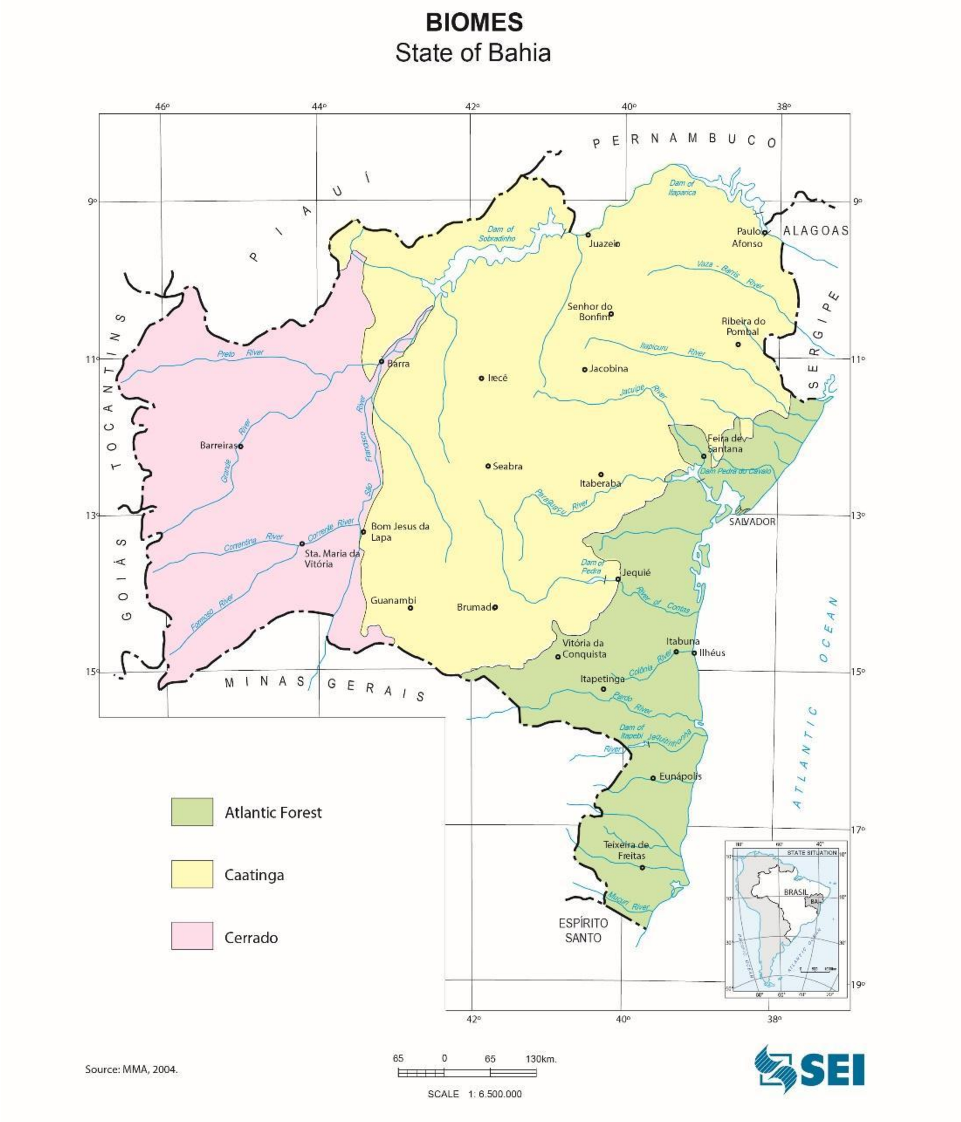
Figure 8: Warranty curve at Station 51280000, in Iaçu.



Source: ANA, 2022. The authors.

The consistent analysis of the firmness of the water guarantee of flows in the state of Bahia requires considering the existence of the three biomes associated with the spatial distribution in the state (Figure 9).

Figure 9: Biomes of Bahia and their spatial distribution.



Source: SEI (2004)

The main contribution of water to the formation of flow in rivers comes from atmospheric precipitation and Bahia has 2 (two) biomes that have the highest dependence on precipitation and 1 (one) biome that has the lowest dependence. In this way, the coexistence with the lands and their various uses are expressively divergent, from the point of view of management, traditions and development of cultures. Table 3 shows the greater or lesser dependence of precipitation on the formation of flows in the six Brazilian terrestrial biomes.

Table 3: Dependence on precipitation to maintain flows in Brazilian biomes

Dependence on Precipitation to Maintain Flow	Increased dependence on the Biome
	Caatinga
	Mata Atlântica
	Pampas
	Pantanal
	Amazonas
	Cerrado
	Less dependence on the Biome

Source: Adapted from Gonçalves 2023a.

With the data of the water guarantee in the Q90 index, it was possible to evaluate the firmness of the water guarantee for several ranges and to propose the multiplicative index for seasonal grants.

Firmness of the water guarantee is understood as the percentage of the flow Q90 in relation to the flow Q0 (peak flow). Table 4 shows the firmness rating and multiplicative index for various firmness ranges.

Table 4: Water Guarantee Firmness Rating.

Firmness of the Water Guarantee (%)	Firmness Rating	Seasonal Multiplicative Index
0	without firmness	******
> 0 a ≤ 3%	Little Firm	1,300xQ_{90}
> 3 a ≤ 10%	Medium Firm	1,200xQ_{90}
> 10 a ≤ 20%	Firm	1,150xQ_{90}
> 20 a ≤ 40%	Very Firm	1,125xQ_{90}
> 40%	Super Firm	1,100xQ_{90}

Source: The authors.

To facilitate the understanding of Firmness, it was calculated in 28 fluviometric stations, spread across 27 rivers in Bahia. An important piece of information is produced - the rivers of Bahia, for the most part, in the Caatinga biome, in the semi-arid, have Not Very Firm guarantees, an aspect that corroborates the indications of conflicts over the use of water, existing in the State. Garjulli (2003) says that "the semi-arid region is mainly characterized by water scarcity, resulting from the incidence of rainfall only in short periods of three to five months a year, irregularly distributed in time and space. This characteristic causes a strong dependence on man's intervention on nature, in the sense of ensuring, through water infrastructure works, the storage of water for human supply and other productive uses"

When analyzing the Caatinga, Atlantic Forest and Cerrado biomes, it can be seen that the Non-Firm guarantees are found in the Caatinga biome and the Not Firm guarantees in the Caatinga and Atlantic Forest biomes. On the other hand, the Moderately Firm are in the Cerrado. The Firme in the Cerrado and Atlantic Forest.

However, the Very Firm and Super Firm guarantees were not found in the cerrado, suggesting the transition between the Bahian biomes. The data obtained can be seen in Table 5, and it is possible to understand the correlation of Firmness with the biomes, when considering the dependence on precipitation for the maintenance of flows in these biomes.

Table 5: Classification of 28 stations in 27 rivers in Bahia, regarding the firmness of the water guarantee of flows.

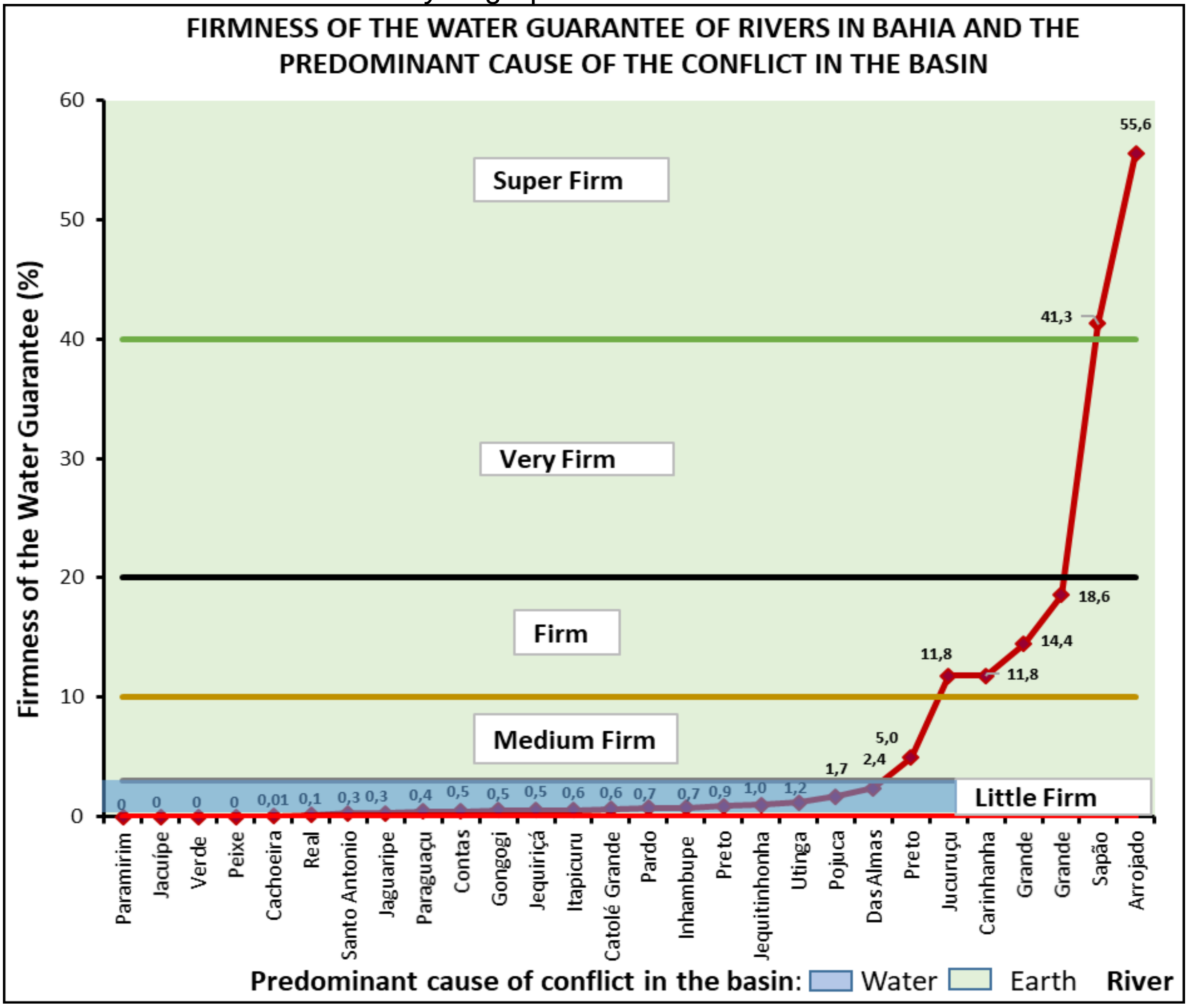
Firmness of the Water Guarantee of Flows in Rivers of Bahia					
without firmness	**Little Firm**	**Medium Firm**	**Firm**	**Very Firm**	**Super Firm**
4	17	1	4	0	2
Biomes found					
Caatinga	Caatinga Mata Atlântica	Cerrado	Mata Atlântica Cerrado	No representative was found in the study	Cerrado

Source: The authors, 2024

The distribution of the firmness of the water guarantee of flows, in their respective zones, with the name of the rivers used in the study, also allows us to establish analogies with the reality of the conflicts existing in these hydrographic basins. Those that have a firm guarantee, classified as Not Firm (0%) or Not Very Firm (>0% to ≤3%), are characterized by the predominance of conflicts over water, where the conflicting parties are, in most cases, traditional residents of the basin.

On the other hand, the river basins that have a firm guarantee defined as Medium Firm (>3% to ≤10%), Firm (>10% to ≤20%), Very Firm (>20% to ≤40%) or Super Firm (>40%), are characterized by the primacy of conflicts over land, where the conflicting parties are, in most cases, residents from outside the basin, and in this case the usurpation of land in the form of land grabbing constitutes one of the biggest clashes in the territory (Figure 10).

Figure 10: Classification of the Firmness of the Water Guarantee of Flow in Bahian Hydrographic Basins - 2024



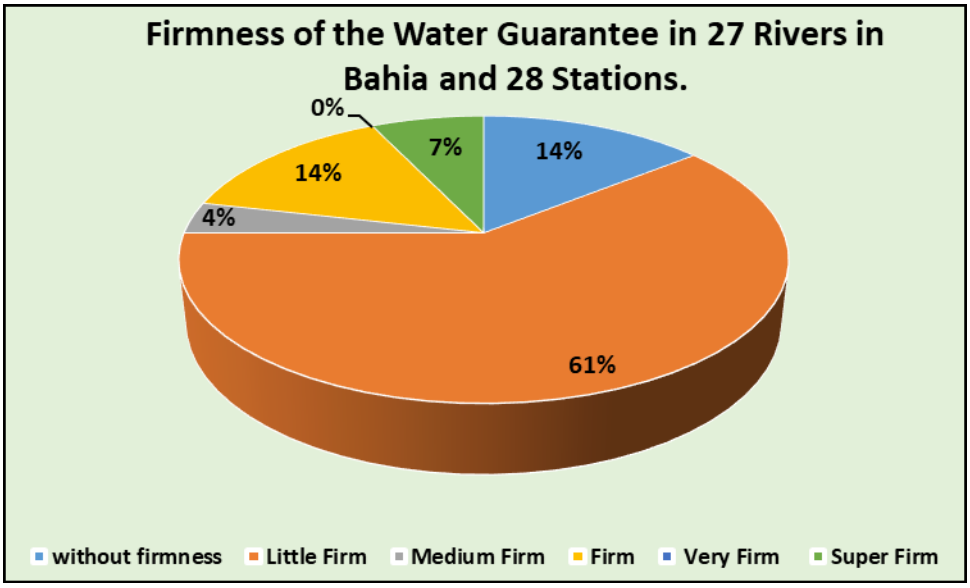
Source: The authors.

However, it is confirmed that 75% of the 28 rivers analyzed have water guarantee of non-firm (14%) or Slightly Firm (61%) flow. However, the other guarantee firms are distributed in 25% of the territory. By analyzing this aspect, it is possible to understand how this distribution has consequences on the social arrangement and on water demands, both of which reflect the supply and the firmness of the water guarantee of existing flows.

The reading in question, in relation to conflicts over water use, can be translated in two ways: the first is associated with excess water, in which the clashes revolve around the land (mainly land grabbing, in the Cerrado biome); in the second case, through water scarcity, where conflicts are linked to water itself (lands that have rivers or the possibility of wells are certainly more valuable in the Caatinga biome).

Especially in Bahia, the Atlantic Forest biome presents conflicts over land and water, as the water flow firmness found is intermediate in relation to the caatinga, where there is water scarcity, and the cerrado, where there is a water surplus (Figure 11).

Figure 11: Firmness of water security in 28 fluviometric stations of 27 rivers in Bahia - 2024



Source: ANA, 2022. The authors, 2024

The Q90 guarantee is widely used in Brazil for the management of concession procedures, as it aims to allow the continuous use of water throughout the year, but limits the period of highest flow to very low withdrawal values. Thus, when inverting the flow guarantees and comparing them with the average flows, it is noted that the months with the lowest guarantee also have the highest average flows.

Based on the Rpv data, ordered in descending order, it was found that there is a direct Relationship between the values of Rpv and the percentage flow guarantee. To coincide the 12 (twelve) months with the 11 (eleven) values of flow guarantees, a second Q50 guarantee was inserted to compare the guaranteed flows with the average flows in Stations 51280000 and 51120000 (Paraguaçu River), in Figures 8 and 9.

The delimitation of this period was carried out by evaluating the coincident months of average flow and guaranteed flow, with temporal attribution by Rpv, between 0 and 50%, in the guaranteed flow, and in the average flow, using up to seven (07) months with higher flows.

This evaluation allows us to infer that in the period from December to May, in the Paraguaçu River, the values offered to be granted may be 1.3 x 80% x Q90. The months in common were highlighted in green and are in the period of higher flows or lower water guarantee values. On the other hand, the months in red were discarded, as they do not appear in the two flow periods (average flow and guaranteed flow).

In Table 6, where the months with the highest and lowest rainfall and average flows in the bed of the Paraguaçu River are noted, at Station 51120000, respectively, in green and red, it is possible to observe that the months of November, December, January, February, March, March and May, with the highest flow values and the calculation of the Rpv, indicates that the months of October and September are those that require higher values of precipitation to generate 1 m³/ s of average flow rate.

Table 6: Correlation of the Precipitation-Flow Ratio (Rpv) and guaranteed flow with the average flow, in the period from 1943 to 1981, in the Paraguaçu River, at Station 51120000, in the municipality of Andaraí.

Month	Rpv (mm / m³/s)	Flow Guarantee (%)	Guaranteed flow (m³/s)	Flow medium (m³/s)	Month
Oct	5.7	100	0.3	6.1	Set
Set	4.9	90	2.7	8.6	Aug
Nov	4.8	80	4.2	11.6	Oct
Jun	4.5	70	5.4	13.2	Jun
Jul	4.1	60	6.9	13.6	Jul
Aug	3.9	50	9	14.9	May
Mar	3.7	50	9	29.6	Apr
Dec	3.5	40	12	29.8	Feb
May	3.2	30	17.1	29.9	Jan
Jan	3	20	26.5	29.9	Nov
Apr	3	10	50.3	33.2	Mar
Feb	3	0	678	43.8	Dec

Source: BAHIA (1999); BRAZIL (2022). The authors, 2024

In Table 7 shows the months with the highest and lowest rainfall and average flows in the bed of the Paraguaçu River, at Station 51280000, respectively, in green and red, it is possible to observe that the months of November, December, January, February, March, March and May, with higher flows and the calculation of the Rpv, records that the months of October and November need higher rainfall rates, to generate 1 m³/s average flow rate.

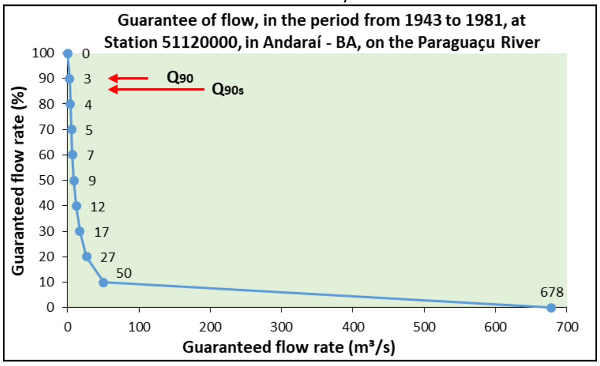
Table 7: Correlation of the Precipitation-Flow Ratio (Rpv) and guaranteed flow with the average flow, in the period from 1943 to 1981, in the Paraguaçu River, at Station 51280000, in the municipality of Iaçu

Month	Rpv (mm / m³/s)	Flow Guarantee (%)	Guaranteed flow (m³/s)	Flow medium (m³/s)	Month
Nov	1.73	100	2.97	22.7	Set
Oct	1.73	90	12	34.6	Aug
Set	1.32	80	17.4	38	Oct
Jun	1.24	70	22.4	48	Jun
Jul	1.07	60	29.2	51.8	Jul
Dec	0.99	50	38.5	60.8	May
Mar	0.98	50	38.5	83.3	Nov
Aug	0.97	40	49.9	107.6	Jan
Jan	0.83	30	68.5	110.2	Apr
Apr	0.8	20	102	120.7	Feb
May	0.78	10	189	124.6	Mar
Feb	0.73	0	1,66	156.7	Dec

Source: BAHIA (1999); BRAZIL (2022). The authors, 2024

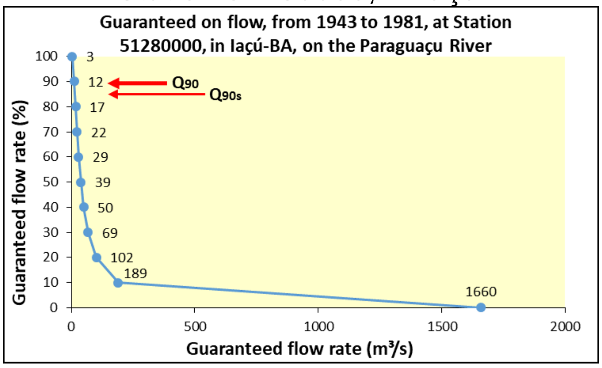
The data of the average flows, at stations 51150000 and 51280000, and of the Rpv allowed the elaboration of the flow guarantee curve with an indicator of a new Q90s (seasonal), in which it is possible to verify the increase in the grantable value (Figures 12 and 13).

Figure 12: Flow guarantee curve of Station 51120000, in Andaraí



Source: ANA, 2022. The authors.

Figure 13: Flow Guarantee Curve of Station 51280000, in Iaçu



Source: ANA, 2022. The authors.

CONCLUSIONS

Based on the results found, it is stated that the theoretical-conceptual framework selected, and the methodology employed are satisfactory.

By analyzing the data from Stations 51280000 and 51120000, it is clear that the period between December and May offers conditions for greater capture and implementation of the seasonal concession in the Paraguaçu River, with an increase of 30% in the flows currently available for concession.

The proposal to increase the availability of seasonal flows by 30% will still reveal lower values than the lowest average flow of each period/season.

The advantage of the method in question is to ensure the increase of water availability at a low cost, without the need for investments in financial resources for the implementation of large-scale catchment works, such as dams.

The advantage of the method refers to the additional availability, which can be implemented for 6 (six) months of the year.

The defined methodology also makes it possible to reflect and assist in the analysis of the probable causes of numerous socio-environmental conflicts related to land and water resources in the state of Bahia, since it identifies the correlation between the caatinga biome, which occupies the largest territorial portion, as being the one that has the least firmness of water guarantee of flows.

RECOMMENDATIONS

The implementation of the seasonal grant in the Paraguaçu River basin is carried out as an experimental model, using reference flows of up to 1.3 x Q90 in the period of highest flow, which runs from December to May, representing a 30% increase in water availability, and traditional values of 1.0 x Q90 in the other six months of the year. This grant can be granted to new users in the period from December to May, or as an additional to increase the flow granted to old users, thus reducing existing conflicts.

We believe that this measure should provide the insertion of traditional communities, with regard to access to water resources, stimulating income generation, through increased food production, with short cycle crops, such as corn, beans, etc.

Whenever possible, it is recommended to use historical flow series from the last two or three decades to calculate the Q90, as they have values closer to the current reality of the basin.

The availability of seasonal flows should preferably be for traditional communities, as a way to rescue, strengthen and support the maintenance of the socioeconomic aspects of the basin, so it is suggested that 60% of the water surplus generated be made available to traditional communities and 40% to farms already implemented, as a form of agricultural expansion.

The next steps of the research refer to the expansion of the use and application of the methodology for seasonal granting to other Brazilian basins and biomes.

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